Received: 12 November 2024 | Accepted: 5 February 2025

DOI: 10.1111/eos.70004

ORIGINAL ARTICLE

European Journal of Oral Sciences | NOF Scandinavian Division IADR | WILEY

Strengthening effect of flavonoid antioxidant on resin–enamel bond strength following tooth bleaching

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Funding information
FAPEMIG, Grant/Award Number: APQ-01185-21; CNPq, Grant/Award Number: 422588/2021-0; CAPES, Grant/Award Number: 001; Conselho Nacional de Desenvolvimento Científico e Tecnológico; Fundação de Amparo à Pesquisa do Estado de Minas Gerais

Abstract

This study aimed to assess the impact of flavonoid-based antioxidant application after in-office bleaching with 35% hydrogen peroxide on the shear bond strength of resin to bovine enamel, comparing it with 10% sodium ascorbate. Bovine enamel blocks ($n = 10$) were randomly assigned to one of five pretreatments: (i) no bleaching, (ii) bleaching without antioxidant application, and (iii) bleaching followed by a 1-min application of 10% sodium ascorbate, (iv) 5% naringin, or (v) 10% naringin. Color analysis was conducted using a digital spectrophotometer. Shear bond strength was assessed on two, 2-mm-diameter resin cylinders per block using a universal testing machine at 0.5 mm/min until fracture. Enamel surface morphology was analyzed using scanning electron microscopy. Shear bond strength values and color parameters (ΔE_{ab}, ΔE_{00}, and ΔWI_D) were analyzed using one-way ANOVA, while *t*-tests were used for the individual color parameters lightness (L^*), green–red (a^*), blue–yellow (b^*), and chroma (C^*) . None of the antioxidants resulted in bond strength values as high as those observed without bleaching. However, application of sodium ascorbate and 5% naringin after bleaching significantly increased bond strength compared with bleached enamel without antioxidant. Antioxidants had no significant impact on color. The predominant failure modes were adhesive between the adhesive and enamel, and mixed.

KEYWORDS
ascorbic acid, composite resin, hydrogen peroxide, naringin, tooth whitening

INTRODUCTION

Esthetic dentistry holds great appeal for the majority of the population, as a white and well-aligned smile is perceived as essential for boosting self-esteem and, consequently, quality of life [1]. Patients report that one of the main characteristics required for an esthetically satisfactory smile is an appropriate tooth color [2]. Thus, the practitioner should not only provide dental anatomy and function but also involve esthetic aspects [3, 4]. As a non-invasive and effective procedure, dental bleaching is helpful to achieve a luminous smile. It can be performed using several regimens, with different compositions and concentrations of product based on hydrogen peroxide (H_2O_2), which is a strong oxidizing agent [5, 6].

As H_2O_2 has a low molecular weight, it is able to diffuse through the interprismatic spaces of enamel towards dentin [6]. Reactive oxygen species generated from H_2O_2 would then be able to cleave the long-chained organic pigments in dentin, the so-called chromophores [7]. The reactive oxygen species can cleave the double bonds of pigment molecules, making them small enough to diffuse out of the tooth structure, or to absorb less light, and consequently obtain a lighter shade [6, 7].

Despite being an effective procedure, tooth whitening can result in residual oxygen in the dental tissues that may interfere with the adhesion mechanism of resin restorations immediately after its application [8–10]. Studies have shown that bleaching significantly reduces the bond strength of adhesives to enamel and dentin, suggesting incomplete infiltration of adhesives or interference with the polymerization process [8–13]. Given the above, there are many studies that seek ways in which to reverse this reduction in bond strength after bleaching [14]. However, because the impaired bond strength after bleaching has been shown to be temporary [10, 11], adhesive procedures are usually delayed after the last bleaching session for periods ranging from 24 h to 3 weeks [8, 10, 11].

The use of antioxidants has been employed in several in vitro studies to reverse the decrease, after bleaching, in bond strength of adhesive to enamel, thus reducing, or avoiding altogether, any delay before placing composite resin restorations, such as in cases of closure of multiple diastemata after removal of orthodontic appliances or replacement of restorations in esthetic areas with compromised coloration [14]. Some examples of these antioxidants are green tea, sodium ascorbate (vitamin C), cranberry extract, grape seed extract (oligomeric proanthocyanidin complexes), and quercetin (flavonoid) [15–19].

According to one study [12], the application of 10% sodium ascorbate following tooth bleaching was found to reverse the reduction in enamel bond strength caused by residual oxygen. However, when comparing 10% sodium ascorbate with 5% grape seed extract, the enamel bond strength produced by the latter, which is rich in flavonoids, was significantly higher than that observed for sodium ascorbate [18]. Flavonoids constitute a broad category of polyphenolic compounds found widely throughout photosynthetic organisms, such as fruits, vegetables, teas, and wines. According to their chemical structure, they are subdivided into subclasses, namely, flavonols, flavones, flavanones, anthocyanidins, flavonoids, and isoflavones. This subdivision is determined by their molecular structural characteristic that considers the oxidation state of the central benzene ring [20, 21].

Naringin is a flavonoid belonging to the flavonone glycoside group, which can be found mainly in citrus fruits [22]. Naringin has been shown to be effective at inhibiting demineralization, promoting remineralization of artificial root caries lesions [23], enhancing the mechanical properties of the demineralized dentin matrix [24], and improving bond strength and longevity in sound [25] or caries-affected dentin when applied prior to a universal adhesive [26]. Recently, naringin has demonstrated potent antioxidant properties, even at low doses [27].

Although there are already promising studies in the dental area using naringin, the potential of naringin to reverse the reduction in bond strength after bleaching has not yet been investigated. Therefore, the present study aimed to evaluate the effect of application of different concentrations of naringin on the bond strength of resin to enamel after tooth whitening, using protocols with reduced time of antioxidant application. The null hypotheses were that: (i) application of naringin to bleached enamel would not reverse enamel bond strength to that obtained for unbleached enamel, and (ii) application of naringin would not affect enamel color after bleaching.

MATERIAL AND METHODS

Specimen preparation

Extracted bovine incisors were cleaned and stored in a 1% chloramine-T solution at 4˚C for no longer than 60 days. Teeth without cracks and defects were selected and had their roots removed using diamond discs attached to a precision cutting machine (Isomet 2000, Buehler). The pulp chamber tissue was removed using endodontic files (Hedstrom files, Maillefer Dentsply). The crowns were cleaned using a Robinson polishing brush, pumice stone, and water. Then, 50 crowns ($n = 10$ per experimental group) with buccal walls of similar thickness (3.5 mm) were selected. The appropriate sample size for evaluating bond strength was calculated considering $\alpha = 0.05$ and $\beta = 20\%$; a result of nine samples per group was obtained, with a power of 80%, average standard deviation of 4.0, and minimal bond strength difference of 7.0 MPa. Each crown was sectioned in a precision cutting machine to obtain blocks of the central region of each tooth containing enamel and dentin, with final measurements of 6 mm wide × 10 mm long × 2 mm thick. The dentin and enamel were flattened using 600-grit silicon carbide sandpaper, and the final enamel thickness was standardized at 1 mm. The blocks were kept in 100% humidity until required for use in the procedures described below.

Bleaching and antioxidant application protocols

The blocks were randomly distributed to one of five exposure regimens using computer generated sequences. Ten blocks were randomly selected and stored in humidity until the beginning of the adhesive procedure; these blocks comprised the control group and were not bleached. Before

TABLE 1 Composition of the materials used, lot number, and pH of the antioxidant solutions.

Material (Manufacturer)	Composition	Batch number	pH
Whitness HP 35% (FGM Dental Group)	Hydrogen peroxide, thickener, red colorant, glycol, and inorganic filler	300,322	–
Sodium ascorbate (ACS Científica—Orion)	Sodium L-ascorbate PA	202,111,280	2.670 (10% in water)
Naringin (Merck)	Naringin ≥ 95%	BCCG5679	7.587 (5% in water) 6.872 (10% in water)
Gluma Etch 35 Gel (Kulzer)	35% phosphoric acid, pigments, thickening agents, water	811,120	–
Single Bond Universal (3M)	2-Hydroxyethyl methacrylate, 2-propenoic acid, 2-methyl-, reaction products with 1, 10- decanediol and phosphorus oxide, ethanol, water, silane-treated silica, acrylic copolymer and itaconic acid, camphorquinone, dimethylaminobenzoate(-4), 2-dimethylaminoethyl methacrylate, 2, 6-di-tert-butyl-p-cresol	2,208,000,118 - 17/01/2024	–
Filtek Bulk Fill Flowable Restorative (3M)	Silanized ceramics, diurethane dimethacrylate, dimethacrylate substitute, ytterbium fluoride, BisGMA, bisphenol A polyethylene glycol diether dimethacrylate, triethylene glycol dimethacrylate	NF00270	–

(1-methylethylidene)bis[4, 1-phenyleneoxy(2-hydroxy-3, 1-propanediyl)] bismethacrylate.

randomization of the remaining 40 blocks, a 35% H_2O_2 gel (Whiteness HP, FGM) was applied to the enamel region for 45 min (three applications of 15 min each), simulating one in-office bleaching session. All materials used are described in Table 1. After this period, the gel was removed by rinsing in distilled water, and the blocks were randomly divided into one of the other four exposure regimens: application of distilled water for 1 min, application of 10% sodium ascorbate for 1 min, application of 5% naringin for 1 min, or application of 10% naringin for 1 min. The antioxidant agents were applied to the entire enamel region, and the same volume (1 mL) of each agent was used. Duration of treatment was chosen based on a previous study reporting positive results [28]. Antioxidants were diluted in distilled water and placed in an ultrasonic bath for 5 min to obtain a homogeneous solution. The antioxidant agent was removed from enamel by rinsing with distilled water, and the blocks were dried with air jets before the adhesive procedures were performed.

Shear bond strength assessment

Two circular regions of approximately 2.5 mm each were delimited on the blocks with the aid of an adhesive tape (ground demarcation tape, 3M). Then, 35% phosphoric acid (Gluma Etch 35%, Kulzer) was applied for 30 s to these delimited areas, after which they were rinsed for 30 s using a water jet, air dried, and then two layers of a universal adhesive (Single Bond Universal, 3M) were applied using a microbrush. The solvent was evaporated between the layers, following the manufacturer's instructions, and then the adhesive was light-cured for 10 s (Elipar DeepCure, 3M). Afterwards, rubber matrices with cylindrical holes of approximately 2 mm diameter and 2 mm depth were positioned in the delimited area, filled with flowable resin (Filtek Bulk Fill Flow color A1, 3M), and light-cured (Elipar DeepCure, 3M) for 20 s to build the cylinders for shear bond strength testing. The blocks were then fixed in a universal testing machine (Ez-Test, Shimadzu) and tested in shear until fracture, at a speed of 0.5 mm/min. The values, in MPa, were obtained from the average of the two cylinders in each block. The antioxidant solutions were evaluated regarding their pH and are also described in Table 1.

Colorimetric evaluation

To evaluate whether the application of antioxidants interferes with the immediate bleaching results, the samples were evaluated using a digital spectrophotometer (Vita EasyShade). Color evaluation was performed after tooth bleaching and after application of antioxidant agents. The samples were kept on a standardized white background for the readings. The lightness (L^*), green–red (a^*), blue–yellow (b^*), and chroma (C^*) values were recorded after whitening and after antioxidant application. The L^*, a^*, b^*, and C^* parameters were used for comparison between groups, and the values of ΔE_{ab} (color difference using CIELAB) and ΔE_{00} (color difference using CIEDE2000) were calculated [29]; the change in whiteness was obtained using the whiteness index for dentistry (ΔWI_D) [30].

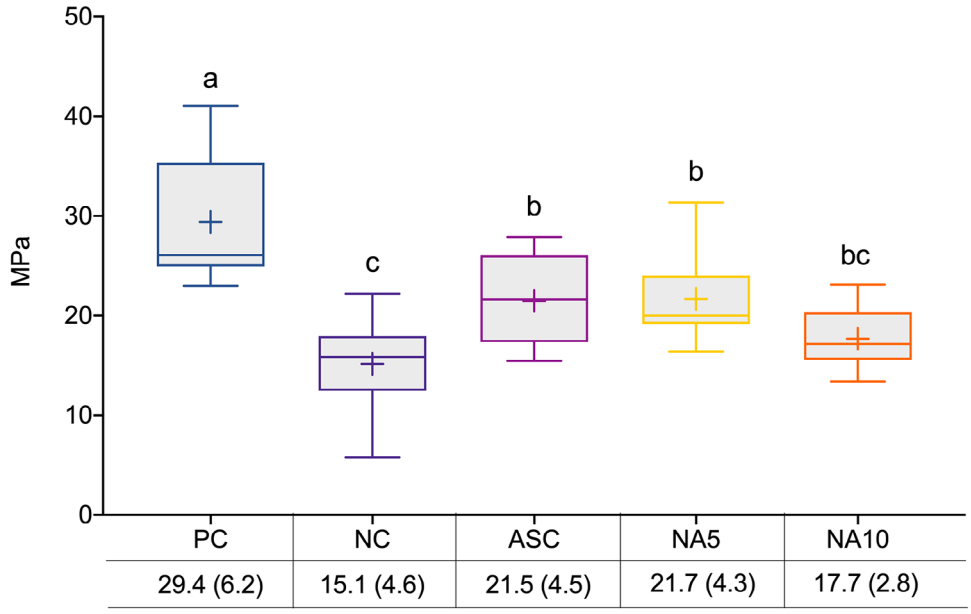

FIGURE 1 Box plot illustrating shear bond strength (MPa) in each group. Specimens of bovine enamel were bleached or not bleached, then treated or not treated with different antioxidants before shear bond strength was evaluated. Different lowercase letters denote statistically significant differences ($p < 0.05$) between groups. ASC, bleaching with 35% hydrogen peroxide (H_2O_2) followed by treatment with 10% sodium ascorbate; NA5, bleaching with 35% H_2O_2 followed by treatment with 5% naringin; NA10, bleaching with 35% H_2O_2 followed by treatment with 10% naringin; NC, bleaching with 35% H_2O_2 but no treatment with antioxidant; PC, no bleaching, no antioxidant application. Mean (SD) of each group are reported below the respective bars.

Failure patterns

The surfaces involved in the fracture of each specimen were analyzed under a stereoscopic magnifier, at 30× magnification, to determine the failure pattern. The blocks were evaluated by keeping the areas involved in the fractures facing upward. Fractures were classified according to the structures involved (70% or more): Type I: cohesive failure within the resin composite; Type II: adhesive failure between the resin composite and the bonding agent; Type III: adhesive failure between enamel and the bonding agent; and Type IV: mixed failure characterized by the presence of more than one type of failure. Representative images were obtained using scanning electron microscopy.

Enamel surface morphology under scanning electron microscopy

To analyze if the antioxidants were able to alter enamel surface morphology, two additional enamel blocks ($n = 2$) were prepared as described above and randomly allocated to one of the five exposure regimens. After the treatments described previously, the enamel was cleaned in an ultrasonic bath for 15 min to remove any debris, left in silica at 37˚C for dehydration, and then sputter coated with gold (MED 010; Balzers). Enamel surface morphology was analyzed using a scanning electron microscope (JSM-6460LV, JEOL), at 1000x magnification, and representative images were obtained from three randomly selected regions of each enamel block.

Statistical analysis

The data were evaluated regarding the assumptions for a parametric test using SIGMASTAT 3.5 SOFTWARE (Systat Software). Shear bond strength and ΔE_{ab}, ΔE_{00}, and ΔWI_D data were analyzed using one-way ANOVA followed by Tukey's post-hoc test, while color parameters L^*, a^*, b^*, and C^* were analyzed using t-tests. Scanning electron microscopy images were analyzed qualitatively.

RESULTS

Shear bond strength test

The mean (± SD) shear bond strength values are given in the x-axis of Figure 1. The shear bond strength value was statistically significantly higher (29.4 ± 6.2 MPa, $p < 0.05$) for the unbleached control specimens than for any of the specimens post-bleaching. The lowest shear bond strength value (15.1 ± 4.6 MPa) was obtained for specimens that had been bleached but had no antioxidant applied. The shear

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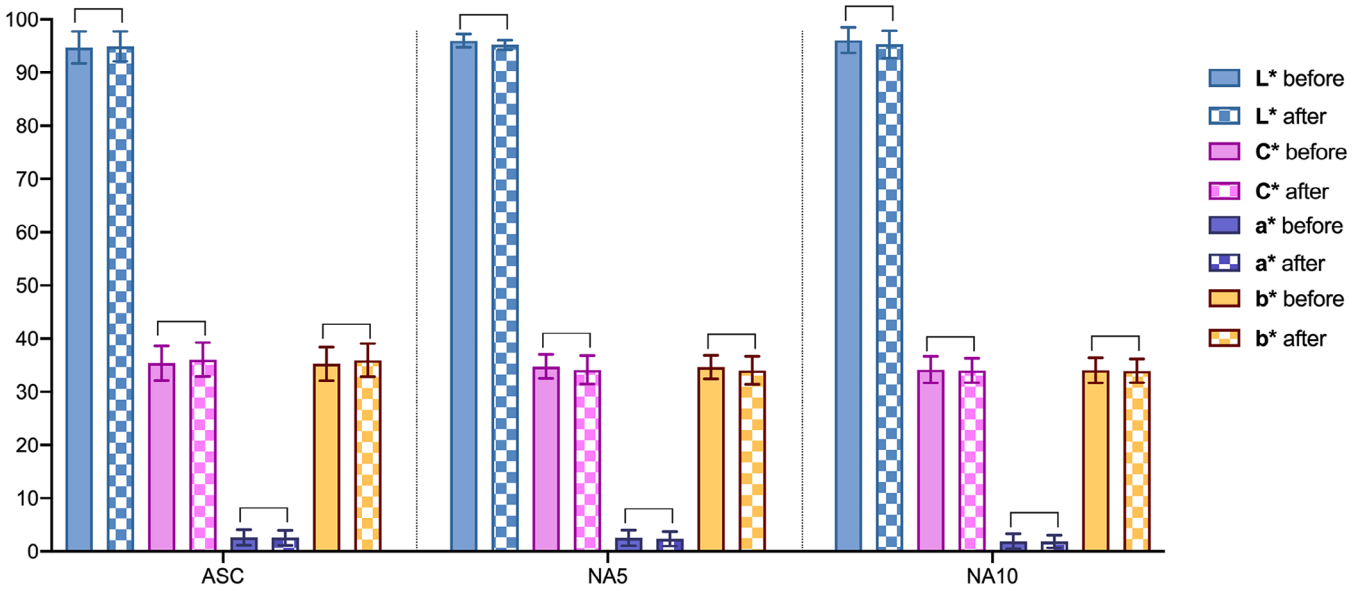

FIGURE 2 Bar chart comparing the color parameters lightness (L^*), green–red (a^*), blue–yellow (b^*), and chroma (C^*), before and after treatment of specimens of bovine enamel with one of the antioxidants 10% sodium ascorbate, 5% naringin, or 10% naringin. Bars connected with a horizontal line indicate no statistically significant difference between groups before and after treatment. ASC, bleaching with 35% hydrogen peroxide (H_2O_2) followed by treatment with 10% sodium ascorbate; NA5, bleaching with 35% H_2O_2 followed by treatment with 5% naringin; NA10, bleaching with 35% H_2O_2 followed by treatment with10% naringin.

bond strength of the specimens treated with 10% sodium ascorbate was not statistically significantly different from that for specimens treated with 5% naringin. However, specimens treated with either 10% sodium ascorbate or 5% naringin had a higher shear bond strength than did specimens that had been bleached but had no antioxidant applied, and the application of 10% naringin did not result in bond strength values that were significantly different from those of the specimens that had been bleached but had no antioxidant applied.

Color analysis

No antioxidant, at the concentrations tested, was able to alter the L^*, a^*, b^*, and C^* parameters (Figure 2). Furthermore, comparison of color variation obtained using the CIELAB system (ΔE_{ab}), with that obtained using the CIEDE2000 system (ΔE_{00}), found no statistically significant differences between the groups tested (Figure 3). Similarly, no significant difference in whiteness (ΔWI_D) was found between the groups (10% sodium ascorbate, $\Delta WI_D = -0.4 \pm 1.4$ a; 5% naringin, $\Delta WI_D = 0.7 \pm 1.4$ a; and 10% naringin, $\Delta WI_D = -0.2 \pm 2.3$ a; data not presented in Figure 3).

Failure pattern

The percentage distribution of type of fracture is shown for each group in Figure 4. Figure 5 shows representative images of each failure mode. The unbleached specimens group was the only group in which type I failure was found (Figures 4 and 5A). Specimens treated with 5% naringin and 10% naringin were the only specimens in which type II failure was found (Figures 4 and 5B). Fractures of type III and type IV were the most prevalent types of failure in all groups (Figures 4 and 5C,D).

Enamel surface morphology

Enamel surfaces of specimens that had not been bleached presented scratches similar to those promoted by sandpaper (Figure 6A). After bleaching, the surface of enamel was rougher than that of unbleached specimens (Figure 6B). Application of 10% sodium ascorbate resulted in a smoother surface than seen for specimens to which no antioxidant had been applied (Figure 6C), whereas the application of 5% or 10% naringin to enamel resulted in a similar morphology to that of non-bleached enamel (Figure 6D,E).

DISCUSSION

The reduction of bond strength between adhesive materials and dental enamel is one of the immediate outcomes caused by bleaching of enamel with H_2O_2 [7–12]. Shear bond strength values can be useful to monitor this parameter [31]. The literature highlights the superiority of shear testing over

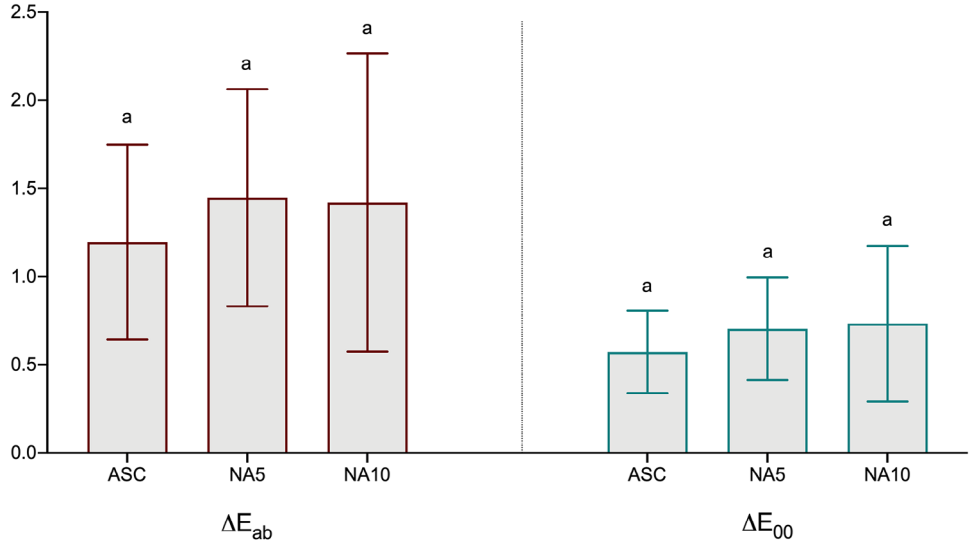

FIGURE 3 Variation of color between samples analyzed using the CIELAB system (ΔE_{ab}) and CIEDE2000 (ΔE_{00}). Specimens of bovine enamel were bleached with 35% hydrogen peroxide (H_2O_2) then treated with 10% sodium ascorbate (ASC), 5% naringin (NA5), or 10% naringin (NA10). Afterwards, color was evaluated using CIELAB (ΔE_{ab}) and CIEDE2000 (ΔE_{00}). The same lowercase letters indicate statistical similarity ($p > 0.05$).

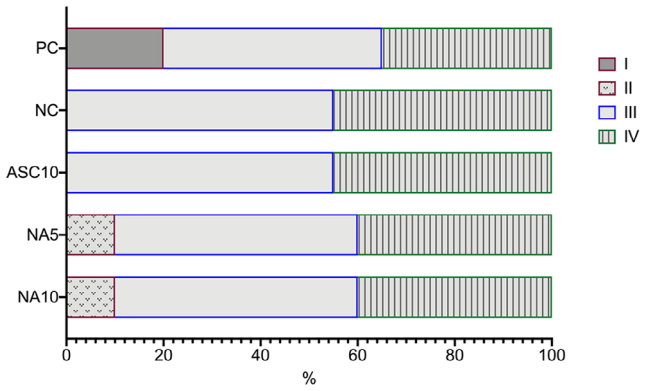

FIGURE 4 Percentage of failure modes for each group of bovine enamel specimens bleached or not bleached, then treated or not treated with different antioxidant. I, Type I (cohesive failure within the composite resin); II, Type II (adhesive failure between the composite resin and the bonding agent); III, Type III, adhesive failure between the enamel and the bonding agent; IV, Type IV (mixed failure characterized by the presence of more than one type of failure). ASC, bleaching with 35% hydrogen peroxide (H_2O_2) followed by treatment with 10% sodium ascorbate; NA5, bleaching with 35% H_2O_2 followed by treatment with 5% naringin; NA10, bleaching with 35% H_2O_2 followed by treatment with 10% naringin; NC, bleaching with 35% H_2O_2 but no antioxidant; PC, no bleaching, no antioxidant.

microtensile testing for enamel, suggesting that the preparation process for microtensile testing may lead to increased crack formation and consequently to lower bond strength values and no significant difference between different groups [32–34]. Considering the shear bond strength results obtained in the present study, the first null hypothesis was accepted because none of the antioxidant agents tested were able to reverse enamel bond strength to values similar to those observed for unbleached specimens. However, application of 5% naringin resulted in shear bond strength values similar to those obtained following application of 10% sodium ascorbate and higher than those obtained for bleached specimens with no application of antioxidant before bonding. These findings are in agreement with the literature that highlights the antioxidant potential of this bioactive compound and, consequently, demonstrates its potential to mitigate the deleterious effects of tooth bleaching by improving the micro shear bond strength in enamel because of its antioxidant and free-radical scavenging properties [35, 36].

Moradian et al. [37] evaluated the effects of three antioxidants, including quercetin, on the shear bond strength of bleached enamel and reported promising results. Quercetin, like naringin, is a flavonoid and among the groups treated with antioxidants, application of quercetin resulted in the highest shear bond strength value, being significantly different from that of the control group in which specimens were bleached with 40% H_2O_2 without the application of antioxidant. However, although the application of quercetin increased the bond strength of resin to bleached enamel, it was unable to fully restore the effects of bleaching, and shear bond strength values comparable to those of the control group (no bleaching) were not achieved [37].

The current findings also revealed that a higher concentration of naringin (10%) did not enhance antioxidant efficacy, as application of 10% naringin resulted in values similar to those obtained for the negative control. In a study by De Carvalho et al. [38], different concentrations of sodium ascorbate

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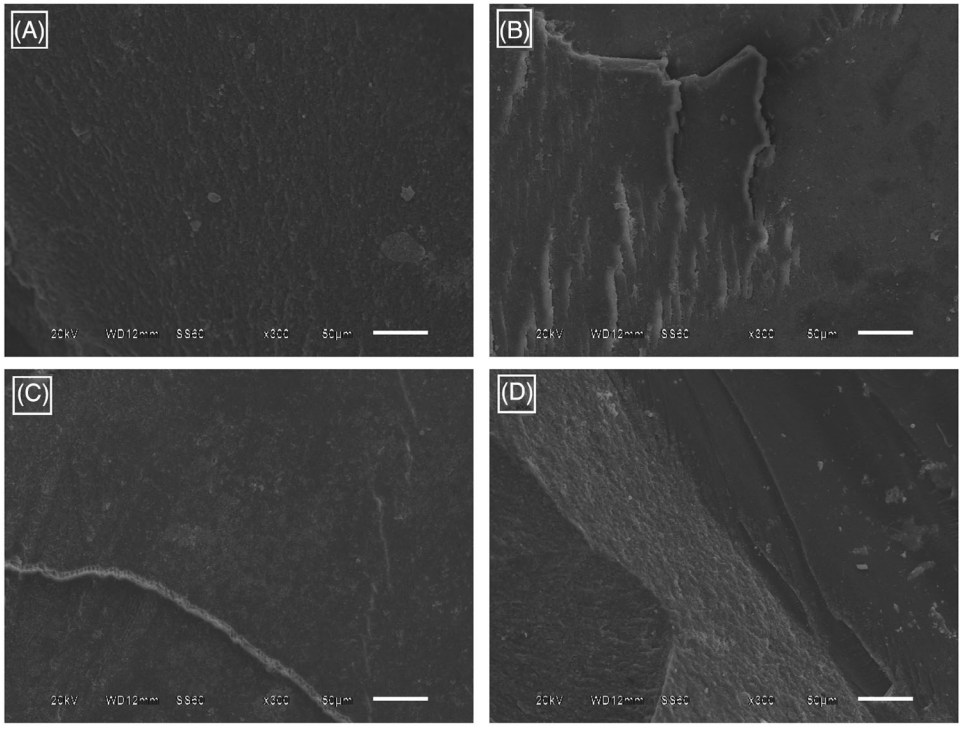

FIGURE 5 Representative scanning electron microscopy images (300× magnification) of each failure mode in bovine enamel specimens bleached or not bleached, then treated or not treated with different antioxidants. (A) Type I: cohesive failure within the resin composite. (B) Type II: adhesive failure between the resin composite and the bonding agent. (C) Type III: adhesive failure between enamel and the bonding agent. (D) Type IV: mixed failure characterized by the presence of more than one type of failure. ASC, bleaching with 35% hydrogen peroxide (H_2O_2) followed by treatment with 10% sodium ascorbate; NA5, bleaching with 35% H_2O_2 followed by treatment with 5% naringin; NA10, bleaching with 35% H_2O_2 followed by treatment with 10% naringin; NC, bleaching with 35% H_2O_2 but no treatment with antioxidant; PC, no bleaching, no antioxidant.

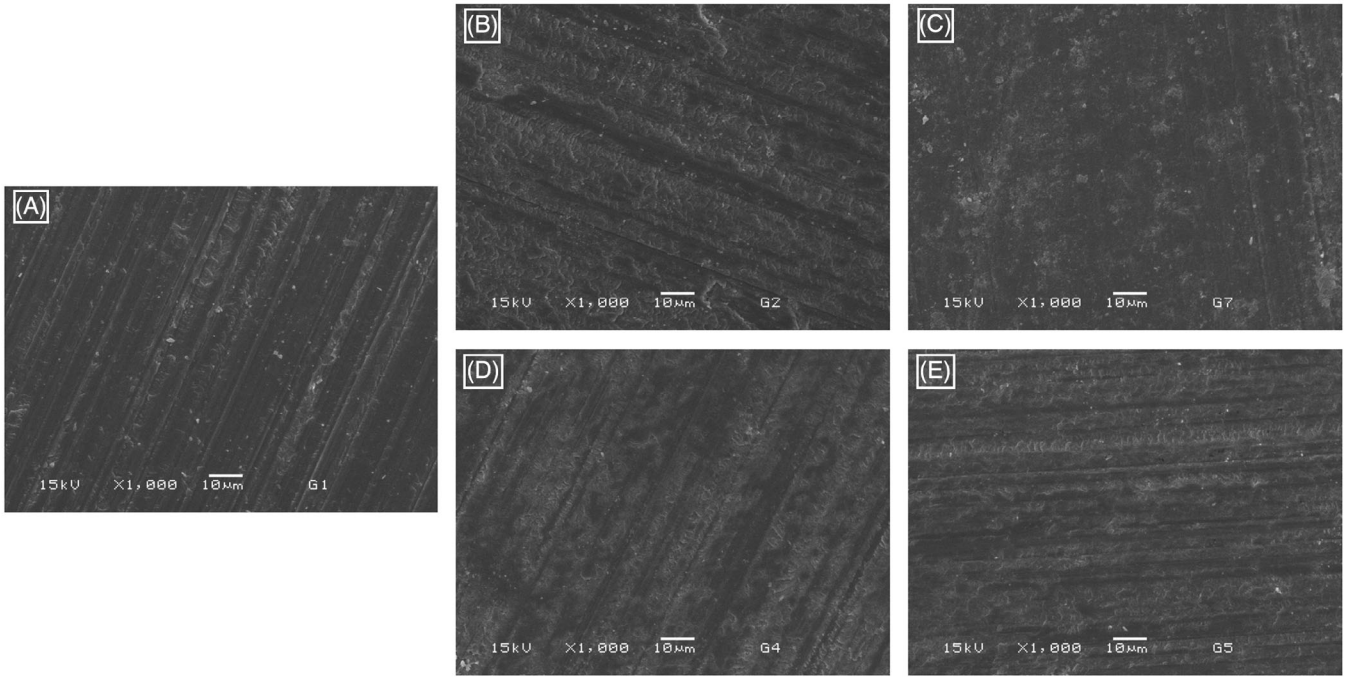

FIGURE 6 Representative scanning electron microscopy images (1000× magnification) of bovine enamel surfaces in specimens bleached or not bleached, then treated or not treated with different antioxidants. (A) No bleaching, no antioxidant (PC). (B) Bleaching with 35% H_2O_2 but no treatment with antioxidant (NC).(C) Bleaching with 35% H_2O_2 followed by treatment with 10% sodium ascorbate.(D) Bleaching with 35% H_2O_2 followed by treatment with 5% naringin (NA5). (E) Bleaching with 35% H_2O_2 followed by treatment with 10% naringin.

were tested, revealing an inverse relationship between antioxidant concentration and the ability to improve bond strength to bleached enamel. Notably, 10% sodium ascorbate applied for 60 min onto bleached enamel exhibited greater efficacy than 20% and 30% sodium ascorbate, also applied for the same duration. As sodium ascorbate is obtained in powder form, it requires to be dissolved in an aqueous medium (such as distilled water, as used in the present study) before application.

Oxygen free radicals, generated during the oxidative process induced by bleaching agents, are responsible for the reduction in bond strength of composites to oxidized substrates by interfering with the polymerization of adhesive monomers [8–13]. Antioxidant agents counteract this interference, enabling not only the effective infiltration of the bonding agent into the conditioned enamel but also its proper polymerization [12, 39, 40]. However, this antioxidant effect should not compromise the bonding mechanism. Similarly to the findings of De Carvalho et al. [38], the present study hypothesized that the increased antioxidant concentration may have contributed to the deposition of powder on the enamel surface, possibly because of the elevated powder–liquid ratio. In this context, it is possible that 10% naringin could lead to the deposition of powder on the enamel, which may not be completely removed during conditioning and rinsing, thereby negatively affecting the adhesion process. Also, it is reported that antioxidants can affect polymerization if they become incorporated into dental adhesives [41]. During radical polymerization, for camphorquinone and amine systems, antioxidants may interfere with chain initiation and propagation by donating hydrogen to the initiating species and the propagating species, ultimately terminating the chain reaction [41]. In this study, none of the antioxidant agents was added to the adhesive, but their residue might have had some effect on the polymerization mechanism of the adhesive tested.

In the present study, 10% sodium ascorbate was used as the positive control as it is considered the gold standard by Moradian et al. [37] and because such a compound was used as a control group by most of the studies investigating alternative antioxidants, as shown in a recent review on this topic [14]. It is a bioavailable form of ascorbic acid (vitamin C) and its use in food products documents its biocompatibility [42]. Several in vitro studies have applied 10% sodium ascorbate to enamel, for various periods of time, in an effort to recover the bond strength of dental enamel following bleaching with H_2O_2; positive outcomes were achieved [10, 38, 43]. The present study employed, for all groups, the application time successfully used by a previous study [28] and the findings corroborate those reported in the literature [28, 38, 40, 44]. In a study conducted by Lima et al. [28], the application of 10% sodium ascorbate to enamel for 1 min, 24 h after a bleaching procedure, was shown to potentially reverse the deleterious effects of 35% H_2O_2 and 16% carbamide peroxide. This was evidenced by a significant increase in shear bond strength, with results comparable to those of the control group (no bleaching) and to the group in which the restoration was performed after 14 days and in which no antioxidant was applied before the adhesive procedures [28]. On the other hand, some studies have pointed out some disadvantages of the use of this antioxidant, such as its low pH (1.8) [45]. An in vitro study showed that the cumulative effect of the bleaching agent (10% carbamide peroxide) and sodium ascorbate resulted in increased porosity of the enamel surface, leading to adherence of larger numbers of *Streptococcus mutans* [46]. Therefore, the present study evaluated naringin at concentrations of 5% and 10% as a viable alternative to sodium ascorbate with a higher pH. However, the enamel morphology analysis showed an inverse result, with surfaces exposed to 10% sodium ascorbate being smoother than surfaces treated with bleach but with no application of antioxidant. This can also suggest that the low pH of sodium ascorbate may interact with the enamel surface. This apparent reduction in roughness does not seem to affect enamel bond strength, as the values obtained for 10% sodium ascorbate were similar to those seen for the other antioxidant agent that had no effect on surface morphology. Yet, these results must be interpreted with caution, as no roughness evaluation or chemical analysis of the enamel surface was performed after each treatment. Also, attention should be paid when using 10% sodium ascorbate for a longer period of time (greater than 1 min) because of its low pH.

Unlike solutions of sodium ascorbate, which are transparent, solutions of naringin are a milky beige color, with the color varying proportionally to its concentration. In view of this, it was evaluated whether the application of the antioxidants tested could interfere with the immediate result of bleaching in comparison with results obtained for specimens treated with 10% sodium ascorbate. In addition to using the CIELAB system (ΔE_{ab}) with its coordinates L^*, a^*, and b^* to detect possible color alterations and consequent alteration in the effectiveness of tooth whitening, we used the CIEDE2000 system (ΔE_{00}) because of its characteristic of greater compatibility with the perception and visual acceptance of tooth color alterations [29]. Moreover, the customized whiteness index for dentistry [47] indicates whether such color shift is translated into darker (negative ΔWI_D values) or whiter (positive ΔWI_D values) teeth. Encouragingly, none of the antioxidants at the concentrations tested interfered with the values of the coordinates recorded after bleaching and the color variations obtained immediately after tooth whitening. According to recent literature in color science, there are established perceptibility and acceptability thresholds for ΔE_{00} and ΔWI_D, the values of which represent changes that would be noticeable and acceptable for the human eye [48]. The perceptibility ($\Delta E_{00} = 0.8$ and $\Delta WI_D = 0.72$ units) and acceptability ($\Delta E_{00} = 1.8$ and $\Delta WI_D = 2.60$ units) values are being considered of utmost relevance to translate the clinical relevance of

research findings [30, 49]. As, in the present study, the ΔE_{00} and ΔWI_D units of all groups were below the threshold, it may be inferred that naringin would not clinically interfere with the color and whiteness changes rendered by tooth bleaching.

Corroborating the results described in the literature, in the present study higher shear bond strength values were obtained for the unbleached specimens than for specimens from any other groups, confirming the premise that whitening significantly reduces the bond strength of adhesive materials to enamel. This fact, which is also confirmed by the reduced shear bond strength values obtained for the bleached but otherwise untreated specimens, can be attributed to incomplete infiltration of adhesives or interference of the polymerization process by residual oxygen from the whitening process [7–12]. The fracture pattern results demonstrate a high percentage of type III and type IV patterns of failure in all groups. Type I failure was found, at a lower percentage than type III and type IV failure, only in unbleached specimens, which may indicate that the bond strength to enamel was higher than the cohesive strength of the resin [50]. In addition, type II failure was found (in a very low percentage), only in the groups treated with 5% and 10% naringin, which may indicate some residual naringin in the enamel interfering with the polymerization of the adhesive layer. This interference may lead to a lower degree of conversion in the adhesive layer, compromising its mechanical strength and interface sealing [41], and ultimately reducing the clinical longevity of the restoration. Although the results are promising for 5% naringin, further studies are still needed to determine the optimal concentration and duration of application of naringin that promotes effective antioxidative capacity, without affecting the enamel properties and without compromising the polymerization reaction of resin materials.

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ACKNOWLEDGMENTS

The authors would like to thank FGM for donating the bleaching gel. This study was financed in part by FAPEMIG (APQ-01185-21), CNPq (422588/2021-0), and CAPES (001). The funding sources were not involved in study design; in the collection, analysis, and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

CONFLICT OF INTEREST STATEMENT

The authors do not have any financial interest in the companies whose materials are included in this article.

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How to cite this article: Carvalho GLM, Carneiro BT, Kury M, Fronza BM, de Castro FNAM, Picolo MZD, et al. Strengthening effect of flavonoid antioxidant on resin–enamel bond strength following tooth bleaching. Eur J Oral Sci. 2025;e70004. https://doi.org/10.1111/eos.70004