

Resin composites containing S-PRG fillers: effects on pH modulation of the surrounding medium, surface roughness, and gloss following erosive/abrasive challenge

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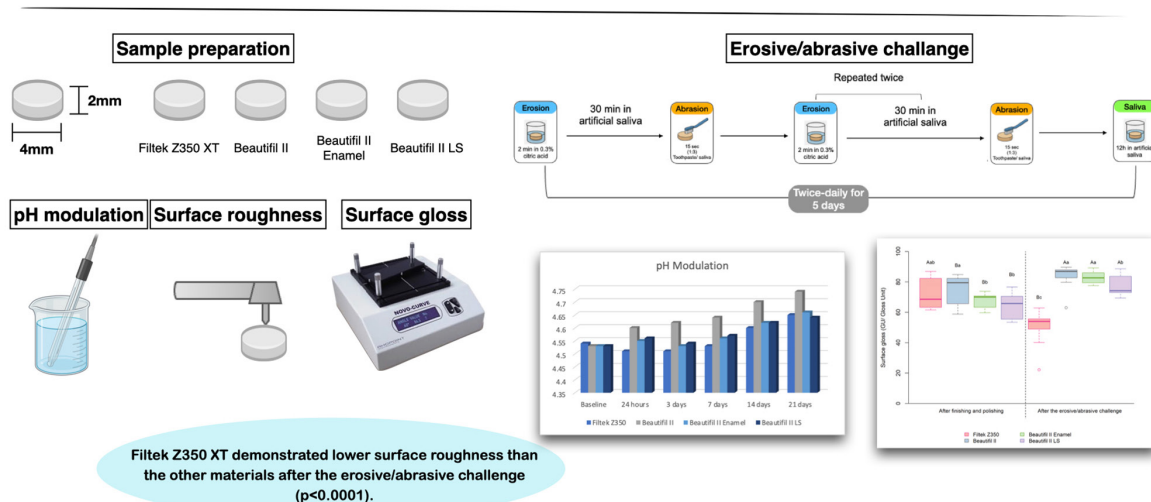
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Abstract

Composite resins containing S-PRG fillers may degrade under pH fluctuations and abrasion, influenced by their composition, particle size, exposure time, and solution acidity. Objective: This study evaluated the ability of resin composites containing S-PRG fillers to modulate the pH of the surrounding medium, as well as their surface roughness and gloss following an erosive/abrasive challenge. Methodology: Resin disks (ø4mm x 2mm) (n=15) were prepared using Filtek Z350 XT (control), Beautifil II, Beautifil II Enamel, and Beautifil II LS (the latter three containing S-PRG fillers). To assess buffering capacity, disks (n=5) were immersed in a demineralizing solution, and pH was measured at baseline and after 1, 3, 7, 14, and 21 days. Separate specimens (n=10) underwent daily erosion cycles using 0.3% citric acid, combined with abrasion via toothbrushing, conducted over a 5-day period to simulate an acidic diet and twice-daily oral hygiene. Surface roughness (Ra) and gloss (GU) were assessed at baseline, after polishing, and following the challenge; surface topography was analyzed by a scanning electron microscope (SEM). Data were analyzed using a generalized linear mixed model for repeated measures over time, in addition to Tukey–Kramer, Kruskal–Wallis, Dunn, Friedman, and Nemenyi tests ($\alpha=0.05$). Results: All materials showed a significant increase in the pH of the surrounding medium over time ($p<0.05$). After 24 hours, Beautifil II exhibited a significantly higher pH than the others ($p<0.05$). Filtek Z350 XT demonstrated lower surface roughness than the other materials after the erosive/abrasive challenge ($p<0.0001$). Following the challenge, Beautifil II and Beautifil II Enamel presented higher gloss values ($p<0.05$). Conclusions: Resin composites containing S-PRG fillers slightly increased the pH of the surrounding medium over time. Surface roughness increased after the erosive/abrasive challenge, although the gloss of the S-PRG-containing composites also improved.

Keywords: Buffering capacity. Resin composites. Spectral gloss. Surface roughness.



Conclusion: Resin composites containing S-PRG filler slightly increased the pH of the surrounding medium over time. Surface roughness increased after the erosive/abrasive challenge, although the gloss of the S-PRG-containing composites improved.

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Introduction

The success of composite resin restorations is directly related to their optical properties, with surface roughness, gloss, and color being among the key factors influencing visual perception.^{1,2} Among these properties, surface smoothness is crucial in biofilm adhesion.³ The greater the ability of the material to maintain a smooth surface in response to stimuli in the oral environment—such as abrasive wear from toothbrushing or erosive wear from dietary acids—the higher its potential for long-term clinical performance. This, in turn, reduces biofilm accumulation both on the surface and at the restoration interface.^{4,5}

However, abrasive wear caused by toothbrushing and the use of dentifrices may lead to a gradual reduction in the gloss of restorative materials over time.⁶⁻⁸ Although increased surface roughness and gloss loss have been associated with higher abrasivity of certain dentifrices,⁹ studies have shown that composite resins containing smaller filler particles—such as nano-hybrid and micro-hybrid formulations—exhibit greater wear resistance than those with larger or more irregular particles.⁷

Erosive wear, particularly from dietary acids, also contributes to changes in the smoothness and gloss of composite resin surfaces, often resulting in increased surface roughness, presumably due to the low pH of the acidic environment.^{6,10-12} Contact with acidic agents may lead to surface degradation of restorative materials in the oral cavity,¹¹⁻¹³ causing texture changes and exposing filler particles. This is likely associated with degradation of the organic matrix or interference with the silane coupling agent, followed by filler loss.^{6,14}

Among the types of composite resins, those containing Surface Pre-Reacted Glass (S-PRG) particles are classified as bioactive materials, capable of eliciting specific beneficial responses from host tissues, such as ion release. This restorative concept is based on a technology that incorporates a trilaminar xerogel structure with a porous external surface capable of interacting with the oral environment.¹⁵ Under mineral imbalance, these particles release ions that help counteract demineralization. The diversity of ions also provides potential benefits, such as antimicrobial and desensitizing effects.¹⁵ In addition to exhibiting mechanical and aesthetic properties similar to those of conventional composite resins,¹⁵ these materials can

release and recharge various ions, including aluminum, fluoride, sodium, borate, strontium, and silicate.¹⁵⁻¹⁷ This may reduce biofilm accumulation, inhibit pH reduction,¹⁸⁻²⁰ prevent secondary caries lesions,²¹ enhance remineralization, and improve biomechanics of demineralized dentin.²²

The pH modulation, or buffering capacity, of materials containing S-PRG fillers results from the rapid release of fluoride ions via ligand exchange within the pre-reacted glass-ionomer hydrogel matrix. This property has been investigated in several contexts, including studies using isolated particles at different concentrations.^{16,19,23,24} However, the buffering capacity of composite resins containing S-PRG particles remains insufficiently clarified.¹⁵ Although some studies have demonstrated this property in materials containing S-PRG particles, most have focused on resin-based sealants^{17,25} or cements formulated with S-PRG and glass-ionomer particles.¹⁹ These materials showed ion release that contributed to pH neutralization. Nevertheless, studies specifically assessing this property in commercially available composite resins containing S-PRG particles are still scarce.

Like other composite resins, those containing S-PRG particles may undergo hydrolytic degradation when exposed to various solutions, particularly under fluctuating pH conditions. This degradation can also be influenced by surface abrasion, the extent of which depends on factors such as chemical composition, particle size, exposure time, and characteristics of the acidic solution.^{12,15,19} Therefore, it is essential to evaluate surface roughness and gloss, along with the effect of pH modulation in an acidic environment, in composite resins containing S-PRG particles subjected to erosive/abrasive challenges, since these materials may experience greater degradation under such conditions.^{12,14,26}

Accordingly, this study aimed to evaluate the effect of pH modulation in an acidic environment, as well as surface roughness and gloss of composite resins containing S-PRG particles when subjected to erosive/abrasive challenges. The null hypotheses tested were that composite resins containing S-PRG particles do not differ from conventional composite resin in terms of: H01) pH modulation in an acidic environment; H02) surface roughness; H03) surface gloss; and H04) changes in roughness and gloss after erosive/abrasive challenges.

Methodology

Experimental design

Sixty disk-shaped samples (\varnothing 4 mm x 2 mm) of composite resins were used as experimental units. Laboratory procedures were divided into two phases. In Phase 1 (n=5), the buffering capacity of the restorative materials was evaluated in an acidic solution. The studied factors were: (I) resin composite type, including a conventional nano-hybrid composite resin (Filtek Z350 XT, Solventum) and three composite resins containing S-PRG fillers (Beautifil II, Beautifil II Enamel, and Beautifil II LS; Shofu, Kyoto, Japan); (II) time points, including baseline, 24 hours, and 3, 7, 14, and 21 days of immersion in a demineralizing solution (2.2 mmol/L CaCl₂, 2.2 mmol/L NaH₂PO₄, 50 mmol/L acetic acid, 0.02% NaN₃; pH 4.5). The response variable was the pH value measured at each time point.

In Phase 2 (n=10), the physical and optical properties were evaluated before and after erosive/abrasive challenges. The factors under investigation were: (I) restorative materials, as described in Phase 1; (II) erosive and abrasive procedures, including immersion in 0.3% citric acid (pH 2.6) and simulated mechanical brushing performed *in vitro*; and (III) time points, including baseline and final (post-challenge). Surface roughness and spectral gloss (response variables) were evaluated both before (baseline) and after the challenges. Details of materials used in the study are provided in Figure 1.

Sample size calculation

The sample size was determined using the G*Power software, considering a 5% significance level ($\alpha=0.05$). For the pH variable, a sample size of five specimens per group (totaling 20 specimens) enabled the detection

of effect sizes of $f=0.64$ for intergroup analyses and $f=0.24$ for intragroup analyses, with 80% power. For surface gloss, a sample size of 10 specimens per group (totaling 40 specimens) enabled the detection of effect sizes of $f=0.48$ (intergroup) and $f=0.23$ (intragroup), also with 80% power. Similarly, for surface roughness, 10 specimens per group (totaling 40 experimental units) enabled the detection of effect sizes of $f=0.45$ (intergroup) and $f=0.20$ (intragroup) with 80% statistical power.

Buffering capacity evaluation

Twenty disk-shaped specimens (2.0 mm thick x 4.0 mm in diameter) were prepared for each composite resin (n=5). Rubber matrices (2 mm in height, 4.0 mm internal diameter) were used to shape specimens by inserting a single increment of material into each matrix. Two polyester strips were used to eliminate air bubbles and produce a smooth surface: one positioned between the glass plate and the matrix, and another placed over the matrix after insertion. A second glass slide was then placed on top, followed by the application of a 500-g weight for 30 seconds. After removing the glass slide, the composite resin was photoactivated for 20 seconds using an LED light-curing device (Valo, Ultradent, South Jordan, UT, USA) at an irradiance of 1000 mW/cm². The top surface of each specimen was then polished using silicon carbide abrasive papers (grits 600 and 1200; Klingspor Abrasivos Industriais, Várzea Grande, Pinhais, Paraná, Brazil), applied manually with light pressure in figure-eight motions for 20 seconds per grit under distilled water cooling. Specimens were rinsed to remove any surface residue.¹⁷ Following preparation, each specimen was immersed in 0.4 mL of a demineralizing solution (2.2 mmol/L CaCl₂, 2.2 mmol/L NaH₂PO₄, 50 mmol/L acetic acid, 0.02% NaN₃;

Resin composite	Manufacturer	Batch	Composition
Conventional nanohybrid (Filtek Z350 XT)	Solventum (Minnesota, USA)	NE38983	Bis-GMA, UDMA, Bis-EMA, PEGDMA, TEGDMA Fillers: 82 wt% (68 vol%) ZrO ₂ , SiO ₂ ; (\leq 3 μ m)
Nanohybrid with S-PRG particles (Beautifil II)	Shofu (Kyoto, Japan)	32264	Bis-GMA, triethylene glycol dimethyl ether, S-PRG 60-70%, DL-camphorquinone, others
Nanohybrid with translucent S-PRG particles (Beautifil II Enamel)	Shofu (Kyoto, Japan)	42313	Bis-GMA (10-15%), TEGDMA, S-PRG (60-70%), pigments, others
Nanohybrid low-shrinkage S-PRG particles (Beautifil II LS)	Shofu (Kyoto, Japan)	122265	UDA (10-20%), silane (1-10%), TEGDMA (1-5%), S-PRG (63/83 -vol%/wt %), silica (1-3%), aluminum oxide (1-3%), pigments, others

Bis-GMA: bisphenol diglycidyl methacrylate; TEGDMA: triethylene glycol dimethacrylate; Bis-EMA: ethoxylated bisphenol dimethacrylate; UDMA: urethane dimethacrylate; PEGDMA: polyethylene glycol dimethacrylate; S-PRG: surface pre-reacted glass ionomer. Information provided by the manufacturers (MSDS and package insert).

Figure 1- Materials used in the present study.

pH 4.5) and stored in Eppendorf tubes incubated at 37° for 21 days.¹⁹ The pH of the immersion solutions was measured at 23 ± 2°C using a pH meter connected to a pH electrode (MS Tecnopon Equipamentos Especiais, RbPH-210, Piracicaba, SP, Brazil) at baseline, 1, 3, 7, 14, and 21 days.

Surface roughness and gloss

Additional 40 disk-shaped specimens (2.0 mm thickness x 4.0 mm in diameter) were prepared following the same previously described procedure (n=10). However, after photoactivation, the finishing and polishing of the top surface were performed using fine and extra-fine aluminum oxide abrasive discs (Sof-Lex Pop-On, Solventum, Saint Paul, MN, USA), applied dry for 10 seconds each. Polishing pressure was standardized using a scale to ensure a maximum load of 300 g. After fabrication, specimens were identified according to their respective groups. Baseline surface roughness and gloss measurements were performed, and specimens were stored in a humid environment at 37°C for 24 hours in a bacteriological incubator. Surface roughness was measured at three time points: baseline, after finishing and polishing, and after erosive/abrasive challenges. A profilometer (Suftest SJ-210, Mitutoyo, Suzano, SP, Brazil) was used for all measurements. The roughness parameter (Ra) was measured using a static load of 5 mN and a speed of 0.5 mm/second. The cutoff value was set at 0.25 µm in sequential mode. Three measurements were taken for each specimen at different locations, and the arithmetic mean was calculated. The values obtained were recorded in a spreadsheet for statistical analysis. Gloss analysis was performed using a glossmeter (Novo-Curve, Rhopoint Instruments, East Sussex, UK), with a square reading area of 2 mm x 2 mm and a 60° light incidence geometry. Results were expressed in gloss units (GU).^{1,27} Gloss measurements were performed after finishing and polishing, and again after the erosive/abrasive challenge. A metal holder was used to block light and eliminate potential interference

from ambient sources.²⁸ Three random measurements were taken for each specimen, and the average value was considered the spectral gloss.

Erosive/abrasive challenge

Erosive-abrasive cycles were performed to simulate an acidic diet and twice-daily toothbrushing over a period of five days (Figure 2).²⁹ These cycles consisted of four stages, repeated daily in the following sequence:

a) Erosion: Specimens were immersed in 0.3% citric acid (pH 2.6) (Machado et al.²⁹, 2019) for two minutes, followed by immersion in artificial saliva (0.213 g/L CaCl₂-2H₂O; 0.738 g/L KH₂PO₄; 1.114 g/L HCl; 0.381 g/L NaCl; 12 g/L Tris buffer; pH adjusted to 7 with KOH) for 30 minutes. All immersions in artificial saliva were conducted under orbital agitation.

b) Abrasion: Specimens were brushed using a soft-bristled toothbrush (Oral B, Procter & Gamble do Brasil, Louveira, SP, Brazil) and toothpaste (Colgate Ação Máxima Anticáries, Palmolive, São Bernardo do Campo, SP, Brazil) in a 3:1 ratio of toothpaste to artificial saliva. A total of 20 mL of this slurry was added in the machine container for each sample. Brushing was performed for 15 seconds (45 strokes) over two minutes using a customized brushing machine (Campinas, São Paulo, Brazil) with a standardized load of 200g 30. After brushing, specimens were rinsed with distilled water for 10 seconds and immersed again in artificial saliva for 30 minutes.

c) Repeated erosion: Disks were subjected to three additional immersions in 0.3% citric acid (pH 2.6) for two minutes each, with each immersion followed by exposure to artificial saliva. The first post-acid immersion lasted 60 minutes, while the second and third lasted 30 minutes each.

d) Second abrasion: The abrasive challenge was repeated as previously described, and specimens were stored in artificial saliva for the remainder of the 12-hour period.

At the end of the five-day erosive/abrasive protocol,

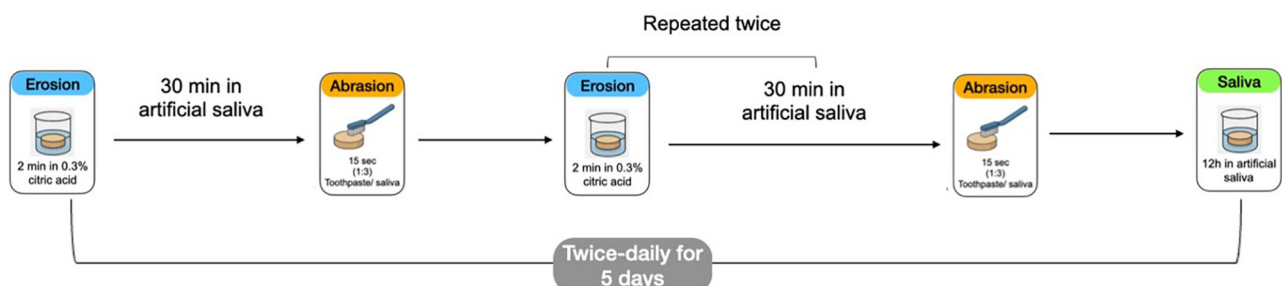


Figure 2- Schematic illustration of the methodology used for the erosive/abrasive challenge.

surface roughness and spectral gloss were reanalyzed.

Surface morphology

The surface micromorphology of the materials was evaluated using a scanning electron microscope (SEM, Leo 440i, LEO Electron Microscopy, Oxford, Cambridge, England) operated at an acceleration voltage of 10 kV and a magnification of 3000x (high voltage: 20.00 kV). Composite resin surfaces (n=2) were analyzed after finishing and polishing, and again after the erosive/abrasive challenge. Prior to imaging, the surface of each specimen was gold-coated for 60 seconds using a sputtering device. Surface features—such as irregularities, porosities, erosions, particle loss, and other alterations—were descriptively assessed by groups.

Statistical analysis

Descriptive and exploratory data analyses were initially performed to determine the appropriate statistical methods for each variable. The pH modulation in an acidic medium was evaluated using a mixed linear model for repeated measures over time, followed by the Tukey–Kramer test for multiple comparisons. Data were reported as means and standard deviations. Non-parametric tests were applied to analyze surface roughness, since the data did not meet the assumptions required for parametric analysis. Group comparisons were conducted using the Kruskal–Wallis and Dunn tests, followed by Bonferroni adjustment, while comparisons over time were performed using the Friedman and Nemenyi tests. Gloss analysis was conducted using a generalized mixed linear model for repeated measures over time to assess the effects of material, time, and their interaction on gloss values. All statistical analyses were performed using R software (R Core Team, 2024 R: A language and environment for statistical computing. R

Foundation for Statistical Computing, Vienna, Austria), with a 5% significance level.

Results

A significant increase in the pH of the surrounding medium was observed over time in all groups ($p < 0.05$) (Table 1). At baseline, no significant differences were found among groups ($p > 0.05$). However, from the 24-hour time point onward, Beautifil II exhibited a significantly higher pH than the other groups ($p < 0.05$). Additionally, at both 24 hours and seven days, Filtek Z350 showed a significantly lower pH than Beautifil II LS ($p < 0.05$).

Beautifil II LS exhibited higher surface roughness than the Beautifil II ($p < 0.05$), although no significant differences were observed compared to the other resins at baseline (Table 2). After finishing and polishing, Beautifil II LS showed significantly greater roughness than Filtek Z350 XT and Beautifil II ($p < 0.05$), but did not differ significantly from Beautifil II Enamel. Following the erosive/abrasive challenge, Filtek Z350 XT exhibited significantly lower roughness than the other materials ($p < 0.05$). All bioactive composite resins demonstrated a significant increase in surface roughness after the challenge compared to their respective baseline values ($p < 0.05$).

After finishing and polishing, surface gloss was significantly higher for Beautifil II compared to Beautifil II Enamel and Beautifil II LS ($p < 0.05$), but did not differ significantly from Filtek Z350 XT (Figure 3). Following the erosive/abrasive challenge, Filtek Z350 XT showed a significant decrease in gloss ($p < 0.05$), whereas the other materials exhibited significant increases ($p < 0.05$). After the challenge, gloss values were significantly higher for Beautifil II and Beautifil II Enamel compared

Table 1- Mean and standard deviation of pH according to treatment and time.

Time	Treatment			
	Filtek Z350	Beautifil II	Beautifil II Enamel	Beautifil II LS
	Mean (standard deviation)			
Baseline	4.54 (0.02) ^{Ac}	4.53 (0.01) ^{Ae}	4.53 (0.01) ^{Ac}	4.53 (0.01) ^{Ac}
24 hours	4.51 (0.02) ^{Cc}	4.60 (0.01) ^{Ad}	4.55 (0.01) ^{Bc}	4.56 (0.01) ^{Bbc}
3 days	4.51 (0.01) ^{Bc}	4.62 (0.02) ^{AcD}	4.53 (0.02) ^{Bc}	4.54 (0.01) ^{Bbc}
7 days	4.53 (0.01) ^{Cc}	4.64 (0.01) ^{Ac}	4.56 (0.01) ^{BcC}	4.57 (0.01) ^{Bb}
14 days	4.60 (0.03) ^{Bb}	4.70 (0.01) ^{Ab}	4.62 (0.01) ^{Bb}	4.62 (0.02) ^{Ba}
21 days	4.65 (0.03) ^{Ba}	4.74 (0.01) ^{Aa}	4.66 (0.01) ^{Ba}	4.64 (0.02) ^{Ba}

Distinct letters (uppercase for horizontal comparisons and lowercase for vertical comparisons) indicate statistically significant differences ($p \leq 0.05$). $p(\text{treatment}) < 0.0001$; $p(\text{time}) < 0.0001$; $p(\text{interaction}) < 0.0001$

Table 2- Median (minimum and maximum) surface roughness (μm) according to composite resin and time point.

Resin composite	Time point			p-value
	Baseline	After finishing and polishing	After erosive/abrasive	
Filtek Z350 XT	0,053 (0,043; 0,075) ^{Bab}	0,084 (0,039; 0,099) ^{ABbc}	0,116 (0,084; 0,161) ^{Ab}	0,0007
Beautiful II	0,046 (0,037; 0,078) ^{Bb}	0,054 (0,037; 0,087) ^{Bc}	0,310 (0,274; 0,436) ^{Aa}	0,0003
Beautiful II Enamel	0,063 (0,037; 0,089) ^{Bab}	0,109 (0,058; 0,138) ^{Bab}	0,307 (0,210; 0,400) ^{Aa}	0,0002
Beautiful II LS	0,064 (0,049; 0,081) ^{Ba}	0,140 (0,077; 0,150) ^{ABa}	0,339 (0,220; 0,410) ^{Aa}	<0,0001
p-value	0,0154	0,0003	<0,0001	

Distinct letters (uppercase for horizontal comparisons across time within each resin, and lowercase for vertical comparisons among resins at each time point) indicate statistically significant differences ($p \leq 0.05$).

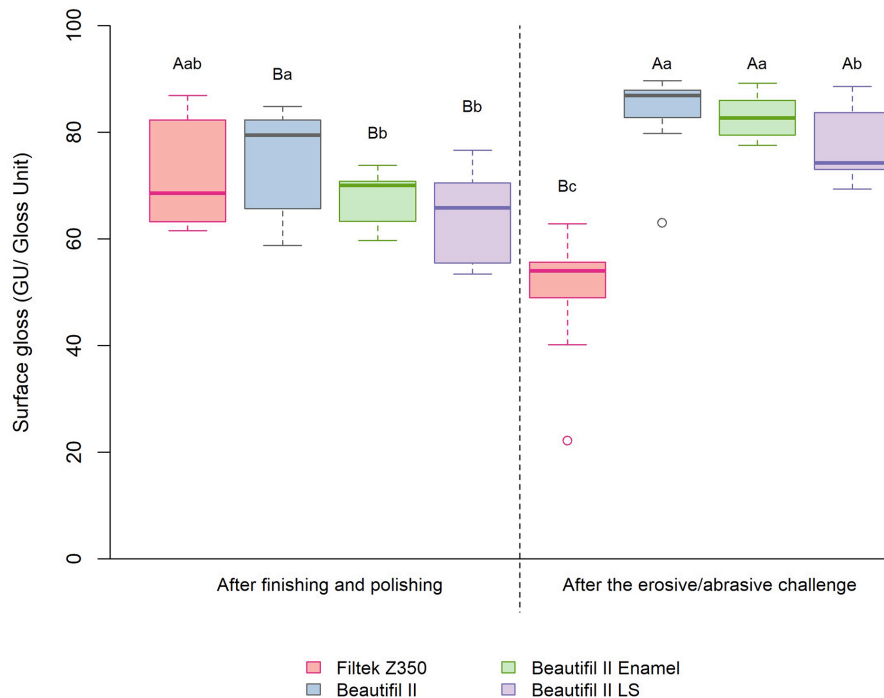


Figure 3- Box plot of surface gloss (GU: Gloss Unit) as a function of restorative material and evaluation time. Different letters (uppercase for comparison within each material over time, and lowercase for comparison among materials within each time point) indicate statistically significant differences ($p \leq 0.05$). $p(\text{material})=0.0006$; $p(\text{time})=0.7506$; $p(\text{interaction})=0.0060$.

to the other two composite resins ($p < 0.05$), with Filtek Z350 XT displaying the lowest gloss among all groups ($p < 0.05$).

Surface micromorphology images (Figure 4) revealed surface irregularities resulting from the finishing and polishing procedures, including scratches and abrasive wear of filler particles in Beautiful II.

After the erosive/abrasive challenge, surface changes were observed in the resins (Figure 5). In the Filtek Z350 XT group, partial removal of the organic matrix was evident, resulting in the exposure of filler particles, although surface smoothness was largely preserved. In contrast, composite resins containing S-PRG particles showed more pronounced surface irregularities, including visible erosions and signs of matrix plasticization.

Discussion

Composite resins containing S-PRG particles may serve various clinical purposes, since their properties are influenced by factors such as particle size and shape, filler content, viscosity, and translucency.¹² These characteristics can directly affect surface roughness and gloss, especially when materials are subjected to erosive and abrasive challenges.³¹ Furthermore, the size of the filler particles and their incorporation into the resin matrix may also influence the buffering capacity of the material—an aspect that may contribute to biofilm inhibition, antimicrobial effects, and protection against enamel demineralization.^{17,19}

In this context, the results of this study indicate that composite resins containing S-PRG particles exhibited a slightly greater pH modulation effect in an

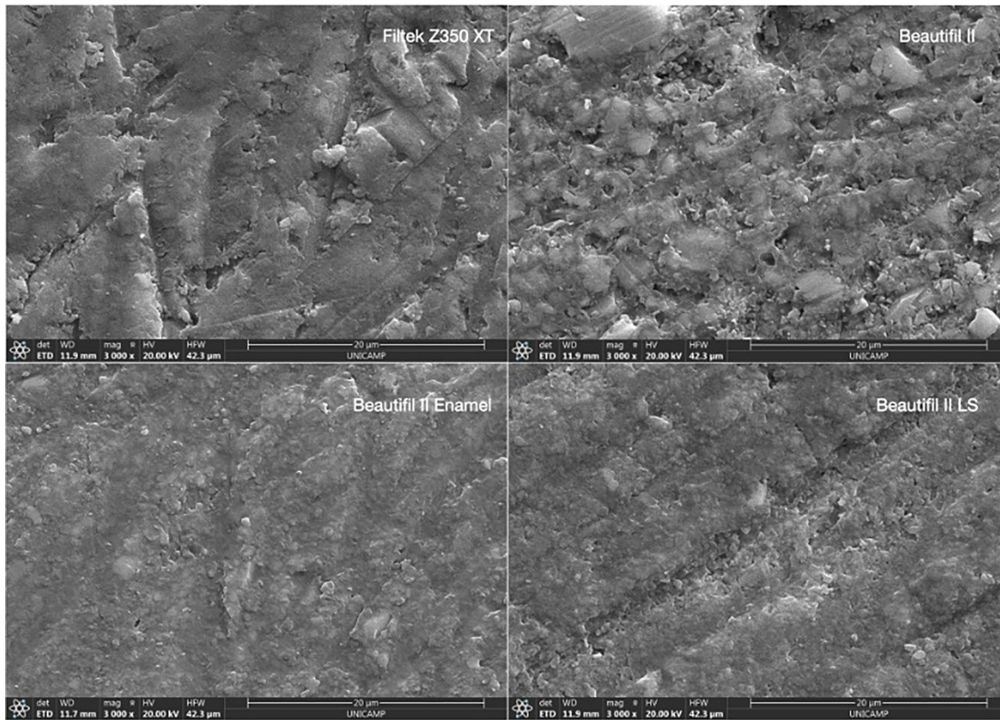


Figure 4- Micromorphology of composite surface after finishing and polishing (3000x magnification).

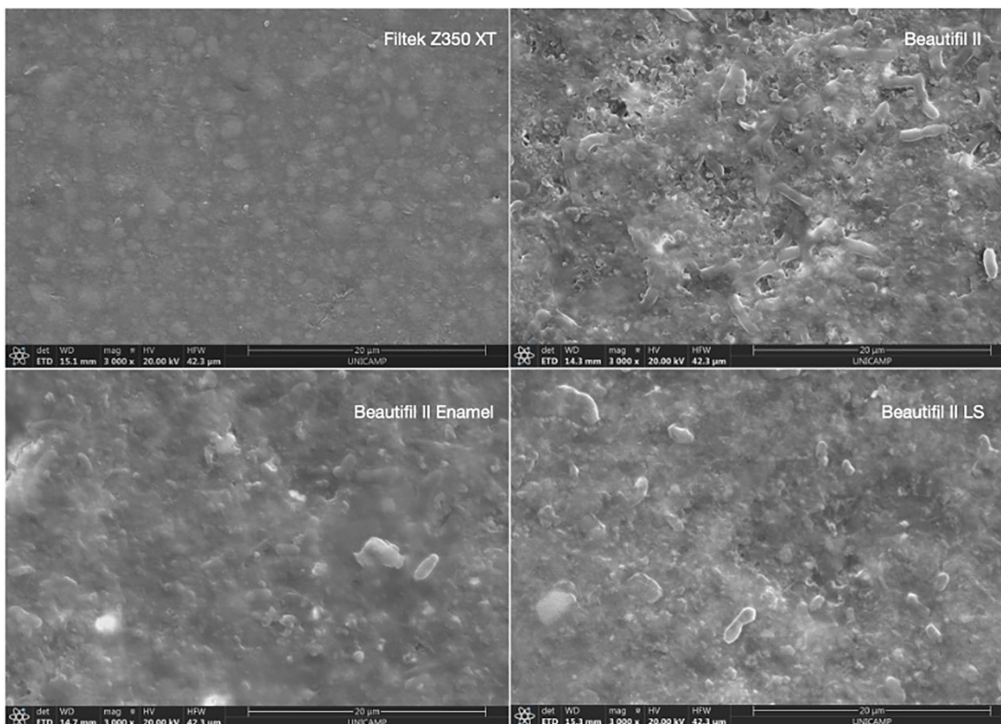


Figure 5- Micromorphology of composite surface after erosive/abrasive challenges (3000x magnification).

acidic medium, leading to the rejection of the first null hypothesis (H01). It is well-established in the literature that oral biofilms contain acidogenic bacteria capable of fermenting dietary carbohydrates, producing organic acids that cause demineralization of dental tissues. Hence, immersion in an acid solution with a pH adjusted to 4.5 was selected to simulate the acid conditions generated by bacterial metabolism, which can reach

pH values close to 4.0 *in vivo*. Although a statistically significant increase in pH was observed over time for resins containing S-PRG—particularly Beautifil II—the overall changes were relatively modest. Values ranged from 4.51 to 4.74, which, although higher than baseline, remain below the critical pH threshold for enamel demineralization (< 5.5). Therefore, despite the observed buffering activity, the clinical relevance

of this modulation remains limited under the conditions tested.

S-PRG particles are known to exhibit permeability due to their processing method, which creates mechanical retention of the resin matrix via surface porosities resulting from the anchoring of the hydroxyl group of Bis-GMA into this porous surface.³² Additionally, the silica-based surface treatment of the particles enables chemical bonding between silicon and the carbon radical of Bis-GMA. This interaction may reduce ion release from the composite resin, unlike what occurs with eluates, as reported in previous studies.^{16,19,23,24}

Since Bis-GMA has a high molecular weight, diluent monomers—such as triethylene glycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDA)—are incorporated to improve viscosity and enable the inclusion of inorganic particles. These monomers are hydrophilic and increase hydrolysis by enhancing water sorption.^{33,34} The nature of the diluent monomer is significant in the ion release mechanism of S-PRG particles.¹⁵ However, even with this more hydrophilic composition, the buffering capacity of these composite resins remained relatively low.

A previous study evaluating a sealant containing S-PRG particles¹⁷ demonstrated a pH-modulating effect in an acidic medium, which may be attributed to the absence of Bis-GMA in its composition. This suggests that the presence of a more viscous monomer—characterized by lower mobility and sorption capacity—may also explain these results, regardless of the particle size and concentration in the composite resin. Acidic buffering capacity was also observed by Shimizubata, et al.¹⁹ (2020) in a study using cements containing S-PRG particles within a glass ionomer cement matrix, which lacks a resin matrix. In contrast, Martins, et al.³⁵ (2024) reported that composites containing S-PRG particles did not protect enamel adjacent to restorations under erosive–abrasive wear conditions in an *in situ* study.

It could be expected that a higher concentration of S-PRG particles in the material would result in greater ion release and, consequently, higher buffering capacity.¹⁹ According to material compositions reported in the respective MSDS documents, which provide approximate concentrations, Beautifil II and Beautifil II Enamel contain between 60% and 70% filler content, while Beautifil II LS contains 82.9%.^{36,37} However, regarding the hygroscopic behavior of bioactive resins,

the composition and proportion of monomers have been shown to exert a greater influence on water sorption than the presence or concentration of bioactive components.¹⁴ Differences in particle size were also observed: Beautifil II contains larger particles (up to ~ 3 µm) (Figure 4), whereas Beautifil II Enamel and Beautifil II LS contain nanometric particles (below 0.1 µm). This may have contributed to the higher pH values for Beautifil II.

Despite differences in particle size, Beautifil II LS exhibited greater surface roughness than Beautifil II, although no significant differences were found compared to the other resins at baseline. This finding led to the rejection of the second null hypothesis (H02). Finishing and polishing are crucial steps in restoration⁸, enabling the surface to be smoothed following occlusal adjustments or anatomical refinements. In this study, surface smoothness achieved using the polyester strip (initial values) was maintained for all composite resins after finishing and polishing. Nevertheless, Beautifil II LS exhibited higher surface roughness than Filtek Z350 XT and Beautifil II after polishing, although no significant difference was found compared to Beautifil II Enamel. This outcome cannot be solely explained by particle size and shape⁸ but may also be associated with its higher filler content (82.9%).^{35,36} Additionally, the presence of pre-polymerized long-chain monomers in Beautifil II LS (as reported by the manufacturer) may affect the material's surface characteristics, potentially interfering with uniform polishing. However, this effect has not yet been explored in the scientific literature.

In addition to surface roughness, spectral gloss is an important parameter for the aesthetics of restorations, since it is influenced by both intrinsic material properties and external factors such as ambient lighting and observer perception.³⁸ The higher gloss observed in Beautifil II compared to the other materials is likely related to its optimized combination of nanometric and spherical particles, which enhances its ability to achieve and retain a high-gloss finish after polishing.⁸ This finding led to the rejection of the third null hypothesis (H03), since significant differences in spectral gloss were found among tested materials.

Following the erosive/abrasive challenge, the gloss of S-PRG-containing composite resins increased, possibly due to plasticization of the resin matrix (Figure 5). In these materials, filler particles of the bioactive resins did not become exposed or prominent in the same manner as in the conventional composite resin.

Nevertheless, surface roughness increased in both Beautiful II and Beautiful II Enamel. Plasticization is known to promote water sorption¹, thereby softening the organic matrix via acid interaction, which may enhance light reflection and increase spectral gloss.³⁸ In contrast, Filtek Z350 XT exhibited filler particle exposure after the challenge. Although surface roughness did not increase significantly, this exposure may have contributed to the reduction in spectral gloss.

Surface smoothness is an important factor in early biofilm retention,^{5,40} and the greater the ability of the material to preserve surface smoothness, the lower its tendency for biofilm adhesion.⁴ Nanofilled composite resins, such as Filtek Z350 XT, typically exhibit lower surface roughness since their filler particles are smaller and more spherical. However, brushing abrasion can increase roughness and reduce gloss.⁸ Surface roughness values above 0.2 μm are known to significantly increase biofilm accumulation.^{5,41} In this study, all materials containing S-PRG particles presented roughness values exceeding this threshold. Nevertheless, bioactive materials offer additional clinical benefits, including enhanced resistance of mineralized dental tissues, pH modulation, antimicrobial properties, and inhibition of enamel demineralization. These advantages should be considered when selecting restorative materials.¹⁵ Since the erosive/abrasive challenge produced differences in both surface roughness and gloss between S-PRG-containing composite resins compared and conventional composite, the fourth null hypothesis (H04) was rejected.

It should also be emphasized that both surface roughness and spectral gloss are affected by erosive and abrasive challenges commonly encountered in the oral cavity.⁴² The simulated challenge in this study lasted only five days, whereas, clinically, other variables—such as filler characteristics, dietary habits, and potential parafunctional activity—may contribute to the degradation of restorative materials. An *in situ* study found that S-PRG-containing resins showed wear resistance comparable to that of conventional composites,³⁴ highlighting the variability in outcomes depending on the methodologies used.

Thus, repolishing restorations is essential for restoring and maintaining surface gloss, which helps prevent biofilm accumulation, gingival inflammation, staining, and aesthetic compromise.⁸ Mechanical biofilm control remains equally important, and the bioactivity

of S-PRG-containing composite resins represents a key advantage over conventional materials.

Although this study provides valuable insights into the behavior of S-PRG-containing composite resins under erosive and abrasive challenges, several limitations must be acknowledged. First, the experimental protocol simulated a short-term exposure (five days), which may not fully reflect the cumulative effects of long-term oral stressors, including variable dietary habits, fluctuations in salivary flow, and parafunctional activities. While a modest buffering effect was observed, the extent of pH modulation remained below the critical threshold for enamel protection, limiting its clinical relevance under the conditions tested. Moreover, the impact of filler concentration and particle size on surface properties and ion release warrants further investigation. Future *in situ* or randomized clinical trials are recommended to evaluate the performance of these materials in complex oral environments, particularly regarding their ability to modulate biofilm formation, preserve surface integrity, and prevent enamel demineralization over extended periods. Comparative studies of formulations with varying hydrophilicity, filler–matrix interactions, and polymerization strategies may further elucidate essential factors influencing both the mechanical stability and bioactivity of S-PRG-containing composites.

Conclusion

The bioactive composite resins demonstrated a pH modulation effect in an acidic environment, leading to a slight increase in pH over time, similar to the trend observed for the conventional composite resin. Although surface roughness increased after the erosive/abrasive challenge, the gloss of the bioactive resins improved.

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Conflict of interest

The authors declare no conflict of interest.

Data availability

All data generated or analyzed during this study are included in this published article.

Authors' contributions

Oliveira Neto, Carlos Alberto Campos: Data curation (Equal); Investigation (Equal); Methodology (Equal); Resources (Equal). **Dal Picolo, Mayara Zaghi:** Investigation (Equal); Methodology (Equal); Writing - original draft (Equal); Writing - review & editing (Equal). **Amaral, Flávia Lucisano Botelho:** Funding acquisition (Equal); Investigation (Equal); Methodology (Equal); Writing - original draft (Equal). **Torres, Carlos Rocha Gomes:** Methodology (Equal); Supervision (Equal); Validation (Equal); Writing - review & editing (Equal). **Kantovitz, Kamila Rosamilia:** Conceptualization (Equal); Funding acquisition (Equal); Methodology (Equal); Writing - review & editing (Equal). **Attin, Thomas:** Conceptualization (Equal); Formal analysis (Equal); Funding acquisition (Equal); Supervision (Equal); Writing - review & editing (Equal). **Basting, Roberta Tarkany:** Conceptualization (Lead); Funding acquisition (Lead); Supervision (Lead); Writing - review & editing (Lead).

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