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Color Repair of a Composite Resin Restoration

GB Rauber • CMC Taguchi • ACL Padilha • RC de Re Silveira • JK Bernardon • LN Baratieri

Clinical Relevance

A color repair technique can effectively correct an unsatisfactory restoration without replacement of the entire restoration, thus avoiding unnecessary removal of healthy tooth structure.

SUMMARY

Fractured teeth with both enamel and dentin involvement might be treated with adhesive composite resin restorations. In cases where a perfect color match between the composite restoration and the remaining tooth structure is not achieved, a repair might be carried out to correct the color of restoration. This proce-

dures avoids the restoration replacement, preserving tooth structure without compromising the esthetic outcome.

INTRODUCTION

Tooth fractures caused by falls or sports injuries are the most common forms of dental trauma.¹ They mostly involve the anterior permanent dentition, affecting around 15% of the population under 18 years.² Crown fractures are classified¹ as simple when they are restricted to enamel and dentin and complex when pulp and/or periodontal injury occurs.

Complex fractures represent between 0.3% and 0.5% of all tooth fractures.^{3,4} In these situations, a multidisciplinary approach is required to reestablish the biologic width, treat the pulpal tissue, and restore the tooth.^{4,5} Simple fractures, when restricted to enamel, do not require restorative treatment. However, when dentin is involved, the tooth requires a restoration due to the hypersensitivity caused by the dentin exposure.

Treatment options include the reattachment of the fragment^{5,6} and direct adhesive restoration with composite resin. Whenever possible, the fragment should be reattached and the fractured tooth restored with its own structure. The reattachment provides optimal form, texture, and color. When the tooth fragment is not available or reattachment is not feasible to treat a fracture involving less than two-thirds of the clinical crown, an adhesive direct

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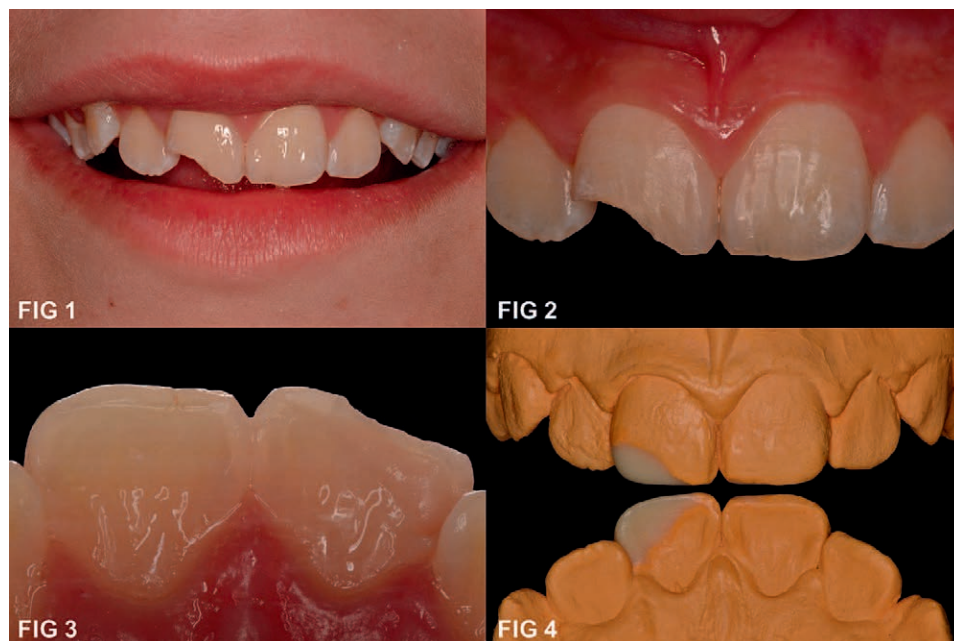


Figure 1. Right maxillary central incisor showing coronal fracture.

Figure 2. Intraoral view of the fractured tooth.

Figure 3. Palatal view of the fractured tooth.

Figure 4. Facial and palatal view of the diagnostic waxing.

restoration with composite resin is the treatment of choice.^{7,8}

The natural layering technique is a popular way to mimic the optical properties of the natural tooth using composite resin increments. However, achieving optimal esthetics is a challenge since the involved structures have different optical characteristics. Now that contemporary materials can closely match the optical characteristics of the natural tooth, clinicians must have a good understanding of how enamel and dentin interact with light.⁹⁻¹²

Because the enamel and dentin are of different thicknesses, each third of the tooth has specific chromatic properties. The cervical third is characterized by higher saturation because of the increased dentin thickness and thin enamel. As a result, the chromatic expression is minimally influenced by enamel, and the color of the dentin dominates. This explains the higher saturation and intermediate value in this third. The middle third has a large volume of dentin and thick enamel, attenuating the chroma of the dentin and increasing its value. The incisal third has a thin layer of dentin in the form of mamelons, and the enamel layer dominates. The opalescent halo and the opaque halo are found in the incisal third. The opalescent halo is the result of enamel opalescence, and the opaque halo, with its whitish-orange color, is the result of the interaction of light with enamel at the incisal edge.⁹⁻¹⁴

The natural layering technique reproduces the optical characteristics of natural dentition by using

composite resin increments with different translucencies.^{13,14} In this technique, the composite resin is placed in three layers: an internal layer, an intermediate layer, and an external layer.⁹ The internal layer is made of a dentin-shade composite resin and is responsible for the chroma and the dispersion of light. The intermediate layer, located in the incisal third, reproduces the optical characteristics that occur in the natural enamel, creating the opalescent and the opaque halo. The external layer is made with an enamel-shade composite resin and sets the value of the restoration; it also replicates fluorescence.⁹

Even with excellent materials and a well-established technique, the restoration may have an unsatisfactory outcome and require a modification. Repairing a composite resin restoration is considered a minimally invasive procedure since in most situations restorative material is added with minimal reduction of the restoration or tooth structure.¹⁵

The goal of this clinical report is to describe the color repair of the restoration of a fractured maxillary central incisor, the esthetic outcome of which was unsatisfactory because of a poor color match.

CLINICAL TECHNIQUE REPORT

A nine-year-old boy presented with a fracture in the right maxillary central incisor due to trauma during a soccer match at school (Figure 1). Clinical and radiographic examinations were performed along

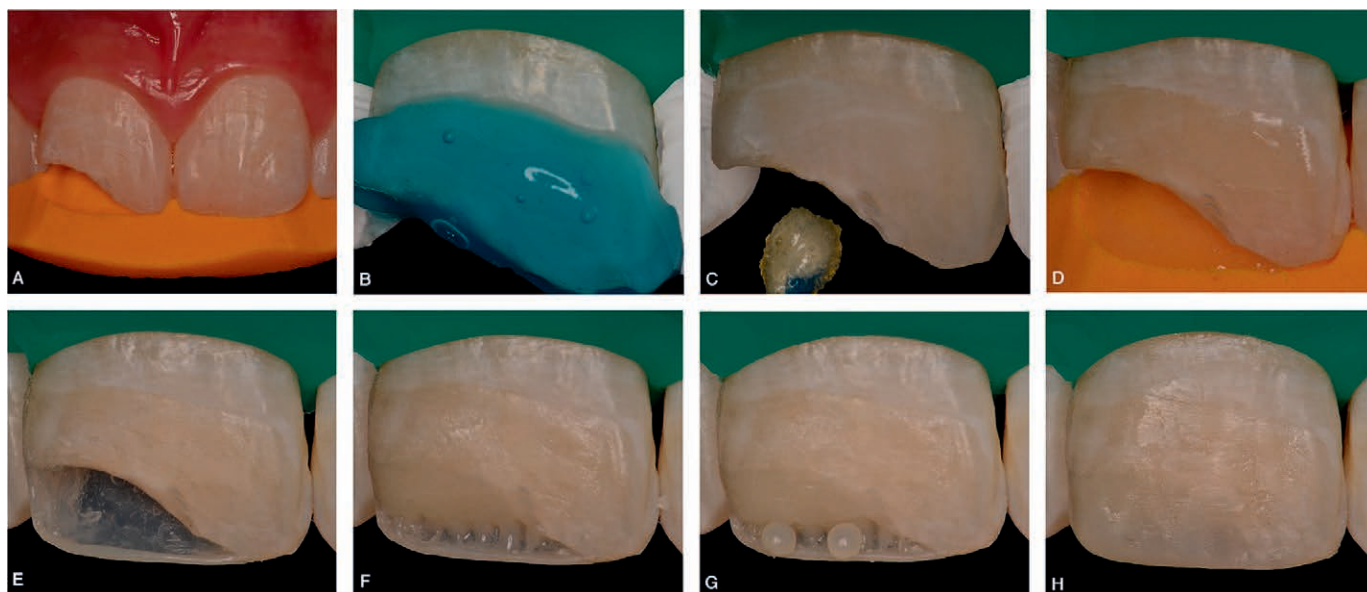


Figure 5. (A) Silicone index fabricated from the cast in position. (B) Acid etching. (C) Application of the adhesive system. (D) Placement of the palatal enamel increment through the silicone index. (E) Replicating the opaque halo with a dentin-shade composite resin. (F) Dentin increments being placed. The mamelons were carved at this stage. (G) Placement of the opalescent-shade composite resin. (H) Placement of the enamel-shade composite resin.

with intra and extraoral photographs. The examinations showed a horizontal coronal fracture in the middle third of the tooth, with no pulpal involvement (Figures 2 and 3). The vitality of the tooth was determined with a positive response to cold.

Emergency treatment consisted of a provisional composite resin restoration. Prior to the restoration of the fractured tooth, impressions of both the maxillary and the mandibular arches were taken to make a diagnostic waxing (Figure 4) and to allow the fabrication of a silicone palatal index (Figure 5A). After one week, dental prophylaxis and shade selection were carried out, as was a trial restoration to determine the thickness of the composite resin increments that would be used.

The restorative procedure was made under rubber dam isolation, and the natural layering technique was used with a nanohybrid composite resin (IPS Empress Direct, Ivoclar Vivadent, Schaan, Liechtenstein). The silicone index was positioned to restore the palatal enamel with an enamel-shade (A3) composite resin (Figure 5D). The opaque halo was then made with a dentin-shade (A3.5) composite resin (Figure 5E). The bulk of the restoration was established with dentin composite resin, replicating the correct tooth angulation and the different dentin thicknesses of each third of the tooth. At this stage, the dentin mamelons were shaped at the incisal edge (Figure 5F). The opalescent halo was reproduced with an opalescent-shade composite resin, placed in

the spaces between the mamelons (Figure 5G). The restoration was finished with the placement of the enamel-shade composite resin (Figure 5H), reproducing the enamel and its surface texture.

After one week, the patient returned and reported high satisfaction with the outcome and no hypersensitivity. However, the value of the restoration did not match that of the remaining tooth structure. Additionally, the restoration had a grayish color, and the opalescent halo was different from that of the contralateral tooth (Figure 6). To improve the color match with the remaining tooth structure, a color repair procedure^{16,17} was recommended. For this purpose, 0.7 mm of the superficial enamel composite resin was removed with a diamond bur¹⁶ (#3216, Microdont, São Paulo, Brazil) to create space for a new layer of a dentin-shade composite resin. A slot was made in the incisal edge in the region of the opalescent halo with a round diamond bur (#1011, Microdont) (Figure 7). The surrounding enamel was then etched, while the composite resin was cleaned by applying 37% phosphoric acid for 30 seconds. A silane-coupling agent (Monobond N, Ivoclar Vivadent) and the adhesive system were applied. The opalescent-shade composite resin was placed into the slot (Figure 8). Then a greater amount of the dentin-shade composite resin was placed, extending beyond the tooth/restoration interface (Figure 9). Finally, a thin layer of the enamel-shade composite resin was placed (Figure 10).

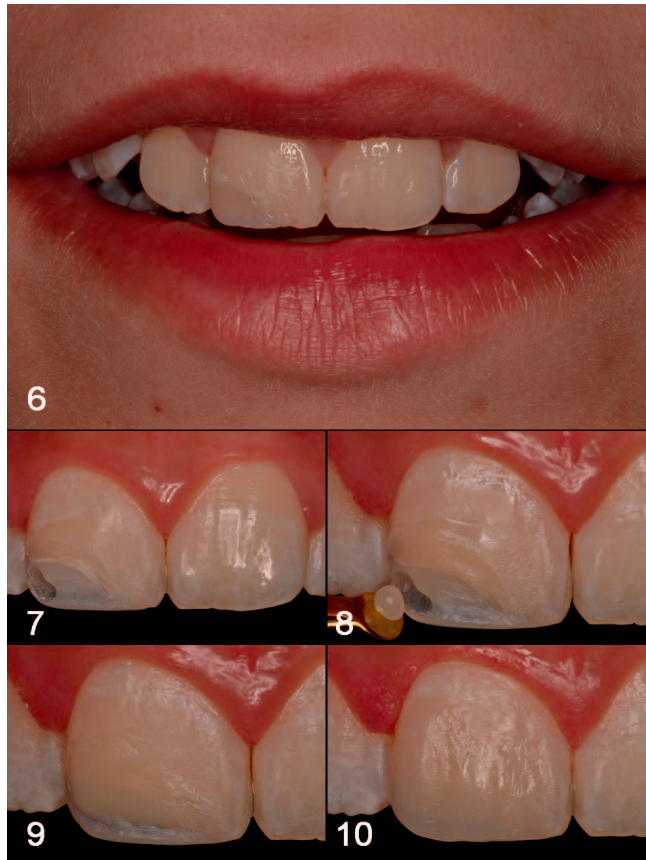


Figure 6. Outcome after one week. The color match was not satisfactory.
Figure 7. Reduction of the unsatisfactory restoration.
Figure 8. Placement of the opalescent-shade increment.
Figure 9. Placement of the dentin-shade increment. To avoid the perception of the junction, this increment was extended beyond the tooth/restoration interface.
Figure 10. Placement of the last increment with enamel-shade composite resin.

The finishing and polishing procedures were accomplished in one week (Figure 11). After the procedure, a satisfactory match was observed between the remaining tooth and the repaired restoration (Figure 12). A mouth guard was fabricated to protect the restoration and prevent future dental trauma during the patient's sports activities (Figures 13 and 14).³¹⁻³⁴

The materials and equipment used in this technique are presented in Table 1.

DISCUSSION

Long-lasting composite resin restorations can be made with a minimally invasive approach thanks to advances in the development of restorative materials with improved mechanical properties.¹⁸ The major challenges of the technique are related to selecting



Figure 11. Intraoral view after the repair; the color of the restoration matches the remaining tooth structure.
Figure 12. Definitive outcome.
Figure 13. Mouth guard in position.
Figure 14. Mouth guard in use.

Table 1: *Materials and Equipment*

Product	Manufacturer
Dental dam rubber dam	Hygenic Akron, OH, USA
Power etching 37% phosphoric acid gel	BM4 Palhoça, Brazil
Tetric N-Bond adhesive system	Ivoclar Vivadent Schaan, Liechtenstein
IPS Empress Direct nanohybrid composite resin	Ivoclar Vivadent
KG Brush disposable applicator	KG Sorensen São Paulo, Brazil
Radii Cal LED unit	SDI Victoria, Australia
Sof-lex polishing disc	3M ESPE St. Paul, MN, USA
Diamond Flex polishing disc	FGM Joinville SC, Brazil
Diamond Excel felt disc	FGM
Diamond bur #3216 and #1011	Microdont São Paulo, Brazil
Polyshok EVA sheets	Sportsguard Laboratories Kent, OH, USA
Scotch-Brite Discs (abrasive discs)	3M ESPE
Monobond N (silane-coupling agent)	Ivoclar Vivadent
Virtual (impression material)	Ivoclar Vivadent

the color, masking the fracture line, and reproducing form, color, and texture.

A strategy to make the procedure more predictable is making a trial restoration, using the same composite resin increments that will be used in the definitive restoration together with the layering technique. However, even with adequate materials, a well-established technique, and the trial restoration, the outcome might still be unsatisfactory.

For the patient illustrated, the grayish color of the restoration was probably because the enamel-shade composite layer was thicker than 1 mm. Excessively thick enamel-shade composite layers have been reported to result in reduced translucency and value.^{19,20} Therefore, the dentin-shade composite resin layer needed to be thicker than the enamel one to mask the fracture line and provide correct value.

The best technique to correct an unsatisfactory restoration is still not well established. Hickel and others²¹ suggest four options for treating unsatisfactory restorations: monitoring, polishing, repair, or replacement.

In daily practice, unsatisfactory restorations are commonly replaced if they cannot be corrected with a less invasive approach.²¹ However, replacing a restoration means loss of healthy tooth structure, as removing an adhesive restoration without removing healthy surrounding tissue is difficult. The removal of additional tooth structure weakens the tooth and may injure the pulp, resulting in a repetitive restorative circle.²²

Not all unsatisfactory restorations must be replaced. Composite resin repairs are a minimally invasive approach, as often they consist of adding restorative material, with or without reduction of the restoration and/or tooth structure.¹⁵ Thus, the advantages of the repair technique are the conservation of tooth structure, low risk of pulp injury, no need for anesthesia, low cost, and minimal chair-side time when compared with a complete replacement; also, repair is well accepted by patients²³ and increases the longevity of the restoration.²⁴

To enhance the bond to the repair composite resin, different surface treatments have been suggested. They include airborne-particle abrasion, treatment with phosphoric acid and/or hydrofluoric acid, application of a silane-coupling agent, and roughening the surface with diamond burs.²⁵⁻³⁰ Although all these procedures have been described, definitive outcome data are lacking.²⁹ In this case report, the surface of the composite resin was roughened with a diamond bur, and the bonding procedure was then performed with a silane-coupling agent and an adhesive system.³⁰ The composite resins selected for repair were the same ones used for the initial restoration. However, the thickness of the dentin composite resin was increased, and the thickness of the enamel composite resin was decreased. In this way, it was possible to correct the value of the restoration and to completely mask the fracture line. The repair protocol allowed a satisfactory outcome without removing the entire restoration.¹⁶

Advantages

The advantages of this composite resin repair technique are as follows:

- Repair is less costly and less time consuming than replacing the restoration; also, the technique is nondestructive and easy to execute.
- The technique is conservative and preserves tooth structure.
- The procedure is painless and well accepted by the patient.

Disadvantages

The disadvantages of this composite resin repair technique are as follows:

- No repair technique has yet achieved optimum bond strength with the existing restoration, and early failure of the repaired restoration might occur.

CONCLUSIONS

The presented repair technique effectively corrected an unsatisfactory restoration without replacing it entirely, thus avoiding the unnecessary removal of healthy tooth structure.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Federal University of Santa Catarina, Brazil.

Conflict of Interest

The authors of this article 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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Seven-year Follow-up of Resin Infiltration Treatment on Noncavitated Proximal Caries

HK Yoo • SH Kim • SI Kim • YS Shin • SJ Shin • JW Park

Clinical Relevance

Clinicians should consider resin infiltration as a good treatment option of noncavitated proximal caries carefully.

SUMMARY

The purpose of this case report is to present success and failure outcomes of seven-year follow-up of resin infiltration treatment (RIT) used for the proximal caries of maxillary premolars. Although resin infiltration can be a good option for micro-invasive treatment, long-term follow-up data are not sufficient,

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and the outcome of this technique can be affected by factors such as technique sensitivity of procedure, patient's caries risk, and depth of caries progression. Therefore, careful case selection, application, and follow-up are needed.

INTRODUCTION

Dental caries is a disease of tooth structures and may result in cavity formation. Conventional invasive treatment for proximal caries is to remove caries lesion and fill the cavity with restorative materials.¹ Cavitated lesions should be restored through invasive treatment because they cannot be cleaned effectively by patients.² The caries removal and restoration put the patient in the restorative cycle. This is because, considering the limited longevity of restorations, they may need to be replaced and result in larger restorations.^{2,3} Therefore, in the case of noncavitated lesions, alternative approaches such as noninvasive treatment and micro-invasive treatment for proximal caries lesions were developed. Noninvasive treatment is managing rather than removing caries lesions and includes things such as biofilm control, antibacterial treatment, and remineralization. Micro-invasive treatment is conditioning the tooth surface before the treatment of the caries lesion. There are two kinds of micro-invasive treatment: sealing and resin infiltration. Sealing is



Figure 1. Preoperative radiograph and clinical photograph. On radiograph, proximal caries were found between the maxillary right first and second premolars (between #4 and #5).

performed to prevent dental caries in the pits and fissures on occlusal or pitted tooth surfaces. It creates an outer barrier to protect, from the outside, bacterial acid attack, and loss of mineral from within the tooth.¹ On the other hand, resin infiltration creates an internal barrier in the proximal and smooth surface caries lesion, so retention loss of this barrier is unlikely to occur, unlike sealing.^{1,4}

The concept of resin infiltration treatment (RIT) was introduced more than 40 years ago.^{5,6} To enhance the penetration of resin into the lesion, the method of using highly permeable resin was first introduced in the mid-2000s.⁷⁻⁹ A product called ICON (DMG, Hamburg, Germany) was released, which consists of low-viscosity resin—triethylene glycol dimethacrylate (TEGDMA). This is a more invasive method than noninvasive treatment such as fluoride treatment for the inhibition of early caries. In RIT, the demineralized surface is treated with hydrochloric acid to increase the micro-porosity,¹⁰ and then water is completely removed with alcohol

to enhance the penetration of the low-viscosity resin.¹¹ This is a new concept of treatment that inhibits the progression of caries by creating an internal barrier.^{1,4} Several people expressed concern about the efficacy of RIT because the acid conditioning for RIT can debilitate the residual strongest component of the teeth; they insisted that remineralization or restorations are more effective for caries management than RIT.¹² However, with careful case selection, procedure application, and close follow-up accompanying RIT, RIT can be a good treatment option as a micro-invasive treatment for caries lesions.

According to the indications claimed by the manufacturer, RIT can be used for proximal dentin caries up to the outer third of the dentin.¹³ Several studies have reported clinical success on these dentin caries up to the outer third. However, most reports of success were short-term results, observed within 3 years.¹⁴⁻¹⁷ Therefore, the purpose of this case report is to present success and failure outcomes of a long-term, seven-year follow-up of RIT used on the proximal caries of maxillary premolars.

CASE REPORT

A 35-year-old male patient came to the Department of Conservative Dentistry for a dental checkup. He had no discomfort, but on periapical radiographic and clinical examination, he had multiple caries. On the maxillary first and second premolars were proximal dental caries limited to the enamel layer (Figure 1).

On #4 and #5, prophylactic treatment, beyond just monitoring the lesions, was needed considering the patient's high caries risk. We excluded placing direct resin restorations, which would have resulted in more tooth loss than the caries area that was limited to the enamel layer. We elected to do resin infiltration on the caries. After application of an orthodontic elastic ring separator for two days to improve accessibility, we used ICON, following the manufacturer's instructions.

A rubber dam and wedge were applied, and ICON etch (15% hydrochloric acid) was applied for two minutes on the #4 and #5 proximal area. After water rinsing for 30 seconds and air drying, the water was removed thoroughly by ICON dry (99% ethanol). The resin infiltration was applied with a proximal nozzle for three minutes and light cured with Mini LED Satelec (1250 mW/cm²; Acteon Group, Merignac, France) for 40 seconds for each

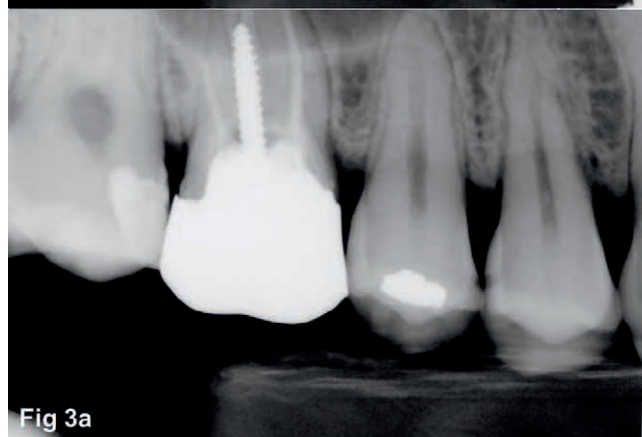
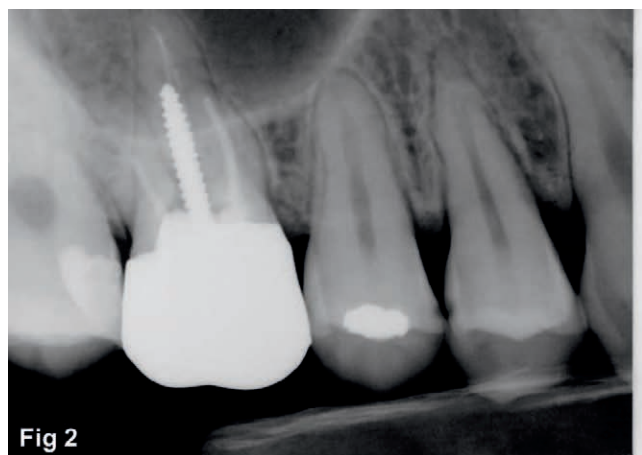


Figure 2. Postoperative radiograph after resin infiltration on #4 and #5 proximal area. There was no difference on the radiograph because infiltrated resin has no radiopaque filler.

Figure 3. (a) Eight-month follow-up on radiograph. (b) Eight-month follow-up on clinical photo. No change was found.

surface. Secondary resin infiltration was applied for one minute and light cured for 40 seconds (Figure 2).

The patient came back after eight months, and no change was observed on the bitewing radiograph or clinically (Figures 3a, 3b). After the visit, he did not return for more than five years; at six

years, he came to our clinic. He was in no discomfort, but the #5 distal proximal caries had progressed deeper into the dentin layer on radiographic and clinical examination (Figures 4a, 4b).

After the examination, we decided to perform a direct resin restoration on the #5 distal area. Under infiltration anesthesia, the caries was removed. When the enamel layer was removed, a widespread caries lesion in the dentin was observed, whereas the #4 mesial proximal caries had not progressed (Figure 5). It was discolored and dark, but the surface was intact, so we just polished the tooth with a silicone rubber point (Jiffy rubber, Ultradent Products Inc, South Jordan, UT, USA). On the #5 distal area, we performed a resin restoration with Tetric-N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) after applying 37% phosphoric acid etching for 10 seconds, Clearfil SE bond (Kuraray, Kurashiki, Japan) application, and light curing with Mini LED Satelec for 10 seconds on bonding application. Tetric-N-Ceram was light cured for 40 seconds (Figure 6).

DISCUSSION

The principle of resin infiltration is penetration of low-viscosity resin (TEGDMA) into the subsurface pores to form hybrid enamel. This hybrid enamel stops demineralization, stabilizes the caries lesion, and acts as a superficial mechanical barrier to inhibit outer bacterial colonization and trap bacteria in the lesion.^{4,18}

Despite performing the same procedure on caries lesions close to each other (#4 mesial, #5 distal) simultaneously in the same patient's maxillary arch, outcomes of seven-year results were different (Figure 7). These different outcomes may have resulted from the degree of caries progression and resin infiltration. In this case, the #5 distal caries lesion had progressed more than the #4 mesial caries lesion, and it came close to the dentin-enamel junction (DEJ) (Figure 1). Dentin is more sensitive to caries than enamel, and furthermore, dentin is wet; this property restricts resin penetration into dentin because displacement of water is a prerequisite of resin infiltration.¹¹ Because the effect of caries inhibition depends on the penetration depth of resin, this effect would be restricted in deep caries lesions beyond the DEJ.

To overcome this limitation, Paris and others suggested that the resin penetration time should be longer than three minutes in caries lesions over

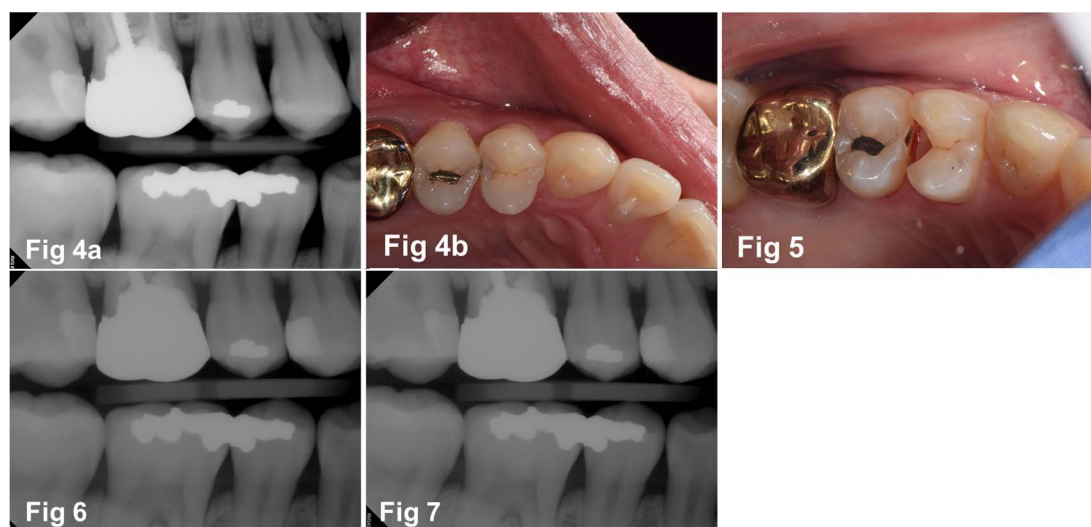


Figure 4. (a) Six-year follow-up on radiograph. (b) Six-year follow-up on clinical photo. #4 mesial proximal caries had not progressed, but the #5 distal proximal caries had progressed to the dentin area, and a distinct color change was observed.

Figure 5. The #5 distal caries was removed, and the #4 proximal surface was discolored but had intact surface, showing that #4 caries had not progressed.

Figure 6. Postoperative radiograph after resin filling on #5.

Figure 7. Seven-year follow-up. The #4 mesial proximal caries was maintained and had not progressed after seven-year follow-up.

400 μm in the primary tooth.¹⁹ The manufacturer's guidelines recommend a three-minute resin infiltration time, and, following the results of this case report, this time might be considered insufficient in permanent teeth with a caries lesion near the DEJ. Because primary teeth are less mineralized and more porous in structure,²⁰ this makes for a higher diffusion coefficient and rapid infiltration. Therefore, a variation of the procedure such as increased resin infiltration time might be considered according to the depth of caries progression. To obtain more evidence-based results, a randomized clinical trial should be considered in the future.

If this patient had been followed up periodically, additional caries progression could have been detected earlier. Because he was not seen for 5 years, he missed the proper treatment time, and wider caries had to be removed. Therefore, the importance of periodic follow-up should be emphasized to patients.

When the clinician decides to use resin infiltration treatment, he or she should consider many factors, such as the state of the caries progression, risk of further caries, and patient compliance. It is difficult for the clinician to assess the surface zone formation in caries lesions to prevent caries progression. Therefore, decisions about caries lesion management and whether to follow-up or

turn to RIT or restoration should be carefully made. Also, periodic follow-up is essential for successful RIT.

SUMMARY

Although resin infiltration can be a good treatment option to inhibit the early progression of caries lesions as a micro-invasive treatment, long-term follow-up data have not accumulated yet. In addition, outcomes of resin infiltration can be affected by factors such as the depth of caries progression, treatment procedure, and compliance of patients. Therefore, careful case selection, application, and follow-up are necessary.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Gangnam Severance Hospital, South Korea.

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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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Clinical Evaluation of Different Delivery Methods of At-Home Bleaching Gels Composed of 10% Hydrogen Peroxide

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AD Loguercio • MF Costa Lima Bandeira

Clinical Relevance

All 10% hydrogen peroxide systems showed similar whitening; however, bleaching strips and the prefilled disposable trays showed lower adverse effects.

SUMMARY

Objectives: This study aimed to compare the tooth sensitivity, gingival irritation, and

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bleaching efficacy of at-home whitening performed with 10% hydrogen peroxide (HP) using a conventional tray-delivered system or two different bleaching systems (strips or prefilled disposable trays).

Methods and Materials: Sixty patients, with maxillary incisors darker than A2 were selected for this single-blind, parallel randomized clinical trial. Teeth were bleached during 14 days with a 30-minute gel contact with teeth per day. The 10% HP was delivered in a bleaching tray (White Class, FGM) in strips (White Strips, Oral-B) or prefilled disposable trays (Opalescence Go, Ultradent). The color changes were evaluated by subjective (Vita Classical and Vita Bleachedguide) and objective (Easyshade Spectrophotometer) methods at baseline and 30 days after the second bleaching session. Tooth sensitivity was recorded during 14 days with a five-point numeric rating scale (NRS) and 0-10 visual analog scale (VAS). The risk of gingival irritation was also recorded during 14 days on a dichotomous scale. All data were submitted to appropriate statistical analysis ($\alpha=0.05$).

Results: No significant difference was observed in the risks of tooth sensitivity among groups ($p>0.09$). However, the conventional bleaching tray produced a higher intensity of tooth sensitivity when compared with the strips and prefilled disposable tray systems ($p<0.04$). Regarding gingival irritation, the prefilled disposable tray system showed a lower risk of gingival irritation when compared with the conventional bleaching tray ($p=0.003$). Significant whitening was observed in all groups after 30 days of clinical evaluation with no significant difference between them ($p>0.06$).

Conclusions: All 10% HP bleaching systems showed similar whitening after a 14-day use. However, the strips and prefilled disposable trays produced lower intensity of tooth sensitivity than the conventional bleaching tray system. The prefilled disposable tray produced lower risk of gingival irritation when compared to the conventional bleaching tray.

INTRODUCTION

Since the introduction of the at-home bleaching technique using 10% carbamide peroxide (CP) overnight,¹ long-term successful results have been reported.^{2,3} Even though at-home bleaching is the most frequently recommended treatment, some patients do not adapt to the technique because they need to wear the bleaching tray for longer periods of time. More comfortable methods, with the same efficacy, are desired by these patients.

In view of this market need, some companies have introduced bleaching strips or prefilled disposable trays that deliver hydrogen peroxide (HP) products for at-home bleaching. The manufacturer claims that HP-based products could be used for shorter periods of time due to the fast HP delivery.⁴⁻⁷ The amount of active HP after one hour for CP gels is around 60%,⁴ but for HP products this amount is lower than 30%.⁶

This can be seen as advantageous for those patients who do not want to wear the bleaching tray for prolonged periods of time. Also, bleaching strips and prefilled disposable tray systems are comfortable, and they have a low cost, as the professional does not need to fabricate a bleaching custom tray (impression, model buildup, tray fabrication, and so on) and the procedure can be done at home.⁸⁻¹⁰

Several clinical studies that compared at-home bleaching with CP- and HP-based products showed that the different delivery systems do not impact

effectiveness and do not increase side effects, such as tooth sensitivity (TS), with the advantage that HP-based products were used for shorter periods when compared with CP-based products in equivalent concentrations.¹⁰⁻¹²

However, only a few studies have compared HP-based products delivered through different methods.⁸⁻¹⁰ These studies did not observe whitening, TS, and gingival irritation between different delivery methods of HP. Also, a closer view of these studies showed that the bleaching agents were usually applied in adults.^{9,10,12-14} However, it is necessary to evaluate these different techniques in young patients, mainly because of the higher importance of smile esthetics in social perception during childhood and adolescence,¹⁵ which is the reason for a significant increase over time of adolescent patients' desires for bleaching,^{16,17} and also because of the scarce number of clinical studies applying at-home bleaching in this specific population.^{9,18,19}

To our knowledge, no study so far has compared, in a single randomized clinical trial, at-home bleaching systems delivered in different ways to young patients. Only such a comparison will allow clinicians to decide which systems possess good whitening efficacy and fewer side effects, such as TS and gingival irritation.

Therefore, the aim of this single-blind, controlled, and parallel randomized clinical trial was to evaluate the absolute risk of TS (primary outcome) of at-home bleaching performed with 10% HP using a conventional tray-delivered system in comparison with bleaching strips or prefilled disposable trays in young patients. Also, the intensity of TS, risk and intensity of gingival irritation, and bleaching effectiveness were evaluated as secondary outcomes. The hypothesis was that bleaching strips or prefilled disposable trays would reduce the absolute risk of postoperative TS when compared to conventional tray-delivered systems. Also, the intensity of TS and absolute risk and intensity of gingival irritation would be lower in the bleaching strips or prefilled disposable trays when compared to conventional tray-delivered systems. Regarding bleaching effectiveness, no differences would be expected when the three systems were compared.

METHODS AND MATERIALS

This clinical investigation was approved by the Scientific Review Committee and by the Committee for the Protection of Human Subjects of the local university (#46945715.6.0000.5020), and it was also

registered in the REBEC (#RBR-8QDF7T). We prepared this article using the protocol established by the Consolidated Standards of Reporting Trials statement. This study was performed between June 2015 and July 2016 at the Federal University of Amazonas. Two weeks before the bleaching procedures, all the volunteers received dental prophylaxis with pumice and water in rubber cups and signed informed consent forms.

Parents and/or guardians gave the consent to patients under 18 years of age to take part in the study. Patients from ages 15 to 18 were also present during these explanations, but they were not the ones responsible for the decision to participate in the clinical trial.

Study Design

This was a single-blind, controlled, and parallel randomized clinical trial in which the evaluator was blinded to the group assignment.

Eligibility Criteria

Patients included in this clinical trial were between 15 and 20 years old and had good general and oral health. The participants had six caries-free maxillary anterior teeth without restorations and periodontal disease. The maxillary central incisors were shade A2 or darker as judged by comparison with a value-oriented shade guide (Vita Classical, Vita Zahnfabrik, Bad Säckingen, Germany). Two calibrated investigators performed this evaluation. They were required to have an agreement of at least 85% (kappa statistic) before beginning the study evaluation (data not shown).

Participants with anterior restorations, dental prosthesis, orthodontics apparatus, or severe internal tooth discoloration (tetracycline stains, fluorosis, and pulpless teeth) were not included in the study. Additionally, pregnant/lactating women, participants with any other pathology that could cause sensitivity (such as recession, dentin exposure, or the presence of visible cracks in teeth), smokers, bruxers, or participants who had previously undergone tooth-whitening procedures were also excluded.

Sample Size Calculation

The primary outcome of this study was the absolute risk of TS. A preliminary study with 20 patients using the tray-delivered 10% HP gel (White Class Calcium, FGM, Joinville, Brazil) showed an absolute risk of TS of 70%. Thus, a minimal sample size of 20 participants per group was required to have an 80%

chance of detecting (as significant at the two-sided 5% level) a decrease in the primary outcome measure from 70% to 30% using a low concentration HP gel.

Randomization and Allocation Concealment

We used blocked randomization (block sizes of three and six) with an equal allocation ratio for the three groups. The randomization list was prepared using the software freely available online (<http://www.sealedenvelope.com>). Opaque, sealed, and consecutively numbered envelopes containing the identification of the groups were prepared by a third person not involved in the research protocol. These envelopes were opened immediately before the beginning of the bleaching procedure.

Study Intervention

In this study, we evaluated a conventional tray-delivered 10% HP bleaching system (White Class Calcium, FGM) in comparison with two different bleaching systems containing 10% HP gel: bleaching strips (White Strips, Oral-B, Procter & Gamble, Cincinnati, OH, USA) and prefilled disposable trays (Opalescence GO, Ultradent Products, Inc, South Jordan, UT, USA) applied to the maxillary anterior teeth.

In patients using the conventional bleaching tray, custom-fitted trays were fabricated. Alginate impressions (Avagel, Dentsply, Petrópolis, RJ, Brazil) were made of each subject's maxillary and mandibular arches, and after disinfection these were filled with dental stone (Asfer, Asfer Indústria Química Ltda, São Caetano do Sul, SP, Brazil). After 24 hours, a 0.9-mm soft vinyl material (Whiteness Placas para Moldeiras, FGM) was used to fabricate in a Plastivac P7 (BioArt, São Carlos, SP, Brazil) the custom-fitted trays that would hold the whitening gel.

Instructions were given to the participants regarding placement of the gel in the tray and the tray over the teeth. The excess material from the labial and lingual surfaces was trimmed to 1 mm from the gingival junction. We instructed all participants to test the fit of the bleaching tray with regard to adaptation before starting the clinical study, followed by wearing the tray with the bleaching agent for 30 minutes once a day for 14 days. We instructed the participants to remove the trays after each bleaching period, wash them with water, and brush their teeth as usual.

The patients from the bleaching strips or tray-delivered groups received instructions on how to

apply the bleaching strips and how to use them. The usage time was the same for the conventional tray-delivered system: 30 minutes once a day. All patients received verbal instructions about oral hygiene, encouraging participants to brush their teeth regularly with fluoridated toothpastes without whitening components.

Color Evaluation

Two calibrated evaluators recorded the shade of each subject's teeth at baseline, during treatment (after the first and second week of bleaching treatment), and one month postbleaching. In the event of disagreements between the examiners during shade evaluation, a consensus was reached through discussion.

The color evaluation was performed with the use of two value-oriented shade guide units—Vita Classical (Vita Zahnfabrik) and Vita Bleachedguide 3D-MASTER (Vita Zahnfabrik)—and with the aid of a spectrophotometer (Easyshade, Vita Zahnfabrik).

For color evaluation with the Vita Classical scale, the 16 tabs of the shade guide were arranged from the highest (B1) to the lowest (C4) value. Although this scale is not linear in the truest sense, for the purpose of analysis the changes were treated as though they represented a continuous and approximately linear ranking. The Vita Bleachedguide 3D-MASTER contains lighter shade tabs and is already organized from the highest (0M1) to the lowest (5M3) value. The measurement area of interest for shade matching was the middle one-third of the facial surface of the maxillary central incisor, according to American Dental Association guidelines.²⁰

The two examiners, blinded to the allocation assignment, scheduled these patients for bleaching and evaluated their teeth against the shade guide at the different time assessments. Color changes were calculated from the beginning of the active phase through to the individual recall times (one month after treatment) by calculating the change in the number of shade guide units (Δ SGU) that occurred toward the lighter end of the value-oriented list of shade tabs.

For the color evaluation with the Vita Easyshade Spectrophotometer (Vita Zahnfabrik), an impression of the maxillary arch was taken with dense silicone paste (Speedex Putty, Coltene, Rio de Janeiro, Brazil). The impression was extended to the maxillary canine and served as a standard color measurement guide for the spectrophotometer. For each tooth to be evaluated, a window was created on the

labial surface of the molded silicone guide using a metal device with a radius of 6 mm and well-formed borders. The shade was determined using the parameters of the Easyshade device where it indicated the following values: L^* , a^* , and b^* , in which L^* represented the value from 0 (black) to 100 (white) and a^* and b^* represented the shade, where a^* was the measurement along the red-green axis and b^* was the measurement along the yellow-blue axis. The color comparison before and one month after treatment was given by differences between the two colors (ΔE), which was calculated using the formula $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (Commission Internationale de l'Eclairage).

Evaluation of TS and Gingival Irritation

The subjects and parents were instructed to fill out a form to record daily whether they experienced TS and gingival irritation. We explained in detail for the patients how to fill out the form, with special attention given to describing the differences regarding TS symptoms (pain evoked by cold or other stimuli associated with some complaints, such as tingling or shooting pain [zingers] of very short duration but variable frequency) and gingival irritation (very localized aggression caused by mechanical trauma or chemical burning).^{11,21,22} The patients were to fill out the form any time they felt pain. We also explained to them that if they did not feel any TS, the intensity in the pain scales would be zero. The patients returned forms to the researcher on the next appointment (one week later).

Each patient was asked to indicate the numerical value of the degree of sensitivity using a five-point numeric rating scale (NRS) where 0 = none, 1 = mild, 2 = moderate, 3 = considerable, and 4 = severe. Patients were also asked to express their pain intensity using the visual analog scale (VAS). This scale is a 10-cm horizontal line with scores of 0 and 10 at each end, respectively, where 0 = no sensitivity and 10 = severe sensitivity. A patient was to mark with a vertical line across the horizontal line of the scale the intensity of the TS. Then the distance in millimeters from the zero end was measured with the aid of a millimeter ruler.

We merged the data from both bleaching sessions. The worst score (NRS) or the highest numeric value (VAS) obtained from both bleaching sessions at each assessment point was taken for statistical purposes and for the determination of the overall risk and intensity of bleaching-induced TS. If the participant scored 0 (no sensitivity) in all time assessments from the 14-day bleaching period, this participant was

Table 1: Baseline Characteristics of the Participants Included in This Clinical Trial

Characteristics	Conventional Tray Delivered	Bleaching Strips	Prefilled Disposable Tray Delivered	p-Value ^a
Age (mean±SD, years)	17.8 ± 1.4	17.7 ± 1.6	17.9 ± 1.4	0.62
Baseline color (mean±SD, SGU) ^b	7.4 ± 2.4	7.2 ± 2.1	6.8 ± 2.3	0.54

^a One-way ANOVA.^b Shade guide units (SGU) obtained with Vita Classical.

considered to be insensitive to the bleaching protocol. In all other circumstances, the participants were considered to have bleaching-induced TS. This dichotomization allowed us to calculate the absolute risk of TS, which represented the percentage of patients who reported TS at least once during treatment. We also calculated the overall intensity of TS during the 14-day period based on the worst score (NRS) or numerical VAS unit.

Statistical Analysis

The analysis followed the intention-to-treat protocol and involved all participants who were randomly assigned. The statistician was also blinded to the study groups.

The mean age (years) of the participants and the baseline SGU were compared using one-way analysis of variance (ANOVA) and the Tukey test. The absolute risks of TS and gingival irritation were compared using the Fisher exact test. The intensity of TS from the VAS was compared using one-way ANOVA and the Tukey test, and the data obtained from the NRS were compared using the Kruskal-Wallis and Mann-Whitney tests. The color change data in ΔSGU (two scales) and ΔE of different groups were compared with one-way ANOVA, and the Tukey test was used for pairwise comparisons. In all statistical tests, the significance level was set at 5%.

RESULTS

The mean age (years) of the participants and the baseline SGU are described in Table 1. One can

observe equivalent data among treatment groups, which ensures that the data were comparable in terms of baseline features ($p>0.54$; Table 1). None of the patients discontinued the intervention or presented adverse effects during the intervention (Figure 1). No medication and/or desensitizer needed to be prescribed/applied to the participants from this study to relieve bleaching-induced TS. Only after finishing the whitening in the maxillary anterior teeth was the same bleaching procedure used in the mandibular anterior teeth (data not shown).

TS

The risks of TS of the different groups ranged from 70% (95% confidence interval [CI] 48-85) to 75% (95% CI 53-89) for bleaching strips and predisposable trays, respectively. The conventional tray-delivered system showed a 95% (95% CI 76-99) risk of TS and was statistically similar ($p>0.09$; Table 2). Regarding TS intensity, bleaching strips and predisposable trays showed lower scores in the VAS (1.4 ± 1.7 and 1.6 ± 2.3 , respectively) and NRS (median 1 for both bleaching methods) compared to the conventional tray-delivered system (3.2 ± 3.2 for VAS and median 2 for NRS). For both scales, significant differences were observed in the TS intensity ($p=0.04$ and $p=0.03$ for the VAS and the NRS, respectively; Table 3). The use of the conventional bleaching tray generated a higher level of TS intensity than bleaching strips and prefilled disposable trays.

Table 2: Comparison of the Number of Patients Who Experienced Tooth Sensitivity (TS) at Least Once During the Three Different Bleaching Regimens Along With Absolute Risk^a

Treatments	Number of Participants With TS		Absolute Risk ^b (95% CI)	Relative Risk ^c (95% CI)
	Yes	No		
Conventional tray delivered	19	01	95 (76-99) A	
Bleaching strips	15	05	75 (53-89) A	1.26 (96-1.66)
Prefilled disposable tray delivered	14	06	70 (48-85) A	1.35 (1.00-1.84)

^a Risks identified with same letters are statistically similar.^b Fisher exact test ($p>0.09$).^c Compared with tray-delivered 10% HP.

Table 3: Tooth Sensitivity Intensity at the Different Assessment Points for the Study Groups and the Statistical Comparison ^a						
Time Assessments	VAS (Mean±SD) ^b			NRS (Median and IR) ^c		
	Conventional Tray Delivered	Bleaching Strips	Prefilled Disposable Tray Delivered	Conventional Tray Delivered	Bleaching Strips	Prefilled Disposable Tray Delivered
First week	2.3 ± 2.8	1.3 ± 1.7	0.9 ± 1.3	1 (1/2)	1 (0.5/1)	1 (0/1)
Second week	1.9 ± 2.8	1.0 ± 1.7	0.9 ± 2.3	1 (0.25/1.75)	0 (0/1)	0 (0/1)
Overall	3.2 ± 3.2 B	1.4 ± 1.7 A	1.6 ± 2.3 A	2 (1/2.25) b	1 (0.75/1) a	1 (0/2) a
^a Values identified with the same uppercase (VAS) or lowercase (NRS) letters are statistically similar.						
^b Mean ± SD: one-way ANOVA and Tukey test (p=0.04).						
^c Median (interquartile range): Kruskal-Wallis and Mann-Whitney tests (p=0.03).						

Gingival Irritation

The risks of gingival irritation in the different groups ranged from 15% (95% CI 5-36 for the prefilled disposable tray) to 75% (95% CI 53-89 for the conventional bleaching tray). Bleaching with the prefilled disposable tray showed the lowest risk of gingival irritation, which was statistically different from the conventional bleaching tray ($p=0.003$); (Table 4). The bleaching strips showed an intermediate result (Table 4). Usually, the gingival irritation was mild and transient, and no significant difference was observed between groups (data not shown).

Color Change

A whitening of approximately 3 to 5 shade guide units (Vita Classical) and 6 to 7 shade guide units (Vita Bleached) and approximately 7 to 10 units in ΔE were detected for the different groups after 30 days of bleaching (Table 5). No statistically significant difference was observed ($p>0.06$).

DISCUSSION

The results of the present study showed no significant difference in the absolute risk of TS for the different bleaching delivery systems, probably because they all contain the same percentage of active HP and were applied for the same period. However, the absolute risk of TS was high for all groups, in agreement with other studies that used similar HP concentration.^{7,8,10,13,14}

As mentioned in the introduction, only young patients were included in this study. It is believed that the amount of HP that reaches the pulp chamber is the main cause of TS.²² Therefore, as the teeth of young patients are more permeable and have a wider pulp chamber, there is less dentin substrate for oxidization in comparison with the teeth of older patients,^{23,24} it would be expected that in the former, higher absolute risk of TS would be reported. With advancing age, there is the formation of secondary dentin associated with a continuous deposition of secondary dentin and reduction of the diameters of dentinal tubules, which in turn increase the thickness of dentin.^{25,26} Therefore, a reduction of dentin permeability with age may reduce the amount of HP that reaches the pulp tissue.²⁷⁻²⁹ Although no individual clinical studies have compared the effect of age on bleaching-caused TS,¹⁶ in some recent clinical trials, authors have reported that the occurrence of TS in incisors was higher than in premolars.^{30,31} Other indirect evidence is the fact that the absolute risk of TS shown in the present study is higher (70%-95%) compared to bleaching studies when similar percentages of HP were used to whiten the teeth of older patients.^{9,32,33}

On the other hand, the intensity of TS in the present study was similar to bleaching studies that evaluated older patients.^{9,32,33} There is no clear explanation for these results, but we hypothesize that as the pulp chambers of young patients are

Table 4: Comparison of the Number of Patients Who Experienced Gingival Irritation (GI) at Least Once During the Three Different Bleaching Regimens Along With Absolute Risk ^a				
Treatments	Number of Participants With GI		Absolute Risk ^b (95% CI)	Relative Risk ^c (95% CI)
	Yes	No		
Conventional tray delivered	15	05	75 (53-89) B	
Bleaching strips	09	11	45 (26-66) AB	1.66 (0.96-2.88)
Prefilled disposable tray delivered	03	17	15 (05-36) A	5.00 (1.71-14.6)
^a Risks identified with same letters are statistically similar.				
^b Fisher exact test ($\alpha=0.05$).				
^c Compared with tray-delivered 10% HP.				

Table 5: Color Change in Shade Guide Units (SGU; Vita Classical and Vita Bleachedguide) and ΔE (Means $\pm$ SD) Between Baseline vs 30 Days After Bleaching for the Three Different Bleaching Regimens

Color Evaluation Tools	Conventional Tray Delivered	Bleaching Strips	Prefilled Disposable Tray Delivered	p-Value ^a
Δ SGU (Vita Classical)	5.6 $\pm$ 2.0	5.5 $\pm$ 2.0	4.6 $\pm$ 1.7	0.18
Δ SGU (Vita Bleached)	8.2 $\pm$ 2.8	6.6 $\pm$ 4.1	7.0 $\pm$ 3.8	0.46
ΔE	10.4 $\pm$ 2.4	9.2 $\pm$ 3.6	7.9 $\pm$ 3.6	0.06

^a One-way ANOVA and Tukey test.

wider than those of older patients, it is possible that HP could be metabolized more rapidly, and this helps explain the lower intensity of TS levels in the young patients. The same rationale could be applied for older patients and justify the lower TS intensity seen in previously published clinical studies.^{9,32,33} However, future studies need to be done to evaluate the effect of age on bleaching-caused TS.

Although no significant difference was seen in the absolute risk of TS, the results of the present study showed a higher intensity of TS for the conventional bleaching tray compared with the strips and the prefilled disposable tray. Apart from the concentration of HP, which was equal among all three systems, other characteristics could be responsible for the different levels of TS intensity, such as the viscosity of the bleaching gel³⁴ and the amount of gel in contact with the dental structure. Although bleaching strips and prefilled disposable trays contain a standardized amount of HP, this does not occur for custom-bleaching trays, as it depends on the subjective interpretation of the dentists' prescription about the dose of gel to be applied daily, and therefore variations are expected to occur.^{1,35,36}

Nevertheless, Haywood and Heymann¹ estimated that a dose of approximate 90 mg was used in custom-bleaching trays for the daily bleaching application. But there are other *in vitro* and *in vivo* studies that report that this amount may vary between 500 and 900 mg per application.^{35,36} Regardless of this variation, the amount of bleaching gel contained in bleaching strips is around 12 mg and in prefilled disposable trays around 60 mg as per manufacturer descriptions. In light of that, we believe that the more plausible hypothesis to explain the higher level of TS intensity of patients who wear custom-bleaching trays is due to the higher amount of product used in such a delivery method.

However, when the findings of the TS are compared with some previously published studies in the same age-group, the results are controversial. Two clinical studies published by Donly and others^{18,19} showed that TS varied between 23% and 49% when using bleaching strips and around 40% when

using conventional tray-delivered systems in childhood and adolescents (ages 12-17 years) with no difference between groups. In a more recently published clinical trial, Pinto and others⁸ showed that more TS was observed in bleaching strips (70%) than conventional disposable-tray systems (20%-40%) when patients 12 to 20 years old underwent bleaching. Also, these differences were observed when HP in at-home bleaching systems was applied in adult patients.^{7,8,10,13,14} However, these controversial results can be attributed mostly to the different methodologies used between these studies. For instance, the evaluation of sensitivity is reported by patients on a scale that is different in each study: "Yes" or "No"¹⁸ and the VAS (0 to 10).⁸

In terms of gingival irritation, the results of the present study showed a higher intensity of gingival irritation for the conventional bleaching tray compared with the strips and prefilled disposable tray, and we hypothesize that the lower amount of gel in the bleaching strips and prefilled disposable trays is responsible for lower gingival irritation than the conventional tray-delivered systems. In the case of gingival irritation, this excess of gel may flow out of the tray and increase the contact with gingival tissue. It is estimated that between 25% and 30% of all subjects needed to remove excess gel every time they performed the procedure.⁸ Matis³⁷ and Christensen³⁸ indicate that at least 25% to 50% of the bleaching agent administered in conventional tray-delivered system is ingested at the beginning of the bleaching. Unfortunately, to the extent of our knowledge, no previous studies have measured the amount of bleaching agent ingested by patients during the use of bleaching strips or prefilled disposable trays, and this was not measured by the authors of the present study as well. Future studies need to be done to evaluate this hypothesis.

Also, the presence of bleaching gel inside the tray can play an important role in the retention of the device to the teeth; therefore, according to Carlos and others,⁹ detachment of the tray and solubility of the bleaching agent in the saliva may have reduced

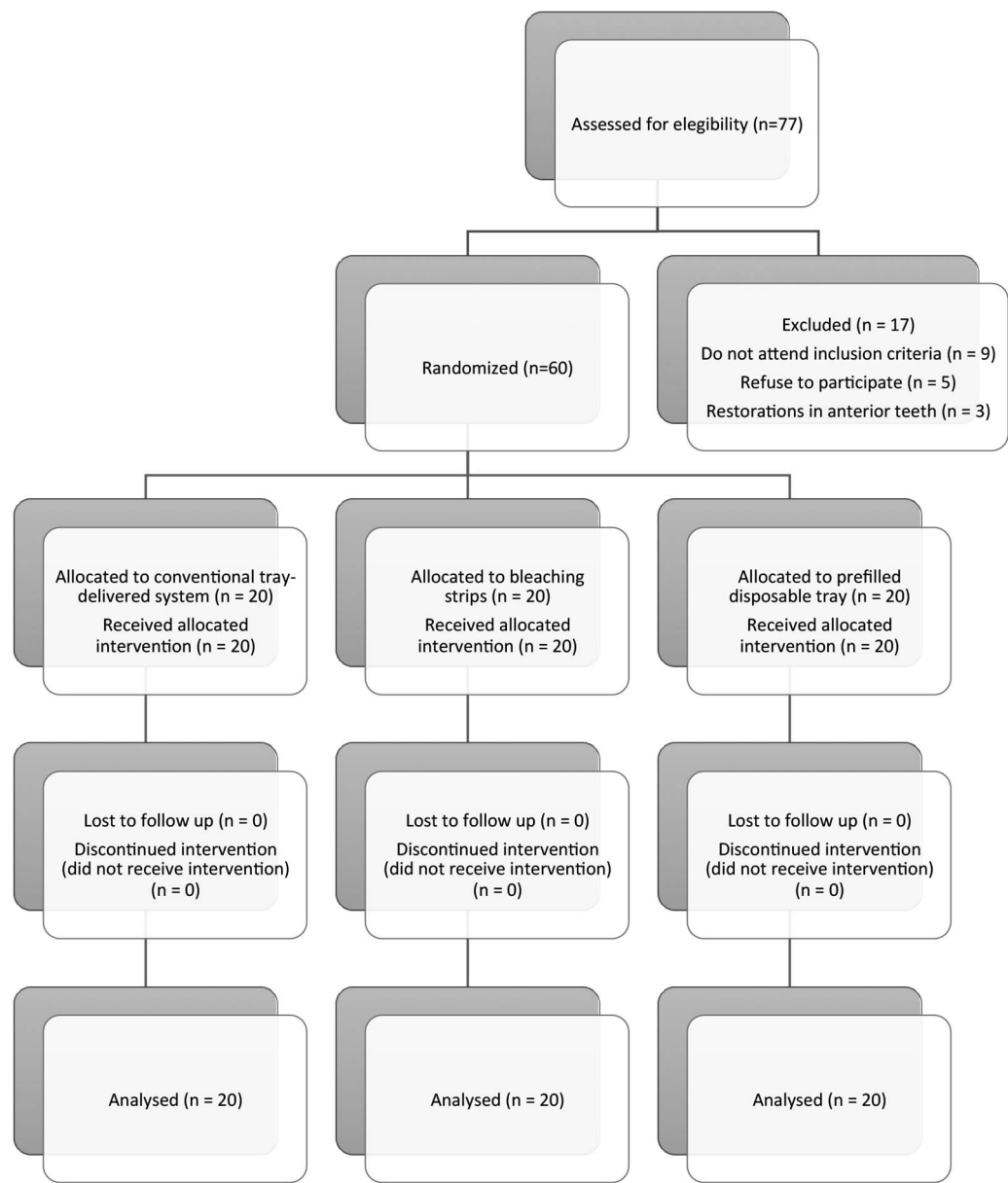


Figure 1. Flowchart of participants.

tray retention, causing patients some discomfort even for a short period of use (30 minutes).

It is worth mentioning that the best result in terms of gingival irritation was shown when prefilled disposable trays were used in comparison with the conventional tray-delivered system. The prefilled disposable trays showed a good tray adaptation to the patient arcade compared to bleaching strips, mainly because the trays were thin and fitted well around the teeth⁹ and used a lower amount of HP in comparison with the conventional tray-delivered system. The clinical studies that evaluated gingival

irritation of different groups showed controversial results,^{8,9,13,39,40} and the different methodologies, as previously mentioned, can explain the variability in the results.

However, the manufacturer of the bleaching strips has launched high-adhesion bleaching strips,^{18,41} probably to work around the problem of displacement of the bleaching strips. In the specific case of bleaching strips, some studies showed that patients found it hard to apply them, whereas patients found the trays very easy to slightly difficult to use,^{8,13} and

this leads patients to prefer a conventional tray-delivered system rather than bleaching strips.³⁹

Finally, regarding the color evaluation, no significant differences were observed between the groups, even when compared with three different instruments to evaluate color change. We used a spectrophotometer because it is a systematic and objective color assessment. On the other hand, Vita Classical is the most commonly used method among clinicians.^{2,7,9,20,30,39,44,46} We also decided to add a second shade guide scale that was specifically designed to evaluate color changes in bleached teeth.^{42,43} Despite these advantages, this scale is still not routinely used to evaluate color in dentistry; unfortunately, the sole use of this scale would preclude comparisons with previous studies in the literature.⁴⁴

All bleaching systems applied showed a significant whitening effect, as previously shown by different clinical studies, since 10% HP is considered a higher concentration to be applied in at-home bleaching.^{9,40,41} At the end of the bleaching protocol, a whitening of approximately 3 to 8 shade guide units was detected for all groups, and the ΔE varied by approximately 7 to 10 units, meaning a clinically important whitening, as previously observed in several clinical studies.^{7-9,45} These results are much closer to those of a comprehensive systematic review published by Matis and others⁴⁶ for at-home bleaching gels.

The results of the present study showed that bleaching strips and prefilled disposable trays under dentist supervision seem to be good options to reduce the intensity of bleaching-induced TS and gingival irritation, two common side effects of at-home bleaching therapies. Also, the use of bleaching strips and prefilled disposable trays can make application of the whitening treatment faster because it is not necessary to make impressions, plaster casts, and tray customization; thus, the bleaching treatment could be easier.

Although all the adverse effects, such as TS and gingival irritation, reported in the present study related mainly to the conventional tray-delivered system, these events are expected and are typically transient and can be easily solved with the transient discontinuation of the bleaching process until the symptoms are relieved, as previously shown in studies of adolescents^{8,18,19} and adults.^{7-9,13,14} More clinical studies should focus on evaluating different whitening delivery systems to help clinicians have stronger recommendations regarding this topic.

CONCLUSIONS

All 10% HP systems showed detectable whitening after a 14-day bleaching with a 30-minute daily usage. However, the use of bleaching strips and prefilled disposable trays showed reduced intensity of TS. Regarding gingival irritation, prefilled disposable trays showed a significantly lower risk of gingival irritation when compared to the tray-delivered system.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of approval of the Federal University of Amazonas. The approval code for this study is 46945715.6.0000.5020.

Conflict of Interest

The authors of this article 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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Color Regression and Maintenance Effect of Intracoronal Whitening on the Quality of Life: RCT—A One-year Follow-up Study

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Clinical Relevance

The color of teeth whitened internally remains stable at one year of follow-up; tooth whitening also has a positive effect in terms of psychosocial impact.

SUMMARY

Objective: This randomized clinical study evaluated two parameters: 1) the clinical color rebound of whitening patients' tooth discoloration using the walking bleaching technique and 2) the impact on psychological and aesthetic self-perception at the one-year follow-up of patients who underwent bleaching of nonvital teeth.

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Methods and Materials: Fifty study participants with nonvital tooth discoloration were recruited. Teeth were assigned randomly into one of two groups: 1) 35% hydrogen peroxide (n=25) and 2) 37% carbamide peroxide (n=25). Intracoronal bleaching was carried out over the course of four sessions using the walking bleach technique. Tooth color was evaluated after each session in order to measure the total color variation (ΔE). The guide was arranged from highest (B1) to lowest values (C4) for evaluating color, and color changes using Vita Classical Shade (Δ SGUs) units were calculated. Subjective and objective assessments were compared with the counterpart of the tooth. Aesthetic perception and psychosocial factors were evaluated before and after treatment by the Oral Health Impact Profile (OHIP) and Psychological Impact of Dental Impact Questionnaire (PIDAQ) surveys.

Results: Color changes (ΔE) were 15.48 ± 5.17 and 14.02 ± 4.85 for carbamide and hydrogen peroxide groups, respectively. There were no significant differences ($p > 0.05$) between these two groups at the one-year follow-up. There was a decrease in the PIDAQ scores after treatment compared to baseline values

($p < 0.05$). The majority of OHIP values regressed to baseline values.

Conclusion: The technique of walking bleaching was highly effective and showed minimal color rebound in nonvital teeth and had a positive effect on patients' psychological impact at the one-year follow-up.

INTRODUCTION

In some cultures of the world, tooth color is one of the most important factors in the achievement of a smile that is aesthetically pleasing.¹ It also has a substantial impact on a person's aesthetic and psychosocial perceptions.² Thus, when a single tooth doesn't match the other teeth, the negative effects can be more pronounced because a situation more visible to social scrutiny exists.³ However, there is no information on the incidence of intracoronar color effects and maintenance on a patient's self-perception or on the psychosocial impact to the patient.⁴ Some authors⁵ have shown that alterations in aesthetic dentistry can cause psychosocial consequences that could have more impact on the person who has problems caused by dental caries lesions. Intracoronar whitening is a widely used, minimally invasive alternative treatment/technique to solve discoloration (dark teeth) of nonvital teeth. Although there are several reports in the literature about external combined with internal bleaching, the main effects are seen within the pulp chamber of a tooth that has been endodontically treated and well sealed.⁶

Possible etiologies of tooth discoloration include 1) history of dental trauma with intrapulpal hemorrhage and posterior pulp tissue necrosis and 2) transfer of metal ions into the dentin substrate of a previous or combined restoration.⁷ The first condition occurs when hemolysis of red blood cells releases iron ions, subsequently forming ferric sulfate, which produces a dark color. The second clinical situation occurs when metal ions penetrate the dentin substrate, causing discoloration of the tooth stump preparation. The first condition has a more favorable prognosis for bleaching, whereas the second does not; thus, consideration of the patient's medical history is very relevant before internal bleaching is undertaken. The recurrence of internal bleaching is much more frequent and damaging and has rarely been studied.⁸

Prospective studies that objectively measure color stability and rebound after intracoronar bleaching and maintenance of the effect on the quality of a patient's life are not available in the literature.

The main objective of this study was to evaluate the following two parameters: 1) color rebound in patients who have undergone bleaching of nonvital teeth with 35% hydrogen peroxide or 37% carbamide peroxide gels using the walking bleaching technique and 2) the impact on aesthetic self-perception and psychosocial impact in this cohort of patients.

The null hypothesis of this article was that there are no differences in the rebound between nonvital bleached teeth treated with either 35% hydrogen peroxide or 37% carbamide peroxide. The second null hypothesis was that there is no impact on aesthetic self-perception and psychosocial impact at the one-year follow-up in patients who have undergone intracoronar bleaching.

METHODS AND MATERIALS

This randomized trial was approved by the ethics committee of the faculty of dentistry of the local university (2016/04) and was carried out according to the standards of consolidated reporting trials⁹ and the Declaration of Helsinki (2002) (1975, revised in 2000).

Study Design

This trial was a randomized, double-blind (patient and evaluator) study. The study groups were selected randomly using Excel 2013 software (Microsoft, Seattle, WA, USA). Patients were recruited through fliers within the local faculty of dentistry and social networks such as Facebook and Twitter.

Sample Size

The sample size was determined using GPower 3.1 software with a significance level of 5%, statistical power of 90%, and a decrease of 25% based on previous studies.¹⁰⁻¹² This study corresponded to a type of therapeutic equivalence, in which a color variation in color tone changes (ΔE) in the range of ≥ 7 to 10, based on effectiveness measurements and necessity of matching the homologous tooth color according to a previous pilot study, was considered significant. This indicated a sample size of 20, and to compensate for the rate of study withdrawal reported in previous studies, a sample size of 25 per group was used.

Entry Criteria

A total of 74 patients were examined in order to assess whether they met the criteria for study inclusion (Figure 1). Inclusion criteria consisted of several parameters: 1) patients >18 years; 2) patients having one or more discolored nonvital

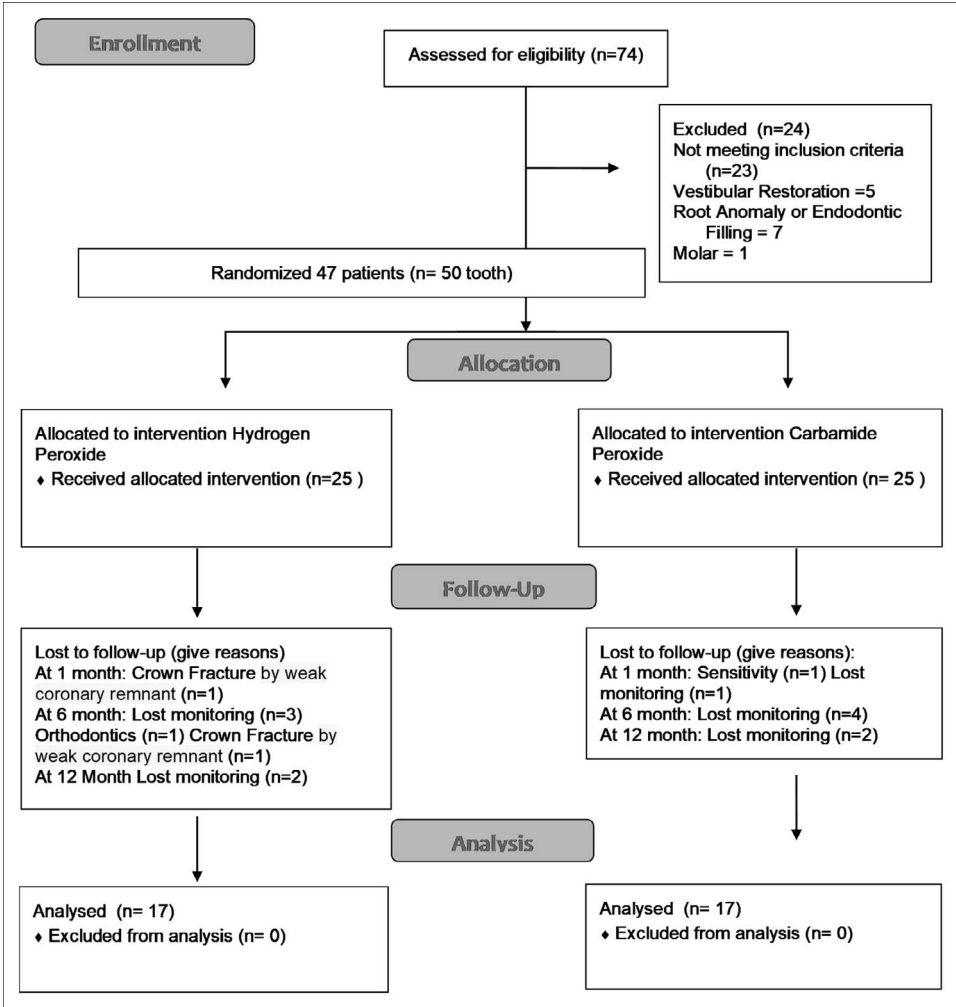


Figure 1. Flow chart of the clinical trial, including detailed information on included and excluded participants.

teeth; 3) patients whose restorations did not include vestibular surfaces; 4) patients with root canal treatment in good condition with no apical lesions; 5) patients with no previous tooth whitening; and 6) patients with a tooth tone of $\geq$ A2 according to the Classic Vita Scale. Exclusion criteria consisted of several parameters: 1) pregnant or breastfeeding patients; 2) patients with enamel hypoplasia; 3) patients with teeth stained by tetracycline; 4) patients with fluorosis or previous metallic restorations related to tooth discoloration; 5) patients receiving fixed orthodontic devices; 6) patients with cancer; and 7) patients with periodontal pathologies. Patients with clinical or radiographic caries, peri-apical lesions, resorption of internal or external tooth structure, or those with periodontal disease were excluded. These patients were referred to specialized treatment clinics.

Patients meeting the inclusion criteria were randomized into two groups of 25 each according to

Table 1: Participants' Baseline Characteristics		
Baseline Features	Groups	
	1 = Hydrogen Peroxide	2 = Carbamide Peroxide
Age, y; mean $\pm$ SD	30.47 $\pm$ 11.71	30.82 $\pm$ 12.14
Minimum age, y	19	20
Maximum age, y	65	65
Male, %	29.4	29.4
Trauma, %	52.9	47.1
Caries, %	41.67	60.87
SGU baseline median (min;max) Vita Classic	15 (7;16)	12 (7;16)
L*, mean $\pm$ SD	71.88 $\pm$ 9.00	76.65 $\pm$ 6.78
a*, mean $\pm$ SD	4.74 $\pm$ 3.44	4.45 $\pm$ 3.70
b*, mean $\pm$ SD	29.78 $\pm$ 3.63	31.85 $\pm$ 7.04
Abbreviation: SD, standard deviation.		

Table 2: Values of ΔE Expressed as Mean and Standard Deviation

Evaluation Times	Color Change by ΔE		Mann-Whitney
	G1 = Hydrogen Peroxide	G2 = Carbamide Peroxide	
Baseline vs immediate subsequent bleaching	Peroxide	13.03 $\pm$ 3.90	0.020
Baseline vs 1 wk after bleaching (before restoration)	16.64 $\pm$ 6.85	14.26 $\pm$ 4.49	0.344
Baseline vs 1 wk after bleaching (after restoration)	16.77 $\pm$ 6.30	13.76 $\pm$ 4.63	0.163
Baseline vs 1 mo after bleaching	15.64 $\pm$ 4.76	13.83 $\pm$ 4.75	0.459
Baseline vs 6 mo after bleaching	14.93 $\pm$ 5.56	12.51 $\pm$ 4.83	0.395
Baseline vs 12 mo after bleaching	15.11 $\pm$ 5.59	13.17 $\pm$ 5.13	0.399

Abbreviation: ΔE , total color variation.

bleaching agent: Group 1 (G1) - teeth bleached with 35% hydrogen peroxide (Opalescence Endo, Ultra-dent, United States) and Group (G2) - teeth bleached with 37% carbamide peroxide (Whiteness Super-endo, FGM, Joinville, SC, Brazil). Bleaching agents were applied according to the manufacturers' instructions in four weekly sessions using an ambulatory technique (walking bleach).

Preparation Session—The canal was prepared under absolute isolation, removing 3 mm of the endodontic filling from the cemento-enamel junction in the apical direction. To protect the endodontic treatment, a 2 mm seal made with a resin-reinforced glass ionomer (Riva light cure, SDI, Australia) was applied and cured for 60 seconds at a distance of approximately 1 cm (1200-mW/cm², Cal Raddi, SDI, AU). Due to the distribution of dentin tubules in the cervical area of the tooth, the coronal limit of the seal was 1 mm below the cemento-enamel junction to guarantee whitening. To confirm the proper sealing of the endodontic treatment, a radiographic control was made.

Four Tooth Whitening Sessions—Application of the whitening agent was conducted according to the manufacturers' instructions. The correct amount of whitening gel was placed in the cavity pulp chamber in the presence of mild moisture (walking bleach technique). The cavity closure was made with

temporary cement (Fermin, Detax, Germany) until the next session, which occurred seven days later. This procedure was repeated in each of the sessions for up to four weeks. The same amount of gel was used at each session.

Final Session—After washing the cavity access with abundant water, a temporary restoration was inserted for seven days and then the final restoration with composite resin was done. Patients were warned not to eat or drink any foods, including coffee, tea, or wine, that might stain their teeth during the study period. Patients were given instructions in writing and provided with contact information if they had any questions or experienced any adverse events.

Evaluation of Color

Objective Assessments—Two calibrated evaluators (Kappa=0.87) measured the tooth color at baseline and at one week, one month, six months, and 12 months after the bleaching. Evaluation of the color was obtained from a 6-mm area in the middle third of the labial surface of the left and right central incisors. To standardize this evaluation, an impression of the maxillary arch was taken to make a guide with silicone putty (Zetaplus Zhermack, Badia Polesine, Rovigo, Italy). A well-formed window was created on the labial surface in the middle third of

Table 3: Comparison of ΔSGU Values at Different Timepoints Using the Vita Classic Scale [Median (Minimum:Maximum)]

Assessment Points	Color Change by ΔSGU		Mann-Whitney Test
	G1 = Hydrogen Peroxide	G2 = Carbamide Peroxide	
Baseline vs immediate subsequent bleaching	10 (1;15)	7 (3;14)	0.064
Baseline vs 1 wk before bleaching (before restoration)	10 (-1;14)	7 (2;13)	0.115
Baseline vs 1 wk after bleaching (after restoration)	9 (1;14)	7 (2;13)	0.072
Baseline vs 1 mo after bleaching	9 (1;13)	7 (1;13)	0.151
Baseline vs 6 mo after bleaching	9 (1;13)	7 (1;13)	0.151
Baseline vs 12 mo after bleaching	8 (1;13)	7 (1;13)	0.205

Abbreviation: ΔSGU , Vita Classical Shade unit.

Table 4: Comparison of ΔSGU Values at Different Timepoints Using the Vita Bleach Guide [Median (Minimum:Maximum)]			
Assessment Points	Color Change by ΔSGU		
	G1 = Hydrogen Peroxide	G2 = Carbamide Peroxide	Mann-Whitney Test
Baseline vs immediate subsequent bleaching	6 (1;9)	4 (3;8)	0.053
Baseline vs 1 wk before bleaching (before restoration)	6 (1;10)	4 (3;7)	0.005
Baseline vs 1 wk after bleaching (after restoration)	6 (1;10)	4 (3;7)	0.005
Baseline vs 1 mo after bleaching	5 (1;9)	4 (2;7)	0.038
Baseline vs 6 mo after bleaching	5 (0;8)	5 (0;7)	0.833
Baseline vs 12 mo after bleaching	5 (0;7)	4 (0;7)	0.736
Abbreviation: ΔSGU, Vita Classical Shade unit.			

the central incisor with a radius of 3 mm, which corresponded to the space for the spectrophotometer's reflectance nozzle (Vita EasyShade Compact, VITA Zahnfabrik, Bad Säckingen, Germany); this device showed high reliability. The color assessed was determined using the obtained parameters L*, a*, and b*. Color alterations after each session were indicated by the differences (ΔE) between the session and baseline values. ΔE was calculated using the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Subjective Evaluation—For the subjective evaluation, 16 (Classic Vita, Vita Zahnfabrik) guide sheets were available—ranging from the highest (B1) to a lowest value (C4)—and a Bleachedguide 3D-MAS-TER Vita Zahnfabrik guide was used; these items were used to evaluate the color. Two calibrated

raters (Kappa=0.85) recorded the upper left and right central incisor shadows at baseline and throughout the study at different assessment points. The researchers checked the color in the middle third of the labial surface of the anterior central incisor following the guidelines of the American Dental Association. Color changes from the beginning of the active phase through different study timepoints were calculated using the change in the number of shade units (ΔSGUs).

Evaluation of Quality of Life

Oral Health Impact Profile Questionnaire—Quality of life was measured using the Oral Health Impact Profile (OHIP)—an aesthetics questionnaire that was validated by the Spanish oral health impact profile.¹³ The questionnaire was administered by a researcher at the beginning of the study and then at

Table 5: Comparison of SGU Values at Different Timepoints Using the Vita Classic Scale [Median (Minimum;Maximum)]		
Assessment Times	Color Change by SGU	
	G1 = Hydrogen Peroxide	G2 = Carbamide Peroxide
Homologous teeth	5 (1;9)	3 (2;10)
Baseline	15 (7;16) ^a	12 (7;16) ^a
Immediate subsequent bleaching	4 (1;12) ^b	5 (1;12) ^b
1 wk after bleaching (after restoration)	5 (1;13) ^b	3 (1;14) ^b
1 wk after bleaching (before restoration)	5 (1;12) ^b	4 (1;14) ^b
Baseline vs 1 mo after bleaching	5 (1;12) ^b	4 (1;14) ^b
Baseline vs 6 mo after bleaching	5 (1;12) ^b	4 (1;14) ^b
Baseline vs 12 mo after bleaching	5 (1;13) ^b	5 (1;14) ^b
Abbreviation: SGU, Vita Classical Shade.		
^a Statistically significant difference intragroup (Wilcoxon test, p<0.05) vs homologous teeth.		
^b Statistically significant difference intragroup (Wilcoxon test, p<0.05) vs baseline.		

Table 6: Comparison of SGU Values at Different Timepoints Using the Vita Bleach Guide [Median (Minimum:Maximum)]		
Assessment Times	Color Change by SGU	
	G1 = Hydrogen Peroxide	G2 = Carbamide Peroxide
Homologous teeth	7 (3;11)	7 (5;9)
Baseline	12 (7;15) ^a	11 (9;15) ^a
Immediate subsequent bleaching	5 (2;12) ^b	7 (4;11) ^b
1 wk after bleaching (after restoration)	5 (3;9) ^b	7 (5;10) ^b
1 wk after bleaching (before restoration)	6 (1;10) ^b	7 (5;10) ^b
1 mo after bleaching	7 (3;12) ^b	7 (5;10) ^b
6 mo after bleaching	7 (1;11) ^b	6 (4;11) ^b
12 mo after bleaching	8 (3;12) ^b	7 (5;11) ^b
Abbreviation: SGU, Vita Classical Shade.		
^a Statistically significant difference intragroup (Mann-Whitney test, p<0.05) vs homologous teeth.		
^b Statistically significant difference intragroup (Wilcoxon test, p<0.05) vs baseline.		

Table 7: PIDAQ. Values of Factors Expressed as Median (Minimum/Maximum) at Different Timepoints[†]

Dimension	G1	Baseline G2	Mann- Whitney	G1	Postbleaching G2	Mann- Whitney	G1	1 mo After Bleaching G2	Mann- Whitney
Dental self-confidence	17 (6:26)	15 (12:26)	0.773	21 (11:30) a	22.5 (12:30) a	0.793	22 (10:30) a	21.5 (6:29) a	0.948
Social impact	24 (8:40)	23 (8:34)	0.845	17 (8:31) a	16 (8:26) a	0.547	12 (8:31) a	17 (8:32) a	0.415
Psychological impact	18 (8:26)	17 (6:24)	0.295	13 (6:24) a	14.5 (6:21)	0.714	12 (6:24) a	14 (6:24)	0.734
Aesthetic concern	9 (3:14)	9 (3:14)	0.607	6 (3:12) a	4.5 (3:12) a	0.099	4 (3:12) ab	6 (3:12) ab	0.227

Abbreviation: PIDAQ, Psychological Impact of Dental Impact Questionnaire.
[†] a = Statistically Significant Difference (Wilcoxon Test, $p < 0.05$) vs Baseline; b = Statistically Significant Difference (Wilcoxon Test, $p < 0.05$) vs One Week After Bleaching (ext.)

one week, one month, six months, and one year after whitening.

Dental Aesthetics Psychosocial Impact Questionnaire—The psychosocial aspect of dental aesthetics (PIDAQ)¹⁴ impact questionnaire consisted of 23 items grouped into four components using factor analyses: 1) dental self-esteem, 2) social impact; 3) psychosocial impact; and 4) aesthetic concerns.¹⁵ The PIDAQ was applied in a manner similar to the OHIP-Aesthetics scale.

Statistical Analysis—After checking the normality of the data distribution and the homogeneity of the variance-covariance matrix, we evaluated the treatment efficacy with respect to color alterations (ΔE and ΔSGU) and analyzed the results using the Wilcoxon test for comparisons within the group and the Mann-Whitney for comparisons between groups. Statistical analyses were performed using SPSS (SPSS Inc, Chicago, IL, USA) 23.0, with $\alpha = 0.05$.

The Wilcoxon test was used for comparison of results of the OHIP-Aesthetics and PIDAQ questionnaires.

RESULTS

Participants' characteristics are shown in Table 1. Tooth distribution (G1=12 upper central incisors; four upper lateral incisors, and one lower central incisor; G2=13 upper central incisors and four upper lateral incisors) at one-year follow-up. There were no statistically significant differences between the characteristics of participants in the groups (Mann-Whitney test, $p > 0.05$.) ΔE is shown in Table 2. Efficacy was similar at all times except at immediate subsequent measurement ($p < 0.05$). These two groups showed high efficiency, with an average ΔE of > 13 units. A slight rebound was similar to one-month follow-up values.

Results for ΔSGU differed over time, as shown in Tables 3 and 4. More effective efficiency was noted in

Table 8: OHIP. Values of Factors and Sum Expressed at Median (Minimum/Maximum) at Different Timepoints[†]

Dimension	G1	Baseline G2	Mann- Whitney	G1	Postbleaching G2	Mann- Whitney	G1	1 mo After Bleaching G2	Mann- Whitney
Functional limitation	5 (2:8)	5 (2:8)	0.541	3 (0:6) a	4 (1:6) a	0.497	2 (1:7) a	4 (0:8) a	0.528
Physical pain	3 (0:6)	3 (0:5)	0.290	3 (1:6)	3 (1:6)	0.366	2 (0:6) a	2 (0:8)	0.522
Psychological discomfort	4 (2:6)	5 (0:6)	0.959	4 (0:6)	3 (2:6)	0.616	4 (0:6)	4 (0:8)	0.693
Physical disability	1 (0:6)	2 (0:5)	0.688	1 (0:4)	1 (0:6)	0.989	1 (0:3)	0 (0:6)	0.709
Psychological disability	2 (0:6)	3 (0:6)	0.240	2 (0:6)	2 (0:6) a	0.797	1 (0:5) a	2 (0:6) a	0.474
Social disability	0 (0:5)	1 (0:4)	0.946	0 (0:4) a	0 (0:4)	0.833	0 (0:6)	0 (0:4)	0.701
Handicap	1 (0:6)	1 (0:4)	0.841	0 (0:5) a	0 (0:4)	0.556	0 (0:6) a	0 (0:4)	0.874
Sum	17 (8:38)	19 (5:32)	0.910	13 (4:33) a	15 (4:35) a	0.472	14 (4:31) a	13 (5:41) a	0.930

Abbreviation: OHIP, Oral Health Impact Profile.
[†] a = Statistically Significant Difference (Wilcoxon tTest, $p < 0.05$) vs Baseline; b = Statistically Significant Difference (Wilcoxon Test, $p < 0.05$) vs One Week After Bleaching (ext.)

Table 7: *Extended*

Dimension	G1	6 mo After Bleaching G2	Mann-Whitney	G1	12 mo After Bleaching G2	Mann-Whitney
Dental self-confidence	19.5 (10:29)	21 (7:25) a	0.480	21 (6:30) ab	19 (11:28) a	0.773
Social impact	15 (8:37)	19 (8:26) a	0.842	15 (8:36) a	16.5 (8:32) a	0.969
Psychological impact	15.5 (6:24)	15 (6:20) a	0.613	13 (6:24) a	14 (6:22) a	0.824
Aesthetic concern	7 (3:15)	8 (3:12) a	0.971	9 (3:15) a	8.5 (3:12) b	0.989

G1. However, values were not significantly different ($p>0.05$). Results of the color comparison of the bleached teeth vs homologous teeth are shown in Tables 5 and 6.

Dental Aesthetics Psychosocial Impact (PIDAQ)

The PIDAQ score was significantly different at the start of the study in comparison with one year later for all factor scores except aesthetic concern in G2. When comparing groups (Table 7), no statistical differences were observed between them ($p>0.05$).

Oral Health Impact Profile (OHIP-Aesthetics)

There were statistically significant differences in G2 ($p<0.05$) for total score, functional limitations, and psychological disabilities. G1 was not statistically

different when compared with baseline. There were no statistically significant differences between groups at the one-year follow-up (Table 8).

DISCUSSION

This randomized trial showed that the effectiveness of two bleaching agents (35% hydrogen peroxide and 37% carbamide peroxide) can be measured objectively and subjectively, and both agents can be applied for intracoronary nonvital teeth using the walking bleach technique. Both products showed high efficiency with very low rebound at the one-year follow-up period. The results showed that the treatment had a positive influence on a patient's psychosocial aspects one year after showing improvement in the tooth color in the majority of participants. Therefore, the first null hypothesis was accepted, as the two

Table 8: *Extended*

Dimension	PH	6 mo After Bleaching PC	Mann-Whitney	PH	12 mo After Bleaching PC	Mann-Whitney
Functional limitation	2 (0:6) a	3 (0:6) a	0.543	3 (0:8) a	3 (1:8) a	0.779
Physical pain	2 (0:5) ab	3 (0:5)	0.600	2 (1:8)	3 (0:6)	0.835
Psychological discomfort	4 (0:6) a	4 (1:6) a	0.905	4 (0:6)	3 (0:7)	0.270
Physical disability	0 (0:5)	1 (0:5)	0.121	1 (0:8)	0 (0:5)	0.210
Psychological disability	1 (0:5)	2 (0:5) a	0.303	1 (0:8)	1 (0:7) a	0.948
Social disability	0 (0:5)	0 (0:3) a	0.822	0 (0:8)	0 (0:6)	0.148
Handicap	0 (0:5)	0 (0:4)	0.401	0 (0:8)	1 (0:7)	0.967
Sum	10 (3:36) a	12 (4:27) ab	0.279	15 (3:54)	12 (4 :39) a	0.427

gels are widely effective according to objective and subjective measurements at the one-year follow-up. The second hypothesis was partially accepted, but the psychosocial impact was maintained, and the aesthetic perception showed a partial regression to baseline values.

Our results showed that after four sessions with the walking bleach technique at one-year follow-up after the treatment, there was a ΔE of 15.11 ± 5.59 for G1 and of 13.17 ± 5.13 for G2. In terms of the final results, no differences between agents ($p > 0.05$) were observed, although there was a tendency for the color to recur after one month of treatment. Subjective evaluation of the color changes also indicated that treatment was very effective.

Few clinical studies have evaluated the effectiveness of nonvital whitening, and the most commonly used bleaching agent is sodium perborate.⁸ In an *in vitro* study by Lim and others,¹⁶ it was concluded that both 37% carbamide peroxide and 35% hydrogen peroxide were more effective than was sodium perborate. This study evaluated the color of each tooth using the Vita Lumin guide; after seven days, there was a change of 8 Δ SGU, and the color shifted by two additional units after 14 days.¹⁶ This study, however, is not considered to have provided a high level of evidence. In the present clinical trial, intracoronar whitening rebound was slight at the one-year follow-up period and was comparable to vital extracoronar whitening rebound results from another clinical trial¹² that was recently published. It is important to mention that the measurements were made on the middle sector of the vestibular face of the central incisors; since color recurrence in a nonvital tooth occurs from the cervical portion of the tooth, this finding could have been obviated by this difference in measurement location.¹⁷

The whitening agents that are most commonly used to whiten nonvital teeth are hydrogen peroxide, carbamide peroxide, and sodium perborate. Hydrogen peroxide is the active ingredient in the tooth whitening gels currently used. It can be applied directly or it can be produced by a chemical reaction of carbamide peroxide or sodium perborate.

High concentrations (35%) of hydrogen peroxide are caustic and can burn tissues on contact and cause free radical release. As a result of its low molecular weight, this substance can penetrate the dentin and release oxygen that breaks the double bonds of organic and inorganic compounds within the dentinal tubules. Carbamide peroxide [$\text{CO}(\text{N}-\text{H}_2)_2\text{H}_2\text{O}_2$] is an organic crystalline white compound

formed by urea and hydrogen peroxide and is used in different concentrations. In a hydrophilic environment, it decomposes into approximately 30% hydrogen peroxide and 70% urea. Currently, the most popular commercial whitening preparations that contain carbamide peroxide also include different concentrations of glycerin because this makes it more chemically stable compared to hydrogen peroxide. Sodium perborate is an oxidizing agent available in powder form. It is stable when dry; however, in the presence of acid, hot air, or water, it decomposes to form sodium metaborate, hydrogen peroxide, and nascent oxygen. Sodium perborate is easier to control and safer than concentrated solutions of hydrogen peroxide.⁸

Visual assessment by colored guides is a complex process that involves individual and general parameters, such as age and experience of the examiner, fatigue of the human eye, external lighting, the color of the wall and the interior, and the angle of perception.¹⁸ The determination of the tooth color by visual means becomes less reliable as a result of the lack of guides of dental colors that are commercially manufactured. The concept of the threshold of perceptibility that varies among individuals is relevant, and despite being able to achieve good agreement rates between evaluators, the error of the subjective assessment is always greater.¹⁹ On the other hand, objective color instruments can measure color tones with greater precision and enable the communication of tone matches.²⁰ The reliability of the device used is important, as it ensures the reliability of these measurements using relatively simple and easy-to-replicate methodologies. Currently, the devices used are highly accurate and provide reliable measurements that correctly guide dentists with respect to the measured color.^{20,21}

The research team was not surprised at the high satisfaction levels of patients who underwent a whitening procedure in this trial and were then followed.²² For various reasons, we have been able to completely match neighboring tooth colors using our nonvital tooth whitening method. Results relative to the aesthetic perception and psychosocial impact were positive and significant with respect to whitening after one month. Whether this effect was maintained over time needs to be confirmed in patients undergoing positive vital tooth whitening² and then correlated with the maintenance of the bleaching procedure effectiveness at one year.

The OHIP-Aesthetic survey also showed positive effects on G2 patients' aesthetic perceptions. This

result is supported by other studies,²³ whose authors evaluated the influence of extracoronary vital bleaching on patients' aesthetic perceptions. Our data confirmed that a patient's quality of life is complex, important, but poorly studied, and there are multiple factors that influence it. However, dental aesthetics appear to be important to a patient's quality of life, although its influence on patients' perceptions and psychological and social factors are unknown. The impact of psychological and social factor perceptions is unknown. No differences in OHIP-Aesthetic scores between the groups was observed, but there were differences in the changes in each group over time. This resulted in an effect that was more pronounced and positive for G2; however, there was a regression of values in G1, likely because the effect was not as durable and because patients were accustomed to the condition after one year. This finding must be further investigated to assess the correlation between perception and aesthetic color changes.

PIDAQ has been shown to decrease the negative impact of cosmetic dentistry for a patient and to decrease the values in social and psychological impact and aesthetic concerns. The psychosocial impact was similar in both groups ($p > 0.05$). We found that a big impact was indicated by the PIDAQ data for all relevant factors, but minimal intervention in a tooth has a major effect in people who undergo intracoronary whitening.

CONCLUSION

Hydrogen peroxide (35%) and carbamide peroxide (37%) were highly effective for the nonvital tooth walking bleach technique and can achieve a high level of color matching with the counterpart teeth and color maintenance at the one-year follow-up, with a slight rebound. Each gel produced a positive impact on patients' psychosocial impact at the one-year follow-up.

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The author (E. Fernández) dedicates this article to his two kids, Elisa and Eduardo, for their enormous inspiration.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of approval of the Ethics Committee of the Faculty of Dentistry of the local University and carried out according to the standards of consolidated reporting trials and the Declaration of Helsinki (2002). The approval code for this study is 2016/04.

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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Laboratory Research

Properties of a New Nanofiber Restorative Composite

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Clinical Relevance

There may not be any significant advantage to the use of the new nanofiber composite resin restorative material (NovaPro Fill) compared to use of the hybrid composite resins (Filtek Z250, Esthet-X HD).

SUMMARY

A new nanofiber-reinforced hybrid composite (NovaPro Fill, Nanova) was recently introduced with reportedly improved mechanical properties. The purpose of this study was to compare the properties (flexural strength/modulus, degree of conversion [DC], depth of cure, and polymerization shrinkage) of the nanofiber composite to those of traditional

hybrid composites (Filtek Z250, 3M ESPE; Esthet-X HD, Dentsply). To determine flexural strength and modulus, composite was placed in a rectangular mold, light-cured, stored for 24 hours, and then fractured in a universal testing machine. For degree of conversion, composite was placed in a cylindrical mold, light-cured, and stored for 24 hours. Measurements were made at the top and bottom surfaces using Fourier Transform Infrared Spectroscopy. To determine depth of cure, composite was placed in a cylindrical mold and light-cured. Uncured composite was scraped until polymerized resin was reached. Remaining composite was measured and divided by two. Polymerization shrinkage was determined by placing the composite material on a pedestal in a video-imaging device while light-curing. Shrinkage was determined after 10 minutes. Data were analyzed with one-way analysis of variance and Tukey post hoc test per property ($\alpha=0.05$). Compared to Filtek Z250, NovaPro Fill had significantly lower flexural strength and modulus, greater volumetric shrinkage, and similar depth of cure, but greater top and bottom DC. Compared to Esthet-X HD, NovaPro Fill had similar flexural strength, shrinkage, and top and bottom DC, but significantly greater depth of cure and flexural modulus.

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INTRODUCTION

Resin composites have become an integral part of the clinical discipline of operative dentistry. A meta-analysis by Heintze and others¹ found that more than 500 million direct dental restorations were placed each year worldwide, of which about 55% were composites or compomers. According to the National Institutes of Health, composites have an average survival time of 5.7 years, and failures are mainly due to secondary caries and fracture of the restoration.² Historically, composite restorations were advocated for use in areas of minimal stress.³ However, demands for naturalistic esthetics from patients as well as clinicians are increasing and have led to the popular use of resin-based materials on posterior teeth, where considerable mechanical challenges occur under function.⁴ To withstand these stresses, modification of filler particle size and morphology resulted in improved mechanical properties.⁵

Most composite materials are composed of a polymeric matrix (typically dimethacrylate), reinforcing fillers (typically radiopaque glass), a silane coupling agent to bind the filler to the matrix, and chemicals that promote or modulate the polymerization reaction. Because of the major influence of fillers on the physical properties of composites, their classification is primarily based on the type and size of filler particles.⁶

Composites have continued to improve via incorporation of various sizes and shapes of filler particles, starting with the macrofills, up to today's microfills, nanofills, and nanohybrids.⁶ Recently, a novel composite restorative material containing calcium-phosphate (hydroxyapatite) nanofibers (NovaPro Fill, Nanova, Columbia, MO, USA) has piqued many interests in the dental community, which seeks to understand the role of nanofiber inclusion and its impact in order to influence composite strength and reliability. The manufacturer claims⁷ that the nanofibers provide superior mechanical strength and greater degree of conversion (DC) than do most conventional composites that are without these reinforcements. Furthermore, past studies have shown that the inclusion of the nanofibers allows one to significantly increase composite physical properties.

In a study by Vidotti and others,⁸ experimental methacrylate composite beams were created by infiltrating polyacrylonitrile nanofiber mats, and greater tensile properties were observed when the beams were tested perpendicular to the direction of

the nanofiber mats. In another study by Guo and others,⁹ zirconia-silica and zirconia-yttria-silica ceramic nanofibers at various concentrations were placed in experimental composite formulations and compared to control composites without nanofillers. The incorporation of the ceramic nanofillers significantly enhanced the mechanical properties compared to the control. Additionally, impregnation of hydroxyapatite nanofibers into methacrylate resin has been shown¹⁰ to significantly improve the flexural strength of resin formulations. However, other studies^{9,10} have found that there was a limit to the amount of nanofiber content by weight before mechanical properties started to decrease. In addition, the DC decreased with the inclusion of nanofiber content.⁹

EverX Posterior (GC 3-2-14 Hongo, Bunkyo-ku, Tokyo, Japan), although not commercially available in the United States, is one example of a short-fiber-reinforced composite that is designed to be used as a dentin replacement in medium- to large-size Class II preparations (ie, sandwiched technique). A study by Abouelleil and others¹¹ found that with the addition of fibers to the methacrylate-based matrix, EverX Posterior could result in comparable or superior mechanical properties to other bulk-fill materials tested, whereas, a recent study by Fronza and others¹² found that the mechanical performance of EverX Posterior was intermediate in comparison to that of other bulk-fill materials.

No research has been published evaluating the new commercially available nanofiber-reinforced composite NovaPro Fill, designed to be incrementally placed to the cavosurface margins in posterior stress-bearing areas. The purpose of this study was to evaluate the properties of the new nanofiber composite resin compared to those of traditional hybrid composite resin restorative materials, Filtek Z250 (3M ESPE, St Paul, MN, USA) and Esthet-X HD (Dentsply, York, PA, USA). The null hypothesis was that there would be no difference in properties among the composite materials.

METHODS AND MATERIALS

Flexural strength and modulus, DC, depth of cure, and volumetric polymerization shrinkage were evaluated for the composites NovaPro Fill, Filtek Z250, and Esthet-X HD in shade A2. Filtek Z250 is a traditional microhybrid composite that has demonstrated excellent mechanical properties in multiple laboratory studies and was used as a control in this study to compare various new restorative materials.¹³ Esthet-X HD is a nanohybrid composite that is

Table 1: Components of Composite Materials Used in the Study								
Composite	Type	Manufacturer	Lot No.	Resin	Filler	Weight, %	Volume, %	Filler Size, μm
Esthet-X HD	Nanohybrid	Dentsply, York, PA, USA	1510141	Bis-GMA, Bis-EMA, TEGDMA	BAFSG, silica dioxide	77	60	0.02-2.5
Filtek Z250	Microhybrid	3M ESPE, St Paul, MN, USA	N830674	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Zirconia, silica	78	60	0.01-3.5
NovoPro Fill	Nanofiber	Nanova, Columbia, MO, USA	UC033116A	Bis-EMA, UDMA, TEGDMA	BAFSG, amorphous fumed silica, titanium dioxide, hydroxyapatite	Not available	Not available	Not available
Abbreviations: BAFSG, barium aluminofluorosilicate glass; Bis-EMA, bisphenol A ethoxy dimethacrylate; Bis-GMA, bisphenol A diglycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.								

marketed as having an ideal combination of polish and strength.¹⁴ See Table 1 for a description of the components of the tested materials.

Flexural Strength/Modulus

To prepare each specimen, a 2 mm × 2 mm × 25 mm stainless-steel mold (Sabri Dental Enterprises, Downers Grove, IL, USA) was placed on a plastic strip-covered glass slide. Each of the composite materials was inserted into the mold. The top surface of the mold was covered with a second plastic strip. The irradiance from the curing light was measured with a laser power meter (FieldMax II, Coherent Inc, Santa Clara, CA, USA) before each group preparation and found to be 1200 ± 10 mW/cm². One side of the specimen was then exposed to a light-polymerization unit (Bluephase G2, Ivoclar Vivadent, Amherst, NY, USA) for 20 seconds each in five separate overlapping increments. Next, the mold was turned, and the opposite side of the specimen was exposed to the light in a similar manner. Then the specimens were removed from the mold and stored in distilled water at 37°C in an incubator (Model 20 GC, Quincy Lab Corp, Chicago, IL, USA). After 24 hours, the specimens were placed on a three-point bending test device, which was constructed with a 20-mm span length between the supporting rods. A central load was applied using a universal testing machine (Model 5943, Instron, Norwood, MA, USA) at a crosshead speed of 0.25 mm/min. The flexural strength was calculated using the following equation:

σFS = 3Fl / 2bd²,

where *F* is the loading force at the fracture point, *l* is the length of the support span (20 mm), *b* is the

width, and *d* is the depth (thickness). Measurements were made using a new electronic digital caliper (GA182, Grobet Vigor, Carlstadt, NJ, USA) calibrated by the manufacturer to industry standards. Flexural modulus was determined from the slope of the linear region of the load-deflection curve using the analytical software (Instron). The mean flexural strength and modulus with the standard deviation were calculated for each of the materials.

Degree of Conversion—Cylindrical molds measuring 2.0 mm in height and 8.0 mm in diameter (Sabri Dental Enterprises) were placed on a plastic strip-covered glass slide on a standard white background. The composite was inserted into the mold. Another plastic strip was then placed on top, and a microscope glass slide was used to flatten the top surface. The glass slide was removed. The light-curing unit was positioned with a clamp so that it was flush with the top surface of the plastic strip-covered composite. The composites were light-cured for 20 seconds. The irradiance from the curing light was measured with a laser power meter, as before.

Following light-curing, specimens were stored in the dark at 37°C in 100% humidity for 24 hours in the incubator. Measurements were made at the top and bottom surface of each sample. DC was determined using Fourier Transform Infrared Spectroscopy (FTIR: Spotlight 400 FTIR Imaging System, PerkinElmer, Bacon, UK). To measure top post-conversion DC, the top surface of each specimen was applied to the attenuated total reflectance (ATR) attachment of the FTIR. The specimen was then turned over, reapplied to the ATR, and conversion was measured for the bottom surface. To measure the DC of uncured composite, the cylindrical mold was placed directly over the ATR. The composite was inserted into the mold as before but was not light-cured.

To determine DC, the spectra were taken under the following conditions: 4000-600 cm^{-1} wave numbers range and 16 scans per spectrum at a 4 cm^{-1} spectral resolution. The stretching vibrations of the aliphatic C=C bonds (1635 cm^{-1}) and the aromatic C=C bonds (1608 cm^{-1}) were used as the analytical and internal-reference absorption bands, respectively.

The DC was calculated from the ratio of the peak heights of the analytical and reference absorption bands normalized by the ratio of the uncured monomers, as shown in the following equation:

$$\text{DC}\% = \left(1 - \frac{(P_1/P_2)_{\text{polymer}}}{(P_1/P_2)_{\text{monomer}}} \right) \times 100.$$

The P_1 and P_2 values represent the absorbance intensities of the aliphatic C = C (1634 cm^{-1}) and aromatic C = C (1608 cm^{-1}) bonds, respectively. The mean top and bottom DC and standard deviation were determined for each material. In addition, the percent bottom/maximum DC ratio was calculated by dividing the bottom surface DC by the maximum DC per material and multiplying by 100.

Depth of Cure—To determine depth of cure, the composites were tested using the scraping technique (ISO 4049).¹⁵ A 4-mm-diameter by 8-mm-long stainless-steel split mold (Sabri Dental Enterprises) was placed on a plastic strip-covered glass slide on a standard white background. The composite was injected into the mold, a plastic strip was placed, and the composite was condensed with a glass slide to displace excess resin. The glass slide was removed, and the composite was immediately polymerized with a curing light for the manufacturer's recommended curing time of 20 seconds. The irradiance from the curing light was measured with a laser power meter, as before. The uncured resin was then scraped with a plastic instrument starting from the deepest point on the underside of the mold until polymerized resin was reached. The length of the remaining polymerized material was measured with an electronic digital caliper and divided by two, according to the ISO standard. The specimens were visually inspected and discarded if any voids were noted. The mean depth of cure and standard deviation for each composite material were calculated.

Volumetric Polymerization Shrinkage—The composites were placed on a pedestal in a video-imaging device (AcuVol, Bisco, Schaumburg, IL, USA). Ten specimens of each composite per group were imaged from the side at a distance of 10 cm. The video

camera digitized and analyzed the images with the provided image-processing software. The specimens were cured for 20 seconds using the aforementioned light-curing unit. Polymerization shrinkage was recorded continuously for 10 minutes after the light initiation. The mean percent shrinkage and standard deviation were calculated for each of the restorative materials.

Scanning Electron Microscopy Imaging

The nanofiber-reinforced composite was imaged with a scanning electron microscope (SEM: Vega TC, Tescan, Warrendale, PA, USA). To prepare specimens for imaging, the composite was placed in the same stainless-steel mold used for flexural strength testing and polymerized as before. The specimens were removed from the mold, placed on a three-point bending test device, and fractured as before. The specimens were sonicated in deionized ultra-filtered water for 10 minutes and then placed in a vacuum desiccator. The specimens were sputter-coated for 60 seconds (108 Auto Sputter Coater, Cressington, Watford, UK) with gold and imaged on the fractured surface.

Statistical Analysis

Ten specimens ($n=10$) were created per group for flexural strength/modulus and volumetric polymerization shrinkage. A sample size of 10 specimens per group in three groups provided 80% power to detect a moderate effect size of 0.6, or approximately 1.2 standard deviation difference among means when testing with a one-way analysis of variance (ANOVA) at $\alpha = 0.05$ (NCSS PASS v11.0.8 2011). Five specimens ($n=5$) were created per group for DC and depth of cure. A sample size of five specimens per group in three groups provided 80% power to detect a moderate effect size of 0.75, or approximately 1.5 standard deviation difference among means when testing with a one-way ANOVA at $\alpha = 0.05$ (NCSS PASS v11.0.8 2011). Data were analyzed with a one-way ANOVA and Tukey post-hoc test to determine the effect of composite type (three levels) on each of the individual properties ($\alpha=0.05$) using statistical software (IBM SPSS, version 24, Chicago, IL, USA).

RESULTS

Significant differences were found between groups per property. The results are summarized in Table 2. Filtek Z250 had the greatest flexural strength ($160.9 \pm 24.2 \text{ MPa}$), a value that was significantly greater ($p=0.004$) than that of Esthet-X HD ($130.5 \pm 12.5 \text{ MPa}$) and NovaPro Fill (135.0 ± 21.4

Table 2: Properties of the Composite Materials ^a			
Property	Properties, Mean (SD)		
	NovaPro Fill	Filtek Z250	Esthet-X HD
Flexural strength, MPa	135.0 (21.4) B	160.9 (24.2) A	130.5 (12.5) B
Flexural modulus, GPa	11.7 (0.6) B	15.5 (0.8) A	10.7 (0.2) C
Shrinkage, %	3.01 (0.08) B	2.17 (0.16) A	3.00 (0.16) B
Depth of cure, mm	3.52 (0.04) A	3.55 (0.12) A	2.74 (0.03) B
DC top, %	58.0 (2.5) A	50.6 (3.8) B	54.7 (3.3) AB
DC bottom, %	49.6 (3.1) A	45.4 (1.5) B	49.0 (1.5) A
DC bottom/maximum ratio, %	81.2 (4.4) A	80.1 (4.7) A	84.2 (2.5) A
Abbreviations: DC, degree of conversion; SD, standard deviation.			
^a Groups With the Same Letter per Row Are Not Significantly Different ($p>0.05$).			

MPa), which were not significantly different from each other ($p=0.90$). The flexural modulus of Filtek Z250 (15.5 ± 0.8 GPa) was significantly greater than that of NovaPro Fill (11.7 ± 0.6 GPa), which was significantly greater than that of Esthet-X HD (10.7 ± 0.2 GPa) ($p<0.001$). Filtek Z250 had significantly less shrinkage ($2.17\%\pm0.16\%$; $p<0.001$) than did Esthet-X HD ($3.00\%\pm0.16\%$) and NovaPro Fill ($3.01\%\pm0.08\%$), which were not significantly different from each other ($p=0.99$). Filtek Z250 exhibited the greatest depth of cure (3.55 ± 0.12 mm), but it was not significantly different from that of NovaPro Fill (3.52 ± 0.04 mm; $p=0.83$), and both had significantly greater ($p<0.001$) depth of cure than did Esthet-X HD (2.74 ± 0.03 mm). NovaPro Fill had the greatest DC on the top surface ($58.0\%\pm2.5\%$), which was significantly greater than that of Filtek Z250 ($50.6\%\pm3.8\%$; $p=0.005$). The DC of the top surface of Esthet-X HD ($54.7\%\pm3.3\%$) was not significantly different than that of NovaPro Fill or Filtek Z250 ($p=0.22$). On the bottom surface, NovaPro Fill ($49.6\%\pm3.1\%$) had the greatest DC, but it was not significantly different ($p=0.95$) from that of Esthet-X HD ($49.0\%\pm1.5\%$). Both were significantly greater than that of Filtek Z250 ($45.4\%\pm1.5\%$; $p=0.008$). However, the DC bottom/maximum ratio was not significantly different ($p=0.27$) among the three groups: Esthet-X HD ($84.2\%\pm2.5\%$), NovaPro Fill ($81.2\%\pm4.4\%$), and Filtek Z250 ($80.1\%\pm4.7\%$).

The SEM images of the nanofiber-reinforced composite were reviewed. As shown in Figures 1 and 2, the nanofibers in NovaPro Fill were found to be bundled and not well organized or aligned.

In summary, compared to Filtek Z250, NovaPro Fill had significantly lower flexural strength and modulus, greater volumetric shrinkage, similar depth of cure, but greater top and bottom DC. Compared to Esthet-X HD, NovaPro Fill had similar flexural strength, shrinkage, and top and bottom

DC, but significantly greater depth of cure and flexural modulus.

DISCUSSION

There are limited published studies in the literature regarding nanofiber-reinforced restorative composites. This is the first study to examine a commercially available restorative composite (in the United States) reinforced with hydroxyapatite nanofibers. Based on the results of this study, the null hypothesis was rejected. Significant differences were found between groups based on property ($p<0.05$). The manufacturers of NovaPro Fill claim that it has superior mechanical properties to other products available on the market. However, in this study, the flexural strength of NovaPro Fill was not significantly greater than that of the other two composites tested.

Despite the significant improvement of restorative composites, these materials still suffer from two key shortcomings: deficiency in mechanical strength and polymerization shrinkage. These shortcomings may contribute to a shorter survival time of composites when compared to amalgams.² The vast majority of restorative composites consist of ceramic-based particles surrounded by a light-curable methacrylate matrix. Monomer solutions typically used are blends of bisphenol A diglycidyl ether dimethacrylate (Bis-GMA), triethylene glycol dimethacrylate (TEGDMA), and urethane dimethacrylate (UDMA).⁸

Recently there has been an increasing interest to reinforced composites with nanofibers. The addition of electrospun nanofibers has been examined utilizing different materials, from nylon and polyacrylonitrile–poly(methyl)methacrylate to hydroxyapatite.¹⁶ In initial laboratory studies, researchers were observing a decrease in flexural properties

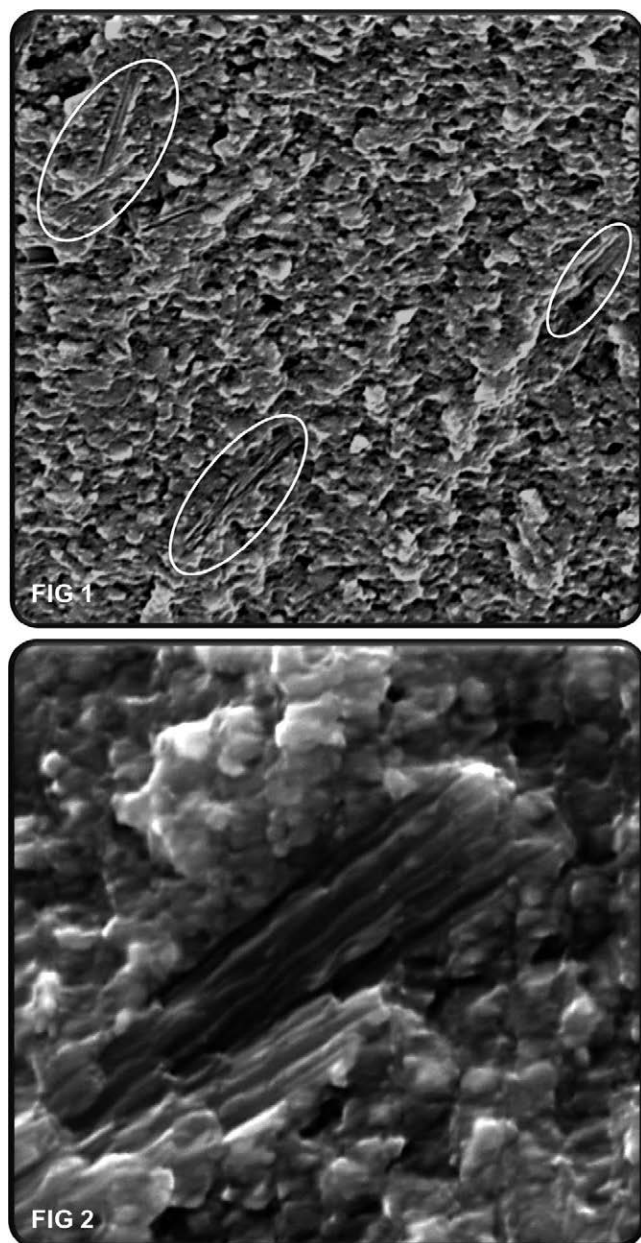


Figure 1. Scanning electron microscope (SEM) image of the nanofibers in the NovaPro Fill composite at 1000 $\times$ magnification. Figure 2. Scanning electron microscope (SEM) image of a bundle of nanofibers in NovaPro Fill composite at 2100 $\times$ magnification.

with certain fiber-to-polymer ratios and resin concentrations. The decrease was due to the limitations of bonding between the fibers and the resin matrix or to the incomplete infiltration of the resin to wet the nanofibers, which resulted in voids that compromised the overall material strength.¹⁷ Many of the studies of nanofiber-reinforced composite focus on the orientation and distribution of the fibers. Of these studies, several have found that when uniform distribution of the fibers is achieved

within the resin, there is a reported increase in toughness of the composite.¹⁸ Vidotti and others⁸ evaluated the influence of different concentrations and mass ratios of nanofiber composites. They found that different ratios of fibers did not affect the flexural strength and modulus of the composites, but the direction of the fibers did affect the tensile properties. However, Fong¹⁹ reported that the addition of 5 wt% relative low-strength polymer (Nylon 6) nanofibers could lead to a 36% increase in flexural strength and a 26% increase in flexural modulus. Recently, Uyar and others²⁰ demonstrated that the mechanical properties of dental composites are improved when using aligned nanofibers. They also found improvements in nonaligned nanofibers; however, the improvement was not statistically significant.²⁰ Nonalignment of nanofibers could have contributed to the strength properties recorded in this study for NovaPro Fill. As shown in the SEM image in Figure 1, the nanofibers in NovaPro Fill were not organized or aligned.

According to Chen and others,¹⁰ the impregnation of the hydroxyapatite nanofibers into Bis-GMA/TEGDMA dental resins may lead to double-sided effects—reinforcement due to a uniform distribution of hydroxyapatite nanofibers, but undermining if the nanofibers amass during processing to form bundles. Vidotti and others⁸ showed that as the hydroxyapatite nanofiber mass fraction increased to 10 wt%, a small portion of the hydroxyapatite nanofibers started to form bundles. When the hydroxyapatite nanofiber mass fraction increased to 20 wt%, more bundles were formed in the dental resin matrix, creating mechanical weak points that led to lower flexural strength values.⁸ A weakening effect due to bundling of nanofiber may have occurred in this study as well. A nanofiber bundle in the NovaPro Fill is shown in a SEM image (see Figure 2). Bundles of the nanofibers in a composite may also decrease the translucency of composites.¹⁰ Therefore, the DC of composites may decrease with a reduction in polymerization, a secondary phenomenon to an increased curing-light attenuation. A reduction in DC may lead to lower mechanical properties.

Nanova⁷ reports that NovaPro Fill has greater DC than do other composite restorative materials. The DCs of both the top and bottom surfaces of NovaPro Fill were significantly greater than those of Filtek Z250, but not significantly different from those of Esthet-X HD. However, when the bottom/maximum DC ratios were calculated, no significant difference was found among all three composites. When

evaluating depth of cure, NovaPro Fill performed similarly to Filtek Z250, with no significant difference between the two composites. Alternatively, both Filtek Z250 and NovaPro Fill had significantly greater depth of cure than did Esthet-X HD.

Finally, this study examined the volumetric shrinkage of the three composites. Polymerization shrinkage has been a restorative challenge for resin-based composites. Residual stress can be generated from shrinkage during curing.¹⁰ A study by Moszner and Salz²¹ showed the polymerization shrinkage of Bis-GMA to be 6.1% and that of TEGDMA to be 14.3%. Commercial composites have included inorganic filler to minimize the total shrinkage rate and to improve marginal adaptation. In 2008, Anttila and others²² showed that fibers could reduce polymerization shrinkage. In this study, NovaPro Fill performed comparably to Esthet-X HD, with no significant difference between the two composites. However, both Esthet-X HD and NovaPro Fill had significantly greater polymerization shrinkage than did Filtek Z250.

CONCLUSIONS

NovaPro Fill had similar flexural strength, shrinkage, and top and bottom DC, but significantly greater depth of cure and flexural modulus when compared to Esthet-X HD. When compared to Filtek Z250, NovaPro Fill had significantly lower flexural strength and modulus, greater volumetric shrinkage, and similar depth of cure, but greater top and bottom DC. Based on the properties tested, there may not be any significant advantage to the use of the new nanofiber composite restorative material (NovaPro Fill) when compared to the use of traditional hybrid composites.

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.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy of the United States Air Force, the Department of Defense, Uniformed Services University of the Health Sciences, or the United States government.

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Effect of Reduced Universal Adhesive Application Time on Enamel Bond Fatigue and Surface Morphology

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Clinical Relevance

Some universal adhesives can achieve stable enamel bonding when applied with reduced application time.

SUMMARY

Objective: The purpose of this study was to evaluate the effect of reduced application times of universal adhesives on enamel bond fatigue and surface morphology of the treated enamel with constant force atomic force microscopy (AFM).

Methods: Four universal adhesives—Adhese Universal (AU), Clearfil Universal Bond Quick (CU), G-Premio Bond (GP), and Scotchbond Universal Adhesive (SU)—were evaluated in a

laboratory for their ability to adhesively bond resin composite to enamel. Shear bond strengths were initially determined using 15 specimens per test group for each adhesive. Shear fatigue strengths were then determined using 20 specimens per test group for each the adhesives. The fatigue specimens were loaded using a sine wave at a frequency of 20 Hz for 50,000 cycles or until failure occurred. AFM observations, surface Ra roughness measurements, and geometric surface area evaluations of enamel surface treated with the adhesive agents were also conducted.

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Results: A strong relationship was found between the initial shear bond strength and shear fatigue strength for enamel surface Ra roughness but not for geometric surface area. The initial shear bond strength and shear fatigue strength of CU and GP were not influenced by different application times, unlike those of AU and SU. While the surface area of enamel treated with the adhesive agents was not significantly influenced by different application times and type of adhesive, surface Ra roughness of the enamel in the AU and SU groups significantly increased with increasing application time, unlike CU and GP.

Conclusions: The results of this study suggest that universal adhesives, used with reduced application times, have adequate Ra surface roughness to provide sufficient resistance to enamel bond fatigue at application times from <1 second to 20 seconds, while the geometric surface area of adhesive-treated enamel did not show any significant changes at these different application times.

INTRODUCTION

A recent trend in adhesives has been the use of universal adhesives in either a self-etch or total-etch mode.¹ Furthermore, they can be used to bond to a variety of substrates, including enamel, dentin, resin composites, glass ceramics, zirconia, and alloys.² These flexible adhesive systems permit the use of the simplest adhesive strategies, with the advantage that clinicians can decide which adhesive strategy to use for specific clinical situations.³ However, Rosa and others,⁴ in a systematic review and meta-analysis, concluded that weak enamel bond strengths have been reported for universal adhesives when used in self-etch mode instead of total-etch mode. Clinical studies of resin composite restorations using universal adhesives in noncarious cervical lesions indicate that performance over six months (Mena-Serrano and others⁵) and 18 months (Perdigão and others⁶) does not depend on the bonding strategies employed. Evaluations over two years (Lawson and others⁷) and three years (Loguercio and others⁸) also indicate acceptable clinical performance for both modes, although total-etch mode appears to be superior. Therefore, the use of universal adhesives, along with phosphoric acid pre-etching of enamel, has been recommended by many researchers to achieve optimal bonding.⁹⁻¹¹ This approach increased bonding performance of universal adhesives to enamel in many situations^{12,13} and

to dentin for universal adhesives with weak acidity (All-Bond Universal: pH 3.2).¹⁴

A potentially simpler option to improve the enamel bonding of universal adhesives is prolonged application time, which was suggested by Cardenas and others.¹⁵ They concluded that prolonged application times of universal adhesives in the self-etch mode might be a viable approach to enhance enamel bonding of the adhesive. Contrary to these reported findings, newly developed products such as Clearfil Universal Bond Quick (Kuraray Noritake Dental, Tokyo, Japan) and G-Premio Bond (GC, Tokyo, Japan) claim that high bond strength can be achieved even when they are applied with a shortened application time (optional manufacturer's instructions). Although reduced application time is clinically appealing, the procedure might negatively impact the creation of an etching pattern and durable enamel bonding. With the optional instructions, it has become important to examine the influence of different application times on adhesive effectiveness and whether such an approach can be applied to other universal adhesives. To date, there is only one publication, from Saikaew and others,¹⁶ that reports the effect of reduced application times on dentin bond strengths of universal adhesives and no independent research on this approach for enamel bonding.

In the past decade, dynamic adhesive bond strength testing assessing bond fatigue, in terms of shear fatigue strength, has been developed at the Creighton University School of Dentistry (Omaha, NE, USA).¹⁷⁻²¹ A method for this bond fatigue strength testing was originally developed by Erickson and others^{22,23} at the Academisch Centrum Tandheelkunde Amsterdam (ACTA) using the ACTA fatigue tester in 2006-2008 and was later modified by Erickson and others¹⁷ and Barkmeier and others¹⁸ using a four-station fatigue cyclor (Proto-tech, Portland, OR, USA) and then by Latta and Barkmeier¹⁹ using a servohydraulic testing machine (MTS 858 Mini Bionix II, MTS Systems Corp, Eden Prairie, MN, USA). Most recently, fatigue testing methods were further modified by Takamizawa and others²⁰ and Tsujimoto and others²¹ using an all-electric dynamic test instrument (ElectonPuls E1000, Instron, Norwood, MA, USA). The present method allows better assessment of a material's total-life tolerance to the repeated low-magnitude loads encountered in the oral cavity, as the cyclic stresses are thought to be more similar to the stresses generated during oral function than the continuous loading to failure applied with traditional shear bond strength testing.^{22,23}

Table 1: <i>Materials Used in This Study</i>			
Adhesive (Lot Number)	Code (pH)	Main Components	Manufacturer
Adhese Universal (164453)	AU (2.5)	Bis-GMA, HEMA, MDP, MCAP, decandiol dimethacrylate, dimethacrylate, ethanol, water, initiators, stabilizers, silicon dioxide	Ivoclar Vivadent (Schaan, Lichtenstein)
Clearfil Universal Bond Quick (1L0003)	CU (2.3)	Bis-GMA, HEMA, MDP, hydrophilic amide monomer, ethanol, water, initiators, silica, silane coupling agent	Kuraray Noritake Dental (Tokyo, Japan)
G-Premio Bond (1603091)	GP (1.5)	MDP, 4-MET, MEPS, methacrylate monomer, acetone, water, initiators, silica	GC (Tokyo, Japan)
ScotchbondUniversal Adhesive (617265)	SU (2.7)	Bis-GMA, HEMA, MDP, decamethylene dimethacrylate, ethyl methacrylate, propenoic acid, copolymer of acrylic and itaconic acid, dimethylaminobenzoate, methyl ethyl ketone, ethanol, water, silane treated silica, initiators, silane	3M (St Paul, MN, USA)
Abbreviations: Bis-GMA, bisphenol A glycidyl methacrylate; HEMA, 2-hydroxyethyl methacrylate; MDP, 10-methacryloyloxydecyl di-hydrogen phosphate; MCAP, methacrylated carboxylic acid polymer; 4-MET, 4-methacryloyloxyethyl trimellitate; MEPS, methacryloyloxyalkyl thiophosphate methylmethacrylate.			

Reported laboratory studies indicate that shear fatigue strength was not influenced by the frequency rate (5, 10, or 20 Hz with enamel in Takamizawa and others²⁴ and dentin in Scheidel and others²⁵) or by the number of cycles (50,000, 100,000, or 1,000,000 cycles with enamel and dentin in Tsujimoto and others²⁶). As a result of these studies, the fatigue load for adhesively bonded resin composite to mineralized tooth structures was standardized using a sine wave frequency of 20 Hz for 50,000 cycles or until failure occurs. This is a time-efficient approach for shear fatigue strength testing of rapidly advancing modern dental adhesive systems.

Recently, Tsujimoto and others²⁷ reported the relationship between shear fatigue strength under standardized conditions and quantitative three-dimensional micrographs obtained with constant force atomic force microscopy (AFM). AFM provides quantitative data about a wide range of surface topography characteristics, including surface roughness and geometric surface area. Additionally, three-dimensional micrographs allow for qualitative comparison of surfaces both in and out of the surface plane. Furthermore, AFM obtains quantitative data at the nanometer scale (~5 nm lateral and <1 nm height resolution) as opposed to the micrometer scale of optical profilometry (~4.4 µm lateral and >100 µm height resolution).²⁸ In addition, the noninvasive testing requires no sample preparation such as the metallic sputter coatings associated with scanning electron microscopy. Important correlations exist between shear fatigue strength testing and quantitative AFM micrographs,²⁷ where three-dimensional topographical mapping of adhesive-treated enamel surfaces offers valuable insight into the effects of reduced application times on nanoscale surface roughness and geometric surface area of adhesive-treated enamel.

The purpose of the present study was to evaluate the effect of reduced universal adhesive application times on enamel bond fatigue and nanoscale surface morphology. The null hypotheses tested were that the application time for adhesion to enamel would not influence 1) the shear fatigue strength 2) or the nanoscale surface roughness and geometric surface area of the resultant enamel surface.

METHODS AND MATERIALS

Study Materials

Four universal adhesives were evaluated in this study: 1) Adhese Universal (AU; Ivoclar Vivadent, Schaan, Liechtenstein), 2) Clearfil Universal Bond Quick (CU; Kuraray Noritake Dental, Tokyo, Japan), 3) G-Premio Bond (GP; GC, Tokyo, Japan), and 4) Scotchbond Universal Adhesive (SU; 3M ESPE, St Paul, MN, USA). Z100 Restorative (3M ESPE) was used as the resin composite for the bonding procedures. The adhesive materials are listed in Table 1 with the associated lot numbers and components.

Specimen Preparation

Sectioned buccal and lingual halves of deidentified extracted human molar teeth with the apical portions removed were mounted in 25-mm brass rings using an acrylic resin (Bosworth Fastray, Keystone Industries, Myerstown, PA, USA). Flat enamel bonding surfaces were prepared on the mounted buccal and lingual surfaces by wet (water) grinding using a gradually increasing sequence (180, 320, 600, 1200, 2000, and 4000 grit) of silicon carbide papers (Struers, Cleveland, OH, USA) up to 4000 grit in a grinder-polisher (Ecomet 4, Buehler, Lake Bluff, IL, USA). A final 4000-grit surface was used to minimize the influence of any directionality of the surface grooving created by the abrasives. These

Table 2: Application Protocol for Universal Adhesives

Adhesive	Adhesive Application Protocol
AU	Adhesive applied to air-dried tooth surface with rubbing motion for 20 s and then medium air pressure applied to surface for 5 s. Adhesive photopolymerized for 10 s.
CU	Adhesive applied to air-dried tooth surface with a rubbing motion and then medium air pressure applied to surface for 5 s. <i>No waiting time is required.</i> Adhesive photocured for 10 s.
GP	Adhesive applied to air-dried tooth surface for 10 s and then maximum air pressure applied to surface for 5 s. <i>Adhesive can provide sufficient bonding strength even when dried immediately after application without waiting time.</i> Adhesive photocured for 10 s.
SU	Adhesive applied to air-dried tooth surface with rubbing motion for 20 s and then medium air pressure applied to surface for 5 s. Adhesive photocured for 10 s.
Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.	

surfaces were then washed with water and dried using a dental three-way syringe at a distance of 5 cm above the surface at an air pressure of 3.8 kgf/cm². The specimens were prepared under ambient laboratory conditions of 22°C ± 2°C and 40% ± 20% relative humidity.

Initial Shear Bond Strength Test

Stainless-steel rings (mold-enclosed method) with an inner diameter of 2.4 mm, an outer diameter of 4.8 mm, and a height of 2.6 mm were used to bond the resin composite to the flat ground enamel surfaces. The bonding site surfaces (bottom side) of the stainless-steel rings were treated with a releasing agent (3% solution of paraffin in hexane) to mechanically isolate the bonded enamel/resin composite interface. The flat ground enamel bonding sites were then treated with the universal adhesives in the self-etching mode. The protocols were based on the manufacturers' instructions (Table 2), modified to allow for different application times. Three groups were prepared for each adhesive: 1) ground enamel treated with universal adhesive and immediately air-dried (<1-second group), 2) ground enamel treated with universal adhesive for 10 seconds and air-dried (10-second group), and 3) ground enamel treated with universal adhesive for 20 seconds and then air-dried (20-second group). In the <1-second group, no rubbing motion was used for any adhesive, and the surface was air-dried immediately after application. In the 10-second and 20-second groups, the adhesives for which the manufacturers specify a rubbing motion (AU, CU, and SU) were rubbed during the treatment period; as GP does not have a rubbing motion specified, it was not rubbed during this period. Thus, each adhesive was applied in accordance with the manufacturer's instructions in one condition and with a modified protocol in the others. A purpose-built fixture was used to position and hold the stainless-steel rings over the bonding

sites, and the resin composite (Z100 Restorative) was placed into the rings using a packing instrument. The resin composite was photo-cured for 40 seconds at a standardized distance of 1 mm using a quartz-tungsten halogen unit (Spectrum 800 Curing Unit, Dentsply Sirona, York, PA, USA) set at 700 mW/cm². The bonded specimens were stored in distilled water for 24 hours (37°C) before initial shear bond strength testing.

Initial shear bond strength tests (24 hours of water storage at 37°C) were carried out on all groups using the stainless-steel ring described above (mold-enclosed method). A chisel-shaped metal rod was used to apply the load on the stainless-steel rings immediately adjacent to the flat enamel surfaces. The specimens (15 per group) were loaded to failure using an all-electric dynamic test instrument (ElectroPuls E1000, Instron, Norwood, MA, USA) with a crosshead speed of 1 mm/min. Initial shear bond strengths (MPa) were calculated for the peak load at failure divided by the bonded surface area.

Shear Fatigue Strength Test

A staircase method, previously described by Draughn²⁹ and Dewji and others,³⁰ was used to perform the shear fatigue strength tests (ElectroPuls E1000). Twenty specimens were prepared for each adhesive group, as described above, and stored in distilled water at 37°C for 24 hours before shear fatigue testing. The fatigue load was applied sinusoidally at a frequency of 20 Hz for 50,000 cycles or until failure occurred (Figure 1). The initial peak load was set at approximately half (45-60 N) of the initial mean shear bond strength determined for each adhesive. The lower load limit was at approximately zero (0.4 N). Subsequent loading was adjusted upward or downward approximately 10% from the previous load, depending on specimen survival or failure, respectively. The test specimens were immersed in room-temperature water (23°C ±

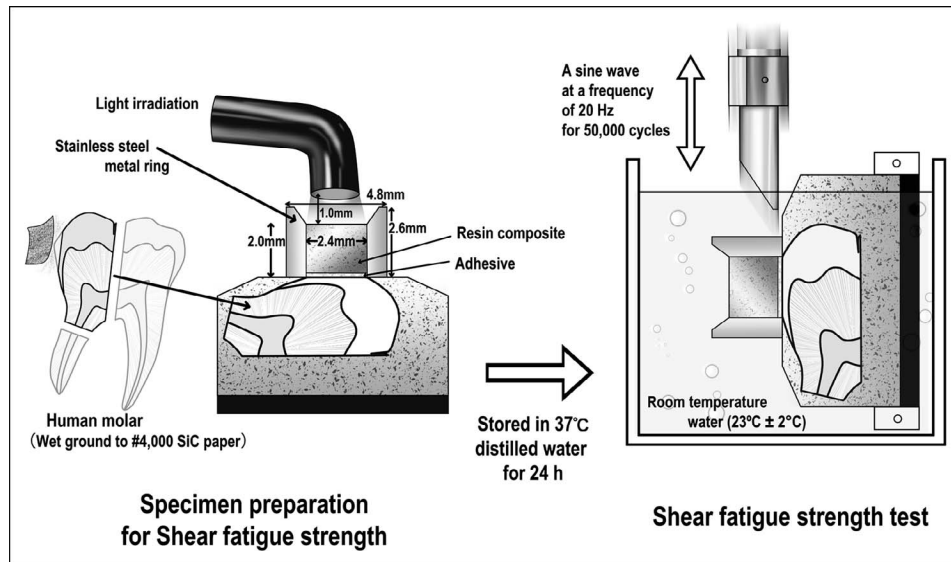


Figure 1. Schematic illustration of the experimental setup for shear fatigue strength testing under standardized conditions.

2°C) during testing to minimize the influence of temperature increases on the bonded specimens. The mean shear fatigue strength ($\bar{X}$) and standard deviation (S) were calculated using the formulas listed below and as described by Draughn:²⁹

$$\bar{X} = X_0 + d \left(\frac{A}{N} - \frac{1}{2} \right)$$

$$S = 1.62d \left(\frac{NB - A^2}{N^2} + 0.029 \right)$$

$$N = \sum n_i, A = \sum i n_i, B = \sum i^2 n_i$$

where X_0 is the lowest stress level considered in the analysis, d is the stress increment employed in the sequential tests, $i = 0$ is the lowest stress level at which a failure occurs, $i = 1$ is the next etc, and n is the number of failures after bond fatigue strength testing at each increment.

Failure Mode Analysis

The bond failure sites after initial shear bond strength and shear fatigue strength tests were assessed using an optical stereomicroscope (MZ16, Leica Microsystems, Heerbrugg, Switzerland) at 20× magnification. The failure types were classified by a calibrated investigator as 1) adhesive failure at the interface, 2) cohesive failure in resin composite, 3) cohesive failure in enamel, and 4) mixed failure (partially adhesive and cohesive failure).

AFM Evaluation

Six representative specimens were selected per group for AFM evaluation. Each specimen was imaged in three separate locations near the center of the specimen. Prior to measurements, specimens were washed with three alternating rinses using acetone and water to remove the adhesive and then five seconds of 80-psi compressed, dried air was used in a sweeping motion to remove any surface debris. Scanning probe AFM measurements were performed (5420 SPM/AFM Microscope, Agilent Technologies, Santa Clara, CA, USA) in an acoustical and mechanical isolation chamber under ambient laboratory conditions (22°C ± 2°C and 40% ± 20% relative humidity). Micrographs were obtained in constant force contact mode with a silicon nitride (Si_3N_4) cantilever (tip radius of ≤10 nm and spring constant [k] of 0.2 N/m) (BudgetSensors, Sofia, Bulgaria) at 512 lines per image at a rate of 4.0 lines per second. In this mode, the AFM is in constant feedback with the cantilever to maintain a constant deflection by increasing or decreasing the AFM specimen separation with piezoelectric motors (Figure 2). Micrographs (30×30 μm) were analyzed quantitatively and qualitatively with image analysis software (Gwyddion, Central European Institute of Technology, Brno, Czech Republic). Enamel surface roughness was quantified in terms of R_a (μm), the arithmetic average of the absolute values of the profile height deviations from the mean, recorded within an equivalent imaging area. Similarly, the geometric surface area measures the modified surface area (above the anticipated 900 μm² for a flat surface) due to height variations across the

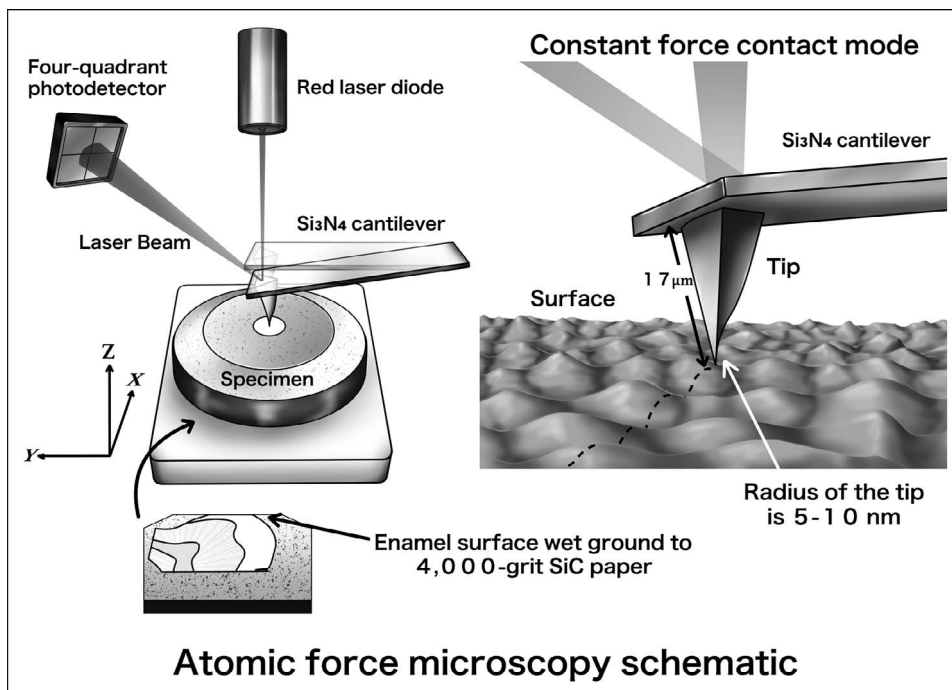


Figure 2. Schematic illustration of constant force atomic force microscopy, where a flexible cantilever with an atomically sharp tip is systematically rastered across the surface of a sample. A laser beam focused on the back of the reflective cantilever captures three-dimensional topography changes that are reflected in changes to the laser beam position on a four-quadrant photodetector.

surface. Qualitatively, intra- and intergroup differences were assessed by viewing the AFM micrographs.

Statistical Analysis

The initial shear bond strength, Ra surface roughness, and geometric surface area data were analyzed using two-way analysis of variance (factors: adhesive and treatment time) followed by the Tukey *post hoc* honest significant difference test ($\alpha=0.05$). A linear regression analysis between initial shear bond strength and shear fatigue strength on the Ra surface roughness and geometric surface area was also conducted. The Fisher exact test was used to analyze the failure mode after initial shear bond strength and shear fatigue strength testing. These statistical analyses were conducted using a commer-

cial software package (SPSS Statistics Base for Windows, IBM, Armonk, NY, USA). The shear fatigue strength data were analyzed using a modified *t*-test with a nominal α of 0.05 (custom program).

RESULTS

Regression Analysis

A strong positive correlation ($R=0.9712$, $R^2=0.9433$, $p<0.0001$) was found between the initial bond strength and shear fatigue strength. In addition, a positive correlation was evident in surface roughness (Ra) for both the initial shear bond strength ($R=0.8415$, $R^2=0.7082$, $p=0.0006$) and shear fatigue strength ($R=0.8507$, $R^2=0.7237$, $p=0.0005$). These correlations were statistically significant at $\alpha=0.05$. Significant positive correlations were not observed for geometric surface area for either initial shear bond strength ($R=0.0730$, $R^2=0.0053$, $p=0.8215$) or shear fatigue strength ($R=0.0738$, $R^2=0.0054$, $p=0.8197$).

Initial Shear Bond Strength

The results for the effect of different application times on the initial shear bond strength of the universal adhesives to enamel are shown in Table 3. The initial shear bond strengths of AU and SU were influenced by the application time of the adhesive agent, as the initial shear bond strengths of the <1-second and 10-second groups for AU and SU were significantly lower than those of 20-second group. On

Table 3: Effect of Reduced Application Times on Initial Shear Bond Strength of Universal Adhesives (in MPa)^a

Adhesive	0 s	10 s	20 s
AU	20.4 (3.0) aA	21.8 (3.0) aA	26.2 (2.9) aB
CU	25.6 (3.1) bA	26.1 (3.2) bA	26.5 (2.8) aA
GP	25.5 (3.2) bA	25.9 (3.6) bA	26.1 (2.4) aA
SU	20.9 (3.7) aA	21.2 (4.0) aA	27.2 (2.5) aB

^a Values in parentheses are standard deviations. Same lowercase letter in same column indicates no significant difference ($p>0.05$). Same capital letter within individual rows indicates no significant difference ($p>0.05$). Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.

Table 4: Effect of Reduced Application Times on Shear Fatigue Strength of Universal Adhesives (in MPa) ^a			
Adhesive	0 s	10 s	20 s
AU	9.7 (1.6) aA	10.3 (1.8) aA	13.2 (2.9) aB
CU	12.6 (2.0) bA	13.2 (1.6) bA	13.6 (2.8) aA
GP	12.5 (2.1) bA	13.7 (2.0) bA	13.8 (2.4) aA
SU	10.2 (2.4) aA	11.0 (1.8) aA	13.9 (3.5) aB
^a Values in parentheses are standard deviations. Same lowercase letter in same column indicates no significant difference ($p>0.05$). Same capital letter within individual rows indicates no significant difference ($p>0.05$). Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.			

the other hand, there was no significant difference ($p>0.05$) in the initial shear bond strength of CU and GP over the three application times. The initial shear bond strengths for the <1-second and 10-second groups of AU and SU were lower than those of all other groups.

Shear Fatigue Strength

The results for the effect of different application times on the shear fatigue strength of the universal adhesives to enamel are shown in Table 4. The shear fatigue strengths of AU and SU were influenced by the application time of the adhesive, as the shear fatigue strengths of the <1-second and 10-second groups for AU and SU were significantly lower than those of the 20-second group. There was no significant difference ($p>0.05$) in the shear fatigue strength of CU and GP over the different application times. The shear fatigue strengths for the <1-second and 10-second groups of AU and SU were lower than those of all other groups.

Failure Mode Analysis

The failure modes for initial shear bond strength and shear fatigue strength testing are shown in Table 5. Adhesive failure was the dominant mode of failure for both the shear bond strength and the shear fatigue strength specimens. The Fisher exact test revealed no statistically significant differences ($p>0.05$) in failure mode, depending on the type of adhesive or different application times. The shear fatigue strength failure mode was adhesive for all adhesives and all application times.

Three-Dimensional Topographic Observations

Qualitative changes in three-dimensional topography are evident in representative AFM topographic images (Figure 3). For AU, different appearances were observed for different application times. Although a smear layer and grinding debris were observed in

Table 5: Failure Mode Analysis of Debonded Specimens After Initial Shear Bond Strength and Shear Fatigue Strength Testing ^a			
Adhesive	Condition	Initial Shear Bond Strength	Shear Fatigue Strength
AU	0 s	[100/0/0/0] aA	[100/0/0/0] aA
	10 s	[100/0/0/0] aA	[100/0/0/0] aA
	20 s	[86/0/7/7] aA	[100/0/0/0] aA
CU	0 s	[100/0/0/0] aA	[100/0/0/0] aA
	10 s	[93/0/7/0] aA	[100/0/0/0] aA
	20 s	[86/0/14/0] aA	[100/0/0/0] aA
GP	0 s	[93/0/7/0] aA	[100/0/0/0] aA
	10 s	[100/0/0/0] aA	[100/0/0/0] aA
	20 s	[86/0/7/7] aA	[100/0/0/0] aA
SU	0 s	[100/0/0/0] aA	[100/0/0/0] aA
	10 s	[100/0/0/0] aA	[100/0/0/0] aA
	20 s	[67/0/13/20] aA	[100/0/0/0] aA
^a Percentage of failure mode [adhesive failure/cohesive failure in composite/cohesive failure in enamel/mixed failure]. Same lowercase letter in same column indicates no significant difference ($p>0.05$). Same superscript capital letter within individual rows indicates no significant difference ($p>0.05$). Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.			

topographic images of the <1-second group, these were less prominent in the 10-second group and had disappeared in the 20-second group. For CU, there were no obvious morphological differences for increased application times. Periodic grooves and an absence of smear layer and grinding debris were observed. For GP, a demineralized enamel surface with clear enamel prisms was seen regardless of the application time. There were no clear morphological differences in enamel prisms or microirregularities of hydroxyapatite crystals with increased application times. For SU, different morphologies were observed with increased application time. Topographic images of the <1-second and 10-second groups revealed periodic grooves on the ground surfaces without smear layer and grinding debris, while enamel prisms or microirregularities of hydroxyapatite crystals were observed only in the 20-second group.

Ra Surface Roughness and Geometric Surface Area Measurements

The surface roughness (Ra) results are shown in Table 6. For AU and SU, values significantly increased ($p<0.05$) with increasing application times. In CU and GP, there were no differences ($p>0.05$) with increased application time. Although time independent, the values for CU and GP were significantly greater at short application times when compared to AU and SU, with GP being the largest.

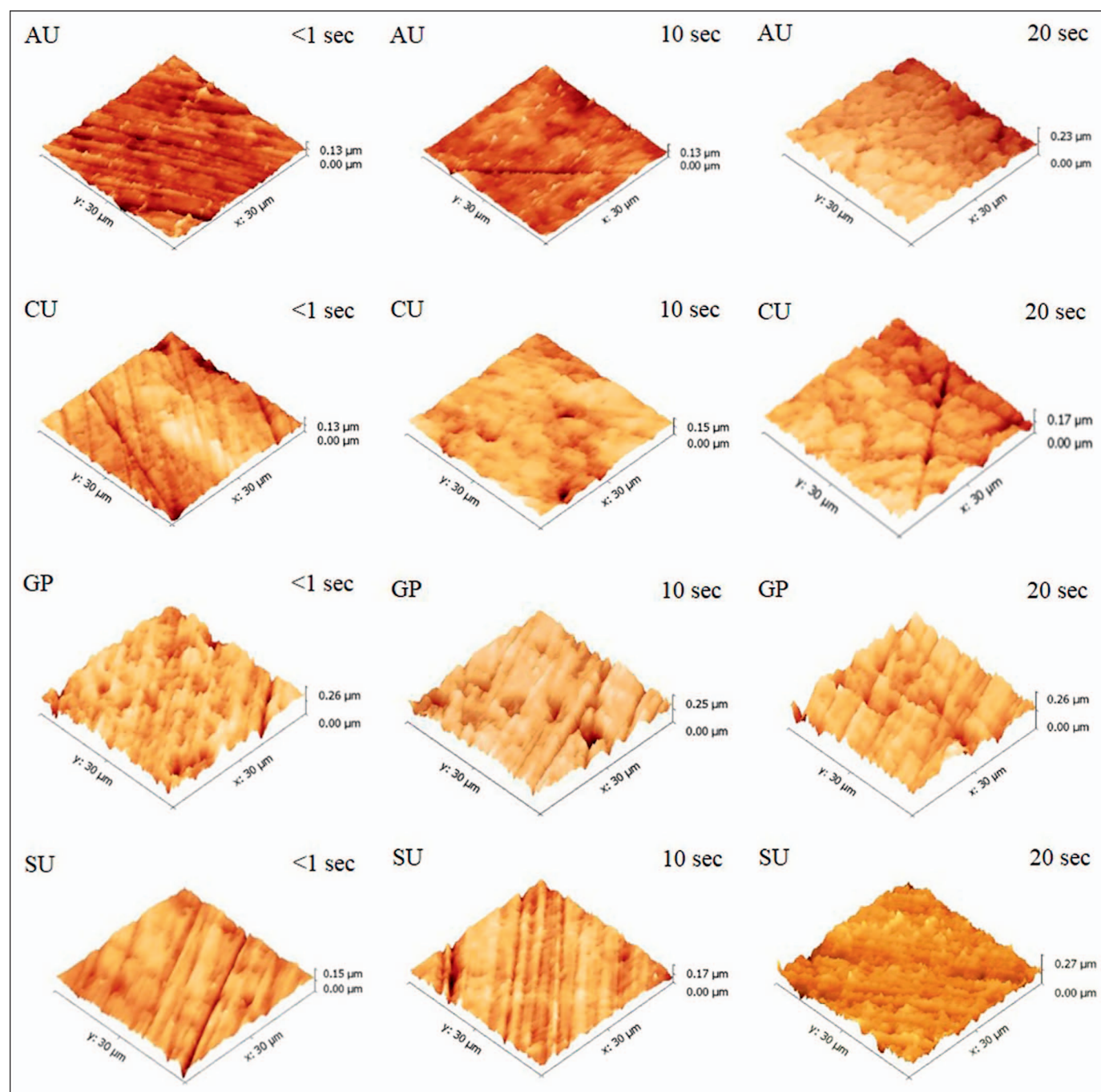


Figure 3. False color three-dimensional topographic images (30×30 μm) of universal adhesive-treated enamel surfaces obtained by constant force atomic force microscopy. Micrograph heights were normalized for accurate visual inspection, where the vertical scale bar shows the maximum feature height in the given micrograph. AU, Adhese Universal; SU, Scotchbond Universal Adhesive; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP).

These significant differences in Ra were not reflected in the geometric surface area values, as seen in Table 7. A perfectly flat surface would have a surface area of 900 μm². Therefore, the measured values (ranging from 903.4 to 906.0 μm² on average) varied only slightly from a flat surface and were not influenced by increased application time.

DISCUSSION

The initial shear bond strength and shear fatigue strength of CU and GP were not influenced by different application times, unlike those of AU and SU. Thus, the claim by the manufacturers that these adhesives can be used even with reduced application

Table 6: Effect of Reduced Application Times on Surface Ra Roughness of Enamel Surfaces (in nm) ^a			
Adhesive	0 s	10 s	20 s
AU	10.2 (1.1) aA	12.9 (2.6) aA	18.3 (3.4) aB
CU	16.5 (3.9) bA	16.8 (1.1) bA	15.3 (2.8) bA
GP	21.1 (2.2) cA	21.1 (3.4) cA	19.6 (3.6) aA
SU	13.0 (1.8) aA	13.6 (3.2) aA	21.2 (4.3) aB
^a Values in parentheses are standard deviations. Same lowercase letter in same column indicates no significant difference ($p>0.05$). Same capital letter within individual rows indicates no significant difference ($p>0.05$). Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.			

times appears to be accurate from a bond fatigue perspective. Per the results of the shear bond strength and shear fatigue strength tests, the first null hypothesis that the adhesive application time to enamel would not influence the shear bond strength and shear fatigue strength was rejected. However, there were no significant differences in failure mode after the shear bond strength or shear fatigue strength tests, and adhesive failures were the most frequently observed type of failure, regardless of the application time or adhesive agent. This is not surprising, as the bonding procedures were performed without phosphoric acid pre-etching of the enamel surface and an absence of etching is known to increase the frequency of adhesive failures.³¹ In addition, the testing was performed using a mold-enclosed method, which is also known to result in an increase in adhesive failures.³²

Strong positive correlations were found between both shear bond strength and shear fatigue strength and the surface roughness. For GP, the Ra was not influenced by the different application times and was significantly higher than those of other tested adhesives, except that of SU-treated enamel for 20 seconds. Topographic images of GP-treated enamel, regardless of the application time, showed a demineralized enamel surface with enamel prisms or microirregularities of hydroxyapatite crystals. The pH of GP (1.5) was lower than the other tested adhesives (2.3-2.7), which may contribute to the enamel bond fatigue strength of GP and Ra of GP-treated enamel even with reduced application times. In addition, GP contains 4-methacryloxyethyl trimellitic acid (4-MET) and 10-methacryoyloxydecyl dihydrogen thiophosphate (10-MDTP) as functional monomers in addition to 10-methacryoyloxydecyl dihydrogen phosphate (10-MDP). The former two monomers are acidic, and it has been reported that 4-MET forms strong chemical bonds with calcium-containing substrates such as enamel³³ (10-MDTP reportedly forms chemical bonds to metal sub-

Table 7: Effect of Reduced Application Times on Geometric Surface Area of Enamel Surfaces (in μm^2) ^a			
Adhesive	<10 s	10 s	20 s
AU	905.0 (2.3) aA	904.9 (3.0) aA	905.0 (2.3) aA
CU	903.9 (2.2) aA	903.4 (1.7) aA	903.4 (2.8) aA
GP	906.0 (2.5) aA	905.8 (2.1) aA	904.9 (3.3) aA
SU	904.6 (3.3) aA	904.2 (3.4) aA	904.7 (1.9) aA
^a Values in parentheses are standard deviations. Same lowercase letter in same column indicates no significant difference ($p>0.05$). Same superscript letter within individual rows indicates no significant difference ($p>0.05$). Abbreviations: AU, Adhese Universal; CU, Clearfil Universal Bond Quick; GP, G-Premio Bond (GP); SU, Scotchbond Universal Adhesive.			

strates,³⁴ a property that was probably not important in this study). The other tested universal adhesives (SU, CU, and AU) contained only a single acidic functional monomer (10-MDP), which suggests that the presence of multiple acidic functional monomer types is beneficial for enamel bonding. However, as manufacturers do not release specific information on the concentration of acidic functional monomers, it is impossible to rule out the possibility that GP simply has a higher concentration of acidic functional monomers and that the variety of types is not important in this context.

For CU, the Ra of treated enamel was not influenced by increasing the application time (similar to GP), but the Ra was significantly lower than all groups of GP and the 20-second group of AU and SU. Topographic images (Figure 3) of CU-treated enamel showed weaker demineralization compared to all groups of GP-treated enamel and the 20-second group of AU- and SU-treated enamel (periodic grooves on the enamel surfaces from grinding are visible) and revealed no application time-dependent morphological differences. CU includes a new hydrophilic amide monomer that purportedly is a key technological factor in the development of rapid bonds. This new hydrophilic amide monomer rapidly permeates tooth substrates due to its higher hydrophilicity, which eliminates chairside waiting time. It also shows a higher degree of polymerization than 2-hydroxyethyl methacrylate, reducing water absorption, which is important to bond durability. CU also includes a new integrated photoinitiator chemistry, also used in Clearfil SE Bond 2, that may provide more free radicals and lead to higher monomer conversion rates.³⁵ These factors may explain the higher bond fatigue durability of CU with reduced application times, even with lower Ra values and weaker demineralization, compared to all groups of GP and the 20-second group of SU. CU and GP could therefore be interpreted as demonstrating funda-

mentally different successful approaches (more acidic functional monomers vs rapid penetration and higher monomer polymerization rate, respectively) to the development of universal adhesives. It is an open question as to whether their combined integration might lead to further improvements.

Naively, an increase in shear bond strength and shear fatigue strength could be associated with an increase in geometric surface area. However, the geometric surface area of universal adhesive-treated enamel was not influenced by different application times for any of the adhesives tested. In addition, there was no correlation between the shear bond strength or shear fatigue strength and surface area of enamel surfaces treated with the universal adhesives. Therefore, the geometric surface area alone of universal adhesive-treated enamel does not seem to be an important factor for bond fatigue strength. Based on the results of Ra values and surface areas, the second null hypothesis that the application time to enamel would not influence the surface roughness was partially rejected.

The overall study results demonstrated that bond fatigue strength of some universal adhesives and surface morphologies were not influenced by different application times, and thus some universal adhesives may be suitable for use with a reduced application time. Generally, clinicians would desire to reduce the application time, which would encourage the use of those kinds of universal adhesives. However, there is some reason to be concerned about the direct clinical applicability of these results. Mine and others³⁶ reported that the surface-preparation method of enamel significantly affected the nature of the smear layer and the interaction with a mild (pH 2.7) one-step self-etch adhesive (Clearfil S³ Bond, Kuraray Noritake Dental). In the bond strength tests used in the present study, the enamel bonding surface was prepared by grinding to 4000-grit SiC paper to minimize the influence of surface scratches and irregularities on bond fatigue strength testing. Tani and Finger³⁷ reported that the thickness of the smear layer decreases with increasing SiC grit numbers. The thickness of the smear layer on the bonding surface used in this study may have been so thin that CU and GP could effectively interact with the enamel substrate. In addition, it has been reported that characteristics of the smear layer vary according to preparation variables³⁸ and that smear layers prepared with a diamond bur are more compact than those prepared by SiC paper when examined under scanning electron microscopy³⁹ and transmission electron microscopy.⁴⁰ Therefore, it is

possible that the denser smear layer created by a coarse diamond bur might hinder functional monomer penetration, and hence the results of this study may not be directly applicable to clinical situations using a diamond bur. Furthermore, a one-step self-etch adhesive (Clearfil S³ Bond) has been shown to be affected by the specific type of diamond bur used, with fine-grit diamond burs producing the highest microtensile bond strength as compared to medium and coarse grit.⁴⁰ Therefore, differences in smear layer preparation and subsequent bonding performance may exist when diamond burs are utilized in laboratory studies to mimic clinical practice.

A previous study¹⁶ that reported the effect of reduced application times of universal adhesives to dentin concluded that bonding to diamond bur-cut dentin always resulted in significantly lower bond strength regardless of the universal adhesive or application time. In addition, lower dentin bond strengths were found with reduced application times of adhesives to bur-cut dentin. Further research is needed on the effect of reduced application time on the bonding performance of universal adhesives with bur-cut enamel.

While recommendations have been made for abrasive papers to mimic bur-cut smear layers for self-etch adhesives on dentin,³⁸ these remain unclear for universal adhesives on enamel. Establishing a methodology for reproducing a clinical bur-cut smear layer with abrasive papers is important, as cutting with hand pieces is affected by a number of factors, including surface orientation, material removal rate, and application force.⁴¹ This may make reproducibility more difficult, but this could be ameliorated by the use of abrasive papers as long as they faithfully reproduce the smear layer.

CONCLUSIONS

The results of this study suggest that certain universal adhesives can be used with reduced application times. These adhesives appear to have adequate enamel bond fatigue strength and surface roughness (Ra) values at application times ranging from <1 second to 20 seconds, while the geometric surface area did not show any significant changes with different application times.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee

guidelines and policies of the Biomedical Institutional Review Board at Creighton University, Omaha, NE, USA. The approval code for this study is 760765-1.

Conflict of Interest

The authors of this article 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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Repolishing Resin Composites After Bleaching Treatments: Effects on Color Stability and Smoothness

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Clinical Relevance

When resin composites are submitted to bleaching procedures, immediate repolishing after the last gel application can improve color stability.

SUMMARY

This study aimed to evaluate the effect of repolishing after bleaching on color stability and smoothness of two resin composites aged in a high-staining beverage. Fifty-six disc-shaped specimens (8×2 mm) of each resin composite were fabricated (Filtek Z250, 3M ESPE, microhybrid, and Filtek Z350 XT, 3M ESPE, nanofilled) and then divided according to treatment: bleached or nonbleached. After treatment application, groups were subdivided according to the surface treatment: repol-

ished or unrepolished. A new subdivision was performed according to aging conditions: immersion in red wine for 15 min/d or in artificial saliva for 24 h/d during 30 days. Color (CIE- $L^*a^*b^*$ system) and roughness (Ra) were assessed at baseline (P0), after bleaching procedures (P1), after surface treatment (P2), and after aging (P3). Color change (ΔE_{00}) was calculated through the CIEDE2000 formula. Statistical analysis was performed using repeated measures analysis of variance and the Tukey *post hoc* test. Bleached repolished groups presented lower color alteration than the bleached unrepolished groups from both resin composites when aged in red wine. Repolishing (P1 vs P2) promoted a slight decrease in roughness values of almost all groups. Nanofilled composite presented greater ΔE_{00} values than microhybrid composite when aged in red wine.

INTRODUCTION

Resin composites and bleaching agents have been widely used due to increasing demand for esthetics. Bleaching procedures are commonly employed for removing intrinsic and extrinsic stains from dental tissue, and those who seek fast results often choose in-office techniques. In addition, the presence of

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resin composite restorations in the areas that are exposed to bleaching agents is very common.

Color change of a resin composite is related to factors such as matrix type, filler type, and coloring agents,¹ and it intensifies when the material is in contact with staining agents or alcoholic and acidic media commonly present in one's diet, further degrading the organic matrix.¹⁻⁴ Roughness is another important factor that determines composite discoloration.⁵⁻⁷ High-quality finishing and polishing improve both the longevity and the appearance of resin composites, whereas rough surfaces contribute to staining, plaque accumulation, recurrent caries, and gingival irritation⁸ in addition to also causing discomfort and cleaning difficulties for the patients.⁹

Teeth and resin composite restorations are exposed to bleaching action during treatments. These restorations are commonly replaced after the treatment due to possible physical and mechanical alterations in their smoothness, hardness, and color stability.¹⁰⁻¹² According to Rodrigues and others,¹³ a resin composite surface becomes more porous and rougher when it is submitted to bleaching procedures, which may facilitate discoloration.¹⁴ Nevertheless, resin composite restorations can be maintained after bleaching in some situations, such as when the dental tissue and restorative material interface in the bleached teeth are not affected¹⁵ and the bleached enamel color matches the restoration color.¹⁶

The consequences of bleaching on resin composites depend on both the bleaching agent and the composite compositions as well as on the frequency and duration of exposure to bleaching.¹⁷ Yu and others¹⁴ evaluated the effect of 15% carbamide peroxide on the staining susceptibility of resinous materials and observed that bleached specimens stained more easily when compared to nonbleached specimens. In a similar manner, Çelik and others¹⁸ analyzed the influence of 20% carbamide peroxide on the color stability of resin composites and did not find greater discoloration in bleached specimens. Polydorou and others¹⁹ did not verify alterations to the surface texture of polished and bleached specimens when studying the effect of 15% carbamide peroxide and 38% hydrogen peroxide on three different resin composites. Hubbezoglu²⁰ found statistically significant differences in the color stability of specimens bleached with 35% hydrogen peroxide. Yu and others²¹ also studied the effect of bleaching agents on these material surfaces and suggested that it may be necessary to polish the restorations that

were in contact with bleaching gel during the treatment.

To date, no research has shown if repolishing resin composite restorations after bleaching treatment has any significant importance. In this context, this study aimed to evaluate the effect of repolishing after bleaching on color stability and smoothness of two resin composites (microhybrid vs nanofilled) aged in a high-staining beverage. The tested hypotheses were that 1) repolishing after bleaching promotes the smoothness of resin composites and a decrease in the color change after aging, 2) bleaching resin composites promotes a color change and increases roughness, and 3) there is no difference between the resin composites after aging.

METHODS AND MATERIALS

Study Design

The characteristics of the materials used in this *in vitro* study are described in Table 1, and Figure 1 describes the study's time line.

The factors analyzed were resin composite (two levels: microhybrid or nanofilled composites), bleaching (two levels: bleached or nonbleached), surface treatment (two levels: repolished or unrepolished), aging media (two levels: red wine or artificial saliva), and study phase (four levels: P0, P1, P2, and P3). The same specimen within each experimental condition was analyzed in all phases (repeated measures approach): baseline (P0), after bleaching procedure (P1), after surface treatment (P2), and after aging (P3). Primary outcomes under investigation were color difference (ΔE_{00}) and roughness (Ra).

Specimen Preparation

The sample size was calculated using information from Sealed Envelope.²² Means and standard deviations of ΔE_{00} needed to calculate the sample size were obtained from a pilot study. It was observed that $n = 7$ was the minimum sample size, considering a 5% significance level and 80% statistical power.

Thus, 56 specimens of each resin composite were fabricated for this study: Filtek Z250 (microhybrid) (3M ESPE, St Paul, MN, USA) and Filtek Z350 XT (nanofilled) (3M ESPE). A stainless-steel matrix with a central hole of 2-mm thickness and 8-mm diameter was positioned over a polyester strip on a glass plate. The resin composite was placed in one increment into the matrix and covered by another polyester strip and a glass plate. An axial load of 500g was applied during 20 seconds to promote

Table 1: <i>Materials and Manufacturers, Type/Color, and Composition of Composite Resins, Bleaching Gels, and Aging Solutions Used</i>		
Material/Manufacturer	Type/Color	Composition ^a
Filtek Z250 (3M ESPE, St Paul, MN, USA)	Microhybrid/A2 Enamel	Matrix based on bis-GMA, bis-EMA, TEGDMA, UDMA; 60% silica/zirconia (0.6 μm) particles
Filtek Z350 XT (3M ESPE)	Nanoparticle/A2E	Matrix based on bis-GMA, bis-EMA, UDMA,TEGDMA; 63.3% silica/zirconia clusters; silica particles (20 nm); zirconia (4-11 nm) and silica/zirconia clusters (0.6-10 μm)
Total Blanc Office H35 (Nova DFL, Rio de Janeiro, Brazil)	—	35% hydrogen peroxide, thickener, plant extracts, amide, sequestering agent, glycol, dye and water
Artificial saliva (Dermapelle Farmácias de Manipulação, Santa Maria, Brazil)	—	Sodium chloride, potassium chloride, calcium chloride, magnesium chloride, potassium phosphate, methylparaben, carboxilometilcelulose, sodium fluoride, xylitol C, and deionized water
Salton Classic Cabernet Sauvignon (Vinícola Salton, Bento Gonçalves, Brazil)	—	Dry red wine fermented of cabernet sauvignon grapes; alcohol content of 13.0%

^a Manufacturer's information.

smoothness and extrude the resin composite excess. The specimen was then photoactivated by an LED light source (Radii, SDI, Bayswater, Australia) with approximately 1000 mW/cm² for 20 seconds through the glass plate and for 20 seconds without it. Immediately after, all faces of the specimens were finished and polished with a medium, fine, and extra-fine sandpaper disc (Diamond Pro, FGM Produtos Odontológicos, Joinville, Brazil) for 20 seconds per disc. A felt disc (Diamond Flex, FGM Produtos Odontológicos) with extra-fine (2-4 μm) diamond paste (Diamond Excel, FGM Produtos Odontológicos) was subsequently used for 20 seconds to achieve final polishing. New discs were used for each specimen. Specimens were rinsed and gently dried with gauze before every disc usage. One previously trained blinded operator carried out all the procedures. A digital caliper (Absolute Digi-matic, Mitutoyo, Tokyo, Japan) was used to measure specimen thickness, and specimens with thicknesses that varied by more than 0.05 mm were discarded.

Specimens were lightly marked with a diamond disc on their bottom surface. These markings were used to obtain a standardized position in the spectrophotometer and the roughness tester.

In the study's first phase, specimens of each composite were randomly allocated into two groups (bleached or nonbleached, n = 28) using information from Random.org.²³ The specimens in both groups were kept in artificial saliva at 37°C for 24 hours until initial hydration.

Bleaching Treatment

A standard Teflon mold (with cylindrical holes of 3-mm depth and 10-mm diameter) was designed to hold and fix the specimens in place and to standardize the bleaching procedures. Specimens were inserted into the mold with the top surface exposed and recessed 1 mm from the mold surface. Bleaching gel (35% hydrogen peroxide, Total Blanc Office, Nova DFL, Rio de Janeiro, Brazil) was manipulated as per the manufacturer's recommendations and applied

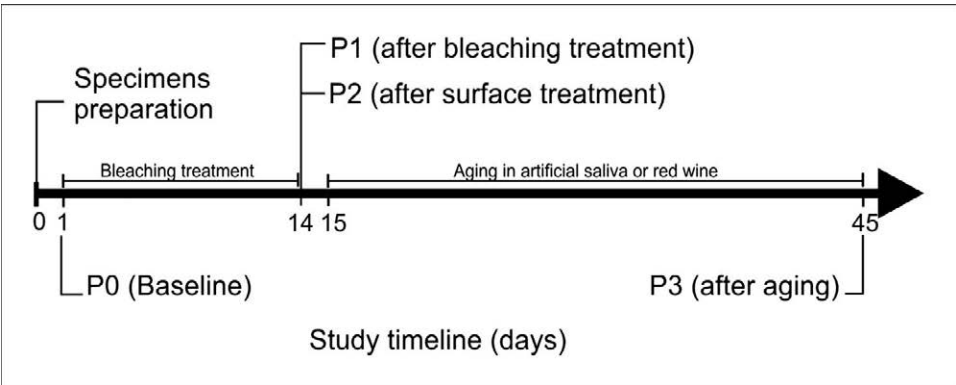


Figure 1. Time line from the specimen preparation to the end of the experiments.

over the top surface of each specimen in the bleached group. During each gel application, the mold containing specimens was placed over humid gauze inside a plastic container and kept at 37°C, ensuring constant humidity until the next application. Each specimen in the bleached group was submitted to two bleaching applications of 20 minutes per session. A total of three sessions were conducted at seven-day intervals. The specimens were rinsed and dried with absorbent paper after each session and returned to the closed bottles containing artificial saliva.

Nonbleached groups were kept immersed in artificial saliva at 37°C during this phase. Saliva bottles were refilled every two days.

Surface Treatment

Immediately after the bleaching procedure, each group was subdivided into two groups according to the top surface treatment employed (repolished or unpolished). A random number sequence divided into two columns (one corresponding to each treatment) was generated using Random.org.²³ Repolished groups had their top surface treated with the same extra-fine sandpaper discs and the felt discs with a diamond paste that were used in the polishing procedures. The polishing discs used in this research (Diamond Pro) had the same diameter of the specimens (8 mm), and their surfaces were fully covered with abrasive grains. Repolishing was performed on all specimens by a single trained operator with a low-speed motor (Kavo Dental, Biberach, Germany) associated to a contra angle hand piece at 10,000 rpm (median motor speed) (Kavo Dental). Pressure was applied to the surface by an air compressor (80-100 psi) and by the equipment weight (130 g). The polishing discs were positioned in parallel to the specimen's top surface, and the low-speed motor was activated and kept on for 20 seconds. The discs were changed every two specimens. Next, specimens were cleaned under running water and gently dried with gauze. Unrepolished groups were kept in closed saliva bottles at 37°C. Specimen thickness was assessed before and after the surface treatment through a digital caliper, and wear of about 0.02 mm was observed from the repolishing. After the surface treatment (P2), all specimens were kept for 24 hours in saliva bottles before the next phase in order to permit the release of any bleaching agent remnants.

Aging Procedure

All groups were again subdivided after surface treatment according to the employed aging condi-

tions (red wine or artificial saliva). A two-column number sequence (one corresponding to each aging condition) was generated as mentioned above. The authors chose red wine because it is an acidic and alcoholic medium rich in staining agents, which could somewhat represent the complex association of erosion, degradation, and pigment sorption. The groups aged in red wine remained in contact with the beverage for 15 min/d (at 37°C) for 30 days. After each daily immersion, the specimens were rinsed and dried with gauze and were stored in closed bottles containing saliva at 37°C until the next contact with the wine. The other groups remained immersed in artificial saliva, which was refilled every two days. The pH values of red wine and saliva were assessed using a pH meter (400-QA, Quimis, Diadema, Brazil). Red wine pH was measured when the bottle was opened (pH=3.55) and seven days after (estimated bottle duration) (pH=3.56). Artificial saliva pH was assessed on the first day of the study (pH=6.38), after 14 days (bleaching phase, pH=6.32), and again after an additional 30 days (aging phase, pH=6.28).

Color Evaluation

Color measurements were conducted at four points: 24 hours after specimen fabrication and hydration in artificial saliva (baseline, P0), after bleaching (P1), after surface treatment (P2), and after aging (P3). An SP60 spectrophotometer (X-Rite, Grand Rapids, MI, USA) in analysis mode, using D65 illuminant, a 10° observer angle, and the CIEL*a*b* color system (Commission Internationale de l'Éclairage), was used for measurements. Color parameters were measured over a neutral gray background (CIEL*=50.30, a*=-1.41, b*=-2.37) (Mennon gray cards, Mennon Photographic and Technical Co, Beijing, China). In the CIE L*a*b* system, L* is the luminosity axis with values varying from 0 (black) to 100 (white), and a* and b* are the color coordinates on a green-red axis and a blue-yellow axis, respectively. A coupling substance (glycerol, C₃H₈O₃) (Vetec Química Fina Ltda, Rio de Janeiro, Brazil) with a refractive index of 1.47 was used to minimize light scattering by eliminating the presence of an air layer between the specimen and the background.²⁴ Before measurements, the spectrophotometer was calibrated according to manufacturer guidelines. For each specimen, the values of L*, a*, and b* coordinates were collected three times, and the median of those readings was used for statistical analysis. Color changes (ΔE_{00}) for all

phases were calculated using the CIEDE2000 formula:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{\frac{1}{2}} \quad (1)$$

where ΔL , ΔC , and ΔH are the differences in lightness, chroma, and hue, respectively, for a pair of measurements and R_T is a function (the so-called rotation function) that accounts for the interaction between chroma and hue differences in the blue region. Weighting functions S_L , S_C , and S_H adjust the total color difference for variation in the location of the color difference pair in L' , a' , b' coordinates, and the parametric factors k_L , k_C , and k_H are correction terms for deviation from reference experimental conditions. In the present study, these parametric factors of the CIEDE2000 color difference formula were set as 1.

The ΔE_{00} values described by Paravina and others²⁵ of 0.8 and 1.8 were considered as clinical thresholds for perceptibility and acceptability, respectively.

The specimens were rinsed after each measurement in order to remove the coupling substance and dried with gauze afterward.

Roughness Evaluation

The smoothness parameter was assessed along with color measurements at P0 (baseline), P1 (bleaching phase), P2 (repolishing phase), and P3 (aging phase). Quantitative measurements were performed with a previously calibrated SJ-410 roughness tester (Mitutoyo, Takatsu-Ku, Japan). The Ra parameters (average roughness in μm) were assessed with a 0.80-mm cutoff, 0.0001- μm resolution (8- μm range), 0.5 mm/s speed, and total length of 4 mm according to ISO 4287.²⁶ Three measurements of the x - and y -axes were performed for each specimen, and the average value was used in the analysis. As resin composite roughness has no agreed on clinical threshold for unacceptable values, this study considered two thresholds: 1) Ra values below 0.2 μm associated with reduced plaque accumulation, risk for caries, and periodontal inflammation²⁷ and 2) Ra values below 0.3 μm associated with the comfort of the patient since most patients do not detect rough surfaces below this threshold.²⁸

Statistical Analysis

Color change (ΔE_{00}) and smoothness (Ra) data were analyzed by the statistical software SigmaPlot, version 11.0 (Systat Software Inc, San Jose, CA, USA). Analyses were carried out separately according to the employed aging conditions. The data were tested for normality (Shapiro-Wilk test) and homoscedasticity (Levene test) and then submitted to repeated measures two-way analysis of variance. All pairwise multiple comparison procedures were conducted using the Tukey test. The correlation between color change and roughness was tested using the Pearson correlation test. The significance level was set at 5% for all analyses.

RESULTS

Groups Aged in Artificial Saliva

Color change (ΔE_{00}) values, standard deviation, and differences found among groups after bleaching treatment (P1), surface treatment (P2), and aging in artificial saliva (P3) are described in Table 2. Interaction between the experimental group (material+treatment) and study phase was not significant ($p=0.481$), and no significant differences were found among the different phases in any experimental condition. On the other hand, the interaction among groups was significant ($p<0.001$). As expected, bleached groups of both composites in P1 presented greater color change than the nonbleached groups. In P2, repolishing did not have any effect on bleached or nonbleached resin composites. In P3, no significant differences among the Filtek Z250 groups were noted. The bleached and repolished groups achieved higher values of ΔE_{00} than the nonbleached repolished Z350 XT group. All groups had clinically perceptible color change ($\Delta E_{00}>0.8$), except for the nonbleached and repolished group, but none had clinically unacceptable alterations ($\Delta E_{00}>1.8$). No difference was perceived between the microhybrid and nanofilled resin composites at any phase ($p>0.05$).

Roughness (Ra) means, standard deviations, and differences found among groups in each of the phases are described in Table 3. Interaction between experimental group (material+treatment) and study phase was significant ($p=0.010$). Significant interaction was also observed within experimental groups ($p=0.013$). Significant differences among phases were detected after surface treatment (P1 vs P2) in almost all repolished groups. Bleaching (P1) did not alter the smoothness of either the microhybrid or nanofilled composites. After repolishing (P2),

Table 2: Means (Standard Deviation) of ΔE_{00} Values of Groups Aged in Artificial Saliva^a

	P1 (After Bleaching)		P2 (After Repolishing)		P3 (After Aging)	
	ΔE_{00}	Clinically Visible Change	ΔE_{00}	Clinically Visible Change	ΔE_{00}	Clinically Visible Change
Filtek Z250						
BR	1.51 (0.25) Aa	Yes	1.25 (0.51) Aab	Yes	1.24 (0.45) Aa	Yes
BU	1.44 (0.46) Aa	Yes	1.44 (0.46) Aa	Yes	1.38 (0.52) Aa	Yes
NR	0.72 (0.48) Ab	No	0.76 (0.30) Ab	No	0.77 (0.28) Aa	No
NU	0.80 (0.20) Ab	Yes	0.80 (0.20) Ab	Yes	1.00 (0.75) Aa	Yes
Filtek Z350 XT						
BR	1.22 (0.31) A1	Yes	1.15 (0.50) A12	Yes	1.18 (0.25) A1	Yes
BU	1.31 (0.24) A1	Yes	1.31 (0.24) A1	Yes	1.12 (0.12) A12	Yes
NR	0.45 (0.28) A2	No	0.49 (0.32) A3	No	0.51 (0.07) A2	No
NU	0.53 (0.37) A2	No	0.53 (0.37) A23	No	0.80 (0.21) A12	Yes

^a Different uppercase letters in the same line indicate phases differences, distinct lowercase letters in the same column indicate differences in bleaching procedures for Z250, and numbers indicate differences in bleaching procedures for Z350 XT (Tukey test, $p < 0.05$). BR, bleached repolished; BU, bleached unrepolished; NR, nonbleached repolished; NU, nonbleached unrepolished.

bleached Z350 XT showed a significant smoothness reduction (bleached and repolished vs bleached and unrepolished). This difference remained after aging in saliva (P3). Roughness values of all phases and conditions were maintained below the thresholds used in this study ($Ra < 0.2 \mu m$ and $Ra < 0.3 \mu m$).

There was no significant correlation between the color change and smoothness of groups aged in artificial saliva ($p = 0.616$, $r = 0.0421$).

Groups Aged in Red Wine

Color difference (ΔE_{00}) values, standard deviations, and differences found among groups after P1, P2, and P3 are described in Table 4. The interaction between the experimental group (material+treatment) and

study phase as well as the interaction within experimental groups were significant ($p < 0.001$ in both). All groups presented a significant and clinically unacceptable color change ($\Delta E_{00} > 1.8$) after 30 days of immersion (P3). No difference was detected among experimental conditions for either resin composites after aging in wine (P1 and P2). Also, the greatest color change was perceived in bleached unrepolished groups after aging for both resin composites. In contrast, similar ΔE_{00} values were attained by bleached repolished and nonbleached groups. Differences between the composites were observed at P3 in all groups, except for nonbleached unrepolished groups (Figure 2).

Roughness (Ra) means, standard deviations, and differences found among groups for all the four phases

Table 3: Means (Standard Deviation) of Ra Values of Groups Aged in Artificial Saliva^a

	P0 (Baseline)	P1 (After Bleaching)	P2 (After Repolishing)	P3 (After Aging)
Filtek Z250				
BR	0.15 (0.06) Aa	0.16 (0.10) ABa	0.11 (0.03) Ba	0.12 (0.04) ABb
BU	0.14 (0.02) Aa	0.17 (0.07) Aa	0.17 (0.07) Aa	0.19 (0.03) Aa
NR	0.15 (0.05) Aa	0.14 (0.06) Aa	0.12 (0.06) Ba	0.10 (0.03) Bb
NU	0.13 (0.03) Aa	0.15 (0.03) Aa	0.15 (0.03) Aa	0.13 (0.02) Aab
Filtek Z350 XT				
BR	0.13 (0.03) A1	0.13 (0.03) A1	0.08 (0.02) B2	0.08 (0.02) B2
BU	0.15 (0.03) A1	0.16 (0.03) A1	0.16 (0.03) A1	0.15 (0.04) A1
NR	0.15 (0.02) AB1	0.16 (0.06) A1	0.10 (0.03) B1	0.12 (0.03) B12
NU	0.16 (0.04) A1	0.15 (0.04) A1	0.15 (0.04) A1	0.16 (0.03) A1

^a Different uppercase letters in the same line indicate phases differences, distinct lowercase letters in the same column indicate differences on bleaching procedures for Z250 and numbers indicate differences on bleaching procedures for Z350 XT (Tukey test, $p < 0.05$). BR, bleached repolished; BU, bleached unrepolished; NR, nonbleached repolished; NU, nonbleached unrepolished.

Table 4: Means (Standard Deviation) of ΔE_{00} Values of Groups Aged in Red Wine ^a						
P1 (After Bleaching)		P2 (After Repolishing)		P3 (After Aging)		
ΔE_{00}	Clinically Visible Change	ΔE_{00}	Clinically Visible Change	ΔE_{00}	Clinically Visible Change	
Filtek Z250						
BR	1.46 (0.28) Ba	Yes	1.27 (0.43) Ba	Yes	8.12 (1.18) Ab	Yes
BU	1.39 (0.53) Ba	Yes	1.39 (0.53) Ba	Yes	9.26 (1.47) Aa	Yes
NR	0.90 (0.56) Ba	Yes	0.81 (0.48) Ba	Yes	7.30 (1.32) Ab	Yes
NU	0.86 (0.30) Ba	Yes	0.86 (0.30) Ba	Yes	8.07 (0.71) Ab	Yes
Filtek Z350 XT						
BR	1.25 (0.34) B1	Yes	1.04 (0.27) B1	Yes	9.87 (1.62) A2	Yes
BU	1.15 (0.23) B1	Yes	1.15 (0.23) B1	Yes	11.81 (1.51) A1	Yes
NR	0.61 (0.21) B1	No	0.61 (0.13) B1	No	9.61 (0.88) A23	Yes
NU	0.62 (0.18) B1	No	0.62 (0.18) B1	No	8.55 (0.60) A3	Yes

^a Different uppercase letters in the same line indicate phases differences, distinct lowercase letters in the same column indicate differences on bleaching procedures for Z250 and numbers indicate differences on bleaching procedures for Z350 XT (Tukey test, $p < 0.05$). BR, bleached repolished; BU, bleached unrepolished; NR, nonbleached repolished; NU, nonbleached unrepolished.

are described in Table 5. Interaction between experimental group (material+treatment) and study phase was significant ($p=0.019$), but interaction within experimental groups was not ($p=0.505$). Statistically significant differences among phases were observed after repolishing (P1 vs P2) in almost all repolished groups. No significant differences were noted among experimental conditions and between the materials ($p>0.05$) when each phase was independently analyzed. Roughness values in all phases and conditions were maintained below the thresholds used in this study ($Ra<0.2\text{ }\mu\text{m}$ and $Ra<0.3\text{ }\mu\text{m}$).

There was no significant correlation between color change and smoothness of groups aged in red wine ($p=0.756$, $r=-0.0241$).

DISCUSSION

Repolishing led to lesser color change in bleached groups that had contact with the staining agent. The results show that Filtek Z250 and Z350 XT bleached unrepolished groups aged in red wine had ΔE_{00} values 14% and 19% greater than the bleached repolished groups, respectively. On the other hand, the surface treatment caused no difference in the color stability of bleached groups that were not immersed in red wine. Since red wine has a low pH (3.55), it may have caused resin matrix softening.²⁹ Repolishing also made surfaces smoother (P1 vs P2), but the Tukey test did not detect this effect in all groups; it also did not detect differences among all bleached repolished vs bleached unrepolished groups

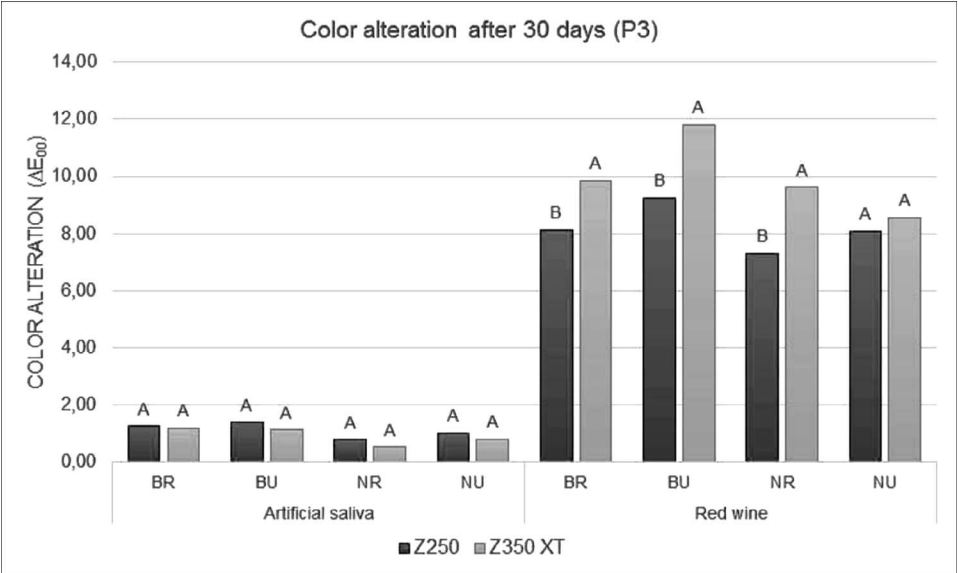


Figure 2. Groups of microhybrid and nanofilled composite resins after 30 days of aging (P3). Distinct letters in the same experimental condition (surface treatment+aging solution) indicate difference between composite resins (Tukey test, $p < 0.05$). BR, bleached repolished; BU, bleached unrepolished; NR, nonbleached repolished; NU, nonbleached unrepolished.

Table 5: Means (Standard Deviation) of Ra Values of Groups Aged in Red Wine^a

	P0 (Baseline)	P1 (After Bleaching)	P2 (After Repolishing)	P3 (After Aging)
Filtek Z250				
BR	0.14 (0.03) ABa	0.16 (0.04) Aa	0.09 (0.01) Ba	0.10 (0.05) Ba
BU	0.15 (0.03) Aa	0.15 (0.07) Aa	0.15 (0.07) Aa	0.17 (0.07) Aa
NR	0.13 (0.03) ABa	0.14 (0.04) Aa	0.10 (0.02) Ba	0.09 (0.01) Ba
NU	0.15 (0.01) Aa	0.14 (0.08) Aa	0.15 (0.09) Aa	0.14 (0.07) Aa
Filtek Z350 XT				
BR	0.14 (0.02) A1	0.14 (0.04) A1	0.11 (0.04) A1	0.11 (0.04) A1
BU	0.15 (0.03) A1	0.14 (0.04) A1	0.14 (0.04) A1	0.15 (0.05) A1
NR	0.16 (0.03) A1	0.16 (0.08) A1	0.10 (0.04) B1	0.10 (0.02) B1
NU	0.14 (0.03) A1	0.16 (0.05) A1	0.16 (0.05) A1	0.15 (0.04) A1

^a Different uppercase letters in the same line indicate phases differences, distinct lowercase letters in the same column indicate differences on bleaching procedures for Z250 and numbers indicate differences on bleaching procedures for Z350 XT (Tukey test, $p < 0.05$). BR, bleached repolished; BU, bleached unrepolished; NR, nonbleached repolished; NU, nonbleached unrepolished.

(Tables 3 and 5). Despite polishing and repolishing procedures having been carried out by a single calibrated operator, the results are not as accurate as those obtained using an automated device. Thus, the differences among results were probably caused due to operator bias. However, roughness did not reach unacceptable thresholds ($0.2 \mu\text{m}$) in any study phase, which suggests that these differences in smoothness caused by the treatments may not have clinical relevance. Therefore, the first listed hypothesis is partially accepted.

Barakah and Taher³⁰ evaluated the effect of polishing systems on the color stability of composites and concluded that polishing improves the color stability of resin composites. Güler and others³¹ observed that polishing with similar discs and diamond paste to those used in this study decreased the color change in resin composites. However, to date, there is no further research regarding the effects of repolishing immediately after bleaching. Our results show that this procedure also significantly improves the color stability of composites. The literature suggests that the bleaching action may cause matrix softening and a decrease in the microhardness and smoothness of restorative materials.^{14,32,33} Our roughness analysis has not shown a statistical difference in all bleached repolished vs bleached unrepolished groups (of both composites and each aging condition) after the repolishing phase (P2). Furthermore, the Pearson correlation test did not detect a significant correlation between color alteration and smoothness. In each measurement, the roughness tester probe tip passed by six points on the specimen's surface. As resin composite is a material handled by the operator, it is possible that minimal defects remained on its surface. Although

these defects may not be large enough to be detected by the roughness tester, they still can lead to clinically significant color alteration. However, repolishing may have eliminated any minimal defects, which seems to interfere with composites' color stability, resulting in a surface that is less susceptible to staining.

Bleaching treatment was unable to promote a greater color change in all groups or an increase in smoothness in any group when compared to nonbleached groups, which leads to the second tested hypothesis being partially accepted. For P1, ΔE_{00} values from bleached groups of both composites (exposed later to saliva or red wine) were similar to and greater than nonbleached composites, but the Tukey test highlighted statistical differences between bleached vs nonbleached groups, but only in the specimens aged in artificial saliva. Nevertheless, no ΔE_{00} value for P1 reached 1.8, which means there was no clinically unacceptable change. A color change in nonstained specimens has been explained by the presence of pigments inherent in the composites and/or by amine compound oxidation or the incomplete breakdown of the polymer of the resin matrix.³⁴ Previous studies have shown that ΔE_{ab} values of resin composites measured immediately after hydrogen peroxide bleaching ranged from 0.56 to 3.71.^{9,30,31} It appears that results can vary according to the resin composite type and bleaching protocol. Moreover, the chosen formula to calculate color alteration can also lead to a variation in results; while CIELAB is commonly employed, we chose to use CIEDE2000 because it is more sophisticated than its predecessors³⁵ and utilizes hue and chroma concepts, reinforcing the importance of the conceptual developments of Munsell.³⁶

Previous studies that used different bleaching agents in distinct concentrations have also not reported significant smoothness alterations in resin composites,^{37,38} whereas other studies observed significant changes.^{39,40} This contrast highlights the material-dependent effect of bleaching on the smoothness of restorative materials. Cengiz and others⁴¹ evaluated the effect of 10% hydrogen peroxide on the smoothness of five commercial resin composite brands, and they detected significant smoothness alterations in bleached groups compared to those in the control group. The present study used a higher concentration of hydrogen peroxide, and significant smoothness alterations caused by bleaching (P1) were not observed. However, the composites and bleaching gels used in the aforementioned study were not the same (type and/or commercial brands) as those used in our research, which may have led to different results. Varanda and others³³ also evaluated the influence of bleaching agents, including 35% hydrogen peroxide, on the smoothness of nano-filled (the same as in the present study) and microhybrid resin composites. In the former, the authors did not find significant alteration, while the latter presented little smoothness alteration, which was suggested might be eliminated by repolishing.

The third tested hypothesis is partially accepted since no color differences were detected between resin composites aged in artificial saliva. Nevertheless, all nanoparticle resin groups that had undergone any treatment (bleaching and/or repolishing) attained higher ΔE_{00} values than the microhybrid groups when exposed to red wine (P3). In addition, no differences in smoothness were observed between the materials in any phase or immersion media, corroborating the results obtained by Kaizer and others.⁴² They conducted a systematic review and did not find enough scientific evidence to show differences in smoothness and gloss between microhybrid and nanofilled resin composites.

Resin composite color changes have been related to the hydrophobic and hydrophilic nature of resin matrix compounds,⁴³ which determines the material's liquid sorption degree. Water sorption causes expansion and plasticizes the resinous compound, hydrolyzing the union agent silane and causing microcracks on the interface of filler particles and resin matrix. In this way, fluids and pigments infiltrate the matrix and cause discoloration.⁴⁴ Higher levels of water sorption have been attributed to composites containing a low concentration of TEGDMA and Bis-GMA monomers in its composition.⁴⁵ Z250 has a low TEGDMA concentration,

which seems to favor its color stability. Moreover, particle size (microhybrid vs nanofilled) also influences fluid sorption. Nanoclusters of composite Z350 XT present microporosities, which facilitate fluid sorption and pigment retention.^{46,47} The quantum effect is a phenomenon that makes the nanoparticles susceptible to different surface interactions, such as adsorption of substances to which they are exposed.^{48,49} The smaller the particle, the more pronounced the quantum effect on them is,^{48,49} which may be another factor contributing to the greater color change of nanofilled composites.

The staining procedures used in our study involved immersion in red wine for 15 minutes per day, which is clinically plausible since a person can easily keep restorations in contact with staining beverages for at least 15 minutes in a day. However, it is known that brushing reduces composite staining,⁵⁰ and this factor was not included in our research. This fact certainly contributed to the ΔE_{00} values being well above the unacceptability threshold and was considered the main limitation of our study. Since people usually brush their teeth at least once a day, our data cannot be directly inferred to clinical situations. In spite of the limitations of an *in vitro* study, our results indicate that when clinicians choose to maintain a resin composite restoration after a bleaching treatment, the simple act of repolishing it immediately after the last bleaching gel application can minimize susceptibility to color change, especially when the patient's diet is rich in pigments.

CONCLUSIONS

Repolishing immediately after bleaching improves the color stability of resin composites when exposed to staining agents. This procedure may also improve its smoothness. Bleaching by itself does not promote clinically unacceptable changes in color or in smoothness. Color and smoothness of both tested composites were affected by bleaching and surface treatments after aging. In addition, the nanofilled resin composite has a greater tendency to staining than the microhybrid resin composite.

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Conflict of Interest

The authors of this article 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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Effect of Tooth-Whitening Procedures on Stained Composite Resins

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Clinical Relevance

A composite resin stained by coffee or wine can be lightened to a clinically noticeable degree by some at-home tooth-whitening therapies.

SUMMARY

In this laboratory study, a composite resin was stained to a visibly discernible level using both coffee and red wine over 14 days (change was considered clinically noticeable and significant when $\Delta E_{ab}^* \geq 2.7$). Color change was measured at one, three, seven, and 14 days of staining. Although the nature of color change was different for the two staining solutions, the overall degree of staining (ΔE_{ab}^*) rendered by either coffee or wine at each time interval

was not significantly different ($p \geq 0.05$). Four whitening protocols were applied to stained composites. Treatment included applications of distilled water (control), Crest Pro-Health [HD] toothpaste, Crest Whitestrips, Opalescence PF bleach (15%), and application of a fine pumice polishing (Preppies). HD toothpaste and Whitestrips were applied daily for 21 days, Opalescence was applied daily for 10 days, and polishing was applied once. Each of the whitening products, applied in a manner simulating at-home or in-office treatment, was effective in producing color improvements (lightening) over controls ($p < 0.05$), but none of the four treatments produced lightening that was significantly different from the other treatments ($p \geq 0.05$). A comparison of final composite color with that measured at baseline showed that Opalescence returned composite color to an acceptable level following exposure to both staining solutions ($\Delta E_{ab}^* < 2.7$), Whitestrips returned color close to baseline for wine-stained composites, and HD paste and polishing permitted residual stain to remain ($\Delta E_{ab}^* \geq 2.7$).

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INTRODUCTION

Various studies have described the value of an attractive smile and the positive psychological

impact of teeth that are intact, properly aligned, and not discolored. The influence of dentition on positive perceptions of social attractiveness (friendliness, social class, popularity, and intelligence)¹ and overall social competence, intellectual achievement, and psychologic adjustment² have been reported.

One study found that job applicants with ideal dental esthetics were thought to be intellectually superior to other applicants and more likely to be hired.³ A survey of nearly 15,000 US adults regarding the importance and value of good oral health found that low-income adults were nearly twice as likely as high-income adults to believe that their teeth affected their ability to successfully interview for a job.⁴ In that same study, 25% of the respondents said they avoid smiling because of the condition of their mouth or teeth.

One of the most common concerns regarding dental appearance is tooth color. Surveys have found that approximately 25% to 55% of adults are dissatisfied with their tooth color.⁵⁻⁷ Since first described in the literature in 1989, vital tooth whitening (bleaching) has become a common and popular procedure worldwide for improving tooth color.⁸

Over many years, studies have been conducted to measure staining of composite resins by multiple beverages or condiments, such as fruit juices, tea, coffee, soy sauce, and cola.⁹⁻²⁰ Among those studies, coffee and red wine are two commonly consumed beverages that have been shown to cause significant composite resin staining. A recent study found that red wine and coffee were the only two of six beverages tested that caused clinically visible color changes of all three categories of direct esthetic restorations tested: nanocomposites, giomers, and resin-modified glass ionomers.²¹

A 2015 survey found that 64% of US adults drank at least one cup of coffee per day.²² Worldwide, per capita coffee consumption is led primarily by Europeans, in particular Northern Europeans. The Netherlands leads the world in per capita coffee consumption at 2.4 cups per day.²³

Wine consumption varies greatly throughout the world, but overall, nearly 25 billion liters were consumed in 2014. The United States, France, Italy, and Germany together accounted for more than 40% of that wine consumption.²⁴ Given these figures for consumption of staining beverages, as well as the aforementioned concerns about tooth color, dental patients are naturally interested in finding ways to

regain optimum tooth and restoration colors when beverage consumption causes discoloration.

Previous laboratory studies have been conducted to determine the lightening effects of both home-applied and office-applied tooth-bleaching products and polishing procedures on stained composite resins. Fay and others²⁵ found that a home bleaching product reduced stain from composite resin with or without the product's active ingredient. Villalta and others²⁶ also determined that bleaching improved the color of red wine- and coffee-stained composite resin to a level that was not clinically perceptible from baseline (prestain) color; however, they noted a weakness in their study was lack of a negative control group to confirm that the improvement was not a spurious result.

Studies comparing the effects of polishing to bleaching stained composite resins have had mixed results. Garoushi and others²⁷ found that repolishing was more effective than an in-office bleaching product (40% hydrogen peroxide bleaching gel) for improving color. In contrast, Türkün and Türkün²⁸ determined that another in-office bleaching product was more effective than simulated office polishing.

The purposes of this laboratory study were 1) to confirm and measure the staining of a composite resin by coffee and red wine and then 2) to determine the degree of lightening that could be regained by using contemporary self-applied at-home whitening products and an in-office polishing technique.

METHODS AND MATERIALS

A microhybrid composite resin, three staining materials, and four whitening/polishing materials were selected for this study. Details about the materials used including manufacturers or producers are listed in Table 1.

Specimen Preparation

Seventy-five composite resin specimens (13-mm diameter × 2-mm-thick discs) were fabricated using Amelogen Plus composite resin, shade A1. A split-mold Teflon (Chemours, Wilmington, DE, USA) well with 2-mm-deep holes was used to make the specimens.

Each specimen well was filled with composite resin to a depth of 1 mm, then light cured for a total of 60 seconds (light tip held in three overlapping positions for 20 seconds to cover the entire 13-mm surface). After a second increment of composite resin was placed, it was covered with a glass microscope slide and light cured for another 60 seconds in the

Table 1: *Materials Used*

Product	Code	Composition/Type	Manufacturer/Producer	Lot No.
Composite resin				
Amelogen Plus	AP	Microhybrid	Ultradent, South Jordan, UT, USA	BBLK2
Staining materials				
Distilled water	DW (negative staining control)			
Red wine	RW	Yellow Tail Cabernet	Casella Wines, Yenda, Australia 2014	
13.5% alc/vol	Sauvignon			
Coffee	CO	Pike Place Roast	Starbucks, Seattle, WA, USA	2016
Whitening and polishing materials				
Distilled water	DW (negative whitening control)			
Toothpaste	TP	Crest Pro-Health [HD]	Proctor & Gamble Cincinnati, OH, USA	4272M108
Whitestrips	WS	Supreme Professional	Proctor & Gamble Cincinnati, OH, USA	(L)5132U44
Whitening gel	BL	Opalescence PF (15%)	Ultradent, South Jordan, UT, USA	BB2QP
Pumice polish	PP	Preppies	Whip Mix, Louisville, KY, USA	5026

same manner as the prior step. A standard power VALO LED curing light (V23689, Ultradent, South Jordan, UT, USA) was used for polymerization of all specimens, and tested for output strength at the beginning and after 25 and 50 specimens were fabricated. The output exceeded 600 mW/cm² at each testing period.

After fabrication, each composite resin disc was numbered (1-75) on the bottom surface with an indelible pen, and the upper surface was polished with Sof-Lex XT (3M ESPE Dental Supplies, St Paul, MN, USA) fine and superfine polishing discs, using a slow-speed handpiece. Specimens were stored in distilled water at room temperature (22±1°C) for one day prior to staining.

Staining Procedure

The specimens were randomly distributed into three groups of 25 that were placed in 100 mL of each test solution in a 250-mL covered plastic specimen jar. To allow the test solutions to maximize contact, specimens were placed on a perforated plastic platform, which was elevated 0.5 mm in each jar. One group was placed in red wine (Yellow Tail Cabernet Sauvignon, Casella Wines, Yenda, Australia) at room temperature, one in coffee (Starbucks Pike Place Roast, Seattle, WA, USA) at approximately 75°C initially and then allowed to cool to room temperature, and one in distilled water (negative control) at room temperature. The coffee solution was prepared using a standard drip coffee maker and paper filter, with a ratio of one tablespoon ground coffee per six fluid ounces of water. Each solution was replaced daily for 14 days. Upon conclusion of the staining procedures and final pretreatment color testing, the specimens were

stored in distilled water for 24 hours prior to the application of color improvement treatments.

Color Testing

The color of each specimen was measured at baseline (prior to staining), 24 and 72 hours, seven and 14 days to determine the rate of color change. Prior to measurement, each specimen was rinsed for five seconds with distilled water and then blotted dry with a paper towel (Envision, Georgia-Pacific, Atlanta, GA, USA). Measurements were procured with a pulsed xenon arc light spectrophotometer (Konica Minolta CM-2002, Konica Minolta, Inc, Tokyo, Japan) against a white background using CIELAB color space relative to CIE standard illuminant D65. Since it was necessary to measure color at multiple time intervals on the same specimen, it was critical to measure color at the same location every time. A positioning jig was constructed with an alignment mark so that the specimen, which also held an alignment mark on its side, could be oriented beneath the port of the spectrophotometer in an identical position each time.

Color differences ΔL^* , Δa^* , and Δb^* caused by staining were determined by subtracting L^*, a^*, b^* values measured at baseline from those measured at one, three, seven, and 14 days. Color changes rendered by whitening protocols were calculated by subtracting color index values measured after 14 days of staining from those measured after administration of whitening regimens. Overall effectiveness of whitening protocols was assessed by subtracting baseline color index values from those measured after whitening. Total ΔE_{ab}^* color change was calculated at the same time intervals according to the expression $\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, where L^* is

lightness ($-L^*$ =black; $+L^*$ =white), a^* is green-red ($-a^*$ =green; $+a^*$ =red), and b^* is blue-yellow ($-b^*$ =blue; $+b^*$ =yellow).²⁹ Based on a recent study of ceramic staining, perceptible discoloration was considered clinically acceptable up to the value of $\Delta E_{ab}^* = 2.7$ in subjective visual evaluations made *in vitro* under optimal lighting conditions.³⁰

Whitening and Polishing Treatments

Materials tested for color improvement included 1) distilled water, 2) Crest Pro-Health [HD] toothpaste, 3) Crest Whitestrips, 4) Opalescence PF bleach (15%), and 5) application of a fine pumice polishing (Preppies). This produced a sample size of five for each group. The sample size was chosen based on a power analysis³¹ of data obtained from previous color measurements. The analysis was powered to detect differences between groups of 2.0 ΔE_{ab} units with 80% power, 60 degrees of freedom (three staining groups $\times$ five treatment groups $\times$ $n-1$ or 4 test samples per group) at $\alpha = 0.05$ level of confidence.

Each treatment was delivered according to the manufacturer's instructions simulating normal clinical or at-home application, over a period of 21 days. All specimens were stored in distilled water at room temperature between treatment applications, and that distilled water was replaced daily. The Pro-Health toothpaste and Whitestrips treatments began on day 1 and were applied twice daily for 21 days, to mimic a typical pattern of brushing by patients and the manufacturer's recommended use for Whitestrips. The distilled water test group (negative control) was placed in fresh distilled water daily. Opalescence PF bleach was applied from days 12 to 21, and the pumice (Preppies) specimens were treated on day 21.

Following is the protocol for each treatment:

1. Distilled water (negative control): Replaced daily.
2. Crest Pro-Health toothpaste: After drying specimens (cotton gauze), specimens were brushed for five seconds with step 1 paste and five seconds with step 2 paste (wiped with cotton gauze but no rinse after step 1; rinsed with tap water after step 2) using an Oral B PRO 5000 electric toothbrush. Five seconds per specimen was chosen as the typical amount of time a patient would brush a stained surface. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.
3. Whitestrips: After drying specimens, Whitestrips were applied for a total of 60 minutes daily. Each specimen received a Whitestrip for 30 minutes,

and then that Whitestrip was replaced with another. The Whitestrips user instructions direct patients to use them twice daily for 30 minutes each. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.

4. Opalescence PF bleach: Beginning on day 12, specimens were treated for seven hours daily. The timing protocol was chosen to mimic a 10-day regimen of overnight tray application applied at bedtime. The bleach was applied to the treatment surface of each specimen with a cotton-tip applicator. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.
5. Preppies: On day 21, these specimens were polished with Preppie paste applied via a rubber cup on slow-speed handpiece for 10 seconds at moderate pressure. The 10-second application was based on the amount of time a typical dental hygienist would polish a severely stained surface. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.

After 24 hours in distilled water, all specimens were measured for the final time using the spectrophotometer.

For statistical treatment of data, mean and standard error values were calculated for each group at each time interval for ΔL^* , Δa^* , Δb^* , and ΔE_{ab}^* . A repeated-measures one-factor generalized linear model (GLM) was employed to identify the presence of significant color changes caused by staining, and a two-factor GLM was used to assess color changes rendered by whitening protocols on stained composites ($p < 0.05$). If significant differences were detected, a Tukey-Kramer post hoc pairwise comparison test was applied to assess differences between groups ($p < 0.05$).³¹

RESULTS

A review of the data set revealed that for two wine-stained groups, one whitened with Crest HD paste and another with Opalescence, two samples in each group recorded unrealistically high ΔE_{ab}^* values during staining. This suggested that errors in color measurement may have occurred, and a statistical test for outliers^{31,32} applied to the data set resulted in removal of the data points. For the two groups, the sample sizes were reduced from five to three.

Color changes induced by staining protocols are presented in Figures 1 and 2. Both wine and coffee

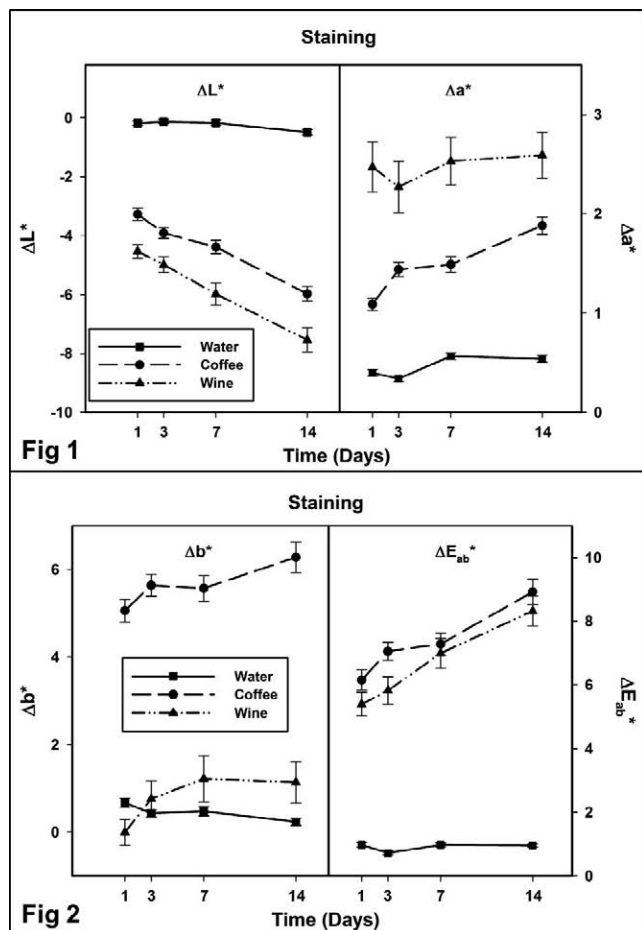


Figure 1. Changes in ΔL^* (left vertical axis) and Δa^* (right vertical axis) color parameters after soaking in control and staining solutions over time. Error bars represent standard errors of means. Note differences in scale between left and right axes. For ΔL^* and Δa^* , all solutions are significantly different from each other at each time interval ($p < 0.05$, GLM/Tukey).

Figure 2. Changes in Δb^* (left vertical axis) and ΔE_{ab}^* (right vertical axis) color parameters after soaking in control and staining solutions over time. Error bars represent standard errors of means. Note differences in scale between left and right axes. For Δb^* , coffee is significantly different from water and wine at all time intervals ($p < 0.05$, GLM/Tukey), whereas wine and water are not significantly different from each other at any time interval ($p \geq 0.05$). For ΔE_{ab}^* , coffee and wine are significantly different from water at each time interval ($p < 0.05$) but not different from each other at any time interval ($p \geq 0.05$).

produced quasi-linear decreases in mean ΔL^* values and increases in mean ΔE_{ab}^* values over the 14-day period. The composite was darkened most by red wine, and continuous exposure to the beverage lowered the mean ΔL^* value from -4.5 to -7.5 between days 1 and 14. Darkening by coffee was significantly less ($p < 0.05$), as ΔL^* values changed from -3.3 to -6.0 over the same time period. The nature of discoloration for the two staining solutions was different, as red wine significantly reddened the composites more than coffee ($2.3 \leq \Delta a^* \leq 2.6$ vs

$1.1 \leq \Delta a^* \leq 1.9$, respectively), and coffee caused significantly greater yellowing than red wine ($5.1 \leq \Delta b^* \leq 6.3$ vs $0 \leq \Delta b^* \leq 1.2$, respectively, all $p < 0.05$). Although the nature of color changes imparted by the two staining solutions was different, the calculated total color changes were similar, as their ΔE_{ab}^* values were not significantly different at any time point ($p \geq 0.05$). Control groups soaked in water underwent minimal color change at all time intervals, as mean ΔE_{ab}^* values ranged from 0.7 to 1.0 units.

Tables 2, 3, and 4 show color parameter changes that were measured after the four whitening methods were applied to stained and control composites. For wine- and coffee-exposed composites (Tables 2 and 3), whitening procedures significantly changed color parameters over those measured for control groups ($p < 0.05$). However, no significant differences were noted among the different whitening methods for any color parameter, regardless of storage media ($p \geq 0.05$). Data presented in Tables 2 and 3 demonstrate that the effects from staining mostly were reversed, as the various whitening methods increased color value (ΔL^* positive), reduced reddening caused by wine (Δa^* negative), and lowered yellowing caused by coffee (Δb^* negative). Interestingly, Crest HD Paste and Whitestrips increased yellowness in wine-stained composites by nearly 2.5 Δb^* units (Table 2). For composites soaked in water, the four whitening methods did not significantly change any color parameter over those measured for the control group ($p \geq 0.05$; Table 4).

To assess the overall color deviation from baseline after staining and whitening, ΔE_{ab}^* values were calculated, and the results are shown in Figure 3. A horizontal line drawn at $\Delta E_{ab}^* = 2.7$ identifies the 50%:50% threshold for maximum acceptable visual color change.³⁰ Although overall color changes delivered by the four whitening methods to stained composites were not statistically different from one another ($p \geq 0.05$), only Opalescence was effective in returning composites to baseline color following exposure to both wine and coffee ($\Delta E_{ab}^* < 2.7$). Whitestrips reduced the effects caused by wine staining to an acceptable level but left excess residual stain from coffee. Brushing with Crest HD paste and polishing with Preppies partially removed the two stains, but excess residual stain remained on composite surfaces ($\Delta E_{ab}^* > 2.7$).

DISCUSSION

When composite discoloration renders an unsightly restoration, clinical intervention is required to either

Table 2: Composite Color Changes Imparted by Whitening Treatments After Storage in Wine (Mean $\pm$ SE)[†]

Whitening Treatment	ΔL^*	Δa^*	Δb^*	ΔE_{ab}^*
Water	-0.4 ± 0.31^a	-2.5 ± 0.18^a	1.0 ± 0.60^a	3.0 ± 0.30^a
HD Paste	4.8 ± 0.59^b	-3.2 ± 0.39^a	2.5 ± 0.34^a	6.3 ± 0.48^b
Opalescence	5.8 ± 0.15^b	-3.4 ± 0.012^a	0.4 ± 0.41^a	6.7 ± 0.17^b
Whitestrips	5.6 ± 0.49^b	-3.3 ± 0.71^a	2.4 ± 1.31^a	7.2 ± 1.26^b
Polish	5.8 ± 1.81^b	-3.5 ± 0.86^a	-1.2 ± 1.16^a	7.4 ± 1.95^b

[†] Groups with different superscript letters denote significant differences at the 0.05 probability level (GLM/Tukey). Comparisons are vertical only.

Table 3: Composite Color Changes Imparted by Whitening Treatments After Storage in Coffee (Mean $\pm$ SE)[†]

Whitening Treatment	ΔL^*	Δa^*	Δb^*	ΔE_{ab}^*
Water	-0.6 ± 0.11^a	-0.6 ± 0.11^a	-1.5 ± 0.23^a	1.7 ± 0.26^a
HD Paste	3.3 ± 0.38^b	-1.8 ± 0.20^a	-5.8 ± 0.52^b	7.1 ± 0.42^b
Opalescence	3.9 ± 0.46^b	-1.8 ± 0.20^a	-7.8 ± 0.80^b	8.9 ± 0.86^b
Whitestrips	2.9 ± 0.41^b	-1.4 ± 0.16^a	-4.8 ± 0.39^b	5.8 ± 0.49^b
Polish	2.9 ± 0.36^b	-2.0 ± 0.22^a	-7.2 ± 0.61^b	8.0 ± 0.63^b

[†] Groups with different superscript letters denote significant differences at the 0.05 probability level (GLM/Tukey). Comparisons are vertical only.

Table 4: Composite Color Changes Imparted by Whitening Treatments After Storage in Water (Mean $\pm$ SE)[†]

Whitening Treatment	ΔL^*	Δa^*	Δb^*	ΔE_{ab}^*
Water	-1.2 ± 0.15	-0.3 ± 0.14	-0.3 ± 0.40	1.6 ± 0.18
HD Paste	-0.3 ± 0.26	-0.7 ± 0.20	-0.9 ± 0.29	1.2 ± 0.39
Opalescence	0.1 ± 0.15	-0.4 ± 0.10	-1.4 ± 0.09	1.5 ± 0.08
Whitestrips	-0.2 ± 0.14	-0.4 ± 0.08	-1.5 ± 0.20	1.6 ± 0.21
Polish	-0.7 ± 0.14	-0.6 ± 0.06	-0.8 ± 0.16	1.3 ± 0.14

[†] No significant differences among whitening treatments for any color parameter ($p \geq 0.05$, GLM/Tukey).

counteract the discoloration or replace the restoration. Composite discoloration has been reported to occur at three levels: surface (or external), subsurface, and body (or intrinsic).¹³ While accumulated food, beverages, and plaque typically serve as surface stains, subsurface stains are attributed to surface stains diffusing into superficial resin layers, with pigments attaching to and potentially reacting chemically with the composite. Intrinsic stain mostly is ascribed to physico-chemical reactions occurring deep within the composite. Stain chemistry, exposure time, composite composition and handling, and environmental conditions (eg, pH and temperature) contribute to the staining process.

Coffee and red wine were chosen as staining agents because of their propensity to stain esthetic restorative materials. Coffee stain originates from the roasting process, which thermally degrades monosaccharides into a brown caramel substance that reacts with chlorogenic acids to produce brown-black pigments. When brewed, the pigments become dispersed into acidic media (pH 4.5-6.5), either as water-soluble

or colloiddally dispersed compounds.³³ For this study, the primary result from coffee exposure was darkening and yellowing of the composite, which was observed as a lowering of ΔL^* values and an increase of Δb^* values continuously over the 14-day period (Figures 1 and 2). For red wine, its observed color is derived from the presence of multiple anthocyanins, which are based on the flavonoid molecule that contains one three-membered and two six-membered ring structures.^{34,35} When deposited onto composite surfaces, the pigments cause the composite to redden, which in this study was observed as an increase in Δa^* by 2.5 units after one day. Interestingly, Δa^* did not remarkably change thereafter, with continued color change being mostly caused by composite darkening (negative ΔL^*). Wine also demonstrates low pH (3.0-4.5), and its alcohol content ranges from 12 to 14 volume percent. Low pH enhances water diffusion, and alcohol plasticizes the resin matrix, which releases residual stresses caused by polymerization shrinkage and creates regions of micro-cracking that have been observed along filler-resin

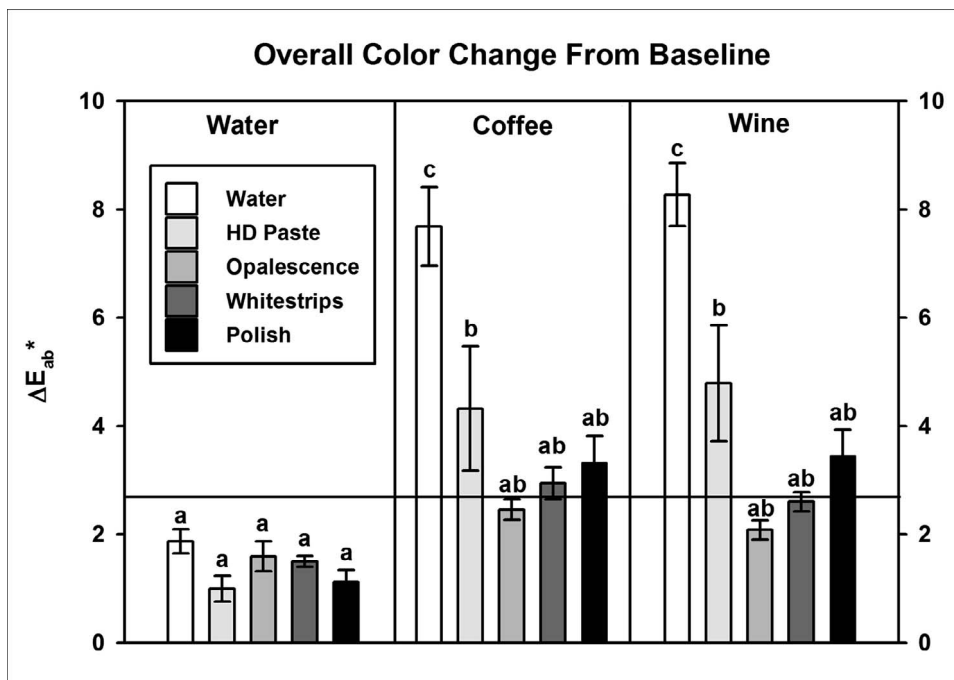


Figure 3. Bar chart of overall mean ΔE_{ab}^* color change from baseline for the four whitening agents. Error bars represent standard errors of means. Groups labeled with the same lower-case letter are not significantly different at the $\alpha=0.05$ level of confidence (GLM/Tukey). The horizontal line drawn at $\Delta E_{ab}^*=2.7$ represents the 50%:50% threshold for maximum acceptable visual color change.

interfaces.³⁶ This promotes deeper stain penetration into the composite.

The staining method employed for this study involved soaking test samples over time and measuring color change. This method does not truly mimic the *in vivo* condition, in which stain exposure time is shorter and oral surfaces are periodically rinsed and exposed to other compounds. However, the soaking method provides an avenue for conducting accelerated staining experiments, and it permits the study of stain accumulation over time. The observation that stain accumulation was continuous over the 14-day period supports the contention that the staining process is partially tied to water diffusion into the composite.²⁷ Amelogen contains a Bis-GMA/TEGDMA (triethylene glycol dimethacrylate) copolymer system, and classic work conducted by Kalachandra and Turner³⁷ demonstrated that for Bis-GMA/TEGDMA systems, increases in TEGDMA content from 0 to 100 weight percent produced a three to six weight percent increase in water uptake over a 14-day period. The presence of TEGDMA imparts hydrophilicity to the polymer system, which enhances composite stainability, particularly when contrasted to a hydrophobic polymer system, such as a silorane-based composite.^{38,39}

The LED curing light used in this study was a standard dental curing light that is used in both dental schools and dental practice. Although the light was expected to deliver sufficient intensity and

wavelength to ensure adequate polymerization of the composite resin, it is noteworthy that previous investigations that compared various halogen and LED curing units reported both significant^{40,41} and nonsignificant⁴² differences in degree of conversion when polymerizing resin-based composites. One study showed that for Amelogen Plus, the percentage degree of conversion ranged from 56.5% to 62.6% among one halogen and three LED curing units.⁴⁰ Vandewalle and others,⁴¹ in their study of one halogen and five LED curing lights, demonstrated that curing lights with the least dispersion of light and lowest diversion angles produced the highest degrees of conversion at greater curing distances. Since degree of conversion can affect water sorption⁴³ and water sorption is tied to stainability, different curing lights may render a composite with different degrees of stainability, particularly when greater thicknesses of composite are polymerized.

The results obtained from staining experiments most closely follow those reported by Manojlovic and others,⁴⁴ in which three days of soaking in coffee and wine produced similar numerical changes in ΔL^* , Δa^* , Δb^* , and ΔE_{ab}^* . Data trends for the four color parameters after seven days' immersion in coffee and wine are similar to those reported by Tan and others,²¹ but Tan's results showed nearly two times greater change for each color parameter. ΔE_{ab}^* values reported by Ertas and others,¹⁶ Villalta and others,²⁶ Fujita and others,³⁶ Catelan and others,⁴⁵ Al-Kheraif and others,⁴⁶ and Yu and others⁴⁷ at matching

immersion times for either coffee or wine were 1.5 to 3.0 times lower than those observed here, and ΔE_{ab}^* values reported by Polli and Arossi,⁴⁸ Schmitt and others,⁴⁹ and Tonetto and others⁵⁰ were 1.3 to 5.5 times higher. In nearly every study, different composite systems were evaluated. Since resin matrix chemistry,^{13,51} filler loading,^{51,52} filler particle size,⁵³ and degree of conversion⁴³ are known to affect water sorption of the composite, it can be concluded that the nature and severity of composite staining are expected to be different for each manufacturer's product. Therefore, it is not reasonable to extrapolate staining experiment results obtained from one composite system and deduce potential stain susceptibility for another composite system.

This study sought to evaluate the effectiveness of four whitening methods in removing stain from Amelogen Plus following exposure to red wine and coffee. The return-to-baseline results demonstrated that for this composite, the passive application of two at-home peroxide-based systems were more effective in restoring baseline color than were two systems relying primarily on surface brushing or polishing. The observation that peroxide-based systems performed better can be attributed to the ability of their components to penetrate the composite subsurface and chemically react with pigment molecules. Brushing and polishing, on the other hand, rely on removal of composite surface layers, with the depth of stain removal being limited by the amount of material loss produced by typical brushing and polishing activities. Crest HD paste contains sodium hexametaphosphate for reducing stain and calculus formation,⁵⁴ but the results presented here suggest that it is less effective in removing stain that has penetrated the composite subsurface than are diffusible peroxide-based systems.

Of the peroxide agents used in this study, Opalescence contains 15% carbamide peroxide and Whitestrips contain 6.0% to 6.5% hydrogen peroxide. When activated by heat, light, or pH, hydrogen peroxide (H_2O_2) dissociates via cleavage of O-H and O-O bonds to produce $H^\bullet$, $^\bullet OOH$, and $2^\bullet OH$ radicals that are capable of decomposing conjugated double bonds and ring structures present within stain. Carbamide peroxide breaks down into hydrogen peroxide and urea, with urea further dissociating into carbon dioxide and ammonia. This creates an alkaline environment capable of producing the perhydroxyl anion (HO_2^-), a compound shown to further the whitening effect.^{55,56} For this study, it is reasoned that the presence of urea and higher peroxide concentration in Opalescence produced a

more aggressive environment for whitening than did Whitestrips, which resulted in nearly complete stain removal for both coffee and wine.

CONCLUSION

Although Amelogen Plus underwent different types of color change when stained with coffee or red wine, four whitening methods reversed the color changes in manners that were not significantly different from one another ($p \geq 0.05$). However, only the carbamide peroxide-based system was capable of returning color to a baseline level that was below the threshold of maximum acceptability for color change ($\Delta E_{ab}^* \leq 2.7$).

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Note

While reviewing the literature during this article's preparation, it was noted that a number of publications incorrectly reported Kalachandra and Turner's³⁷ results for water diffusion into Bis-GMA/TEGDMA copolymer systems, either through direct citation or through citation of articles incorrectly reporting the results.^{16,17,57-65} The publications incorrectly stated that water uptake increased 3-6 weight percent for TEGDMA weight increases between 0 and 1 weight percent, when instead the range of studied TEGDMA weight increases were between 0% and 100%. Part of the confusion may lie in incorrectly interpreting the abstract, where it was stated that the *proportion* of TEGDMA increased from 0 to 1.0. However, a review of results presented in table I clearly show that five Bis-GMA/TEGDMA weight percentage ratios were studied by Kalachandra and Turner (100/0, 70/30, 50/50, 30/70, and 0/100) and that 6 weight percent water uptake was achieved with the 0/100 formulation, which corresponds to 100 weight percent TEGDMA.

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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Effect of Remineralizing Gels on Microhardness, Color and Wear Susceptibility of Bleached Enamel

E Crastechini • AB Borges • CRG Torres

Clinical Relevance

Tooth bleaching reduces enamel microhardness and increases tooth-wear susceptibility. The use of remineralizing gels during bleaching procedures recovers enamel microhardness and reduces abrasive wear, increasing bleaching safety without compromising efficacy.

SUMMARY

Objectives: To evaluate the effect of a remineralizing gel combining fluoride and calcium silicate/phosphate or a sodium fluoride gel on bleached enamel microhardness, color, and wear susceptibility.

Methods and Materials: Two hundred forty bovine enamel-dentin samples were prepared. Baseline analysis of Knoop microhardness, color coordinates ($L^*a^*b^*$), and surface profile

were performed. According to the baseline microhardness values, specimens were stratified into six groups (n=40): NC (negative control)—no treatment; BL (positive control)—bleaching with 40% hydrogen peroxide gel (Opalescence Boost, Ultradent); BL/Rs—bleaching + application of calcium silicate/phosphate gel (Regenerate Serum, Unilever - Rs); Rs/BL—Rs + bleaching; Rs/BL/Rs—Rs + bleaching + Rs; and BL/F—bleaching + 2% sodium fluoride gel. After the treatment described for each group, color change (ΔE) and microhardness were evaluated again. To evaluate abrasion susceptibility, samples were randomly divided into two subgroups, according to the toothpaste used (Cp—Close Up or Rt—Regenerate), and underwent 100,000 brushing strokes. The profile of each sample was evaluated and the mean wear calculated. The data were analyzed by ANOVA and Tukey tests.

Results: All bleached groups showed a significant reduction of microhardness in relation to the negative control. The groups treated with remineralizing gels showed a significantly higher microhardness and less wear than the positive control, although nonsignificant differences were observed among them. Nonsig-

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nificant differences in ΔE were found among bleached groups. The groups brushed with Regenerate toothpaste showed significantly less wear than those brushed with Close Up toothpaste.

Conclusions: The remineralizing gels did not interfere with bleaching efficacy. However, all the treatments minimized the surface hardness reduction caused by the bleaching procedure and enamel loss after abrasion. Regenerate toothpaste resulted in less enamel abrasion.

INTRODUCTION

Some studies have demonstrated that tooth bleaching agents can produce changes in the enamel surface properties,¹⁻⁶ while others showed no alterations.^{7,8} The changes were attributed to the low pH of bleaching gels,^{2,3,9} but other studies reported that even neutral pH bleaching gels can cause morphological alterations in the enamel surface.^{1,10} These changes were characterized by increased surface porosity, degradation of the organic matrix, and loss of calcium and phosphate, causing reduction in surface microhardness.^{1,4-6} This reduction may increase enamel wear produced by tooth brushing. The intensity of this wear depends on the pH of the bleaching gels, the abrasive potential of the toothpaste, and the timing of tooth brushing after bleaching.¹¹⁻¹³ All these factors lead to increased surface roughness and staining susceptibility.¹⁴

With the intention of reversing the demineralizing effects of bleaching agents on dental enamel, several studies have investigated the effects of treatment using remineralizing gels after bleaching to recover enamel surface microhardness. Many substances were tested, such as sodium fluoride,^{15,16} nano-hydroxyapatite, hydroxylated apatite, and casein phosphopeptide-amorphous calcium phosphate.¹⁷ Fluoride is widely used in postbleaching treatment, since fluoride-containing agents promote the deposition of calcium fluoride on the enamel surface.¹⁸ This increases the incorporation of fluoride ions into the demineralized area in the form of fluorapatite or fluoridated hydroxyapatite.^{19,20}

Other remineralizing substances have been added to bleaching gels in an attempt to protect the enamel surface. Borges and others¹³ added 0.5% calcium gluconate to the bleaching gel and concluded that this supplementation reduced surface wear by abrasion. In addition, da Costa and Mazur²¹ tested different carbamide peroxide bleaching gels containing 0.11% sodium fluoride or amorphous calcium phosphate

(ACP), as well the effect of subsequent application of 1.23% acidulated phosphate fluoride gel for 5 minutes after tooth bleaching. They concluded that fluoride or ACP in the bleaching agent did not prevent reduction in microhardness after bleaching. However, the final application of a fluoride gel led to significant microhardness recovery.

Recently, an enamel remineralizing system has been described, indicated for treatment of dental erosion. It consists of a specific association of calcium silicate and sodium phosphate salts with fluoride ions. The same active ingredients are available as a gel (boosting serum) and as a remineralizing toothpaste.²²⁻²⁴ Previous investigators, using this system and comparing it with the use of regular fluoride toothpaste after erosive cycles, have concluded that gel application followed by the use of remineralizing toothpaste produced a significantly higher enamel remineralization than regular toothpaste alone.²²⁻²⁴ It was also shown that this system formed hydroxyapatite on the surface of the demineralized enamel.²⁵ Considering the remineralizing potential of this product, it can be speculated that the application of this remineralizing gel immediately before or after dental bleaching may be favorable for protecting or remineralizing.

Considering that bleaching may promote demineralization and reduction of enamel microhardness, thus increasing its abrasion susceptibility,^{1,4-6} and that some postbleaching treatments may remineralize the enamel surface, the incorporation of this step in the bleaching protocol seems highly advisable.^{15,16} In this sense, the use of fluoride or other remineralizing agents that induce deposition of hydroxyapatite on the demineralized surface is quite promising.^{15,16}

The aim of this study was to evaluate the protective and remineralizing potential of the new calcium silicate/phosphate system and the 2% sodium fluoride gel on bleached enamel microhardness and wear with different toothpastes. The interference of remineralizing agents on the bleaching efficacy was also investigated. The null hypothesis tested was that treatment with remineralizing gels would not result in significant differences in relation to enamel microhardness reduction, color change (ΔE), or wear after bleaching and that the kind of toothpaste would not influence abrasive wear.

METHODS AND MATERIALS

Specimen Preparation

Freshly extracted bovine incisors were obtained from animals with an average age of 3 years. The teeth

were cleaned and stored in a 0.1% thymol solution, pH 7.0, throughout the period of preparation of the enamel-dentin specimens.²⁶

Two hundred forty cylindrical specimens (enamel-dentin) were obtained from the labial surface of the teeth. They were cut with a diamond trephine mill having a 3-mm internal diameter. All specimens were embedded in acrylic resin using a silicone mold 6 mm in diameter and 3.1 mm deep. At the bottom of the mold, there was a cavity on the second level 3 mm in diameter and 0.1 mm deep. In the lateral area of the mold, there was a curved projection for producing a lateral groove in the specimen, allowing for correct positioning of the sample in the profilometer. The specimens were placed inside this internal cavity with the enamel surface facing the bottom of the mold. The mold was then filled with self-curing acrylic resin (Classico, Campo Limpo Paulista, SP, Brazil) and taken to a pressure chamber (City, Guarulhos, SP, Brazil), filled with water, and subjected to a pressure of 30 psi for 10 minutes until total polymerization. The resin in which the samples were embedded worked as a reference for wear measurement, since it was not subjected to the abrasive challenge.

The sample side corresponding to the enamel surface was polished with silicon carbide sandpapers P1200, P2400, and P4000 (Extec Corp, Enfield, CT, USA) under cooling water for 30, 60, and 120 seconds, respectively.²⁷ After each sanding and final polishing, the specimens were cleaned in an ultrasonic bath of deionized water (Odontobrás, Ribeirão Preto, SP, Brazil) for 10 minutes to remove waste and abrasive grains.

Two parallel scratches were then made on the resin at the sides of the embedded tooth. These scratches served as guides to orient superimposition of the baseline and posttreatment profiles. To avoid a wrong color evaluation at the baseline due to enamel/dentin dehydration during specimen preparation, the teeth were immersed in artificial saliva for 7 days, using the formulation proposed by Klimek and others.²⁸

Baseline Color, Microhardness, and Surface Evaluation

Baseline color evaluation was performed using a colorimetric reflectance spectrophotometer (CM 2600d, Konica Minolta, Osaka, Japan), collecting the color data according to the CIE L*a*b* color space. The device was connected to a microcomputer

and the SpectraMagic NX software (Konica Minolta) was used to control the device and perform the readings. The apparatus was adjusted to the standard illuminant D65, small area view mode, with the specular component included. The observer angle was set to 2°. The device was adjusted to perform three consecutive readings to obtain the mean values of L*, a*, and b* per sample.

Baseline microhardness (Knoop hardness number [KHN]) of the enamel surfaces for all specimens was measured with a microhardness tester (FM-700, Future-Tech, Tokyo, Japan) using a Knoop indenter under a 50-g load and 10-second dwell time.²⁷ Three indentations were performed on each specimen with a 100-μm distance between them, and the mean value was calculated. The indentations were made in an area away from the reading path of the profilometric evaluation.

The baseline profiles of the enamel surfaces were measured. In order to ensure the exact repositioning of the samples during the surface analyses both before and after the experimental procedure, the contact profilometer (MarSurf GD 25, Mahr, Göttingen, Germany) was equipped with a custom-made jig. The diamond stylus of the profilometer moved 4.2 mm from the resin surface reference on one side, passing over the first scratch, and then toward the enamel and over the resin and second scratch on the other side. Three profile measurements were performed for each specimen at intervals of 0.25 mm, the second one being exactly at the center of the enamel surface.

Distribution of Experimental Groups

According to the baseline microhardness values, specimens were stratified into six groups (n=40) to avoid initial differences among the groups. The groups were NC (negative control) no treatment performed; BL (positive control) application of 40% hydrogen peroxide (H₂O₂) bleaching gel (Opalescence boost, Ultradent, South Jordan, UT, USA); BL/Rs bleaching gel, followed by the application of calcium silicate/phosphate fluoride gel Regenerate Boosting Serum (Unilever, Le Meux, France); Rs/BL application of the calcium silicate/phosphate fluoride gel followed by bleaching; Rs/BL/Rs application of calcium silicate/phosphate fluoride gel followed by bleaching and a new application of calcium silicate/phosphate fluoride gel; and BL/F bleaching followed by application of 2% sodium fluoride gel. Additional information about the products tested are shown in Table 1.

Table 1: Composition, Manufacturer, and Batch Number of the Products Used

Product	Composition	Manufacturer	Batch No.
Opalescence Boost 40%	40% hydrogen peroxide, 3% potassium nitrate, 1.1% sodium fluoride (4950 ppm fluoride ions), thickener, pH regulators	Ultradent, South Jordan, UT, USA	BBWBT
Regenerate Boosting Serum	NR-5 Serum: glycerin, calcium silicate, PEG-8, trisodium phosphate, sodium phosphate, water, PEG-60, sodium lauryl sulfate, aroma/flavor, hydrated silica, synthetic fluorphlogopite, sodium saccharin, polyacrylic acid, CI 77891, limonene, sodium monofluorophosphate (1450 ppm fluoride ions) Activator gel: Water, glycerin, cellulose gum, benzyl alcohol, ethylhexylglycerol, phenoxyethanol, CI 42090, sodium fluoride (1450 ppm fluoride ions)	Unilever, Le Meux, France	41929CYB
Flugel Neutral 2%	2% sodium fluoride (9000 ppm fluoride ions), sodium saccharin, hydroxyethyl cellulose, propylene glycol, glycerin, deionized water	DFL, Rio de Janeiro, RJ, Brazil	L16101442
Regenerate Enamel Science Advanced toothpaste	Glycerin, calcium silicate, PEG-8, silica hydrate, trisodium phosphate, sodium phosphate, water, PEG-60, sodium lauryl sulfate, aroma, synthetic fluorphlogopite, sodium saccharin, polyacrylic acid, tin oxide, limonene, CI 77891, sodium monofluorophosphate (1450 ppm fluoride ions)	Unilever, Le Meux, France	L: 50348CB
Close Up Bioactive Protection Toothpaste	Calcium carbonate, water, sorbitol, hydrated silica, sodium lauryl sulfate, aroma, cellulose gum, potassium citrate, benzyl alcohol, sodium silicate, sodium saccharin, CI12490, CL74160, lanolin, sodium monofluorophosphate (1450 ppm fluoride ions)	Unilever, Ipojuca PE, Brazil	118210322019

Surface Treatments

Opalescence boost 40% bleaching gel was applied according to the manufacturer's instructions. The product comprises two syringes (red and clear), which were attached to mix the two components and create the gel. Next, all the content was transferred to one of the syringes and applied on the enamel surface for 20 minutes. About 6.20 mg bleaching gel was applied per specimen. After this period, the gel was aspirated and a new application was performed for another 20 minutes. In total, three consecutive applications of bleaching gel were performed, resulting in 60 minutes of gel contact time with the enamel surface. After the final application, the specimens were washed with an air-water spray.

The Regenerate Boosting serum, a calcium silicate/phosphate and fluoride-based remineralizing gel, is presented in two separate tubes, one containing the serum gel and the other the activator gel. Before using, equal amounts of the gels were weighed on a precision scale and mixed for application. The mixture was applied over the enamel surface for 3 minutes, then removed with an air-water spray. The gel was applied immediately before or after the bleaching agent, depending on the experimental group. In the BL/F group, a 2% neutral sodium fluoride gel (Flugel, DFL, Rio de Janeiro,

Brazil) was applied for 3 minutes after the bleaching agent and then washed off. In the negative control group, the samples received no treatment.

Immediately after the treatments, the final microhardness was measured to verify the immediate effects of the treatments on the enamel surface. The percentage of surface microhardness change (SMC) was calculated using the formula $\%SMC = ([SM_{baseline} - SM_{final}] / SM_{baseline}) * 100$. The specimens were then immersed in artificial saliva for 7 days for rehydration, and a final color reading was performed. The posttreatment readings were performed in the same way and with the same parameters used at baseline.

Based on the data of the color coordinates L^* , a^* , and b^* , obtained before bleaching and after the procedures for each sample, the ΔE was calculated using the formula $\Delta E = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$. This was conducted according to the instructions of Commission Internationale de l'Eclairage.²⁹ ΔE values greater than 3.3 indicate a perceptibility threshold for more than 50% of the observers.³⁰

Abrasive Wear

After the final microhardness and color readings, the specimens were submitted to abrasive wear. For this, each group was randomly divided into two

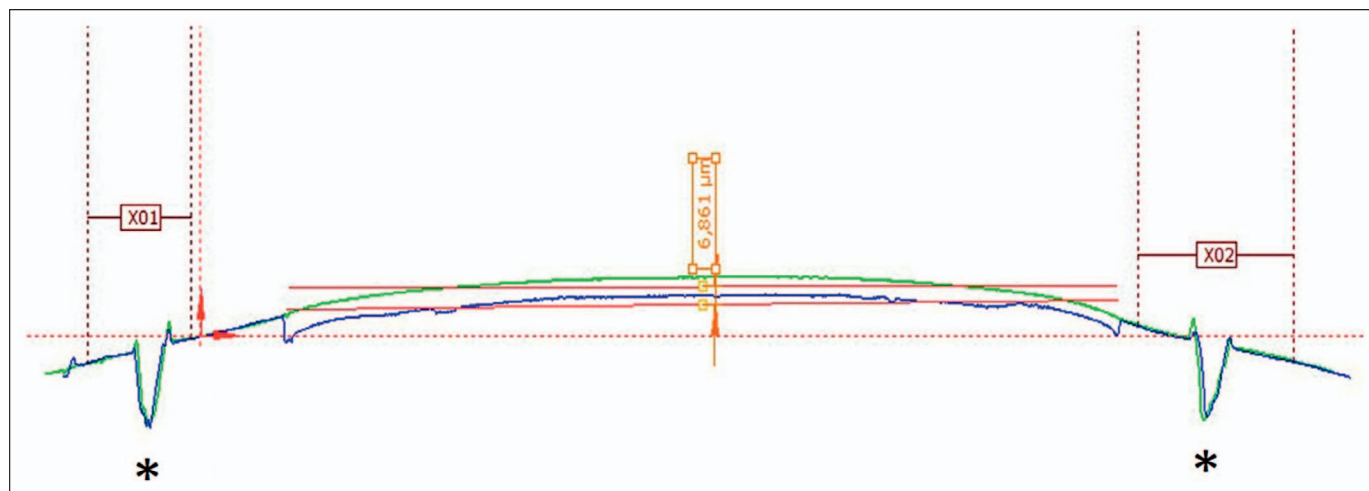


Figure 1. Superimposition of the baseline (blue) and final (green) profiles for quantification of wear using the scratches marked with asterisks as guides. Regression lines for each profile are shown in red. The surface loss is determined by the distance between the regression lines.

subgroups ($n=20$). In the first subgroup (Rt), the remineralizing toothpaste Regenerate (Unilever, Le Meux, France) was used, while in the second subgroup (Cp) a regular fluoride-containing toothpaste, Close Up Bioactive protection (Unilever, Ipojuca, PE, Brazil), was used. The specimens were placed on a holder with a metal perforated mask protecting the acrylic resin and the scratches of the abrasion, exposing only the enamel area. They were placed into a brushing machine (MEV-2T, Odeme, Luzerna, Santa Catarina, Brazil) and underwent 100,000 brushing strokes¹² receiving 50,000 strokes for two consecutive days, with a load of 200 g, according to ISO/TS 14569-1.³¹ During brushing, the samples were immersed in a toothpaste slurry, prepared with toothpaste diluted in artificial saliva (1:2 w/w).¹² The specimens were stored in a closed container at 100% relative humidity overnight.

In order to obtain a homogeneous wear, the toothbrushes were fixed in an automatic brushing machine so that their long axes were at an angle of 12° to the brushing direction. This avoided the formation of nonbrushed tracks induced by the bristles on the enamel surface.³² In addition, the brushing direction was perpendicular to the reading direction of the profilometer.

After tooth brushing, the final profile reading of each sample was performed. The final profiles were superimposed on the corresponding baseline ones, using dedicated software for contour evaluation (MarSurf XCR 20, 4.50-07 SP3, Mahr, Göttingen, Germany). The parallel scratches were used as a reference for profile superimposition. For each pair of superimposed profiles in the area corresponding to

the wear, regression lines were calculated in both the baseline and final profiles. The distance between these lines was measured in micrometers by the same software (Figure 1). Three values were obtained for each specimen, and the mean was calculated.

Statistical Analysis

The baseline and after-treatment microhardness data, as well the percentage of surface microhardness change, were compared with one-way ANOVA, followed by the Tukey test. To analyze the baseline color of the samples and the ΔE after bleaching, one-way ANOVA was performed followed by the Tukey test. For the wear analysis, data were submitted to two-way ANOVA (treatment $\times$ type of toothpaste), followed by the Tukey test. The software Statistica for Windows (Statsoft, Tulsa, OK, USA) was used for all the analyses with a significance level of 5%.

RESULTS

There were no statistically significant differences among the groups in relation to the baseline microhardness ($p=0.1119$) or color coordinates ($p>0.05$ for L^* , a^* , and b^*). After the treatments, an ANOVA test showed statistically significant differences for absolute microhardness values ($p=0.0001$), percentage of surface microhardness change ($p=0.0001$), and ΔE ($p=0.0001$) among the groups. All groups that were bleached showed a significant reduction of final microhardness in relation to the negative control (Table 2). However, all groups that received the treatment with remineralizing gels showed a significantly smaller percentage of microhardness reduc-

Table 2: Means (Standard Deviation) of Baseline and Final Microhardness, Percentage of Surface Microhardness Change (SMC), Color Difference, and Wear

Groups*	Baseline Microhardness (KHN)	Final Microhardness (KHN)	% SMC	Color Difference (ΔE)	Wear (μm)**
BL	325.68 (13.14) a	246.28 (30.46) a	23.16 (9.15) a	3.75 (1.04) b	3.36 (0.84) c
Rs/BL/Rs	318.25 (12.18) a	263.55 (18.66) b	17.12 (5.87) b	3.72 (1.28) b	2.19 (0.70) a
BL/Rs	323.83 (11.47) a	264.06 (28.54) b	18.43 (8.55) b	3.87 (0.91) b	2.23 (0.91) a
Rs/BL	320.54 (13.26) a	265.22 (23.58) b	17.19 (7.32) b	3.88 (0.94) b	2.13 (0.85) a
BL/F	323.51 (16.34) a	269.10 (25.66) b	16.73 (7.82) b	4.03 (1.22) b	2.12 (0.71) a
NC	325.68 (13.14) a	323.28 (10.96) c	0.70 (1.66) c	1.31 (0.58) a	2.85 (0.98) b

* Groups followed by the same letters in columns do not present significant differences according to the Tukey test.
** Results of Tukey test for the factor treatment in relation to wear.

tion than the positive control, which received only the bleaching gel. Regarding color difference, the bleached groups showed a significantly higher ΔE than did the negative control group. The ΔE was produced by the reduction of values on the b^* coordinate and an increase on the L^* coordinate, which means a reduction of chroma and an increase of lightness. No significant differences in ΔE were found among bleached groups, regardless of whether remineralizing gels were used (Table 2).

Results of the two-way ANOVA test concerning abrasive wear showed significant differences among the treatments ($p=0.0001$) and between toothpastes ($p=0.0001$). No interactions were observed between the two factors ($p=0.4860$). Results of the Tukey test for the factor treatment showed that the groups treated with remineralizing gels had significantly less wear than did the group only bleached. However, nonsignificant differences were observed among them. Only the positive control, just bleached, showed greater wear than did the negative control group (Table 2). In relation to the factor type of toothpaste, the groups brushed with Regenerate showed significantly less wear ($2.04 \pm 0.80 \mu m$) than those that brushed with the regular toothpaste ($2.92 \pm 0.88 \mu m$). The means (μm) of surface loss for each group and toothpaste are shown in Figure 2.

DISCUSSION

In the present study, dental bleaching caused a significant reduction in enamel microhardness of about 23.16%. Similar percentages were found in other studies, ranging from 11.12% to 25%, increasing with application time.^{10,33} The literature is inconsistent as to which percentage of enamel microhardness reduction is considered clinically relevant. Acid etching of enamel surfaces for adhesive purposes, a common clinical procedure in daily dental practice, effects a microhardness reduction of 73.78%.³⁴ In a previous in vitro study, the correla-

tion between microhardness of eroded enamel surfaces with toothbrush wear was investigated. The specimens were immersed in carbonated beverage ($pH=2.91$) for 1, 5, or 15 minutes before brushing (8000 strokes).³⁵ The percentage of microhardness reduction and wear after treatments were, respectively, 11.52% ($0.63 \mu m$), 14.18% ($1.19 \mu m$), and 30.69% ($2.22 \mu m$). Regression analysis showed a significant negative linear correlation between hardness and abrasive wear. Therefore, even a microhardness reduction of only 11% can significantly influence enamel wear.

Another study showed a positive correlation between peroxide concentration and microhardness reduction.³⁶ We tested the most concentrated product on the market, containing 40% H_2O_2 , which is a nonspecific oxidizing agent that acts not only on the decomposition of chromophore molecules but also on tooth structure.² H_2O_2 can penetrate enamel structure mainly via proteins (amelogenin and enamelin), causing fragmentation of the polypeptide chain due to cleavage of the peptide bonds.³⁷ As the organic

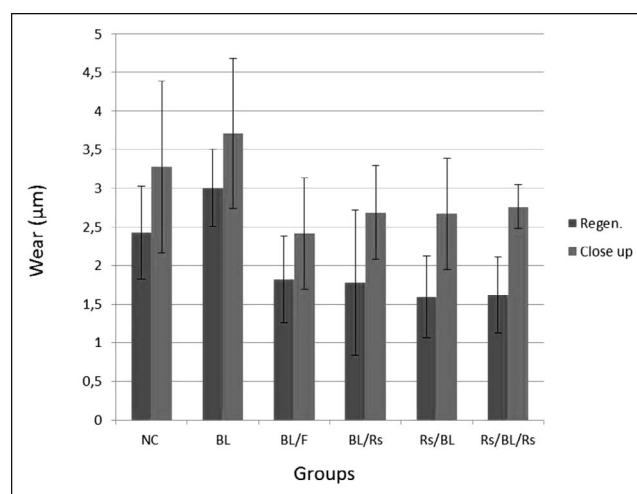


Figure 2. Means of wear for all groups with the two different toothpastes.

content also affects enamel integrity, its changes by oxidization may also indirectly alter the mineral content.²

It has been reported that bleaching gels with an acidic pH cause more demineralization and reduction of enamel surface microhardness than those with a higher pH.^{2,3,10} However, some bleaching agents with a pH close to neutral also cause some changes in the enamel by decreasing its surface microhardness.^{1,10} In the present study, Opalescent Boost bleaching gel has a pH of 7.4, yet it reduced enamel microhardness. It is speculated that, besides the nonspecific oxidative effect, the low concentration of calcium and phosphate in the whitening gel formulation makes it undersaturated compared with hydroxyapatite, promoting its demineralization regardless of the pH.¹⁰

When a solid is immersed in a solution, the interface between the two phases becomes a site for continuous exchange of the components from solid (in the case of enamel, Ca^{2+} , PO_4^{3-} , and OH^- ions).³⁸ The ions are released from the solid surface and dissolve in the solution (dissolution) and, in the same way, other ions leave the solution to attach to the solid surface (crystal growth). When the rate at which ions enter the solution equals that at which they attach to the crystal surface, the solid and solution are in a state of equilibrium and there is no net change in the solid. At equilibrium, the solution is said to be saturated with respect to the solid.³⁸ If the solution is undersaturated, the solid loses ions to the solution until a balance is reached, and if the solution is supersaturated, the solution loses ions to the solid until, again, equilibrium is reached.³⁸ Remarkably, this balance varies according to the pH and background ion concentration.³⁸ Lussi and Hellwig³⁹ studied the effects of various beverages on promoting enamel softening during the erosive process and observed that it depends not only on the pH of the substances, but also on the concentration of Ca^{2+} ions in their composition.

Studies have found that remineralization by saliva can recover the microhardness reduced by the bleaching procedure, repairing the lost calcium and phosphate ions.⁴⁰ However, this process can take up to 15 days before the surface microhardness returns to baseline values.⁴¹ During this period in which the enamel is not completely repaired, teeth would be more susceptible to loss of structure due to abrasive wear, such as during toothbrushing.^{12,13,42} The abrasive wear can be intensified, for example, if highly abrasive toothpastes and strong brushing forces are used. A study suggested delaying tooth

brushing at least 1 hour after bleaching in order to reduce enamel wear.¹³ However, more studies are needed to confirm the effectiveness of brushing delay.

The application of fluoridated agents in a gel or solution on the enamel surface after bleaching is being recommended for remineralization and increasing microhardness.^{15,21,33,43-45} This procedure can promote formation of calcium fluoride deposits on the enamel surface.¹⁸ When the local pH decreases, F^- ions are released from calcium fluoride deposits; this release is accompanied by Ca^{2+} ion release from the tooth surface due to demineralization. The presence of these ions changes the fluoride content into hydroxyapatite molecules by replacing OH^- ions for F^- ions, forming fluorapatite or fluoridated hydroxyapatite.⁴⁶ Fluorapatite is formed when all hydroxyl ions of the hydroxyapatite molecule are replaced by fluoride, while fluoridated hydroxyapatite is formed when this replacement by fluoride is partial.⁴⁷ Fluorapatite is less soluble and more acid resistant than fluoridated hydroxyapatite.⁴⁷ These ionic changes lead to a greater tendency for the ions to join the structure, repair the enamel surface, and produce an increase in microhardness.^{19,20} Lewinstein and others³³ observed that exposure, even to a low concentration of fluoride, can restore surface microhardness after bleaching. However, China and others¹⁵ concluded that only a neutral fluoride increases the microhardness of enamel bleached with 35% H_2O_2 , while the application of acidulated fluoride causes an even greater reduction. In the present study, the effect of a neutral 2% fluoride gel³³ (9000 ppm fluoride ions) on the surface of the bleached enamel was tested. It is a highly concentrated fluoride compound commonly applied in-office for caries prevention. This postbleaching application increased the surface microhardness compared with the positive control group, but the surface did not return to its baseline surface microhardness values.

In an attempt to protect the enamel during bleaching, 1.1% of sodium fluoride (4950 ppm of fluoride ions) was incorporated in the bleaching gel analyzed in this study. However, it did not prevent enamel surface demineralization, indicating that something was interfering with its protective effect, possibly an interaction with H_2O_2 or other ingredients of the formulation.

The calcium silicate/phosphate fluoride gel was tested as a protective agent when applied before bleaching, as a remineralizing agent when applied after, and with both actions when applied before and

after the bleaching procedure. This double application was tested in an attempt to intensify its effect on the enamel microhardness. In all cases, its application resulted in statistically higher final values of microhardness compared with the group that was only bleached. Based on this, in relation to microhardness, the null hypothesis was rejected. The use of this gel before bleaching significantly reduced the demineralizing effect of the H_2O_2 gel, while its use afterward promoted enamel remineralization. However, the use prior and after did not show any significant differences in relation to when it was used only once.

The remineralization process using this system starts when calcium silicate is deposited onto the enamel surface, causing an exchange of calcium ions with the hydrogen ions in the oral fluid, leading to the formation of silanol groups (Si-OH) in the surface layer of deposited calcium silicate. This causes an increase in the local pH, generating a negatively charged surface with the formation of silicon oxide (Si-O) groups. The calcium ions in the oral fluid are attracted to the surface of the calcium silicate layer. Consequently, the concentration of calcium and phosphate ions in the oral fluid is high enough to nucleate hydroxyapatite on the calcium silicate surface.^{20,25,48} The formation of hydroxyapatite over the enamel using this system has been demonstrated in both *in vitro* and *in situ* studies.^{25,49}

The mode of action of calcium silicate/phosphate fluoride formulations on enamel remineralization by the deposition of hydroxyapatite has been investigated. This effect was observed after the use of toothpaste alone^{24,25} and after the use of toothpaste followed by the boosting gel.^{22,23} Both the gel and the toothpaste have fluoride in their composition, which may allow an additional mode of action for repair and protection by promoting the formation of calcium fluoride deposits on the enamel surface.¹⁸ A previous study found that the minimum concentration of fluoride necessary for the formation of calcium fluoride deposits on the enamel surface is 0.1%, and the first globules will be precipitated in the first 20 seconds.⁴⁹ These two mechanisms acting together may increase remineralization of the enamel surface. It must be noted that applying calcium silicate/phosphate fluoride gel over the bleached enamel, even though containing only 1450 ppm of fluoride ions, did not show statistically different mineralization effects in relation to the neutral 2% fluoride gel containing 9000 ppm of fluoride ions (Table 1). This might be related to the synergistic action of the hydroxyapatite formation with the

fluoride mineralization mechanism of the boosting serum gel.

It could be supposed that the mineralizing potential of boost serum gel, applied before bleaching, could interfere with tooth enamel permeability, or even prevent the penetration of H_2O_2 into the tooth structure and reduce its bleaching effect. Additionally, when applied after bleaching, some ingredient in both gels' formulation could produce some kind of tooth staining, impairing the whitening results. In the present study, the previous application of calcium silicate/phosphate fluoride gel did not interfere with the ΔE promoted by bleaching. Studies evaluating the use of desensitizing agents containing 2% sodium fluoride before bleaching with 35% H_2O_2 also showed no interference with the ΔE .⁵⁰ However, no previous studies have analyzed the interference of the calcium silicate/phosphate fluoride gel on the bleaching effect. It has been observed that the application of both remineralizing gels postbleaching did not interfere with the ΔE of the tooth structure. Sodium fluoride gel is colorless, while calcium/phosphate silicate gel is slightly milky white. All bleached groups, despite the remineralizing treatments, presented statistically similar ΔE overall. The bleaching effect was related to a reduction in the b^* coordinate and an increase in the L^* coordinate. The a^* value was not significantly influenced by the bleaching procedure. Thus, in relation to ΔE , the null hypothesis was accepted.

Regarding abrasive wear, the group that received only bleaching treatment showed a significantly higher wear than the nonbleached one (Table 2). A negative correlation between hardness and wear was observed, since the reduction of surface microhardness caused by bleaching increases the enamel loss by toothbrush abrasion. Other studies showing the relation between enamel bleaching and wear have obtained similar results.¹¹⁻¹³ In addition, the bleached groups in which the remineralizing gels were applied showed less wear than did the group that was only bleached, indicating that this procedure could offer some clinical benefits to the patients subjected to this kind of treatment. Thus, in relation to wear, the null hypothesis was rejected.

Another important aspect in relation to abrasive wear is that the groups that were bleached and received the remineralizing gels showed less wear than did the negative control group (Table 2). This might be due to the fact that after bleaching treatments and before the color reading, the specimens were immersed in artificial saliva for 7 days. The artificial saliva may have interacted with any

calcium fluoride deposited on the enamel, forming fluorapatite or fluoridated hydroxyapatite, or continued to promote hydroxyapatite formation/deposition when the calcium silicate/phosphate fluoride gel was used.^{40,41} Both these processes may have further increased remineralization and enamel surface microhardness, leading to less enamel wear than the bleached as well as the nonbleached groups.

Significant differences were observed in the wear caused by the toothpastes tested. The groups that were brushed with Regenerate showed less wear than those brushed with Close Up. The use of a less abrasive toothpaste after bleaching might be clinically relevant, avoiding additional tooth wear on those patients receiving this kind of treatment, although this should be confirmed in controlled clinical trials. Thus, in relation to the kind of toothpaste, the null hypothesis was rejected. Two suppositions could be made about this result. The first is that the remineralizing effect of Regenerate could protect the surface from abrasion by hydroxyapatite formation,^{25,48} increasing enamel microhardness.³³ The second is probably related to lower abrasivity of the abrasive particles in this toothpaste.

One factor that impacts toothpaste abrasivity is the relative hardness of the abrasive particles. Regenerate contains hydrated silica as an abrasive, while the Close Up used in this study has a combination of hydrated silica and calcium carbonate. Moh's hardness is used to measure material hardness on a scale of 0 to 10, wherein 10 represents the hardness of a diamond. In this scale, the hydrated silica has a hardness of 2.5 and the calcium carbonate, 3.⁵¹ However, previous studies have tested various toothpastes having calcium carbonate and hydrated silica alone or in combination, but no statistically significant differences between the toothpastes in terms of enamel wear were found.⁵²⁻⁵⁴ In contrast, the relation between toothpaste abrasiveness and wear was evaluated by Borges and others,¹³ who subjected bleached enamel and dentin to brushing abrasion with slurries having different degrees of abrasivity; they observed that the higher the abrasiveness, the greater the tooth wear. However, it should be noted that the relationship between toothpaste abrasivity and dental wear is complex; it depends on the concentration and size of the abrasive particles.⁵³ In addition, the presence of the acquired pellicle has been shown to reduce enamel wear from toothpaste abrasion.⁵⁴

It should be emphasized that this is an *in vitro* study, which has limitations in reproducing conditions found in the oral cavity, eg, the presence of saliva. The acquired pellicle and its action, together with bleaching and remineralization treatment, may modify the results of the current study such that complementary investigations are necessary to confirm their impact. The importance of clinical studies to evaluate the performance of calcium silicate/phosphate fluoride formulations or fluoride gels for longer periods of use after the bleaching treatment is worthy of further study.

CONCLUSIONS

Considering the limitations of this *in vitro* study, we concluded that

1. Bleaching reduced enamel microhardness and increased abrasion suitability.
2. Although the remineralizing gels tested did not prevent microhardness reduction and wear of bleached enamel, they did bring about their decrease without interfering with the bleaching efficacy.
3. Regenerate toothpaste resulted in less enamel abrasive wear than did Close Up.
4. There were no significant differences among the remineralizing gels in their effect on microhardness, color, or wear.

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Conflict of Interest

The authors of the manuscript entitled "Effect of Remineralizing Gels on Microhardness, Color, and Wear Susceptibility of Bleached Enamel" declare no conflict of interest in relation to this article.

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Effect of Simulated Mastication on the Surface Roughness and Wear of Machinable Ceramics and Opposing Dental Enamel

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Clinical Relevance

The new polishing systems for CAD-CAM ceramics including Vita Mark II, e.max, Suprinity, and Enamic can be good alternatives to reglazing, after clinical finishing, because the roughness and wear rate of both the ceramic and the opposing enamel will either not change or decrease.

SUMMARY

Objective: Computer aided design-computer aided machining (CAD-CAM) ceramic crowns are replacing ceramo-metal ones due to newly developed mechanical properties and esthetics. To obtain knowledge about their interactions due to polishing and occlusal contacts with the opposing dental enamel specimen, including surface roughness and wear, the three-body wear simulation was investigated.

Methods and Materials: The surface roughness (RA) and wear rate (mm) of four CAD-CAM

blocks with different compositions including Vita Mark II, e.max, Suprinity, and Enamic, after two surface treatments of glazing and polishing, and their opposing enamel specimens, were investigated using a mastication simulator and atomic force microscope.

Results: The roughness of all ceramic and to a greater extent enamel samples, with the exception of enamel opposing polished Enamic samples, was decreased after wear. No significant difference in wear was evident for the ceramic samples between the glazed and polished treatments. Lower wear rates were recorded only for polished Vita Mark II and polished Enamic in comparison to the glazed ones.

Conclusion: The newly developed polishing systems for CAD-CAM ceramics can be good alternatives to reglazing, because the roughness and wear rate of both the ceramic and the opposing enamel will either not change or decrease.

INTRODUCTION

Ceramic crowns are readily replacing conventional ceramo-metal ones, claiming esthetic advantages and

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mechanical and clinical performance. The contemporary combination of computer intelligence and updated dental materials has led to a new series of more accurate ceramic crowns with less laboratory and chair time, called computer aided design-computer aided machining (CAD-CAM) technology.¹⁻⁴

Despite the precise fit and accuracy of the CAD-CAM crowns, the intraoral finishing step would presumably leave a rougher surface, enhancing plaque and stain accumulation.⁵ Newly introduced ceramic polishing systems, however, claim to be capable of creating a desirable ceramic surface.^{6,7} The properties and composition of the ceramic and the polishing protocol induce the degree of their effectiveness.⁷ What seems to be the most effective protocol is using a porcelain polishing kit with diamond polishing pastes.^{6,7}

Feldspathic CAD-CAM blocks [(Na₂K)AlSi₃O₈] were among the first machinable porcelains with excellent esthetics. They are used for different purposes such as veneers and crowns.⁸⁻¹⁰ One such block used today is Vita Mark II (VITABLOCS Mark II, Zahnfabrik, Bad Säckingen, Germany). A more durable lithium disilicate block (Li₂Si₂O₅) was later introduced in 2006 with higher strength (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein, Austria).¹¹ A hybrid block of ceramic (86% wt feldspathic network) integrated with polymer network, called VITA Enamic (Zahnfabrik), has superior elasticity and flexural strength and is claimed to have similar wear rate as dental tissues. It is specifically suggested for conservative preparations as it can be manufactured in very thin thicknesses (0.2-0.5 mm).¹² Another CAD-CAM block has lithium disilicate glass composition, strengthened with zirconia (10% wt), called Vita Suprinity (Zahnfabrik) (Table 1).

Conventional feldspathic porcelain causes enamel wear.¹³ Zirconia and, to a less extent, lithium disilicate were reported to have minimal surface roughness after polishing compared with feldspathic ceramic, which had the highest roughness.^{14,15} Feldspathic ceramics have in turn represented the most enamel wear.¹⁵ Zirconia caused lower wear rates when polished rather than the glazed or veneered forms of zirconia or lithium disilicate.¹⁶ Overall, enamel specimen wear is the highest when the opposing ceramic is glazed.¹⁷

The aim of this *in vitro* study was to evaluate the surface roughness and wear rate of different CAD-CAM ceramics and opposing dental enamel in a wear test. Therefore, the null hypothesis was that there would be no statistically significant difference in the

average roughness and wear between different CAD-CAM ceramics and the opposing dental enamel specimen.

METHODS AND MATERIALS

Specimen Preparation

In this laboratory study, four CAD-CAM ceramic blocks were used to prepare ceramic bases for mastication simulation. VITABLOCS Mark II (VMII) was a feldspathic ceramic. IPS e.max CAD and VITA Suprinity were two lithium disilicate glass ceramics, with the exception that Suprinity contains 10% by weight zirconia. The last block used was VITA Enamic, a feldspathic porcelain modified with acrylate polymer. The materials and their manufacturer are summarized in Table 1.

Two single crown blocks were used to prepare 10 slices of each ceramic. The blocks were mounted in epoxy resin bases and precisely cut into 2-mm-thick slices using a Precision Sectioning machine (Nemo, Mashhad, Iran) using a water stream coolant. Cutting speed for the Suprinity and e.max ceramics was set at 2 mm/hr, and for VMII and Enamic, the speed was 10 mm/hr. The blocks were assigned to eight subgroups (n=5) according to their surface treatments (finished and polished or finished, polished, and reglazed).

After block preparation, all specimens were glazed and crystallized (10 minutes, 950°C for VMII, 13 minutes, 840°C for e.max, and 12 minutes, 840°C for Suprinity) as suggested by the manufacturer (Table 1). The Enamic slices were etched with 5% hydrofluoric acid (VITA Ceramic ETCH) and silanated (VITASIL). The glaze (VITA Enamic glaze, predominantly methyl methacrylate) was applied and light cured (Bluephase C8; Ivoclar Vivadent) for 60 seconds. A fine grit fissure diamond bur (D&Z, Kalletal, Germany) was used to imitate the clinical finishing procedure of the ceramics. VMII blocks were polished using black to light blue grit, Sof-Lex ceramic polishing disks (Table 1), using each disk for 1 minute. The Optrafine polishing kit was used to polish the e.max specimens. Light blue and dark blue diamond polishers were applied for 1 minute each, followed by nylon brushes in conjunction with the diamond polishing paste. The Suprinity and Enamic blocks were polished with the pink diamond polisher for 1 minute and then the gray polisher for another minute. Half of the specimens in each ceramic group were reglazed after being polished.

The enamel specimens (n=40, 2 × 2 mm) were cut from the buccal surface of sound human lower first

Table 1: CAD-CAM Ceramic Blocks, Manufacturers, Glazing, and Polishing Systems				
CAD-CAM Block	Chemical Composition	Manufacturer	Glazing	Polishing System
VITABLOCS Mark II	SiO ₂ , Al ₂ O ₃ , Na ₂ O, K ₂ O, CaO, TiO ₂	Zahnfabrik, Germany	VITA AKZENT Plus spray	Sof-Lex discs, 3M ESPE, USA
IPS e.max CAD	SiO ₂ , Li ₂ O, K ₂ O, P ₂ O ₅ , ZrO ₂ , ZnO, Al ₂ O ₃ , MgO	Ivoclar vivadent, Austria	IPS e.max CAD Crystall Glaze	Optrafine, Ivoclar vivadent, Austria
VITA Suprinity	SiO ₂ , Li ₂ O, ZrO ₂ , K ₂ O, P ₂ O ₅ , Al ₂ O ₃ , CeO ₂	Zahnfabrik, Germany	VITA AKZENT Plus spray	VITA SUPRINITY Polishing Set clinical, Zahnfabrik, Germany
VITA Enamic	SiO ₂ , Al ₂ O ₃ , Na ₂ O, K ₂ O, B ₂ O ₃ , CaO, TiO ₂ Methacrylate polymer network	Zahnfabrik, Germany	VITA Enamic Glaze	VITA Enamic Polishing Set clinical, Zahnfabrik, Germany

molars, with no visible caries, cracks, or abnormalities. The surfaces were polished using silicon carbide sand paper from course to fine grit (800-1200), respectively, until surfaces were evened out.

Wear Test

Enamel specimens were fixed by cyanoacrylate on the force applying handle of the mastication simulator (Pedeb 1; Dental Material Research Center, Babol University of Medical Sciences, Babol, Iran), and the ceramic block was placed in the base of the simulator, immersed in a tooth paste solution (Crest; Procter & Gamble, Cincinnati, USA) (one part to five parts distilled water) as a third party lubricant. A static 2-kg vertical force was applied by the upper handle while moving in a circle (10 mm diameter) for 120,000 cycles.^{18,19}

Roughness and Wear Measurement

The surface roughness (Ra) of all specimens (enamel and ceramic) was measured using an atomic force microscope (AFM, nanosurf, easyScan 2 FlexAFM; Nanoscience Instruments, Inc. Woburn, USA), before and after the wear test (Figures 1 and 2). The surfaces were also scanned before and after the test

using a three-dimensional scanner (CEREC Inlab; Dentsply Sirona, Salzburg, Austria). The obtained images through the scanner were then overlapped, and the height loss and wear of the tested materials were precisely measured using the ruler tool in Photoshop software (mm, Adobe Photoshop CC 2015; Adobe, New York, USA). The starting point of the measurement was the original surface of the specimen, whereas the end point was the depth of the worn surface in ceramics or the new worn surface of the enamel specimen.

The acquired data were analyzed by the SPSS20 software (IBM, New York, USA) using independent-samples *t*-test, analysis of variance, and Tukey *post hoc* analyzing tests.

RESULTS

Roughness

According to Table 2, the surface roughness of the polished VMII presented the highest roughness before and after wear, which was statistically significant. This roughness was higher than that of the glazed VMII. The roughness of all ceramic groups decreased after the wear test, although this

Table 2: Mean Roughness (Ra) and SD of Ceramic Surface Before and After Wear ^a			
Ceramic	Surface Treatment	Before Wear (Ra)	After Wear (Ra)
VITABLOCS Mark II	Glazed	1.9262 ± 0.8026 ^{aA}	1.0214 ± 0.7226 ^{aA}
	Polished	77.7668 ± 8.8988 ^{bA}	35.6404 ± 11.2324 ^{bB}
IPS e.max CAD	Glazed	10.9404 ± 1.5379 ^{cA}	10.0024 ± 1.4791 ^{cdA}
	Polished	13.0676 ± 2.7249 ^{cdA}	5.7216 ± 3.34 ^{acdA}
VITA Suprinity	Glazed	9.508 ± 0.8039 ^{cA}	6.3526 ± 0.7573 ^{cdA}
	Polished	17.7348 ± 1.6906 ^{dA}	4.2794 ± 1.7903 ^{adB}
VITA Enamic	Glazed	12.2802 ± 0.7424 ^{cA}	6.7726 ± 1.8005 ^{cdB}
	Polished	8.499 ± 0.4502 ^{cA}	4.9456 ± 0.8132 ^{adA}

^a Equal superscript lowercase letters indicate no statistically significant differences within each column. Equal superscript uppercase letters indicate no statistically significant differences within each row.



Figure 1. Ceramic roughness measurement before and after the wear test by AFM (Ra).

amount was only significant in the VMII polished, Suprinity polished, and Enamic glazed groups.

As presented in Table 3, the primary roughness of all the enamel samples was not significant ($p=0.959$). After the wear test, a noticeable decline of roughness was observed in the enamel specimens in all groups, although it was insignificant for the polished Enamic antagonists. The VMII ceramic

demonstrated the highest amount of enamel specimen surface roughness change when glazed or polished.

Wear

According to Table 4, there was no significant difference in wear recorded comparing the glazed or polished group of each individual ceramic type. In

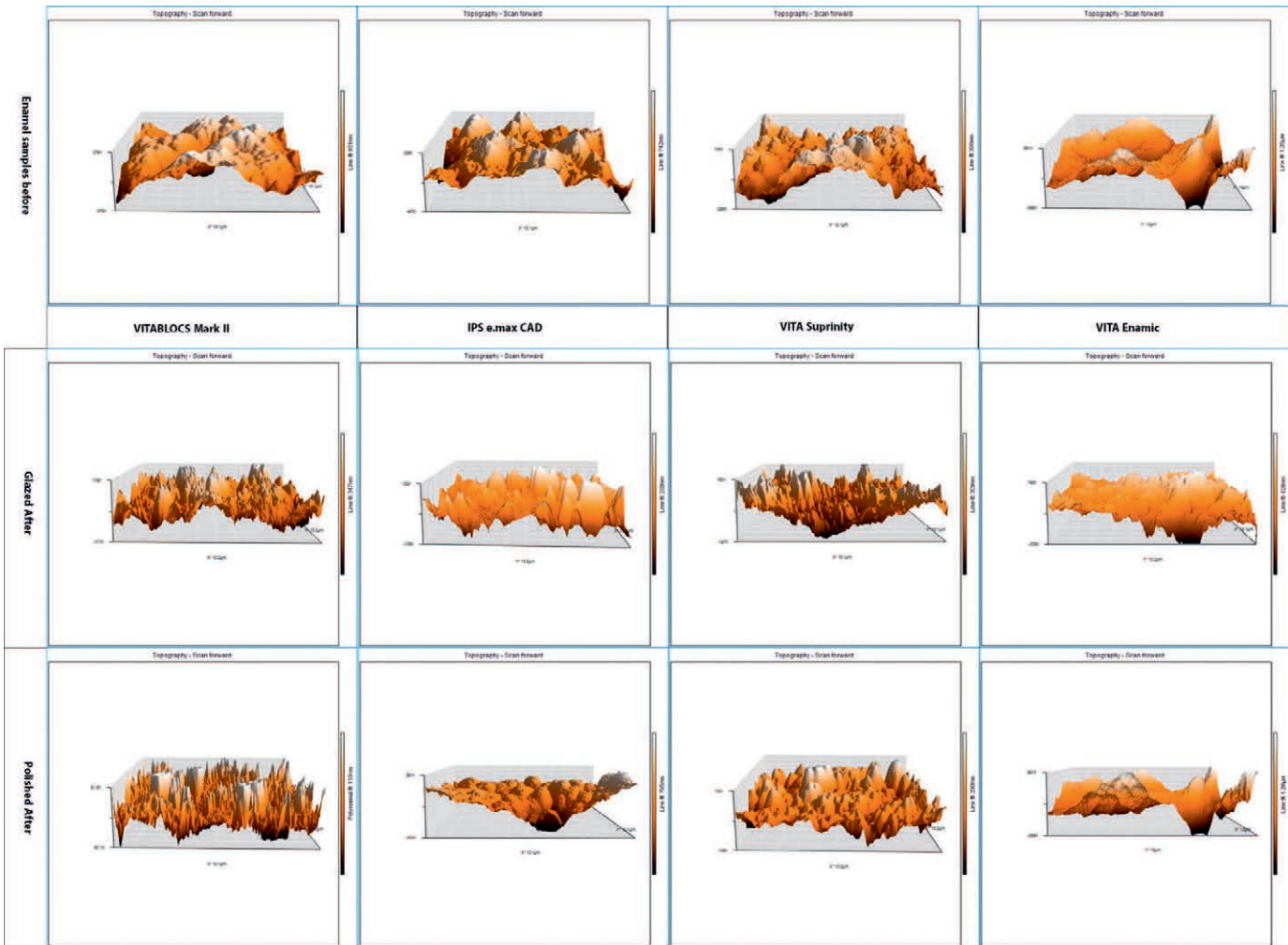


Figure 2. Enamel roughness measurement before and after the wear test by AFM (Ra).

the glazed group, the highest wear was for the Suprinity group, which was only significant over that of the e.max group ($p=0.04$). The same was true about the Suprinity polished group, with a significant difference from the VMII group ($p=0.02$).

According to Table 5, no significant difference was recorded for the e.max and Suprinity glazed groups ($p=0.25$), whereas the rest of the wear rates between the enamel specimens opposing the glazed ceramics were noticeable ($p<0.01$). A significant enamel

Table 3: Mean Roughness (Ra) and SD of Opposing Enamel Surface Before and After Wear ^a			
Opposing Ceramic	Surface Treatment	Before Wear (Ra)	After Wear (Ra)
VITABLOCS Mark II	Glazed	153.0584 ± 25.1985 ^{aA}	16.0172 ± 12.6506 ^{aB}
	Polished	154.624 ± 15.7964 ^{aA}	11.6506 ± 7.9549 ^{aB}
IPS e.max CAD	Glazed	141.989 ± 16.4766 ^{aA}	35.7532 ± 15.4292 ^{abB}
	Polished	158.3184 ± 35.6935 ^{aA}	50.6798 ± 31.5919 ^{abB}
VITA Suprinity	Glazed	124.1968 ± 23.5288 ^{aA}	58.5862 ± 24.2284 ^{abB}
	Polished	157.8234 ± 35.2398 ^{aA}	24.6616 ± 18.0767 ^{abB}
VITA Enamic	Glazed	156.2248 ± 24.4407 ^{aA}	82.5626 ± 24.4421 ^{bB}
	Polished	156.4388 ± 24.0212 ^{aA}	143.0776 ± 21.6449 ^{cA}

^a Equal superscript lowercase letters indicate no statistically significant differences within each column. Equal superscript uppercase letters indicate no statistically significant differences within each row.

Table 4: Mean Ceramic Wear (mm) and SD After 120,000 Wear Cycles^a

Ceramic Treatment	VITABLOCS Mark II	IPS e.max CAD	VITA Suprinity	VITA Enamic
Glazed	0.148 ± 0.1257 ^{abA}	0.088 ± 0.0216 ^{aA}	0.222 ± 0.0614 ^{bA}	0.124 ± 0.0114 ^{abA}
Polished	0.050 ± 0.200 ^{aA}	0.092 ± 0.5070 ^{abA}	0.164 ± 0.09127 ^{bA}	0.084 ± 0.026 ^{abA}

^a Equal superscript lowercase letters indicate no statistically significant differences within each row. Equal superscript uppercase letters indicate no statistically significant differences within each column.

specimen height was lost compared with opposing glazed VMII and glazed Enamic ceramics.

VMII and Enamic ceramics demonstrated a significantly lower enamel specimen loss when polished rather than glazed.

DISCUSSION

The results of this study show that the enamel specimens that were tested against the polished Enamic blocks had the smallest amount of roughness change, presumably showing the least enamel specimen surface alterations. The most vigorous amount of enamel specimen roughness change was evident in VMII and polished Suprinity antagonists, although all the other groups with the exception of the polished Enamic group became significantly rougher ($p < 0.01$).

The primary roughness of the polished VMII was significantly and noticeably higher than all the other ceramic groups, depicting an insufficient polishing process. The highest amount of enamel specimen loss was also evident in the VMII groups; however, the rougher surface of the polished VMII caused significantly less enamel specimen height loss in comparison to the glazed treatment. In a study, unpolished and unglazed VMII resulted in similar enamel specimen and ceramic wear as a pressed ceramic (IPS Empress), with similar composition (Leucite crystals/feldspathic porcelain). However, the results were significantly higher than gold and Dicor machinable ceramics.²⁰

Overall, the wear of the enamel specimens was less evident when the antagonist ceramic was polished, which can be a positive motivation toward the polishing systems of modern CAD-CAM ceramics. The only group with significantly higher enamel

specimen wear in only the polished ceramic groups was the e.max. In a similar study of wear, all ceramic specimens presented similar and wear-friendly properties, against the enamel specimen and compared with the control group. The ceramics included e.max CAD and LAVA Plus Zirconia.²¹ In our study, the polished Suprinity group and the polished e.max group were worn statistically in a similar fashion. Because the methodology and material components of the tested specimens were different, the grounds for comparison are limited.

The highest amount of enamel specimen wear was observed in the VMII glazed and to some extent glazed ceramics. Polished VMII ceramics were the group with the least height loss after the wear test. This would suggest that polished VMII ceramics would not be worn after clinical function; in return, the opposing dental enamel specimen would suffer height loss to a greater extent. The glazed VMII would also cause a great deal of enamel specimen loss, but the ceramic would be almost equally worn. Whether that is a matter of significance remains to be seen.

The best results were seen in the polished Enamic and all Suprinity ceramics, with the least enamel specimen wear. This is definitely a plus finding in addition to other superior benefits of these newer CAD-CAM systems. In fact, Suprinity ceramic specimens were more likely to be worn than the antagonist enamel specimens. Also, despite that the enamel specimen was significantly worn in the Enamic polished group, the surface roughness properties remained unchanged. In one study, e.max CAD and Enamic demonstrated signs of abrasive wear, which was similar to the enamel specimen control group.²² In another study on the wear and roughness of several restorative materials,

Table 5: Mean Enamel Wear (mm) and SD After 120,000 Wear Cycles^a

Opposing Ceramic Treatment	VITABLOCS Mark II	IPS e.max CAD	VITA Suprinity	VITA Enamic
Glazed	2.000 ± 0.247 ^{aA}	0.702 ± 0.0917 ^{bA}	0.498 ± 0.1696 ^{bA}	1.224 ± 0.1078 ^{cA}
Polished	1.252 ± 0.139 ^{aB}	1.048 ± 0.1735 ^{aA}	0.396 ± 0.0687 ^{bA}	0.470 ± 0.2214 ^{bB}

^a Equal superscript lowercase letters indicate no statistically significant differences within each row. Equal superscript uppercase letters indicate no statistically significant differences within each column.

e.max CAD and Enamic ceramics were indifferent in antagonist enamel specimen wear, although the polishing technique was very different to this study. VMII and e.max ceramics had lower roughness than the zirconia and Enamic specimens, whereas they were not different from the enamel specimen group. However, the surface roughness was measured after a toothbrush simulator and not the wear test.²³

The methodology and the newer materials used in the present study limits the comparison of the results to other wear simulating studies. It is best to further investigate the efficacy of other polishing systems and protocols on a wider variety of ceramics.

CONCLUSIONS

According to the findings of the present study, the CAD-CAM ceramic polishing systems are a safe and accommodating replacement for the reglazing of the studied ceramic restorations, because the roughness and wear rate of both the ceramic and the opposing enamel specimen will either not change or decrease. Further investigation for other ceramic and polishing systems is necessary to reach a unanimous conclusion in the case of all ceramics.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of approval of the Babol University of Medical Sciences in Mazandaran, Iran.

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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Effect of Thickness on Light Transmission and Vickers Hardness of Five Bulk-fill Resin-based Composites Using Polywave and Single-peak Light-emitting Diode Curing Lights

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Clinical Relevance

There is no evidence of a clear advantage for using a polywave light-curing unit over a single-peak light-curing unit when photopolymerizing bulk-fill resin-based composites that use a combination of camphorquinone and germanium-based photoinitiators.

SUMMARY

Objectives: This study compared light transmission through different thicknesses of bulk-fill resin-based composites (RBCs) using a polywave and a single-peak light-emitting diode light-curing unit (LCU). The effect on the surface hardness was also evaluated.

Methods: Five bulk-fill RBCs were tested. Specimens (n=5) of 1-, 2-, 4-, or 6-mm thickness were photopolymerized for 10 seconds from

the top using a polywave (Bluephase Style) or single-peak (Elipar S10) LCU, while a spectrophotometer monitored in real time the transmitted irradiance and radiant exposure reaching the bottom of the specimen. After 24 hours of storage in distilled water at 37°C, the Vickers microhardness (VH) was measured at top and bottom. Results were analyzed using multiple-way analysis of variance, Tukey post hoc tests, and multivariate analysis ($\alpha=0.05$).

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Results: The choice of LCU had no significant effect on the total amount of light transmitted through the five bulk-fill RBCs at each thickness. There was a significant decrease in the amount of light transmitted as the thickness increased for all RBCs tested with both LCUs ($p < 0.001$). Effect of LCU on VH was minimal ($\eta_p^2 = 0.010$). The 1-, 2-, and 4-mm-thick specimens of SDR, X-tra Fill, and Filtek Bulk Restorative achieved a $VH_{\text{bottom/top}}$ ratio of approximately 80% when either LCU was used.

Conclusions: The total amount of light transmitted through the five bulk-fill RBCs was similar at the different thicknesses using either LCU. The polywave LCU used in this study did not enhance the polymerization of the tested bulk-fill RBCs when compared with the single-peak LCU.

INTRODUCTION

The use of resin-based composites (RBCs) for direct restorations has become routine in dental practice. The mechanical properties and abrasion resistance of RBCs continues to improve,¹ and they can offer an esthetic restoration for the patient. However, adequate polymerization is required to meet the manufacturer's specifications for the RBC that should, in turn, improve the long-term success of the RBC restoration. It is known that restorations that are poorly polymerized may fail prematurely because of the increased incidence of secondary caries, bond failure to the tooth, margin defects, or restoration fracture.^{2,3} Additionally, the biocompatibility of the restoration is negatively affected if the RBC is inadequately polymerized.⁴

Contemporary RBCs use blue visible light to initiate the photopolymerization reactions. This technology is based on the use of photoreactive systems that absorb photons at specific wavelengths of light from the light-curing unit (LCU). The photoinitiator molecule forms free radicals that initiate the polymerization process by converting the carbon-carbon double bond in the methacrylate groups in the monomer into carbon-carbon single bonds, thus forming both longer polymer chains, and cross-linked chains. The success of this technology depends on matching the emission spectrum from the LCU to the wavelength-dependent photoabsorption of the photoinitiator present within the RBC and on the RBC receiving sufficient photons.⁵

This spectral matching was not a problem when quartz tungsten-halogen (QTH) units were used

because these LCUs delivered a broad-emission spectrum of light ranging from ~ 375 to ~ 510 nm. However, light-emitting diodes (LEDs) have become the most commonly used light source in contemporary LCUs, and these LEDs emit a narrower range of wavelengths compared with QTH units.⁶

Most contemporary LED units use blue LED chips that produce a relatively narrow band of wavelengths, with a typical full width at half of the maximum wavelength peak of only ~ 25 nm. The emission spectrum from these units usually peaks in the 450-nm to 470-nm wavelength range and they deliver almost no light below 420 nm.⁷ These blue LED units will efficiently cure resins that use camphorquinone (CQ), which is the most commonly used photoinitiator in RBCs.

However, the bright yellow color of CQ limits its use, particularly in very light or translucent shades of RBC.⁸ Therefore, some RBCs and bonding systems include alternative photoinitiators that are not as chromogenic as CQ,⁹ such as monoacylphosphine oxide and derivatives of dibenzoyl germanium, which are primarily activated by shorter wavelengths (below 420 nm) of violet light.¹⁰ This requirement for shorter wavelengths has proven to be a problem for single-emission-band LED units that emit light mainly in the 450-nm to 470-nm wavelength range and has led to the introduction of a third generation of broad-spectrum multiple-peak LED violet/blue LCUs.^{7,11-13} These broad-spectrum violet/blue LCUs use a combination of two or more different color LED chips to deliver light in both the 440-nm to 470-nm range and shorter wavelengths below 420 nm.^{11,12} One manufacturer, Ivoclar Vivadent, has registered the term *polywave* to describe their broad-spectrum LED violet/blue LCU. Such broad-spectrum LED units have been reported to polymerize 2-mm thick specimens of some resins to a greater extent than single-emission-band LED blue curing units, even though both units were delivering similar irradiance values.¹²

Recently, bulk-fill RBCs have become popular to fill posterior teeth. While most early bulk-fills were flowable composites, high-viscosity bulk-fill RBCs are now available. These materials can be light cured in increments of 4 or 5 mm, instead of the customary 2-mm thickness.¹⁴ The photoinitiator system used in most bulk-fill RBCs is still CQ based, as in the regular light-cured RBCs, although Tetric EvoCeram Bulk Fill includes additional initiators, such as Ivocerin. This germanium-based initiator system has a greater photo-curing activity than CQ and an absorption spectrum that extends from below

Table 1: *Materials, Manufacturers, and Chemical Composition of Matrix and Filler and Filler Content by Weight (w) and Volume (v)%^a*

Material and Shade	Abbreviation	Manufacturer, Batch	Resin Matrix	Filler	Filler (w/v) %
TetricEvo Ceram Bulk Fill, IVA	Evo-Bulk	Ivoclar-Vivadent, V02758	Dimethacrylate	Ba-Glass, YbF ₃ , mixoxide, PPF	79–81/60–61
SDR Posterior Bulk Fill Flowable U	SDR	Dentsply, 1603000897	Mod UDMA, EBPADMA, TEGDMA	Ba-Al-F-B-Si glass, Sr-F-Si glass	68/45
X-tra Fill, U	X-tra Fill	Voco, 1626156	Bis-GMA, UDMA, TEGDMA	Inorganic filler	86/70.1
Filtek Bulk Fill Flowable Restorative, A2	Filtek-Flo	3M-ESPE, N672461	UDMA, Procrylat, Bis-EMA, Bis-GMA	Zirconia/silica and ytterbium trifluoride	64.5/42.5
Filtek Bulk Fill Posterior Restorative, A2	Filtek-Bulk	3M-ESPE, N698655	AUDMA, UDMA and 1, 12-dodecane-DMA	Zirconia/silica and ytterbium trifluoride	76.5/58.4

Abbreviations: Bis-EMA, ethoxylated bisphenol A glycol dimethacrylate; Bis-GMA, bisphenol glycidyl dimethacrylate; EBPADMA, ethoxylated bisphenol-A-dimethacrylate; PPF, prepolymerized fillers; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.
^a Data were provided by the manufacturers (missing entries indicate where the data was unavailable). Other abbreviations according to periodic system of elements.

380 nm up to 460 nm, with a peak absorption close to 408 nm.¹⁵

The polywave style of LED units should polymerize all types of RBC. However, due to the location of the LED emitters within the unit, the spectral irradiance may not be uniformly distributed across the light tip,^{16,17} thus affecting the photocuring of some RBCs.¹⁸ Furthermore; the lower wavelengths from these devices may be unable to penetrate the thicker specimens of bulk-fill RBCs in sufficient quantity to activate the photoinitiators at the bottom of the RBC.

The aim of this study was to quantify and compare the amount of light that was transmitted through different thicknesses of five bulk-fill RBCs using a polywave and a single-peak LED curing light, and to evaluate their effect on the Vickers microhardness at the bottom of the specimens. The tested null hypotheses were that 1) the same amount of light would be transmitted at each thickness through the five bulk-fill RBCs, 2) there would be no difference in the radiant exposure delivered in the 350–425 nm wavelength region from the polywave LCU at the bottom of the five brands of RBC, and 3) the hardness at the bottom of the specimens would be the same after using either of the two LCUs.

METHODS AND MATERIALS

The five bulk-fill materials used are reported in Table 1. For each material, four different thicknesses (1, 2, 4, and 6 mm) were tested. The specimens were prepared in white Delrin ring-shaped molds. The specimens were light cured by positioning the curing light tip at 0-mm distance, perpendicularly, and centered over the sample's surface. A mechanical

arm was used to repeatedly and accurately position the LCU over the specimens. Two different commercial LCUs were used; one was a single peak light (Elipar S10, 3M, St Paul, MN, USA) that delivered, according to the manufacturer, an irradiance of 1200 mW/cm² in the wavelength range of 430–480 nm, and the other was a broad spectrum polywave light (Bluephase Style, Ivoclar Vivadent, Schaan, Liechtenstein) that delivered, according to the manufacturer, an irradiance of 1100 mW/cm² in the wavelength range of 385–515 nm. Both LCUs were used according to the manufacturer's recommended exposure time of 10 seconds. The light guide used was the original version supplied with the Bluephase Style LCU (the manufacturer has subsequently updated its light guide to provide a more homogenous light output, but this also decreased the radiant power output). Five specimens were made in each group.

A laboratory-grade USB4000 spectrophotometer (Ocean Optics, Dunedin, FL, USA) inside a MARC Resin Calibrator (BlueLight Analytics Inc, Halifax, NS, Canada) was used to measure, in real time, the transmitted irradiance that was emitted from the bottom of the specimens during light curing. The light was collected through a 4-mm-diameter cosine corrected detector (CC3, Ocean Optics). This detector is designed to collect all the radiation (light) arriving at 180°, thus eliminating some of the optical interface problems associated with the geometry of light collection. The MARC software quantified the total radiant exposure that reached the bottom of the specimens from both LCUs by integrating the area under the irradiance curves in the 350–425 nm and the 425–500 nm wavelength ranges. To protect the tip of the light guide and the sensor of the spectrometer, a 10-µm-thin transparent plastic foil

covered the top and bottom of the specimens. This foil did not affect the transmitted wavelengths of light, but the two thicknesses combined reduced the irradiance reaching the detector by 10%.

To remove any oxygen inhibition layer, the cured specimens were lightly polished using copious water coolant and silicon carbide paper (grit size 1200 and 4000), and then stored in distilled water at 37°C for 24 hours. The specimens were blotted dry and Vickers microhardness (VH) was measured. A 200-g load was delivered by the Vickers indenter with a dwell time of 30 seconds using a microhardness tester (Matsuzawa Seiki Co, Ltd, Tokyo, Japan). Three indents were made no closer than 1 mm to the specimen margins and 1 mm distant from each other. They were averaged to yield a single mean microhardness (VH) value for the top and bottom surfaces of each specimen. A VH bottom/top ratio ($VH_{b/t}$) was also calculated.

Statistical Analysis

A statistical program SAS version 9.2 (SAS, Cary, NC, USA) was used to perform the analyses. Averages and standard errors of the means were calculated for the light irradiance, the radiant exposures at each increment thickness, and for each material. The normality of data was checked and confirmed before the results were compared between the two LCUs for each RBC at each increment thickness among the different incremental thicknesses, within each material, and among the 5 RBCs using multiple-way analysis of variance (ANOVA). Multiple-way ANOVA was also used to determine if there were significant differences in the VH at the bottom for the different RBCs at each increment thickness and each LCU. Tukey post hoc tests were used to assess the adjusted significant pair differences; α was set at 0.05. A multivariate analysis (general linear model, $\alpha=0.05$) was used to assess the effect of the RBC, increment thickness, and LCU on the light irradiance, radiant exposure, and VH. For each increment thickness and RBC, the mean response and standard error of the mean were plotted for all dependent parameters (light irradiance, radiant exposure, and VH) using GraphPad Prism 5 (GraphPad Software, San Diego, CA, USA).

RESULTS

The mean values of the amount of transmitted light irradiance and the radiant exposure arriving at the bottom of each of the RBC specimens by each LCU are summarized in Table 2, together with the percentage of the light that arrived at the bottom

of the specimens compared to what was delivered to the top surface. Multiple-way ANOVA revealed no significant difference in the total amount of light transmitted through the four different thicknesses when comparing the polywave LCU or the single-peak LCU: $p=0.79$, $p=0.76$, $p=0.39$, and $p=0.45$ for 1-, 2-, 4-, and 6-mm thicknesses respectively for irradiance; and $p=0.25$, $p=0.27$, $p=0.99$, and $p=0.58$ for the 1-, 2-, 4-, and 6-mm thicknesses, respectively, for the radiant exposure.

At each increment thickness, there was a significant difference in the amount of transmitted irradiance and total radiant exposure arriving at the bottom of the specimens among the five bulk-fill RBCs ($p<0.001$) for both LCUs (Figure 1). The amount of transmitted light irradiance and total radiant exposure were the highest in SDR and the lowest in Filtek Bulk Fill Flowable at all thicknesses and for both LCUs. Multivariate analysis showed that the radiant exposure and irradiance were significantly affected by the brand of RBC (0.698, 0.699) and by the thickness (0.965, 0.970), respectively.

Figure 2 shows graphs of the emission spectra through SDR (the most translucent RBC) and Filtek Bulk Fill Flowable (the least translucent) from both LCUs, and at each thickness. Figure 3 shows that the transmitted radiant exposure in the 350-425 nm wavelength range from the polywave LCU was less than one tenth of the light transmitted in the 425-500 nm wavelength range. In 10 s, less than 0.2 J/cm² of light in the 350 to 425 nm range was transmitted through 6 mm of any of the tested RBCs. The radiant exposure in the 350-425 nm wavelength range that reached the bottom of the specimens relative to what was delivered to the top was the lowest for EvoCeram Bulk Fill: 10%, 7.7%, 1.7%, and 0.0% at the 1, 2, 4, and 6 mm thicknesses, respectively.

There was a significant drop in the VH at the bottom as the increment thickness increased for both LCUs ($p<0.0001$). The decrease in the VH at the bottom and $VH_{b/t}$ ratio of the specimens with each increase in thickness followed the same pattern for both LCUs (Figure 4). The 1-, 2-, and 4-mm thickness of SDR, X-tra Fill, and Filtek Bulk Fill Posterior bulk-fill RBCs achieved a $VH_{b/t}$ ratio within one standard deviation of 80% when either LCU was used. At the 6-mm thickness, none of the tested RBCs achieved the 80% $VH_{b/t}$ value using either LCU.

Multivariate analysis showed that the brand of RBC had a significant effect ($\eta_p^2=0.946$) as well as

Table 2: Mean Irradiance and Mean Radiant Exposure Among the Different Materials Through 1 to 6 mm of Each RBC and the Percentage (%) of What Reached the Bottom Relative to What Was Delivered to the Top (0 mm)^a

Increment Thickness	Bluephase Style					Elipar S10				
	Material	Irradiance		Radiant Exposure		Material	Irradiance		Radiant Exposure	
		Mean (SE)	%	Mean (SE)	%		Mean (SE)	%	Mean (SE)	%
0		1083		11.7			1196		12.5	
1	SDR	779.2 ^a (64.0)	72	8.3 ^a (0.7)	71	X-tra Fill	766.0 ^a (65.5)	64	7.8 ^a (0.7)	62
	Evo-Bulk	743.2 ^a (17.9)	69	8.0 ^a (0.2)	68	SDR	757.0 ^a (19.7)	63	7.7 ^a (0.3)	62
	X-tra Fill	716.2 ^a (24.7)	66	7.7 ^a (0.3)	66	Evo-Bulk	692.0 ^a (36.9)	58	7.2 ^a (0.4)	58
	Filtek-Bulk	641.6 ^{a,b} (12.2)	59	7.0 ^{a,b} (0.2)	60	Filtek-Bulk	688.8 ^a (14.6)	58	7.1 ^a (0.1)	57
	Filtek-Flo	544.8 ^b (25.3)	50	5.8 ^b (0.2)	50	Filtek-Flo	476.0 ^b (8.0)	40	4.8 ^b (0.1)	38
2	SDR	533.8 ^a (44.0)	49	6.0 ^a (0.5)	51	SDR	582.2 ^a (12.0)	49	5.9 ^a (0.1)	47
	X-tra Fill	508.0 ^{a,b} (19.6)	45	5.5 ^{a,b} (0.2)	47	X-tra Fill	500.4 ^b (17.3)	42	5.2 ^b (0.2)	42
	Evo-Bulk	421.0 ^{b,c} (10.7)	39	4.5 ^{b,c} (0.1)	39	Evo-Bulk	423.0 ^c (18.1)	35	4.2 ^c (0.1)	34
	Filtek-Bulk	367.0 ^{c,d} (10.3)	34	3.9 ^c (0.1)	33	Filtek-Bulk	363.6 ^c (5.6)	30	3.7 ^c (0.1)	30
	Filtek-Flo	323.0 ^d (8.8)	30	3.5 ^c (0.1)	30	Filtek-Flo	256.0 ^d (18.7)	21	2.6 ^d (0.2)	21
4	SDR	244.0 ^a (24.0)	23	3.1 ^a (0.6)	26	SDR	257.0 ^a (6.7)	21	2.7 ^a (0.1)	22
	X-tra Fill	162.2 ^b (9.0)	15	1.7 ^b (0.1)	15	X-tra Fill	174.0 ^b (7.0)	15	1.8 ^b (0.1)	14
	Evo-Bulk	108.2 ^{b,c} (6.9)	10	1.2 ^b (0.1)	10	Evo-Bulk	135.8 ^c (3.5)	11	1.4 ^c (0.0)	11
	Filtek-Bulk	107.4 ^c (9.5)	10	1.1 ^b (0.1)	10	Filtek-Bulk	131.2 ^c (6.5)	11	1.3 ^c (0.1)	10
	Filtek-Flo	89.8 ^c (3.2)	8	1.0 ^b (0.0)	8	Filtek-Flo	87.2 ^d (5.2)	7	0.8 ^d (0.1)	6
6	SDR	93.2 ^a (4.5)	9	1.0 ^a (0.1)	9	SDR	116.9 ^a (10.9)	10	1.2 ^a (0.1)	10
	X-tra Fill	62.2 ^b (6.5)	6	0.7 ^b (0.1)	6	X-tra Fill	67.4 ^b (4.1)	6	0.7 ^b (0.0)	6
	Filtek-Bulk	40.2 ^c (3.3)	4	0.4 ^c (0.0)	3	Evo-Bulk	42.2 ^c (0.1)	4	0.4 ^c (0.0)	3
	Evo-Bulk	37.4 ^c (3.3)	3	0.4 ^c (0.0)	3	Filtek-Bulk	39.8 ^c (1.6)	3	0.4 ^d (0.0)	3
	Filtek-Flo	30.4 ^c (2.5)	3	0.3 ^c (0.0)	3	Filtek-Flo	29.2 ^c (2.0)	2	0.4 ^c (0.0)	3

^a Mean irradiance (mW/cm²) and radiant exposure (J/cm²) are reported together with the standard errors of the means. Means with the same letter among the same increment thickness and light-curing unit are not significantly different. (Tukey honestly significant difference test, $\alpha=0.05$).

the increment thickness (0.881), but there was only minimal effect of the LCU (0.010) on the VH values.

DISCUSSION

Table 2 shows that the Elipar S10 delivered a slightly greater radiant exposure (12.5 J/cm²) in 10 seconds compared with the Bluephase Style (11.7 J/cm²). However, after passing through 1 to 6 mm of RBC, the irradiance and total radiant exposure delivered in the 350-500 nm wavelength range from the polywave and the Elipar S10 LED LCUs were similar for each RBC, but different among the five RBCs. Therefore, the first null hypothesis was accepted and proved the assumption that differences in light transmission appear to be more dependent on RBC material and thickness, rather than on the LCU, provided that similar radiant exposures are delivered.^{19,20}

The second null hypothesis that there would be no difference in the radiant exposure delivered in the 350-425 nm wavelength region from the polywave LCU at the bottom of the five brands of RBC was

rejected. Figures 2 and 3 show that as the increment thickness increased, the radiant exposure in the 350-425 nm wavelength range that arrived at the bottom from the Bluephase Style was significantly decreased. Figure 3 shows that the light transmitted through 1 mm of RBC in the 350-425 nm wavelength range was less than one tenth of the light transmitted in the 425-500 nm wavelength range and became minimal in comparison to the radiant exposure delivered in the 425-500 nm wavelength range as the increment thickness increased. The Tetric EvoCeram Bulk Fill RBC transmitted the least amount of energy in the 350-425 nm wavelength range. In the 350-425 nm range, only 1.7% of what was delivered to the top reached the bottom of the specimens, and nothing could be detected (0%) at the bottom of the 6-mm-thick specimens. This raises questions about the need to include the lower short wavelengths in LED curing lights used to cure bulk-fill RBCs and supports the findings of a 2017 publication by Sampaio and others¹⁶ that the amount of violet light was insufficient to cure the RBC at greater depths. They found that overall

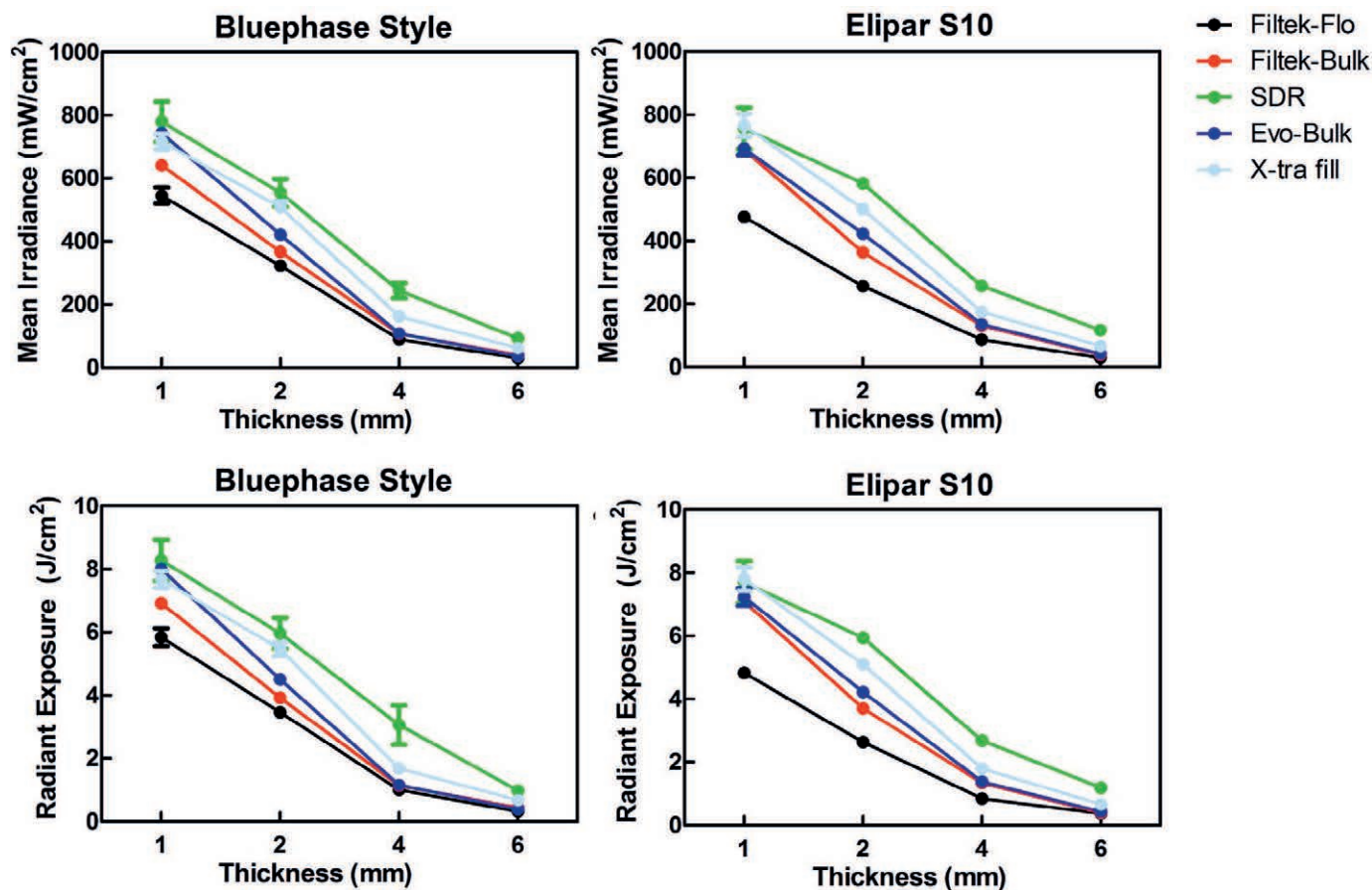


Figure 1. Irradiance and radiant exposure transmitted to the bottom surfaces of the specimens at the different thicknesses from both LCUs. There was a significant decrease in the transmitted irradiance and radiant exposure as thickness increased in all RBCs tested with both LCUs ($p < 0.001$).

light-curing was the worst in the deeper regions that were exposed mostly to violet light, and this translated into lower degree of conversion values in this region.¹⁶ Other studies have also found that increasing the RBC thickness had a greater negative effect on transmission of violet light (350-425 nm) than on blue light (425-550 nm).^{21,22}

The increased absorption of violet light compared with the longer wavelength blue light may be related to the relationship between the wavelength of the light from the LCU and the dimensions of the filler particles used within the RBC. According to the Rayleigh effect, the filler particles within the RBC will be more likely to scatter shorter wavelengths of light.¹⁰ This effect will be more pronounced at the shorter wavelengths (below 425 nm) delivered by the polywave LED LCU compared with the longer wavelength (at 460 nm) delivered by both LED LCUs.²³

Another explanation for the reduced effectiveness of the polywave LCU as the RBC thickness increases

may be the differences in the absorption of CQ and the alternative photoinitiators used within the RBC. A study that used a phenanthrenequinone (PQ) initiator reported that its peak absorption was at 413 nm, and it had eight times the absorbance of CQ; However, even when 1200 mW/cm² was delivered for 40 s to an RBC that used the highly reactive PQ initiator, the depth of cure was less (2.7 mm) compared with similar CQ-based RBCs (4.2 mm). It was suggested that due to the high absorbance of PQ, most of the light photons were depleted in the top layers of the RBC and never reached the bottom of the RBCs.²⁴ Ivocerin has higher absorbance than CQ and therefore, may also absorb most of the violet light in the first one or two millimeters of the RBC, thus preventing the lower wavelengths from reaching deeper into the RBC.

The photoinitiator content of RBC materials is not always disclosed and varies greatly among different brands of similar shades, or even among different shades within the same product brand.²⁵ Thus, the manufacturers of broad-spectrum polywave LCUs

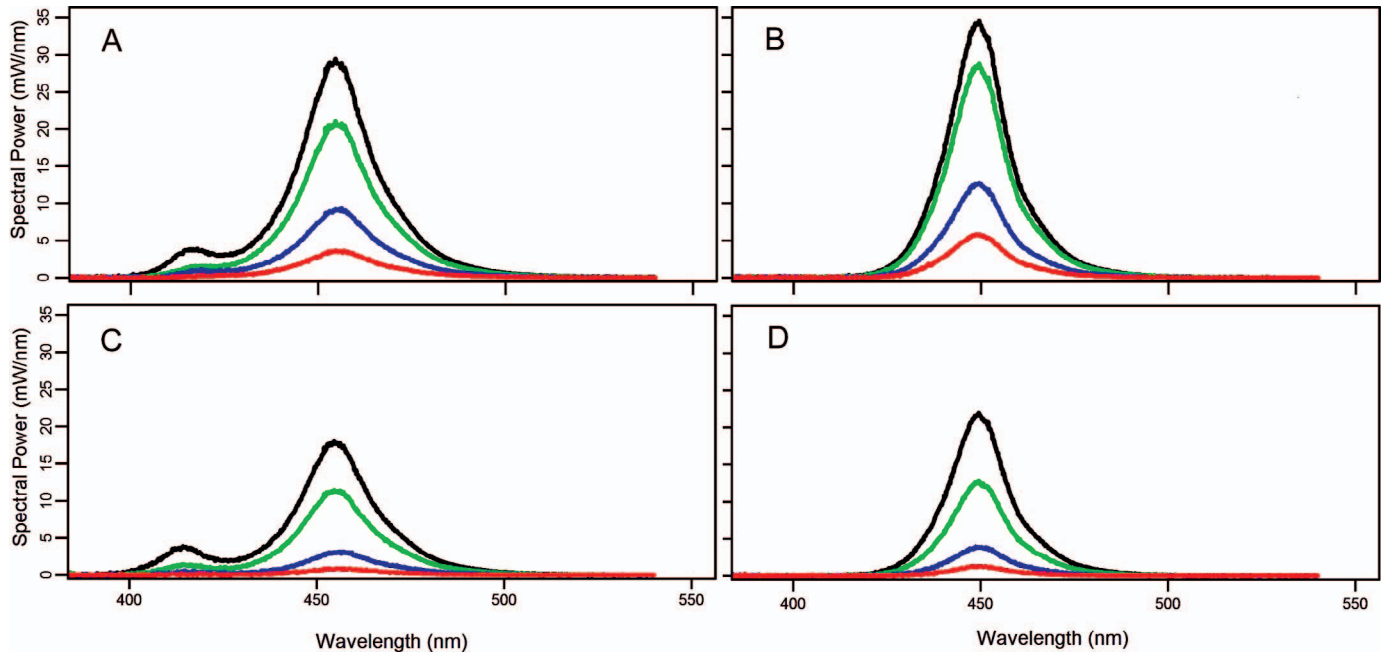


Figure 2. Effect of specimen thickness on the emission spectrum transmitted to the bottom surfaces of the specimens from (A) Bluephase Style with SDR, (B) Elipar S10 with SDR, (C) Bluephase Style with Filtek Bulk Fill Flowable, and (D) Elipar S10 with Filtek Bulk Fill Flowable at 1 mm (black), 2 mm (green), 4 mm (blue), and 6 mm (red) thick RBC.

(e.g., Ivoclar Vivadent, GC, Ultradent, and Kulzer) claim that because their units produce a broad emission spectrum compared with other single-peak LED-based units, they can photo-cure all current RBCs, no matter what photoinitiator is used.^{23,26}

According to the manufacturer, the Elipar S10 LED LCU delivers an emission spectrum of 430-480 nm with a single peak emission at 455 ± 10 nm. This LCU was chosen because it can efficiently cure RBCs that contain CQ, which is the most commonly used photoinitiator in RBCs. However, the Elipar S10 was also found to be effective at photo-curing EvoCeram Bulk Fill, even though this LCU delivers very little light below 430 nm. This may be attributed to the

use of Ivocerin in EvoCeram Bulk Fill. Although Ivocerin has a peak absorbance close to 408 nm, it is sensitive to light up to 460 nm, and nearly 50% of its peak absorbance occurs at 440 nm.²⁷ The overlap in the absorbance of Ivocerin and the emission spectrum from the Elipar S10 allowed the initiation of the Ivocerin by the Elipar S10 LCU. The Bluephase Style LED LCU was chosen because it uses three LED emitters: one violet and two blue, with spectral emissions peaking near 410 nm (violet) and 457 nm (blue) and it is known to be a polywave broad-spectrum violet/blue LCU.

There was a significant difference in the amount of light that was transmitted among the five bulk-fill

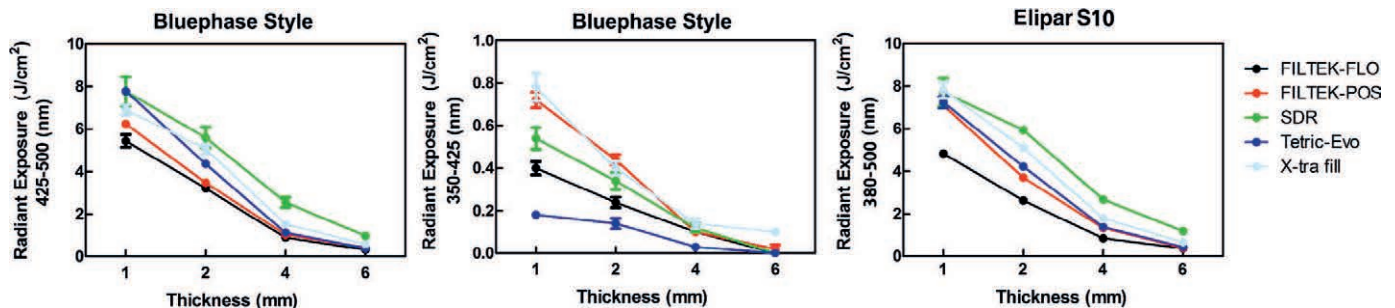


Figure 3. Radiant exposure transmitted to the bottom surfaces of the specimens delivered in the 350-425 and 425-500 nm wavelength ranges to the bulk-fill RBCs at different thicknesses from the Bluephase Style and in the 380-500 nm range from the Elipar S10. Note the different radiant exposure scale in the 350-425 nm range and how very little violet light passed through 4 mm of RBC. There was a significant decrease in the transmitted radiant exposure as thickness increased in all RBCs tested with both LCUs ($p < 0.001$).

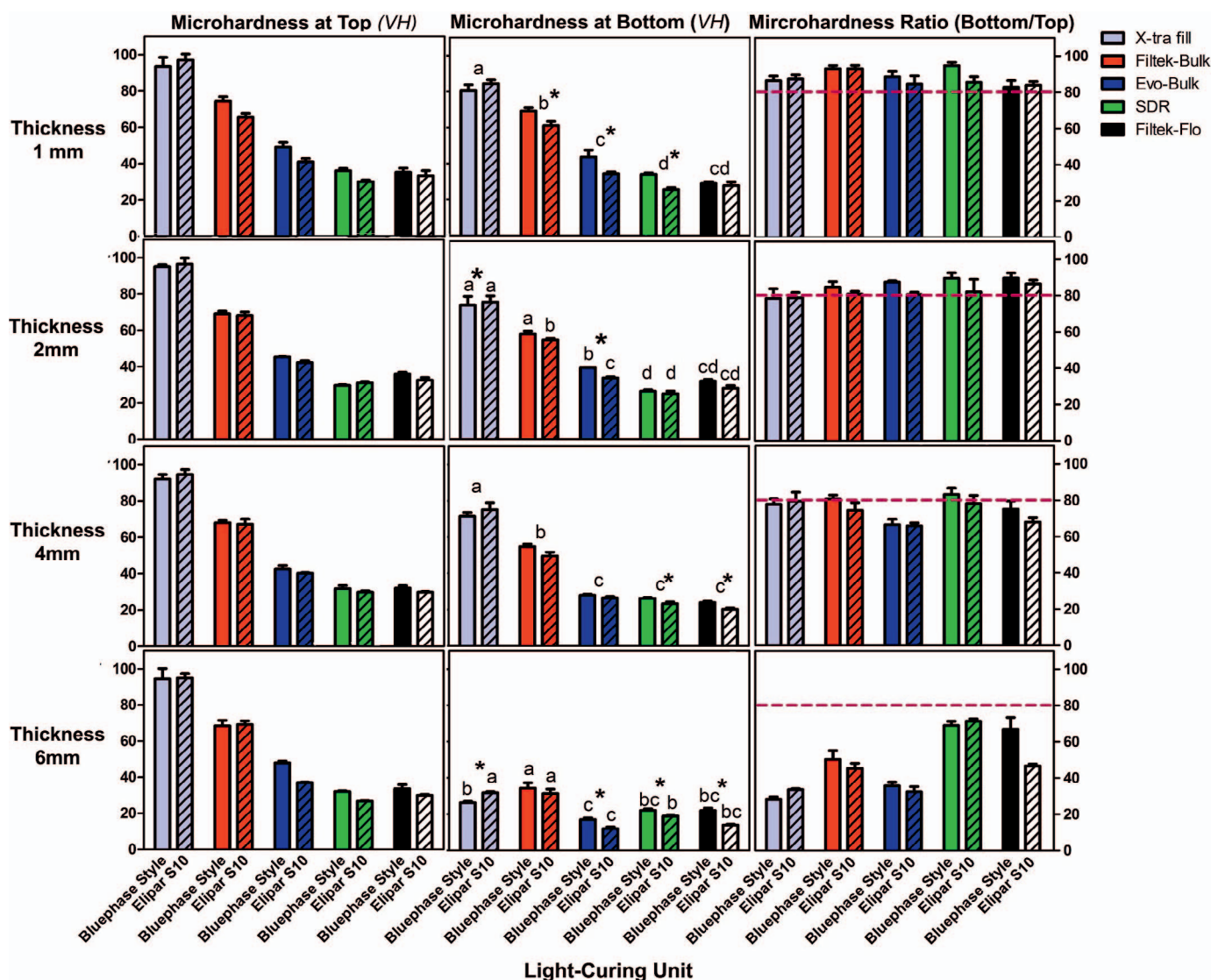


Figure 4. Vickers microhardness (VH) values at the top, at the bottom and the bottom to top ratio (VH_{bt}) of each bulk-fill RBC at the different increment thicknesses using both LCUs. Vertical lines represent the standard errors of the means. Letters represent significant differences between the bulk-fill RBCs at same thickness. Asterisks represent significant differences within the same bulk-fill RBC at the same thickness between the two LCUs ($p < 0.05$). The horizontal dotted line represents the 80% VH_{bt} ratio.

RBCs ($p < 0.0001$). The high translucency of X-tra Fill relative to the other RBCs, even with high filler amount, may be related to the larger filler particle size and because the manufacturer has matched the refractive indices of the filler particles and the resin matrix.²⁸ This improves the light transmission through the RBC.²⁹ The decreased filler content in SDR and the presence of a special photoactive group in this RBC may have enhanced its light transmitting properties. The lower translucency of Filtek Bulk Fill Flowable may be related to the addition of small particle zirconia fillers into this RBC. Due to its high refractive index, zirconia has been reported to reduce light transmission through some experi-

mental materials. However; this partial substitution of particulate glass fillers with zirconia/silica fillers (2.5 and 5.0 wt%) should improve the mechanical properties, such as flexural strength and fracture toughness of the RBC.³⁰ Thus, when formulating an RBC, it is a compromise between achieving adequate light transmission and obtaining the optimum physical properties for the RBC.

Since both LCUs delivered a similar radiant exposure, the depth of cure was only minimally influenced by the LCU used; consequently, the third null hypothesis was partially accepted. The decrease in the hardness at the bottom of the specimens with each increase in thickness followed the same pattern

for both LCUs. This is in agreement with a study by Menees and others,³¹ who found that the effect of the LCU type on the depth of cure was not significant when two bulk-fill RBCs were irradiated with either a polywave or a single-peak LED LCU. This may be because the percentage of reduction in the total radiant exposures transmitted to the bottom of the specimens relative to what arrived at the top was similar in the two LCUs (Table 2). With decreasing light penetration and increasing distance from the irradiated surface, a decrease in the degree of conversion and hence a decrease in the hardness values would be expected.³²

It has been previously reported that the emission spectrum across the light tip of the polywave Blue-phase Style with the original nonhomogenizer light guide was not uniform.³³ This resulted in nonuniform nanohardness across the top and bottom surfaces; the nano hardness within the bulk of the specimens was also not uniform.³⁴ In a previous study that investigated 1.2 mm thick conventional RBCs that did not contain Ivocerin, increasing exposure duration beyond manufacturers' recommended times reduced the effects of beam inhomogeneity on surface and subsurface microhardness, especially for RBCs that contained both CQ and 2,4,6-trimethylbenzoyldiphenylphosphine oxide (Lucirin TPO) as the photoinitiators.³⁵ The hardness of RBCs has been used as an indirect method to assess the depth of cure³⁶ with a bottom to top hardness ratio ($VH_{b/t}$) of 80% is often used as a minimally acceptable hardness threshold value.³⁷ The use of a 10-second exposure time in this study may explain why not all the RBCs reached the 80% $VH_{b/t}$ value at the 4-mm thickness and suggests that longer exposure times may be required.

Menees and others³¹ reported differences in the depth of cure when a metal mold was used compared with a tooth mold. They also reported greater deviation in the data when using a tooth mold and suggested that stainless steel molds are preferred.³¹ White semitransparent Delrin molds instead of metal molds were used to prepare the samples in this study. Although these semitransparent molds are not what is specified by the ISO standard 4049 depth-of-cure test,³⁸ they may represent what occurs in the tooth more accurately instead of the completely opaque metal molds that are used in the ISO test. The white Delrin also offers consistent optical properties compared with using a tooth. However, despite using these semitransparent white molds, not all bulk-fill materials reached the 80% $VH_{b/t}$ value at the 4-mm depth when using the 10 s exposure time.

At the 6-mm thickness, none of the tested materials achieved the 80% $VH_{b/t}$ value using either LCU; thus, dentists may still need to use bulk-fill RBCs in two or more increments in deep cavities and should not attempt to light cure a 6-mm increment. This may be related to the drastic decrease in irradiance and radiant exposure that arrives at the bottom relative to what arrives at the top as the thickness increased for all five RBCs (Table 2 and Figures 1 through 3). The EvoCeram Bulk Fill had the lowest depth of cure and the most drastic decrease in the $VH_{b/t}$ ratio values, especially as the thickness increased. This observation is similar to findings of other studies.^{32,39} Furthermore, this supports the observation that the depth of cure of CQ-based materials can be greater than that of TPO-based materials,⁴⁰ and the additional photoinitiator (Ivocerin) in EvoCeram Bulk Fill is not able to fully compensate for the lower translucency of this product. At 4 mm, SDR transmitted the greatest amount of light (3 J/cm^2) of all the tested RBCs and it showed the lowest drop in the $VH_{b/t}$ value for both LCUs (Table 2 and Figure 4). Of note, clinical studies have reported good successes for SDR when it was capped with a conventional composite in 5-year randomized controlled studies.^{41,42} It was also reported that provided at least 3.23 J/cm^2 was delivered to SDR, changes in the radiant exposure had only a small impact on the degree of conversion and the depth of cure of this RBC.²⁰ A similar result was reported for Filtek Bulk Fill Flowable (3M) which required only 5.30 J/cm^2 to achieve a 4 mm depth of cure.²⁰ Table 2 shows that only $\sim 1 \text{ J/cm}^2$ was transmitted at 4 mm, which may be why it did not achieve an 80% $VH_{b/t}$ ratio after 10 seconds of light exposure.

A reduced decrease in the degree of conversion as the incremental thickness increased has been reported when monomers of a higher molecular weight are used.⁴³ The SDR Posterior Bulk Fill Flowable that was used in this study included a high molecular weight urethane-based methacrylate resin polymerization modulator to delay gelation and reduce polymerization shrinkage without affecting the degree of conversion.⁴⁴ This may have increased the depth of cure. The same technology is used in SDR flow + Bulk Fill Flowable that has improved mechanical strength, wear resistance, and radiopacity.⁴⁵ Optimizing the resin components may also explain why the bulk-fill RBCs SDR, X-tra Fill, and Filtek Bulk Fill Posterior achieved a $VH_{b/t}$ ratio that was within one standard deviation of 80%. These materials contain urethane dimethacrylate (UDMA),

and the copolymerization of bisphenol A-glycidyl methacrylate (bis-GMA) with UDMA or triethylene glycol dimethacrylate (TEGDMA) increases the conversion and creates a highly cross-linked, dense and stiff polymer network.⁴⁶

The results show that the polywave broad-spectrum violet/blue LED LCU used in this study did not enhance the polymerization of the bulk-fill RBCs tested compared with the single-peak LED LCU, provided that similar radiant exposures were delivered. The effect of other polywave LED units on additional bulk-fill RBCs, particularly different shades and those that contain the alternative photoinitiators in addition to CQ, together with extended exposure durations, should be addressed in future studies using experimental resins of known formulations.

CONCLUSIONS

Within the limitations of the current study that used five commercial RBCs, the following conclusions may be made:

1. When similar radiant exposures were delivered, multiple-way ANOVA revealed no significant difference in the total amount of light transmitted through the four different thicknesses when comparing the polywave LCU or the single-peak LCU
2. After passing through 1 mm of RBC, the transmitted light in the 350-425 nm wavelength range was less than one tenth of the light transmitted in the 425-500 nm wavelength range and became minimal as the increment thickness increased.
3. Twenty-four hours after light curing and after polishing the RBCs, the 1-, 2-, and 4-mm thickness of SDR, X-tra Fill, and Filtek Bulk Fill Posterior bulk-fill RBCs achieved a $VH_{b/t}$ ratio that was within one standard deviation of 80% when either LCU was used.
4. When similar radiant exposures were delivered, the polywave broad-spectrum violet/blue used in this study did not enhance polymerization of the tested bulk-fill RBCs compared with the single-peak LCU.

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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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Fracture Resistance of Endodontically Treated Maxillary Premolars Restored With Different Methods

VA Mergulhão • LS de Mendonça • MS de Albuquerque • R Braz

Clinical Relevance: Ceramic inlays, as well as composite resin restorations with or without a horizontal fiber post, seem to restore the fracture resistance of endodontically treated maxillary premolars to a level compared to that of intact teeth.

doi: <https://doi.org/10.2341/17-262-L>

The Role of Occlusal Factors in the Presence of Noncarious Cervical Lesions in Young People: A Case-Control Study

**A Alvarez-Arenal • L Alvarez-Menendez • I Gonzalez-Gonzalez
E Jiménez-Castellanos • M Garcia-Gonzalez • H deLlanos-Lanchares**

Clinical Relevance: Some occlusal factors such as protrusive and non-working-side lateral interferences, as well as bruxism, are risk factors for the presence and development of noncarious cervical lesions.

doi: <https://doi.org/10.2341/18-028-C>

Caries Diagnosis in Dental Practices: Results From Dentists in a Brazilian Community

**EPS Tagliaferro • A Valsecki Junior • FL Rosell
SRC Silva • JL Riley • GH Gilbert • VV Gordan**

Clinical Relevance: Dental caries diagnosis is performed by most dentists from a Brazilian community using visual-tactile and radiographic methods.

doi: <https://doi.org/10.2341/18-034-C>

Comparison of Internal Adaptation of Bulk-fill and Increment-fill Resin Composite Materials

FS Alqudaihi • NB Cook • KE Diefenderfer • MC Bottino • JA Platt

Clinical Relevance: The filling of deep, wide cavities with bulk-fill resin composites is appealing. However, some bulk-fill resin composites result in larger internal resin-dentin gaps than observed for an incremental-fill resin composite.

doi: <https://doi.org/10.2341/17-269-L>

Minimally Invasive Adhesive Rehabilitation for a Patient With Tooth Erosion: Seven-year Follow-up

NI Pavesi Pini • LM De Marchi • AL Ramos • RC Pascotto

Clinical Relevance: This case report discusses a full-mouth rehabilitation using direct composite resin and whether this technique is viable for a young patient with tooth erosion. The seven-year follow-up indicates that a conservative approach with an appropriate diagnosis of the patient is a good choice for achieving esthetics, function, and restoration longevity.

doi: <https://doi.org/10.2341/17-181-T>

Fracture Resistance of Endodontically Treated Maxillary Premolars Restored With Different Methods

VA Mergulhão • LS de Mendonça • MS de Albuquerque • R Braz

Clinical Relevance

Ceramic inlays, as well as composite resin restorations with or without a horizontal fiber post, seem to restore the fracture resistance of endodontically treated maxillary premolars to a level compared to that of intact teeth.

SUMMARY

Purpose: The purpose of this *in vitro* study was to evaluate the resistance and patterns of fracture of endodontically treated maxillary premolars (ETPs) restored with different methods.

Methods and Materials: Mesio-occluso-distal cavities were prepared in 50 extracted caries-free human maxillary premolars after endodontic treatment. The teeth were divided into five groups (n=10), according to the restor-

ative method. G1: intact teeth (control group); G2: conventional composite resin; G3: conventional composite resin with a horizontal glass fiber post inserted between buccal and palatal walls; G4: bulk-fill flowable and bulk-fill restorative composites; and G5: ceramic inlay. For direct restorations, Filtek Z350 XT, Filtek Bulk Fill Flowable Restorative, and Filtek Bulk Fill Posterior Restorative were used. Indirect restorations were fabricated from a pressable lithium disilicate glass-ceramic (IPS e-max Press) and adhesively cemented (RelyX Ultimate). All specimens were subjected to thermocycling (5°C to 55°C/5000 cycles) and additionally submitted to cyclic loading 50,000 times in an Electro-Mechanical Fatigue Machine. Next, the specimens were subjected to a compressive load at a crosshead speed of 1 mm/min until fracture. The fractured specimens were analyzed to determine the fracture pattern using a stereomicroscope, and then representative specimens were carbon coated to allow for the studying of the fracture surface under scanning electron microscopy. One-way analysis of variance (ANOVA) was used to compare fracture resistance of the groups.

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The results of fracture patterns were submitted to the Fisher exact test ($\alpha=0.05$).

Results: All specimens survived fatigue. Mean (standard deviation) failure loads (N) for groups were as follows: G1: 949.6 (331.5); G2: 999.6 (352.5); G3: 934.5 (233.6); G4: 771.0 (147.4); and G5: 856.7 (237.5). The lowest fracture resistance was recorded for G4, and the highest ones were recorded for G2, followed by that of G1 and G3. One-way ANOVA did not reveal significant differences between groups ($p>0.05$). The highest repairable fracture rates were observed in G1 (100%) and G3 (80%).

Conclusions: ETPs restored with conventional composite resin with or without horizontal fiber post, bulk-fill composite, and ceramic inlay showed fracture resistance similar to that of sound teeth. Conventional composite resin restorations exhibited the highest prevalence of unrepairable fractures, and the insertion of a horizontal fiber post decreased this prevalence. Intact teeth showed 100% of repairable fractures. It is difficult to extrapolate the results directly to a clinical situation due to the limitations of this study.

INTRODUCTION

Endodontically treated teeth present a greater risk of biomechanical failure than teeth with pulp vitality. Cusp fractures are more concentrated in premolars due to the anatomical shape, the ratio of unfavorable crown to root, and exposure to shear and compressive forces.¹ In addition, endodontic access jeopardizes structural integrity, resulting in increased cusp deflection during function and leading to a higher occurrence of fractures.² The substantial loss of structure may worsen the situation when endodontic treatment is associated with mesio-occluso-distal (MOD) cavities. The prognosis of endodontically treated premolars (ETPs) is influenced by different parameters, such as amount of hard tissue loss,³ depth and design of the cavity preparation,^{4,5} presence of a minimum ferrule height preparation of 1.5 to 2.0 mm,⁶ and post and core material used.⁷

Restorative treatment techniques and materials for ETPs, such as the use of post and core, total or partial crowns, direct composite resin, and amalgam or ceramic restorations, are described in the literature. Glass fiber posts can be used due to their favorable physical properties.⁸ The use of horizontal glass fiber posts in MOD cavities restored with

composite resin increased fracture resistance of ETPs.⁹

Bulk-fill resin composites have emerged as a new category of low- and high-viscosity composites that can be used in class I and class II restorations in increments of 4 or 5 mm.¹⁰⁻¹² The difference in the chemical monomeric resin formulations and filler characteristics, such as the type, volume fraction, density, and particle size and distribution, can affect the depth of cure and mechanical properties,¹³ justifying further investigations for the indication of bulk-fill resin composites in MOD cavities.

Ceramic restoration is another option for restoring ETPs. Ceramics have many advantages, such as translucency, fluorescence, chemical stability, biocompatibility, high compressive strength, and a thermal expansion coefficient similar to tooth structure.¹⁴ Despite their desirable characteristics, ceramics are fragile under tensile and occlusal forces, making them susceptible to fracture.¹⁵

The purpose of this *in vitro* study was to evaluate fracture resistance and failure modes of ETPs restored with composite resin or ceramic using different methods. The null hypothesis was that there would be no significant difference among the sound and restored maxillary premolars.

METHODS AND MATERIALS

Tooth Selection and Preparation

Fifty recently extracted caries-free maxillary premolars that were removed for orthodontic reasons were selected, cleaned with periodontal curettes, and stored in 0.1% thymol solution (F.Maia Ind. Com., Cotia, Brazil) at room temperature for two weeks and then kept in 0.9 NaCl solution at 4°C. Endodontic access cavities were prepared with round burs #1012, #1013 (KG Sorensen, Cotia, Brazil), and an Endo-Z bur (Dentsply Maillefer, Ballaigues, Switzerland). Endodontic treatment was performed according to the crown-down technique using the Pro-Taper system (Dentsply Maillefer), which includes rotary instruments made of nickel-titanium (NiTi) alloy (M-Wire) and the X-Smart-Endo-motor (Dentsply Maillefer). The apical foramen was prepared to file F2, size 25. Irrigation was performed by alternating 2.5% NaOCl solution and 17% EDTA solution. The root canals were dried with paper points (Cellpack Protaper, Dentsply Maillefer) and obturated 1 mm short of the apex with Sealer 26 (Dentsply Indústria e Comércio Ltda, Petropolis, Brazil) and tapered gutta-percha cones (Guta Percha Protaper, Dentsply Maillefer) using the single-cone

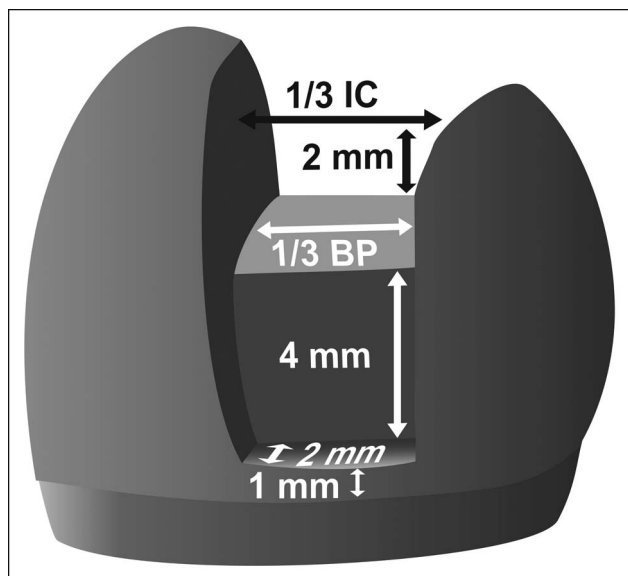


Figure 1. Dimensions of MOD inlay preparation. IC, intercuspal distance; BP, buccopalatal distance.

technique. The access cavities were sealed with temporary filling (Coltosol, Coltene, Brazil).

MOD cavity preparation was performed in all teeth except the control group. Diamond burs were replaced every six preparations to ensure high cutting power. For all preparations, conical diamond burs #3131 (KG Sorensen) were used in a high-speed hand piece mounted on a device used to standardize the preparation of all specimens. The dimensions of the MOD inlay cavities are shown in Figure 1. On completion of the preparations, all internal angles were rounded. Only one operator was responsible for performing all the cavity preparations. Root surfaces were then dipped into melted wax (Wilson Polidental, Cotia, Brazil) up to 2.0 mm below the cemento-enamel junction (CEJ), resulting in a 0.2- to 0.3-mm-thick wax layer to act as a spacer. Next, the teeth were centrally embedded in acrylic resin (Vipi Flash, Pirassununga, Brazil) up to 2 mm apical to the CEJ to simulate the bone level using polyvinyl chloride cylinders as molds. The teeth long axes were oriented perpendicular to horizon by using a custom-made parallelometer. After resin polymerization, the teeth were removed from the cylinder, and the wax was removed from the root surface and resin cylinder "alveolus." The polyether impression material (Impregum Soft, 3M ESPE, Seefeld, Germany) was placed in the resin cylinders, the tooth was reinserted into the cylinder, and the excess impression material was removed with a surgical blade. The method used to simulate the periodontal ligament was described by Soares and others.¹⁶

The teeth were randomly divided into five groups (n=10) as follows: G1: control group, intact teeth without cavity preparation or endodontic treatment; G2: MOD preparation with conventional composite resin restoration; G3: MOD preparation with conventional composite resin restoration and a horizontal glass fiber post inserted between the buccal and palatal walls; G4: MOD preparation with bulk-fill flowable and bulk-fill restorative composites; and G5: MOD inlay preparation with lithium disilicate glass-ceramic restoration (IPS e-max Press, Ivoclar Vivadent, Schaan, Liechtenstein).

Restorative Procedure

All specimens, except the intact teeth (G1), had 2 mm of root canal filling removed from canal orifices with Gates Glidden drills (#2-3, Dentsply Maillefer) for subsequent insertion of bulk-fill flowable composite. A probe was used to control the depth of the intraorifice cavity. The selective enamel etching technique was carried out according to the instructions of the dentin adhesive. Tooth enamel was etched using 37% phosphoric acid (Condac 37, FGM Produtos Odontológicos Ltda, Joinville, Brazil) for 15 seconds, rinsed with water spray for 15 seconds, and air-dried. The dentin bonding agent (Single Bond Universal, 3M ESPE) was then applied to the entire tooth structure of the MOD cavities, rubbed in for 20 seconds, air-dried for five seconds, and light cured for 10 seconds using a LED light curing unit (1200 mW/cm², Radium-cal, SDI, Bayswater, Australia). The light output of the Radium-cal was measured by a specific radiometer for LED (Demetron L.E.D Radiometer, SDS/Kerr, Orange, CA, USA). Flowable composite (Filtek Bulk Fill Flowable Restorative, 3M ESPE) was applied in the root canal orifices and polymerized from proximal and occlusal areas. A metal matrix band was placed around the tooth using a Tofflemire retainer, and conventional composite resin (Filtek Z350XT, 3M ESPE) was placed in the teeth of G2 by using an oblique layering technique. Each layer was 2 mm thick. In G4, the MOD preparations were restored with the bulk-fill technique that consisted of one 4-mm increment of Filtek Bulk Fill Flowable Restorative (3M ESPE) including proximal boxes plus one 2-mm capping layer of Filtek Bulk Fill Posterior Restorative (3M ESPE). In both techniques, each composite resin increment was light cured for 20 seconds. The perforations in the teeth of G3 for the horizontal glass fiber post were made at the prominent point on the buccal and palatal surfaces at the midpoint between mesial and distal. The holes were carried

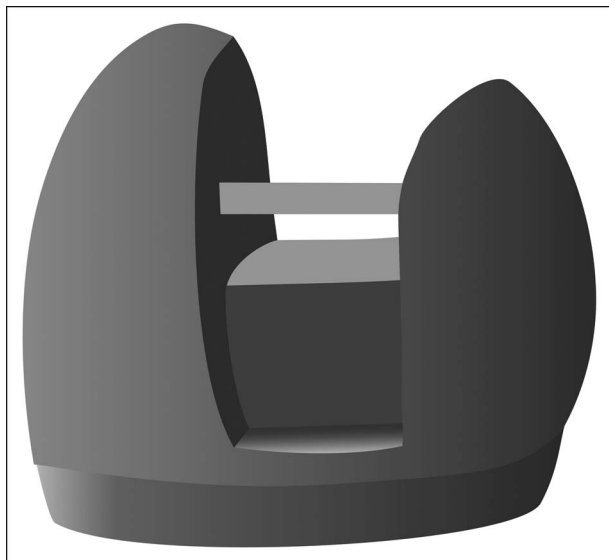


Figure 2. Horizontal glass fiber post view.

out with round diamond burs #1013 (KG Sorensen) with air-water spray. The post extremities were cut close to the buccal and palatal surfaces. Glass fiber posts (White Post DC number 0.5, FGM Produtos Odontológicos) of 1.4 mm diameter were cleaned with 70% alcohol, and then Single Bond Universal adhesive was applied on their surfaces and light cured for 10 seconds. The walls of the MOD cavities were etched using the selective enamel etching technique described previously. The posts (Figure 2) were fixed in the holes using dual-curing resin cement (RelyX Ultimate, 3M ESPE). Composite resin (Filtek Z350 XT, 3M ESPE) was applied and polymerized according to the incremental technique. After 24 hours in distilled water at 37°C, the composite resin groups were submitted to finishing procedures with flexible discs (Sof-lex, 3M ESPE).

Fabrication of Ceramic Restorations

Impressions of preparations in G5 were made with polyvinylsiloxane material (Express XT, 3M ESPE). All restorations were fabricated from a pressable lithium disilicate glass ceramic (IPS e.max Press) according to the manufacturer's instructions.

Adhesive Luting

The intaglio surface of the restoration was etched with 5% hydrofluoric acid etching gel (Condac porcelana 5%, FGM Produtos Odontológicos) for 20 seconds, rinsed thoroughly with water for 15 seconds, and dried with water-free and oil-free air, according to the manufacturer's instructions. Single Bond Universal Adhesive (3M ESPE) was applied to

the entire surface to be luted, allowed to react for 20 seconds, and dried for five seconds with gentle air. Since Single Bond Universal Adhesive contained silane in its composition, there was no need to apply silane, separately, on the restoration. The selective enamel etching technique was performed as described previously. The dual-curing resin cement (RelyX Ultimate, 3M ESPE) was mixed and applied on the intaglio surface of the restoration, which was seated on the prepared tooth. The excess luting cement was removed, and the margins of the restoration were covered with an air-inhibiting gel (Liquid Strip, Ivoclar Vivadent). The restoration was seated with finger pressure, and the occlusal and proximal surfaces of the tooth were light cured for 60 seconds. The teeth of all groups were stored in an incubator at 37°C in 100% humidity for a week. The materials used in the restorative procedure are presented in Table 1.

Thermocycling, Cyclic Loading, and Fracture Load

All specimens were thermocycled between 5°C and 55°C in water with a 30-second dwell time at each temperature, following a regimen of 5000 cycles, which represents six months of clinical function,^{17,18} and additionally submitted to cyclic loading 50,000 times, which represents approximately three to 12 months of clinical service,¹⁹ in an Electro-Mechanical Fatigue Machine- MSFM (Elquip, São José dos Pinhais, Brazil). A loading cycle frequency of 2 Hz or 120 revolutions per minute with a load ranging from 0 to 100 N was selected to simulate high physiologic masticatory forces. During the cyclic loading, the specimens were kept in distilled water at 37°C ± 1°C. The specimens were placed in the machine in a way that the indenter, used as an antagonistic surface to simulate the opposite teeth, could apply the load on the occlusal surfaces of the specimens. All specimens survived the cyclic loading.

To determine the fracture resistance, a 6 mm diameter stainless-steel cylinder mounted in a universal testing machine (EMIC DL 10000, Brazil) was used to apply compressive load on the long axis of the restored teeth at a crosshead speed of 1 mm/min until fracture. The cylinder was centered over the tooth until it contacted the occlusal surface of the restoration on the buccal and lingual cusp inclines. The compressive load required to cause fracture was recorded in N. The specimens were examined regarding the kind, location, and direction of the failure with a stereomicroscope (Axio Zoom V16, Zeiss, Oberkochen, Germany). Failures were classi-

Table 1: *Materials Used in the Restorative Procedure*

Material	Manufacturer	Batch Number
Filtek Bulk Fill Posterior Restorative (composite resin)	3M ESPE (St Paul, MN, USA)	N 685666
Filtek Bulk Fill Flowable Restorative (composite resin)	3M ESPE	N 772034
Filtek Z350XT (composite resin)	3M ESPE	559841
RelyX Ultimate (resin cement)	3M ESPE	1617300197
White Post DC (fiber post)	FGM (Joinville, Brazil)	020916
IPS E-Max Press (lithium disilicate–reinforced ceramic)	Ivoclar Vivadent (Barueri, Brazil)	V08364

fied as repairable when the fracture line was above the simulated bone level and unrepairable when the fracture line was below the simulated bone level according to the classification of Zicari and others²⁰ (Figure 3). Representative specimens were carbon coated (Carbon Coater 108carbon/A, Cressington, Watford, England) to allow for the studying of the fracture surface in a scanning electron microscope (JSM-6460, JEOL, Akishima, Tokyo, Japan).

The Shapiro-Wilk test showed that data were normally distributed. The homogeneity of variance was tested using the Levene test and one-way analysis of variance (ANOVA) was used to compare fracture resistance of the groups. The results of fracture patterns were submitted to the Fisher exact test. The significance level was 5% (SPSS, version 23, SPSS Inc, Chicago, IL, USA).

RESULTS

The mean fracture resistance and standard deviations are displayed in Table 2. They ranged from 771.0 (147.4) N to 999.6 (352.5) N. The lowest fracture resistance was recorded for G4 (Bulk fill) and the highest for G2 (conventional composite resin), followed by those of G1 (control group) and G3 (conventional composite resin and horizontal fiber post). One-way ANOVA did not reveal significant differences between groups ($p > 0.05$).

The mode of failure is presented in Table 3 and Figure 4. Regarding the repairable mode of failure, the frequencies for the groups were as follows: G1 (100%), G3 (80%), G4/G5 (50%), and G2 (30%). Significant difference was found in failure modes among the groups ($p < 0.007$). G1 showed a significant difference when compared to G2, G4, and G5.

DISCUSSION

The null hypothesis that there would be no significant difference among the sound and restored premolars was accepted. The fracture resistance exhibited by all groups was superior to those efforts

developed during normal masticatory function, situated between 22.65 and 45.40 Kgf.²¹

Previous studies²²⁻²⁶ and the present study were common in that the use of ceramic inlays showed fracture resistance similar to that of healthy teeth. In contrast, other studies²⁷⁻³⁰ showed that ceramic inlay restorations used in premolars were not able to restore the total resistance to load of healthy teeth. It needs to be pointed out that different cements and ceramic systems were used in the studies and that cements with higher flexural modulus exhibit higher values of fracture resistance.²² This may help to explain the different performance of the ceramic inlays in the mentioned studies.

In the present study, the MOD cavities restored with conventional composite resin exhibited fracture resistance comparable to the ceramic inlays, which is

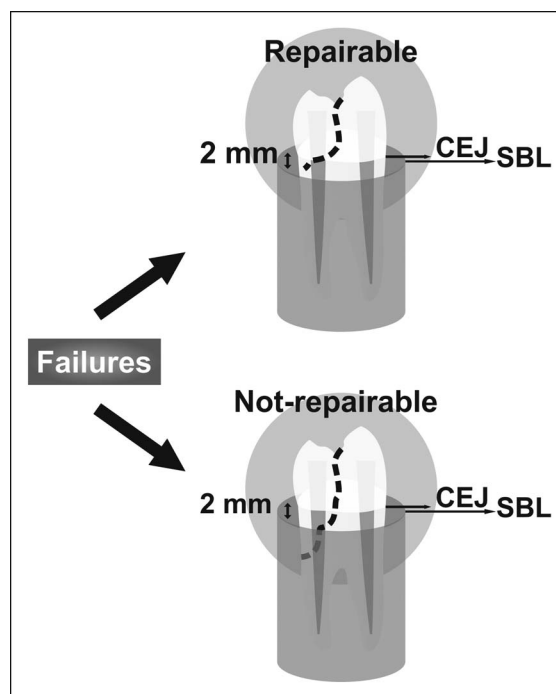


Figure 3. *Fracture mode classification. CEJ, cemento-enamel junction; SBL, simulated bone level.*

Table 2: Mean Fracture Resistance (N), Standard Deviation Values, and Variation Coefficients of Experimental Groups			
Group	Mean (N)	Standard Deviation (N)	Variation Coefficient (%)
G1	949.6	331.5	34.9
G2	999.6	352.5	35.3
G3	934.5	233.6	25.0
G4	771.0	147.4	19.1
G5	856.7	237.5	27.7
p-value	$p^a = 0.372$		
Abbreviations: G1, control group; G2, conventional composite resin; G3, conventional composite resin with horizontal fiber post; G4, bulk fill; G5, ceramic inlay.			
^a One-way analysis of variance.			

in agreement with the findings of other studies.^{26,29,30} Although ceramic restorations present disadvantages with regard to antagonist wear and friability, ceramic inlays show better clinical performance than composite inlays, according to the results of two systematic reviews.^{31,32} Although the difference was not statistically significant (Table 2), the fracture resistance of ETPs restored with composite resin was slightly higher than that of ETPs restored with ceramic inlays. Since IPS e-max Press has higher fracture toughness than Filtek Z 350 XT, an explanation for the higher fracture resistance of the composite resin group would be the lower elastic modulus of the composite that resulted in lower stresses in the composite restorations.³³

Previous studies^{26,34} and the present study were common in that maxillary premolars restored with composite resin exhibited statistically similar fracture resistance compared to sound teeth. This finding may be attributed to the ability of the resinous materials to undergo elastic deformation similarly to tooth structure.³⁵ In contrast, other studies^{9,29,30,36-38} revealed that premolars restored with composite resin showed statistically lower

fracture resistance than that of intact teeth. In the present study, the dominant mode of failure for the composite resin group was unrepairable, including axial fractures, while that for the sound teeth was repairable. These findings are in agreement with earlier studies.^{9,39} In the investigation by Plotino and others,⁴⁰ intact teeth showed more restorable fractures than all the prepared ones.

A systematic review⁴¹ showed that root canal-treated teeth (RCT) covered with crowns have a higher long-term survival rate ($81\% \pm 12\%$ after 10 years) than RCT without crown coverage ($63\% \pm 15\%$ after 10 years). RCT without crown coverage included teeth restored with resin composites, amalgam, and cements. The authors concluded that the survival rate for RCT without crown coverage is quite satisfactory for the first three years, while there is a significant decrease in the survival of RCT after this period. Although in the present study the MOD composite showed quite satisfactory fracture resistance result, it should be highlighted that the strengthening effect of the MOD composite will significantly decrease with years.

In this study, ETPs restored with composite resin placed in increments and in bulk did not provide statistically significant different mean fracture resistances that can be compared with previous studies.^{37,42-47} Bulk-fill flowable composites present characteristics, such as low viscosity, elastic buffer effect, low modulus of elasticity,⁴⁸ high degree of conversion,⁴⁹ and less polymerization shrinkage and shrinkage stress⁵⁰ causing less cuspal deflection when compared to a conventional composite used in increments. Regarding the mode of failure, the present study and that by Atalay and others⁴⁴ were common in that the bulk-fill technique exhibited higher prevalence of repairable fractures than those of the incremental filling technique, and it should be considered a great advantage of the bulk-fill technique. In this study, the bulk-fill group showed 50% of repairable fractures. Other studies^{45,46} revealed

Table 3: Fracture Mode of Each Group						
Group ^a	Repairable		Unrepairable		Group Total	
	n	%	n	%	n	%
G1 A	10	100.0	—	—	10	100.0
G2 B	3	30.0	7	70.0	10	100.0
G3 AB	8	80.0	2	20.0	10	100.0
G4 B	5	50.0	5	50.0	10	100.0
G5 B	5	50.0	5	50.0	10	100.0
Abbreviations: G1, control group; G2, conventional composite resin; G3, conventional composite resin with horizontal fiber post; G4, bulk fill; G5, ceramic inlay.						
^a Statistically different percentages ($p < 0.05$) are indicated by different letters (Fisher exact test).						

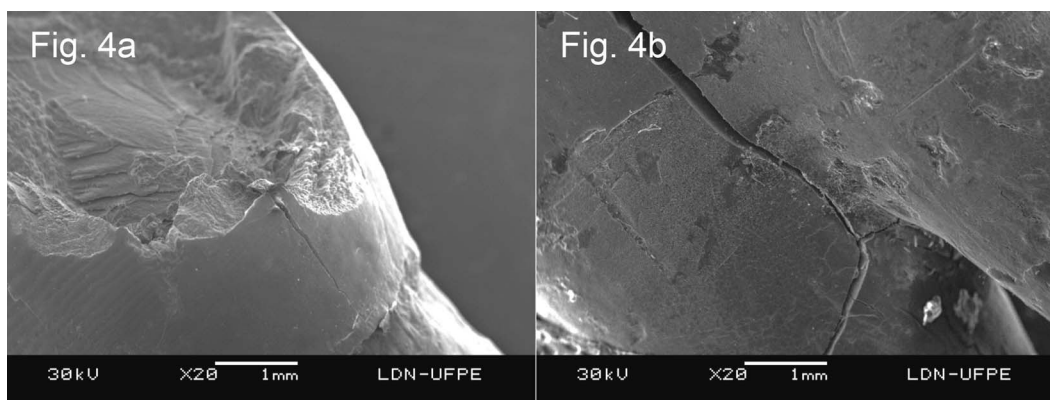


Figure 4. SEM images of the fracture surface. A, repairable fracture (control group); B, unrepairable fracture (conventional composite resin group).

that specimens restored with nanohybrid or bulk-fill composites were more prone to unrepairable fractures.

With regard to the use of fiber posts, the current study investigated if posts placed horizontally between the buccal and palatal walls of premolars would increase the fracture resistance. A study revealed that the extension of a horizontal glass fiber post through the buccal and palatal cusps strengthens the composite resin restoration and through adhesion reinforces the cusps and enhances the fracture resistance of ETPs.⁹ Considering that, in the present study, the holes made to support the posts were less than 1 mm deep, one must consider that the integrity of the tooth was not adversely affected prior to occlusal load. The choice for glass fiber posts was due to their low elastic modulus, which matches that of dentin.⁵¹ The achieved fracture resistance values of G1 (healthy teeth) 949.6 (331.5) N and G3 (conventional composite resin with horizontal fiber post) 934.5 (233.6) N were comparable with those of Karzoun and others⁹ (994.5±147.3 N and 961.3±245.2 N, respectively). In both studies, ETPs restored with composite resin and a horizontal fiber post provided a mean fracture resistance that was similar to the control group (healthy premolars). In that study, ETPs restored with composite resin and horizontal fiber post provided higher fracture strength compared to those restored with composite resin, whereas in the present study, these two groups did not differ statistically. Regarding the fracture pattern, in the current study, G3 (conventional composite resin with horizontal fiber post) showed 80% repairable fractures, whereas G2 (conventional composite resin) showed 30% repairable fractures. This result suggests that the use of a horizontal fiber post in the

composite resin restoration seems to be a promising approach for practitioners.

Different fracture resistance results may be justified by the differences in the testing parameters, such as crosshead speed and the different loading tip shapes and sizes, including the direction and location of the applied load. Some studies recommend the use of tin foil^{52,53} or 1.0 mm-thick polyethylene film⁵ to be placed between the occlusal surface and the load cell to distribute the loading forces more homogeneously. In the present study, as well as in previous studies,^{4,9,27,37,42,43,54,55} tin foil or any kind of film was not used, and this may have influenced the results together with the other factors mentioned above. A study⁵³ suggested the use of a natural tooth to act as the antagonist during dynamic loading, but in this study, a 6-mm-diameter metal jig was used, and this may have affected the crack propagation.

In vitro tests still remain an indispensable method to evaluate the performance of materials, and considering the available protocols, thermal cycling seems to be a valid *in vitro* method to accelerate the aging of restorative materials.¹⁷ Although this aging method is, together with cyclic loading, the most widely used, there is a lack of a standardized protocol.⁵⁶ Adhesive failures may be found between the bonding resin and dentin after thermocycling, showing that this method has an influence on bond-strength values.⁵⁷ Many investigations that used the ISO standard (ISO TR 11450)⁵⁸ protocol (500-cycle regimen) concluded that thermocycling did not affect the bond strength of adhesive systems.^{18,59,60} Thermocycling stresses the bond between resin and tooth and, depending on the adhesive system, may affect bond strength;⁶¹ furthermore, it can affect the marginal integrity of the restoration, causing micro-leakage.⁶² A study⁶³ concluded that a regimen of

30,000 cycles was able to decrease bond strength. This finding suggests that thermocycling has a negative effect on the restorative interface after a large number of cycles, indicating that the most important factor that accelerates the aging process during thermocycling may be the deleterious effect of water.⁶⁴

Clinically, dental restorations are subjected to biochemical challenges in addition to mechanical loads. These additional challenges will accelerate the degradation of the tooth-restoration interfacial bond.⁶⁵ In the present study, ETPs were subjected to cyclic loading before the fracture test in order to simulate clinical function. Many studies that investigated fracture resistance of restorations of endodontically treated teeth used only static load.^{9,22,29,39,43} Results of a study⁶⁶ indicated that the most important influence on dentin fatigue is attributed to the high shrinkage stress of the composite filling. The level of occlusal load in the simulation of 1,000,000 cycles does not produce high fatigue of dentin when the residual stress is close to zero; therefore, the authors of that study emphasized that it is important to minimize the shrinkage stress of the composite materials when restoring vital or devitalized teeth. Studies that used mechanical testing differ with regard to the number of cycles, varying from 1000 to 8000,⁶⁷ 50,000,⁶⁸ 100,000,⁶⁹ 200,000,⁷⁰ and up to 1,200,000 cycles,^{52,54,71} which is equivalent to five years of clinical performance.⁷¹ Cyclic loading is a great way to describe fatigue behavior, but its expense has caused the development of other methods that have been used for dental composites and other materials; the staircase method is an example that is more economical and easier to perform than the fatigue resistance test.⁷² A study concluded that the dental materials community has not yet adopted fatigue testing as one of the most important methods for evaluating the potential clinical success of new restorative materials.⁷³ The author of that study stated that new approaches have recently been developed for evaluating the durability of the bonded interface that consider fatigue failures promoted by the synergistic degradation of cyclic loading with biofilm attack and cyclic loading after activation of endogenous dentin proteases. However, it should be highlighted that the thermocycling and fatigue testing do not represent the weakening effect on dentin bonding that progressively increases over the years in clinical function.

It is difficult to extrapolate the results of this study directly to a clinical situation. One of the limitations

is that this investigation used freshly extracted, intact teeth, and in a common clinical situation, an endodontically treated tooth would have been previously restored before completing endodontic therapy. Tooth walls might have irregular outlines and thicknesses, and the intact dentin would be thinner than that designed in the present study. It must be considered that the decision to include in the study only caries-free maxillary premolars was necessary in order to standardize the preparation procedures, according to the methodology of other studies.^{9,22,29}

Although a compressive load test is important when investigating the behavior of the restorations under certain circumstances, other tests, such as finite element analysis, tension tests, and long-term clinical trials, are necessary to evaluate the performance of restorations.

CONCLUSIONS

ETPs restored with conventional composite resin with or without horizontal fiber post, bulk-fill composite, and ceramic inlay showed fracture resistance similar to that of sound teeth. Conventional composite resin restorations exhibited the highest prevalence of unrepairable fractures, and when a horizontal fiber post was inserted in these restorations, there was a dominance of repairable fractures. Intact teeth showed 100% repairable fractures. It is difficult to extrapolate the results directly to a clinical situation due to the limitations of this study.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of University of Pernambuco Ethics Committee. The approval code for this study is: 50910015.5.0000.5207.

Conflict of Interest

The authors of this article 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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The Role of Occlusal Factors in the Presence of Noncarious Cervical Lesions in Young People: A Case-Control Study

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Clinical Relevance

Some occlusal factors such as protrusive and non-working-side lateral interferences, as well as bruxism, are risk factors for the presence and development of noncarious cervical lesions.

SUMMARY

Objective: The aim of this retrospective case-control study was to evaluate the influence of

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different occlusal characteristics and self-reported bruxism in the presence of noncarious cervical lesions (NCCLs).

Methods and Materials: The participants were 280 students (140 cases and 140 controls), with an average age of 24.5 years, from six schools of dentistry in Spain. Clinical examination was carried out to record the NCCLs and the static and dynamic occlusal characteristics. The side of mastication and bruxism was collected by questionnaire. Data variables were analyzed by means of univariate and multivariate logistic regression. Odds ratios and the respective 95% confidence intervals were calculated ($p < 0.05$).

Results: The presence of NCCLs was significantly more likely in subjects with protrusive interferences (odds ratio [OR]=1.82); with lateral interferences, especially on the nonworking side (OR= 1.77); or who were self-reported bruxists (OR=1.72). In the multivariate analysis, protrusive interferences, bruxism, age, and the presence of attrition were risk factors for the development of NCCLs. These factors re-

sulted in a model with an area under the receiver-operating characteristic curve of 0.667 and a positive predictive value of 61.43%.

Conclusions: There was no significant relationship between most occlusal factors and the presence of NCCLs. Only bruxism, protrusive interferences, age, and occlusal wear were risk factors. The predictive model was not sufficiently explanatory. Occlusal factors alone do not appear to be sufficient to explain the presence of NCCLs.

INTRODUCTION

The etiology or risk factors that may influence the initiation and progression of noncarious cervical lesions (NCCLs) is a topic under discussion. Numerous studies with different designs support the multifactorial etiology of these lesions, whether they are cross-sectional studies,¹⁻⁴ clinical trials,⁵⁻⁷ systematic reviews,⁸⁻¹¹ or simply informative texts.¹²⁻¹⁴ Thus, several factors alone or in combination and with different mechanisms of action can contribute to the onset and progression of tooth structure loss at the cemento-enamel junction (CEJ). Wear in the cervical region of a tooth is most commonly related to factors that can cause dental erosion or biocorrosion (chemical degradation of the enamel due to the presence of exogenous or endogenous acids), abrasion (mechanical wear related to brushing factors), and abfraction (disruption of the enamel hydroxyapatite crystals due to increased stress of occlusal origin).^{5,9,10-12,14-16} However, the scientific evidence reported in a recent systematic review⁸ shows that the multifactorial etiology is insufficient and not at a very high level. Furthermore, in the dental literature, most of the studies were cross-sectional; no randomized clinical trials or cohort studies, and only two case-controls studies^{7,17} were found. Therefore, the relationship between risk factors and the onset and progression of NCCLs is controversial and not sufficiently clarified. NCCLs can be a major public dental health problem, with the prevalence in samples representative of the population in a range between 31.6% and 81.3% in the oldest age group.^{1-3,18} When the sample is not representative and the subjects are dental students, military people, or patients of dental clinics or schools and of smaller sample size, high prevalences in the range of 39% to 67.8% are also reported.^{15,16,19-21} However, the prevalence of teeth with occlusal disturbances or attrition in the presence of NCCLs is not frequently reported. In a sample of 2707 subjects and 54,204 teeth, only 19.5%-23.9% of teeth with NCCL showed

contacts in protrusion or laterotrusion, and 23.6% of teeth with NCCLs had neither occlusal nor incisal facets.³

Possible risk factors of an occlusal nature or related to parafunctional activities are generally assumed by practitioners, but they are also under discussion. During the parafunctional activity of clenching or grinding teeth, increased tooth contact occurs as a result of a greater, more prolonged contraction force of the masticatory muscles compared with during chewing or swallowing. This increase in the occlusal load is transformed to compression, tensile, or shear stress, which, when located in the cervical area of a tooth, can deform it and cause disruption of the joints of the enamel hydroxyapatite crystals, thus initiating an NCCL. A thin layer of enamel in this area, lower mineral content, larger pores, and higher protein content found in the cervical enamel compared with the occlusal enamel favor demineralization in the cementum-enamel union. In addition, *in vivo* and *in vitro* biomechanical studies support the existence of stress concentration in the CEJ (in the cervical region of the tooth).²²⁻²⁸ Different clinical studies report the importance and association of bruxism with NCCLs,^{2,7,20,29,30} while others find no greater percentage or risk of NCCLs in subjects with self-reported bruxism compared with nonbruxers.^{1,16,31}

As with parafunctional activity, occlusal disorders, especially premature contacts and occlusal interferences in excursive movements, and the type of guidance may increase the occlusal load and with it stress in the cervical region of the teeth. The progression of NCCLs has been linked to increased occlusal forces,^{16,32} with a greater area of occlusal contact,¹⁶ and with some occlusal disorders or characteristics.^{15,17,19,33,34} By contrast, other clinical, review, and *in vitro* studies reject or question the role of occlusal factors in the development of NCCLs.^{8,9,30,33,35-37}

Consequently, although numerous studies have been carried out over a period of many years to clarify the role played by occlusion and bruxism in the onset and development of NCCLs, this role remains unknown. There is neither sufficient nor strong enough evidence to support an association between NCCLs and occlusal disorders or bruxism.^{8,9,11,22,33} Most of the available studies are cross-sectional with nonrepresentative samples, inadequate sample sizes, significant variability in ages and method of recording, and also heterogeneity of the independent variables (occlusal disturbances) and lack of control confounders. Studies with a

Table 1: Univariate Logistic Regression: Distribution of the Sample According to Age, Sex, and Static Occlusal Factors

Variable, Occlusion	Cases, n (%)			Controls, n (%)			OR (95% CI)	p Value
	Males	Females	Total	Males	Females	Total		
n (%)	53 (18.9)	87 (31.1)	140 (50.0)	53 (18.9)	87 (31.1)	140 (50.0)	1 (0.62-1.62)	0.980
Age, y								0.432
18-20	7 (13.21)	16 (18.39)	23 (16.43)	11 (20.75)	9 (10.34)	20 (14.29)	Reference category	
21-23	27 (50.94)	49 (56.32)	76 (54.29)	31 (58.49)	56 (64.37)	87 (62.14)	0.76 (0.39-1.49)	0.424
24-26	9 (16.98)	16 (18.39)	25 (17.86)	8 (15.09)	19 (21.84)	27 (19.29)	0.80 (0.36-1.81)	0.600
27-29	10 (18.87)	6 (6.90)	16 (11.43)	3 (5.66)	3 (3.45)	6 (4.29)	2.32 (0.76-7.05)	0.139
Chewing side								0.616
Right	14 (26.42)	27 (31.03)	41 (29.29)	17 (32.08)	32 (36.78)	49 (35.00)	Reference category	
Left	8 (15.09)	13 (14.94)	21 (15.00)	8 (15.09)	13 (14.94)	21 (15.00)	1.19 (0.57-2.49)	0.634
Both	26 (49.06)	33 (37.93)	59 (42.14)	21 (39.62)	31 (35.63)	52 (37.14)	1.35 (0.77-2.37)	0.285
DK/NA	5 (9.3)	14 (16.09)	19 (13.57)	7 (13.21)	11 (12.64)	18 (12.86)	1.26 (0.58-2.71)	0.553
Angle's malocclusion classification								0.531
Class I	33 (62.26)	56 (64.37)	89 (63.57)	35 (66.04)	65 (74.71)	100 (71.43)	Reference category	
Class II	15 (28.30)	22 (25.29)	37 (26.43)	14 (26.42)	13 (14.94)	27 (19.29)	1.54 (0.87-2.72)	0.139
Class III	5 (9.43)	9 (10.34)	14 (10.00)	4 (7.55)	9 (10.34)	13 (9.29)	1.21 (0.54-2.71)	0.643
Overbite								0.790
No	36 (67.92)	64 (73.56)	100 (71.43)	39 (73.58)	63 (72.41)	102 (72.86)	Reference category	
Yes	17 (32.08)	23 (26.44)	40 (28.57)	14 (26.42)	24 (27.59)	38 (27.14)	1.07 (0.64-1.81)	
Overjet								0.223
No	31 (58.49)	48 (55.17)	79 (56.43)	33 (62.26)	56 (64.37)	89 (63.57)	Reference category	
Yes	22 (41.51)	39 (44.83)	61 (43.57)	20 (37.74)	31 (35.63)	51 (36.43)	1.35 (0.83-2.18)	
Crossbite								0.728
No	47 (88.68)	78 (89.66)	125 (89.29)	50 (94.34)	73 (83.91)	123 (87.86)	Reference category	
Anterior	3 (5.66)	3 (3.45)	6 (4.29)	1 (1.89)	5 (5.75)	6 (4.29)	0.98 (0.31-3.13)	0.978
Posterior	3 (5.66)	6 (6.90)	9 (6.43)	2 (3.77)	9 (10.34)	11 (7.86)	0.80 (0.32-2.01)	0.643
Protrusive guidance								0.557
No	3 (5.66)	4 (4.60)	7 (5.00)	4 (7.55)	1 (1.15)	5 (3.57)	Reference category	
Yes	50 (94.34)	83 (95.40)	133 (95.00)	49 (92.45)	86 (98.85)	135 (96.43)	0.70 (0.21-2.27)	

Abbreviations: CI, confidence interval; DK, doesn't know; NA, no answer; OR, odds ratio.

higher level of evidence (case-control) are also inconclusive, reporting as a risk factor only the right canine guidance⁷ or significant differences with premature contacts and working-side contacts but not in balancing and protrusion.¹⁷ The progression of NCCLs did not improve as a result of occlusal adjustment of the group function during lateral excursive movements performed in a clinical trial,³³ nor did the presence of premature contacts in centric relation in a control group design influence the development of NCCLs.³⁵ All of this makes it difficult to identify a causal relationship between NCCLs and occlusal factors.

In keeping with this, the null hypothesis established was that self-reported bruxism and occlusal alterations (occlusal factors) are not risk factors for the development of NCCLs. In addition, the aim of

this study was to identify, through a case-control design with univariate and multivariate logistic regression analysis, whether bruxism and different static and dynamic occlusal factors are significantly associated with NCCLs, to show the intensity of such an association, and to formulate a predictive model.

METHODS AND MATERIALS

Participants in the study were 280 (140 cases and 140 controls) undergraduate dental students from six randomly selected schools of dentistry in Spain. The students of each faculty were invited to participate in the study; those who responded positively were selected to form the sample. Table 1 shows the distribution according to age and sex. The dental literature reveals great variability in the prevalence of NCCLs owing to their complexity and

multifactorial etiology. The variability in the selection of the sample and sample size, the nonhomogenization of the participants' ages, greater exposure to certain risk factors, as well as geographical, cultural, and socioeconomic factors are some of the factors that contribute to the indeterminacy of the prevalence. Therefore, the prevalence of NCCL cases is not known. With this assumption, the authors opted for a prevalence of 50% between cases and a moderate odds ratio ($OR=2$) to estimate the prevalence between controls. Thus, the maximum sample size was obtained for the quoted percentage. Without the Yates correction, a sample size of 274 subjects was obtained for a confidence level of 95% and a power ($1 - \beta$) of 80%. Cases and controls were selected in an initial clinical examination (approximately 50 per school of dentistry). Subjects in whom the explorer detected cervical wear of any shape corresponding to a score of 2 (defect less than 1-mm deep) or more on the Tooth Wear Index classification of Smith and Knight were considered as cases.³⁸ Detection was visual or by means of a periodontal probe. The tip of the probe was positioned perpendicular to the surface of the tooth, and from the bottom of the gingival sulcus, it was moved along the CEJ to approximately half of the coronal height. If a gap was noticed, it was considered an NCCL. For each case, a control of the same sex and similar age was selected. In addition, exclusion criteria included absence of any tooth except the wisdom teeth, orthodontic treatment at the date of clinical examination, presence of prosthetic restorations or caries in the cervical region of the teeth. Before the selection of participants, an Institutional Review Board approved the study data collection protocol. All participants also signed informed consent.

After the cases and controls were selected, each participant responded to an ad hoc questionnaire, and their responses were recorded. The questionnaire was similar to the one used in the different studies that have evaluated risk factors of NCCLs and included questions about whether the participant clenched or ground their teeth and their preferred chewing side, in addition to issues related to other possible risk factors (exogenous or endogenous acids and brushing habits). The occlusal clinical examination was then performed. This included the exploration of static occlusal parameters (Angle's malocclusion, overjet, overbite, and crossbite), dynamic parameters (interferences in excursive movements and occlusal guides for protrusion and lateral mandibular movements), and

attrition evaluated by visual examination of the occlusal surface of the teeth. The occlusal guides and contacts were recorded with 40- μ m articulating paper (Bausch Arti-Check, Bausch Articulating Papers Inc, Nashua, NH, USA).

Based on the questionnaire and the clinical examination, 16 independent occlusal variables were collected (see Tables 1 and 2). All participants were examined in a dental chair using the equipment light, dental mirrors, and periodontal probe calibrated in millimeters. At each school of dentistry, a single trained dentist (associate professor), assisted by a dental hygienist, carried out the clinical examinations to select cases and controls. The examiners were calibrated as follows: all examiners were informed in a previous ad hoc protocol of the strategy of data collection. Subsequently, 14 subjects randomly selected from the cases and controls of the School of Dentistry of Madrid were examined by the gold standard (occlusion expert). On different days, the same subjects were evaluated by the examiner of each school of dentistry, and the results for excursive movement interferences and NCCL or non-NCCL items were compared with the gold standard using Cohen's kappa coefficient. The average results of the interobserver variability with respect to the gold standard were 0.82 for the NCCLs and 0.81 for interferences in excursive movements. A repeat examination with the same subjects to measure intraexaminer variability was performed at three weeks by each examiner. The results were compared with the previous examination, giving average results of 0.89 and 0.85, respectively.

In the data analysis, only the independent or predictor variables related to occlusal factors, bruxism, and attrition (occlusal wear) were used. All study variables were analyzed in both the univariate and multivariate logistic regression analysis. The OR and 95% confidence interval (CI) were calculated. The level of statistical significance was set at 0.05. Statistical analysis was carried out using the software Stata v.13 (StataCorp LLC, College Station, TX, USA).

RESULTS

Tables 1 and 2 show the distribution of cases and controls according to age and sex, the distribution of the different occlusal factors, and the results of the univariate logistic regression analysis. Of all variables related to occlusion, only participants with protrusive interferences, with nonworking side interferences both in right and left lateral movements, or with interferences on the nonworking side,

Table 2: Univariate Logistic Regression: Distribution of the Sample According to Dynamic Occlusal Factors and Bruxism

Variable, Occlusion	Cases, n (%)			Controls, n (%)			OR (95% CI)	p Value
	Males	Females	Total	Males	Females	Total		
Right canine guidance								0.631
No	1 (1.89)	8 (9.20)	9 (6.43)	5 (9.43)	6 (6.90)	11 (7.86)	Reference category	
Yes	14 (26.42)	24 (27.59)	38 (27.14)	13 (24.53)	24 (27.59)	37 (26.43)	1.25 (0.46-3.37)	0.653
Group function	38 (71.60)	55 (63.22)	93 (66.43)	35 (66.04)	57 (65.54)	92 (65.71)	1.23 (0.49-3.12)	0.655
Left canine guidance								0.371
No	3 (5.66)	8 (9.20)	11 (7.86)	4 (7.45)	3 (3.55)	7 (5.00)	Reference category	
Yes	11 (20.75)	25 (28.74)	36 (25.71)	17 (32.98)	37 (42.53)	54 (38.57)	1.25 (0.46-3.37)	0.109
Group function	39 (73.58)	54 (62.07)	93 (66.43)	32 (60.38)	47 (54.02)	79 (56.43)	1.23 (0.49-3.12)	0.560
Protrusive interferences								0.018
No	30 (56.60)	53 (58.62)	83 (57.86)	38 (71.70)	62 (71.26)	100 (71.43)	Reference category	
Yes	23 (43.40)	36 (41.38)	59 (42.14)	15 (28.30)	25 (28.74)	40 (28.57)	1.82 (1.11-2.99)	
Right laterality interferences								0.178
No	27 (50.94)	43 (49.43)	70 (50.00)	34 (64.15)	55 (63.22)	89 (63.57)	Reference category	
Working side	8 (15.09)	11 (12.64)	19 (13.57)	9 (16.98)	11 (12.64)	20 (14.29)	1.21 (0.59-2.43)	0.598
Nonworking side	12 (22.64)	22 (25.29)	34 (24.29)	7 (13.21)	15 (17.24)	22 (15.71)	1.96 (1.06-3.65)	0.033
Both	6 (11.32)	11 (12.64)	17 (12.14)	3 (5.66)	6 (6.90)	9 (6.43)	2.40 (1.01-5.71)	0.048
Left laterality interferences								0.181
No	25 (47.17)	45 (51.72)	70 (50.00)	38 (71.70)	50 (57.47)	88 (62.86)	Reference category	
Working side	6 (11.32)	10 (11.49)	16 (11.43)	6 (11.32)	11 (12.64)	17 (12.14)	1.18 (0.56-2.51)	0.661
Nonworking side	14 (26.42)	24 (27.59)	38 (27.14)	7 (13.21)	19 (21.84)	26 (18.57)	1.82 (1.02-3.31)	0.043
Both	8 (15.09)	8 (9.20)	16 (11.43)	2 (3.77)	7 (8.05)	9 (6.43)	2.23 (0.93-5.36)	0.072
Laterality interferences in Non-working side								0.020
No	28 (52.83)	47 (54.02)	75 (53.57)	40 (75.47)	54 (62.07)	94 (67.14)	Reference category	
Yes	25 (47.17)	40 (45.98)	65 (46.43)	13 (24.53)	33 (37.93)	46 (32.86)	1.77 (1.09-2.87)	
Laterality interferences in Working side								0.301
No	35 (66.04)	58 (66.67)	93 (66.43)	38 (71.70)	63 (72.41)	101 (72.14)	Reference category	
Yes	18 (33.96)	29 (33.33)	47 (33.57)	15 (28.30)	22 (25.90)	39 (27.86)	1.31 (0.78-2.18)	
Bruxism								0.0193
No	20 (14.28)	24 (17.14)	44 (31.43)	23 (16.43)	38 (27.15)	61 (43.57)	Reference category	
Diurnal	11 (7.86)	15 (10.74)	26 (18.57)	8 (5.71)	12 (8.57)	20 (14.28)	1.80 (0.89-3.62)	
Nocturnal	13 (9.29)	19 (13.57)	32 (22.85)	15 (10.71)	24 (17.14)	39 (27.86)	1.14 (0.62-2.08)	
Both	9 (6.43)	29 (20.71)	38 (27.14)	7 (5.00)	13 (9.28)	20 (14.28)	2.63 (1.35-5.12)	0.004
Attrition								0.070
No	37 (69.81)	52 (59.77)	89 (63.57)	38 (71.70)	65 (74.71)	103 (73.57)	Reference category	
Yes	16 (30.19)	35 (40.23)	51 (36.43)	15 (28.30)	22 (25.29)	37 (26.43)	1.59 (0.65-1.14)	

Abbreviations: CI, confidence interval; DK, doesn't know; NA, no answer; OR, odds ratio.

regardless of the lateral movement direction, showed significantly more chance of suffering NCCLs, with an OR value in the range of 1.77 to 1.96, depending on the variable considered (see Table 1). Likewise, subjects who reported being bruxers had significantly more NCCLs than nonbruxers with OR=2.63 (CI=1.35-5.12; $p=0.0193$). It may be that some of the occlusal factors were not significant simply because the reference category was too small. A larger sample size with a greater population in the

categories could reach statistical significance. Table 3 shows the distribution of cases and controls according to dietary type, brushing habits, and the presence of gastroesophageal diseases.

Data from the multivariate logistic regression analysis showed that risk factors in the presence of NCCLs were protrusive interferences (OR=1.93; CI=1.12-3.22; $p=0.017$), bruxism (OR=1.72; CI=1.01-2.96; $p=0.048$) and, to a lesser extent, age (OR=1.16; CI=1.04-1.29; $p=0.008$) and occlusal wear

Table 3: *Univariate Logistic Regression: Distribution of Cases and Controls According Dietary Type, Brushing Habits, and the Presence of Gastroesophageal Diseases*

Variable, Dietary, Brushing, and GERD	Cases, n (%)			Controls, n (%)			OR (95% CI)	p Value
	Males	Females	Total	Males	Females	Total		
Frequency of brushing								0.475
Maximum twice daily	14 (10.00)	19 (13.57)	33 (23.57)	9 (6.43)	14 (10.00)	23 (16.43)	Reference category	
More than twice daily	39 (27.86)	68 (12.86)	107 (76.43)	44 (31.43)	73 (52.14)	117 (83.57)	0.64 (0.35-1.20)	
Brush bristles hardness								0.280
Smooth/medium	41 (29.29)	74 (52.86)	115 (82.14)	44 (31.43)	81 (57.86)	125 (88.57)	Reference category	
Hard	11 (7.86)	11 (7.86)	22 (15.72)	9 (6.43)	6 (4.29)	15 (10.43)	1.59 (0.79-3.22)	0.194
DK/NA	1 (0.71)	2 (1.43)	3 (2.14)	0 (0.00)	0 (0.00)	0 (0.00)	—	—
Brushing technique								0.714
Vertical/variable	46 (32.86)	76 (54.26)	122 (87.14)	47 (31.57)	77 (57.00)	124 (88.57)	Reference category	
Horizontal	7 (5.00)	11 (7.86)	18 (12.86)	6 (4.28)	10 (7.14)	16 (11.43)	1.14 (0.55-2.34)	
Consumption of soft drinks/day								0.638
Any	25 (17.86)	36 (25.71)	61 (43.57)	22 (15.71)	43 (30.71)	65 (46.43)	Reference category	
Once	21 (15.00)	34 (24.28)	55 (39.28)	21 (15.00)	34 (24.28)	55 (39.29)	1.06 (0.64-1.77)	0.808
Twice or more	7 (5.00)	17 (12.14)	24 (17.14)	10 (7.14)	10 (7.14)	20 (14.28)	1.28 (0.64-2.54)	0.484
Consumption of acidic or citrus fruits/day								0.376
Any	26 (18.57)	30 (21.43)	56 (40.00)	21 (15.00)	45 (32.14)	66 (47.14)	Reference category	0.
Maximum twice daily	23 (16.43)	43 (30.71)	66 (47.14)	29 (20.71)	34 (24.28)	63 (45.00)	1.23 (0.75-2.03)	0.401
More than twice daily	4 (2.86)	14 (10.00)	18 (12.86)	3 (2.14)	8 (5.71)	11 (7.86)	1.93 (0.84-4.42)	0.121
Vomiting or gastroesophageal reflux/day								0.802
No	52 (37.14)	80 (57.14)	132 (94.29)	49 (35.00)	82 (58.57)	131 (93.57)	Reference category	
Yes	1 (0.71)	7 (5.00)	8 (5.71)	4 (2.86)	5 (3.57)	9 (6.43)	0.88 (0.33-2.35)	

Abbreviations: CI, confidence interval; DK, doesn't know; GERD, gastroesophageal reflux disease; NA, no answer; OR, odds ratio.

(OR=1.07; CI=1.01-1.13; $p=0.014$; Table 4). In addition, the model obtained has an area under the receiver-operating characteristic (ROC) curve of 0.667, sensitivity of 60.71%, specificity of 67.14%, and correctly classifies 61.43% of the cases. These values place the model in an intermediate position between the ideal model with the curve near the top left-hand corner with 100% sensitivity and specificity and the worst model represented by the diagonal drawn from the bottom left-hand corner to the top right-hand corner (Figure 1). The behavior of the tendencies of sensitivity and specificity according to the chosen cutoff point is shown in (Figure 2).

DISCUSSION

This case-control study was carried out to support or refute the relationship of some occlusal factors with the presence of NCCLs in a population of young people (dental students). The homogeneity of subject origin, the average age of the sample (22.55 years, with the largest number of participants in the range of 21-23 years), and the fact that a matching strategy for cases and controls has not been used can be

limitations. In any case, the selected sample of dentistry students may not be representative of the general population, so the translation of the results to the general population for their age range or for another range must be done with reservation. However, the use of nonrepresentative samples such as dental students, members of the military, or patients of dental clinics is frequent in studies of this type.^{15,16,19-21} Moreover, most cross-sectional, case-control, and *in situ* studies consider age to represent a risk factor, be an important factor, or have a significant association with the presence and pro-

Table 4: *Variables of the Multivariate Logistic Regression Model*

Model Variable	OR	Standard Error	95% CI-OR	p Value
Protrusive interferences	1.93	0.51	1.12-3.22	0.017
Self-reported bruxism	1.72	0.47	1.01-2.96	0.048
Age	1.16	0.06	1.04-1.29	0.008
Subject with attrition	1.07	0.03	1.01-1.13	0.014

Abbreviations: CI, confidence interval; OR, odds ratio.

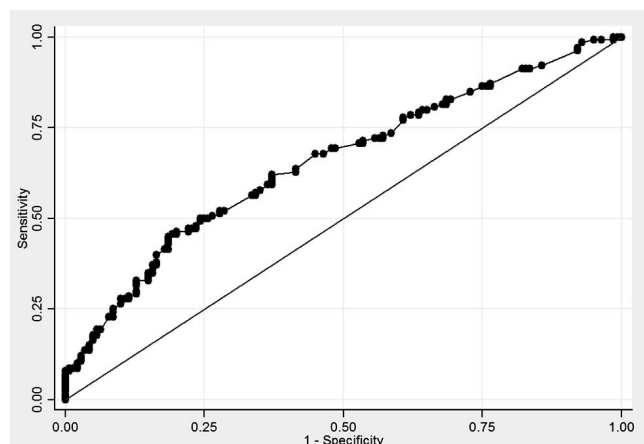


Figure 1. ROC curve of the logistic regression model. Area under ROC curve = 0.67; Corrected classified: 61.43%; Sensitivity: 60.71% Specificity: 67.41%.

gression of NCCLs, with greater prevalence as age increases.^{1-4,15,16,18,19,39,40} Thus, despite the variability of the different studies in relation to the selection and sample size, age groups, and other biases, the importance of age is based not only on data from recent studies,^{4,16,19} which report high percentages of NCCLs in young adults from 20 to 45 years old, from 4% to 58.7%, and from 31.6% to 81.3% in the oldest age group of other studies,^{1-3,15,18} but also on the recording of higher ORs in the older groups vs the younger ones^{1,2} (8.1 in the group of patients 50-59 years of age and 2.3 in the group of patients 30-39 years vs those 20-29 years¹; 2.45 in the group of patients 65-74 years old vs OR of 1 in the group aged 35-44 years²) or with a value of 1.1 in a multivariate analysis¹⁶ very similar to the 1.16 of the predictive model of the present study. All of this is due to a longer time of exposure to possible risk factors, intrinsic and extrinsic, and also to changes in the cervical region of the teeth with a greater probability of gingival recession and greater exposure of the CEJ and cementum.

Although some studies do not find any such relationship of age with NCCLs,^{35,41} nor with the depth of the lesions,⁵ the data of the predictive model of the present study, even with the small age range of participants (18-29 years), support the influence of age on the presence of NCCLs and the idea that the onset can occur at very young ages. In addition, the results support the importance of some occlusal factors and bruxism for the onset of NCCLs despite the short period of time that may have elapsed in this sample from the presence of these factors and the registration of the NCCLs. Likewise, data reveal that bruxism and all those occlusal factors that have

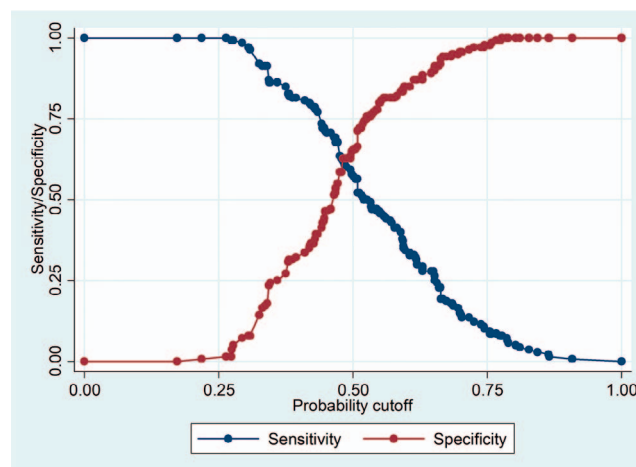


Figure 2. Behavior of the sensitivity and specificity according to the chosen cutoff point.

been shown to be risk factors (protrusive interferences and attrition), or simply to have a significant association in the univariate analysis, can transmit early stress to the CEJ, thereby initiating an NCCL, without the need for the concurrence of other factors or situations that increase the frequency and severity of the lesions at an older age. These factors and situations include changes in the composition and microstructure of enamel and dentin, more frequent crazing and vertical microfractures in older enamel, greater gingival recession and bone loss with greater root surface and cementum exposed, longstanding exposure to factors generating cervical stress, and longer time of action of other factors not related to occlusion.

The data of this case-control study show that self-reported bruxism is a risk factor for the development of NCCLs. These lesions are significantly more frequent (2.63 times) in subjects who clench and grind their teeth than in those who do not normally do so. The possible contribution of parafunctional activity has been reported in previous studies of different design with contradictory results, supporting^{2,7,18,20,29,30,32,42} or not^{1,16,31} its influence. Bruxism was a variable in Bader's old case-control study model⁷; in a study of young adults (average age of 28.37 years) diagnosed as sleep bruxers, NCCLs were significantly more frequent than in the control group³⁰ and significantly more numerous in the laterotrusive grinding pattern involving incisors, canines, premolars, and molars of 51 sleep bruxers.⁴² Comparing 102 self-reported adult bruxers and nonbruxers, a significant association was found between bruxism and attrition, abfraction, and occlusal pits,¹² while in a prospective 5-year study,

the progression of NCCLs was not significantly associated with self-reported bruxism.³² Some prevalence studies with logistic regression analysis indicate bruxism as a risk factor (OR=1.37).² Other studies report in older patients (65- to 74-year-olds) a significantly higher average of teeth with NCCLs in bruxers compared with nonbruxers,¹⁸ and in younger patients (age range 19-58 years), NCCLs were significantly associated with tooth clenching.²⁰ However, other studies did not find an association with bruxism in a sample of 1023 subjects aged 20 to 69 years,¹ in 159 self-defense force officials with an average age of 36.2 years,¹⁶ or in bruxism diagnosed by flat occlusal morphology.³¹

On the other hand, it is common for dentists to identify bruxism by the presence of occlusal wear facets. Although these may indicate a history of grinding, it should be recognized that not all occlusal wear is caused by bruxism, since there are other factors with similar or different action mechanisms that lead to tooth tissue loss. The occlusal wear facets may be the result of the elimination of occlusal disturbances or the result of other attrition factors. In this respect, the literature is also inconclusive when associating occlusal wear and NCCLs, with previous studies that support it^{3,16,19,31,40,41} and others that do not.^{5,6,32,36} Regardless of the design of the study, not having registered the variables using a single- or double-blind method may have influenced these results. A single nonblinded examiner, in the face of an NCCL, may be more careful in the occlusion examination than when there is no lesion, thus trying to confirm his or her suspicion. Only one study of those cited checked this bias.³⁶ Nevertheless, the present study data do not lend a great deal of support to occlusal wear (attrition) as a risk factor for the presence of NCCLs (at the significance limit in univariate regression and OR=1.07 in the multivariate logistic regression model).

In grinding and clenching situations (bruxism), occlusal contacts may be traumatic because they induce greater occlusal load, are of longer duration, and have a greater horizontal component. It has been reported that bruxers are able to apply occlusal loads that are five to seven times greater than normal subjects and with a longer tooth contact time (30 minutes) during a 24-hour period than nonbruxers (10 minutes). Moreover, during grinding, an eccentric occlusal load occurs between sloped cusps that causes greater cuspal deflection, especially at the end of the movement, compared with a centric occlusion load. The cuspal deflection was reported to

be 200-400 μm in lateral movement and 20 μm in centric occlusion.⁴³ All of this can contribute to an increase in tensile, compression, and shear stresses in the cervical region of the teeth, favoring the development of NCCLs.

On the other hand, it remains to be clinically demonstrated whether the occlusal characteristics that can transmit stress to the CEJ play an important role as risk factors for the presence and development of NCCLs.^{8,9} The results of this study support this statement. Of all the variables related to occlusion, only interference in the protrusive and lateral excursive movements (in particular on the nonworking side) are risk factors for the presence of NCCLs in the univariate logistic regression analysis and only protrusive interferences in combination with bruxism, age, and attrition in the multivariate logistic regression model. The increased risk of the presence of NCCLs in patients with protrusive interferences is not shared by the results of previous studies,^{3,17,36} nor is the increased risk of NCCLs due to interferences on the nonworking side during lateral movements in agreement with a tooth-paired case-control study that reported a significant association with premature contacts or protrusive and working-side contacts.¹⁷ Nor does it agree with the protective effect attributed to the presence of a nonworking-side contact⁷ or with the low percentage (20%) of teeth with NCCLs and nonworking-side interferences reported by Miller.³¹ The greater distance from a contact on the nonworking side to the pivoting condyle, with a greater lever effect and greater moment of rotation, can generate and transmit more stress to the tooth, thus favoring the presence of NCCLs compared with a contact on the working side. Even so, some studies report a significant association with contacts on the working side.¹⁷ However, unlike studies that support the risk of a particular occlusal guidance scheme (canine or group function) in the etiology of NCCLs,^{3,7,19,31,34,41,44} this study does not share this idea, being in greater agreement with those that do not report a significant association.^{15,30,32,33,36,45}

In this study, the best predictive model indicated that occlusal disorders such as protrusive interferences and attrition (occlusal wear) in combination with self-referred bruxism and age are the risk factors for the presence of NCCLs. However, this model has an area under the ROC curve of 0.667, a positive predictive value of 62.50%, and a classification power of 61.43%. It is a poor determinant model that shows that occlusal factors alone are not sufficient to explain the presence of NCCLs in the

age range of the study. Other factors must be incorporated into the model to increase its predictive capacity. Therefore, the results support the multifactorial etiology of NCCLs. The term *biotribocorrosion* has been suggested in an attempt to combine all possible mechanisms of action that may play a part in the development of NCCLs, either through wear and/or chemical, electrochemical, or piezoelectric degradation. The cervical stress concentration of occlusal origin may act synergistically with other factors having an abrasive or local pH-lowering action to induce NCCLs.

The combination of mechanical stress and low pH has been shown to accelerate the loss of dentin⁴⁶ and increase subsurface demineralization with static loading⁴⁷; in addition, the combination of erosion and abrasion due to brushing increases tooth wear.⁴⁸⁻⁵⁰ In one of the few available case-control studies, Bader and others⁷ found a model that, in addition to diet (fruit juices), low salivary buffering capacity, and brushing factors (brushing hard, more than three times a day) as risk factors, also included occlusal alterations (right canine guidance) and bruxism. In another study, whose unit of analysis was the teeth, and in which a univariate analysis was performed, the premature contacts and contacts on the working side represented the significant differences.¹⁷

In keeping with the aforementioned long-term clinical trials, including several age groups and controlling confounders and effect modifiers are necessary to establish a causal relationship between occlusal risk factors and the onset and progression of NCCLs. It is also necessary for dentists to understand the importance of the etiology and risk factors of NCCLs, but not on the basis of their experience or on theories unsupported by high-level clinical evidence. Given the limited scientific evidence of occlusion in the development of NCCLs, irreversible treatments such as occlusal adjustment should be avoided.²² In addition, patients should be informed of the clinical consequences, prevention methods, and the need to control the risk factors for these lesions, as well as the combined effect of several of these factors, which may favor a greater presence and progression of NCCLs compared with a single risk factor.

In addition to the possible limitation of age, the present study is not free of other limitations. In a case-control design, the cause (exposure) and effect data are post hoc, with the exposure data being recorded at the same time as the effect, often indirectly. Therefore, the relationship between the independent variables may not reflect conditions at

the time of the onset of the NCCLs, which is a limitation. A score of 2 or higher of the Tooth Wear Index of Smith and Knight³⁸ was used in this study. This index is frequently used to evaluate cervical wear in NCCLs.^{2,4,5,16,18} For the cervical region of a tooth, a score of 2 (defect less than 1-mm deep) represents well-established wear compared with a score of 0 (no change of contour) or a score of 1 (minimal loss of contour), in which there is no wear or, at most, loss of enamel surface characteristics and is therefore difficult to detect visually or by the periodontal probe. This study aimed to register only well-established lesions with a minimum score of 2. This can be a limitation since examiners may have tried to register possible initial level 1 injuries in young people. The self-reported questionnaires are not the ideal method for recording bruxism because of possible imprecision in the patients' responses, but they are used in all studies related to NCCLs. Premature contacts that are often clinically and didactically important have not been recorded in this study, and this may be a limitation since a significant association has been noted in some studies^{15,17} but not in others.^{30,35}

CONCLUSIONS

According to the results obtained and taking into account the limitations of studies of this type, the following conclusions can be deduced:

1. There is no significant relationship between most occlusal disturbances and the presence of NCCLs. Only protrusive and lateral interferences, especially on the nonworking side, are statistically significant.
2. The predictive model includes protrusive interferences, bruxism, age, and attrition as risk factors but with only 61.43% correct classification. Therefore, the occlusal factors alone do not appear to be sufficient to explain the presence of NCCLs.
3. The young age, narrow age range, and good health of the subjects; the short period of time of actuation of the risk factors; and the possible nonrepresentability of the sample of the general population are limitations that make the transfer of the results to the general population more difficult.
4. The influence of occlusal factors corresponds to the beginning of the NCCL process since time is one of the primary factors in the progression of NCCLs, and only a short period has passed in the sample under study.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the School of Dentistry at the University of Oviedo in Spain.

Conflict of Interest

The authors of this article 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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Caries Diagnosis in Dental Practices: Results From Dentists in a Brazilian Community

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Clinical Relevance

Dental caries diagnosis is performed by most dentists from a Brazilian community using visual-tactile and radiographic methods.

SUMMARY

The aim of this study was to assess practices related to diagnosis of dental caries among dentists (n=217) from Araraquara, São Paulo State, Brazil. Data on sociodemographic information and practitioner characteristics were collected using a pretested questionnaire, and data on practices related to caries diagnosis were gathered by using a translated and culturally adapted questionnaire from the US National Dental Practice-Based Re-

search Network. Descriptive statistics and regression analyses were used for data analysis. Respondents reported using in most of their patients radiographs (Rx) to diagnose proximal caries (59%), explorer (Ex) for the diagnosis of occlusal caries (64%) and on the margins of existing restorations (79%), as well as air jet (AJ) with drying (92%). Magnification (M) (25%), fiber optic transillumination (FOTI; 14%), and laser fluorescence (LF) (3%) were used in the minority of patients. Regression analysis revealed that the following dentists' characteristics were significantly associated ($p<0.05$) with the use of diagnostic methods on a greater percentage of their patients: advanced degree (Rx, FOTI), higher percentage of patients with individu-

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alized caries prevention (Rx, FOTI, M), more years since dental school graduation (Ex, M), and work in an exclusively private practice model (LF). In conclusion, most Brazilian dentists from Araraquara reported they most commonly use visual, tactile, and radiographic imaging for the diagnosis of dental caries. Some dentists' characteristics, such as time from dental school graduation and having a postgraduation course, were associated with the use of certain diagnostic methods.

INTRODUCTION

Diagnosis is an outcome of identifying the signs and symptoms of a disease process, based on scientific knowledge of the disease process and its clinical application.¹ The diagnosis is a result of detection and exclusion of diseases, followed by a prognosis and treatment decision.²

Dental caries is a dynamic disease process that results from metabolic activity in dental biofilm³ that demineralizes enamel and dentin over time.⁴ It is a preventable disease, but with a skewed distribution in the population and a substantial economic and quality-of-life onus.⁵

Correct caries diagnosis is one of the cornerstones in designing an appropriate treatment decision with no over-/undertreatment. Identifying the methods dentists use during daily clinical practice for caries diagnosis and the factors associated with their use is, therefore, a relevant issue.⁶ Studies with dentist members of a dental practice-based research network (PBRN) from the United States, Denmark, Norway, and Sweden have shown that dental explorers and radiographs are still the most commonly used diagnostic methods.⁶ In Brazil, little is known about dental practice patterns of Brazilian dentists regarding caries diagnosis, and this is the first paper showing results that used the same questionnaire (after translation and cultural adaptation) used in the countries described above to assess dental practices.

Therefore, the aim of this paper was to assess the practices related to diagnosis of dental caries among dentists from Araraquara, São Paulo State, Brazil.

METHODS AND MATERIALS

Ethical Aspects

All participants provided informed consent prior to participation in this study.

Participants, Recruitment, and Data Collection

The study participants were 217 dentists who met all inclusion criteria: currently practicing in Araraquara; treating dental caries; not retired; and able to provide signed informed consent.

The recruitment process initiated in 2013, enlisting dentists working in Araraquara. As we did not know which dentists met the inclusion criteria, we sent the questionnaires by mail to all dentists (n=801) for whom we had address/contact information. To increase the response rate, the following strategies were used: prepaid return envelope, questionnaires sent to work address; a second copy of the questionnaire to nonrespondents; precontact by telephone; and collection of completed questionnaires at work address.⁷ Among those who were found, only 4% did not want to participate and 14% did not meet all inclusion criteria. In 25% of the professionals, we did not know their reason for not participating. For 9% of dentists, the address could not be verified and 21% could not be located.

Data were collected from 2014 to 2015, and the overall response rate was 27%. Most participants were female (60%) and younger than 50 years of age (71%). Sex comparison between participants (60% female) and nonparticipants (54% female) showed no difference between them ($p=0.156$). Information from the Regional Council of Dentistry of São Paulo State showed that dentists from Araraquara were 57% female and 66% younger than 50 years of age, suggesting that the sex and age of participants had similar distributions to dentists from Araraquara (Rocha E, Statistical Data [Internet], Message to the first author, 20 March 2015 [accessed on 20 March 2015]).

Questionnaires

Two paper questionnaires were sent to the dentists: one with questions on academic, demographic, and socioeconomic profile, practice setting, and patient characteristics and another with the translated version of the "Assessment of Caries Diagnosis and Caries Treatment" Questionnaire from the US National Dental PBRN. The Caries Questionnaire contains questions on caries-related diagnostic and clinical decision-making processes for clinical scenarios, caries risk assessment, and use of prevention techniques.

Translation and cultural adaptation of the questionnaire including initial translation, back-translation, committee review,⁸ and pretesting

Table 1: Participant Characteristics by Sex and for the Total Sample

Characteristic	Males (n=86) [Percentage (n) or Mean (SD)]	Females (n=131) [Percentage (n) or Mean (SD)]	Total Sample (n=217) [Percentage (n) or Mean (SD)]
Age (missing = 1)	46.5 (13.0)	39.3 (10.4)	42.2 (12.0)
Type of practice			
Private practice	48% (41)	49% (64)	48% (105)
Private/public hybrid	29% (25)	24% (32)	26% (57)
Public health	19% (16)	21% (27)	20% (43)
Other	5% (4)	6% (8)	6% (12)
Years since dental school graduation	23.6 (12.5)	17.0 (10.5)	19.6 (11.8)
Type of dental school			
Public institution	76% (65)	77% (101)	76% (166)
Private institution	24% (21)	23% (30)	24% (51)
Specialization			
No specialization training	40% (34)	37% (49)	38% (83)
Specialization training	60% (52)	63% (82)	62% (134)
Advanced degree ^a			
No advanced degree	78% (67)	63% (83)	69% (150)
Master's degree	2% (2)	9% (12)	7% (14)
Doctorate	20% (17)	28% (36)	24% (53)
Mean percent of patient by age, years ^b			
1-18 ^a	18% (21)	27% (28)	23% (26)
19-44	34% (18)	34% (19)	34% (19)
45-64 ^a	33% (16)	27% (18)	30% (17)
65+	15% (12)	12% (11)	13% (11)

^a Significantly different at $p < .05$
^b The percentage for the "patients seen by age" variable represents the average of the percentage of patients reported as seen within each of the age group categories and is followed by the standard deviation.

(comprehension of questions with 21 dentists, and test-retest reliability across seven days with 17 dentists. Intraclass correlation coefficient [ICC]: 22 [42%] questions with satisfactory correlation [$0.40 \leq \text{ICC} \leq 0.75$] and 31 [58%] with excellent correlation [$\text{ICC} \geq 0.75$], according to Szklo and Nieto⁹) were performed to produce a Brazilian version of the questionnaire.¹⁰

Measures

Results on dentists' demographic and clinical training and practices are presented in Table 1. Table 2 shows the series of questions about caries diagnostic methods, such as use of radiographs; dental explorer for the detection of primary occlusal caries and secondary/recurrent caries at the margins of existing restorations; air drying (AD) for primary caries; laser fluorescence (LF) for primary caries on occlusal surfaces; and fiber optic transillumination for proximal lesions in anterior teeth. The response choices were 0%, 1%-24%, 25%-49%, 50%-74%, 75%-99%,

and 100%. The percentages for each caries diagnostic method were coded to the categories' median to maintain the interval nature of the data so that parametric statistics could be used: 0% = 0%, 1%-24% = 12.5%, 25%-49% = 37%, 50%-74% = 62%, 75%-99% = 87%, 100% = 100%.⁶

Statistical Analyses

First, practitioner and practice characteristics were tested as predictors of the use of each diagnostic method using the general linear model. These variables included dentist sex (male=0 and female=1), years since dental school graduation, dental school attended as private or public (public=0 and private=1), specialization training completed (general dentistry=0 and specialization=1), received an advanced degree (no advanced degree=0, masters=1, doctorate=2), treating primarily pediatric patients (adult or mixed ages=0, pediatric=1), exclusively a private practice model (public health or hybrid private/public health

Table 2: Questions to Assess Methods Used to Diagnose Dental Caries
Instructions. These questions have to do with methods that you may use to diagnose dental caries. Please circle the one number that best corresponds to your answer. Patients can vary substantially from one practice to the next, but we are interested in the patients in YOUR practice.
• When you examine patients to determine if they have a caries lesion on a proximal (mesial or distal) surface, on a posterior tooth, on what percent of these patients do you use radiographs to help diagnose the lesion?
• When you examine patients to determine if they have a caries lesion on the occlusal surface, on what percent of these patients do you use radiographs to help diagnose the lesion?
• When you examine patients to determine if they have a primary occlusal caries lesion, on what percent of these patients do you use a dental explorer to help diagnose the lesion?
• When you examine patients to determine if they have a caries lesion at the margin of an existing restoration (recurrent/secondary caries) on what percent of these patients do you use a dental explorer to help diagnose the lesion?
• When you examine patients to determine if they have a primary caries lesion on the occlusal surface, on what percent of these patients do you use laser fluorescence (for example, Diagnodent™)?
• When you examine patients to determine if they have a primary caries lesion, on what percent of these patients do you use air-drying to help diagnose the lesion?*
• When you examine patients to determine if they have a caries lesion on a proximal (mesial or distal) surface of an anterior tooth, on what percent of these patients do you use fiber optic transillumination to help diagnose the lesion?
• When you examine patients to determine if they have a caries lesion, on what percent of these patients do you use some sort of magnification to help diagnose the lesion?
**Respondents who reported using air-drying were also asked: Approximately how long do you dry the tooth surface? The response choices were: 1-2 seconds, 3-4 seconds, 5 seconds, more than 5 seconds
Participants had the following response choices:
1—Never or 0%
2—1% to 24%
3—25% to 49%
4—50% to 74%
5—75% to 99%
6—Every time or 100%
The percentages for each method used were recoded to the categories' median to maintain the interval nature of the data so that parametric statistics could be used: 0% = 0, 1%-24% = 12.5, 25%-49% = 37, 50%-74% = 62, 75%-99% = 87, 100% = 100.

models=0, private=1), whether caries risk was assessed (not performing caries risk assessment=0 and performing caries risk assessment=1), and percentage of patients who received individualized caries prevention.

Practitioner and practice characteristics that were significant at $p<0.10$ were included in each model in the first step. A stepwise entry model was used with entry set at 0.10 and removal at 0.15 as there was no theoretical rationale for variable entry priority.¹¹

RESULTS

Table 3 summarizes the frequency of use of caries diagnostic methods. Air drying was the method used in almost all patients (92%), on average, to diagnose caries. The use of an explorer in occlusal surfaces and in the margin of existing restorations is also common for most patients. The diagnosis of proximal caries using radiographs is performed on average in 59% of the patients. On the other hand, magnification (25%), fiber optic transillumination (FOTI; 14%), and LF (3%) were used in the minority of patients.

Table 4 shows results of linear regressions of the frequency of use of each diagnostic method, using practitioner and practice characteristics as covariates. Significant associations at $p<0.05$ are described below.

As shown in Table 4, dentists who use radiographs to diagnose caries on posterior teeth on a greater percentage of their patients are more likely to have an advanced degree ($p=0.002$ for occlusal lesions and $p<0.001$ for proximal lesions) and provide a higher percentage of patients with individualized caries prevention ($p<0.001$ for proximal surfaces). On the other hand, those with a greater number of years since dental school graduation use radiographs on proximal ($p=0.010$) and occlusal ($p=0.007$) surfaces on a smaller percentage of their patients.

Dentists who use explorers on occlusal surfaces and on the margin of an existing restoration on a greater percentage of their patients have a greater number of years since dental school graduation ($p=0.041$ for occlusal lesions; $p=0.038$ for margin of a restoration). However, those who have received specialty training ($p=0.039$) and those with an advanced degree ($p=0.004$) use explorers on occlusal surfaces on a smaller percentage of their patients.

Dentists who use LF on occlusal surfaces on a greater percentage of their patients are more likely to work in an exclusively private practice model ($p=0.003$).

Dentists who use fiber optic transillumination for proximal caries on a greater percentage of their patients are more likely to have received an advanced degree ($p=0.022$) and provide a higher percentage of patients with individualized caries

Table 3: Frequency of Use of Caries Diagnostic Method

Diagnostic Method	Not Used at All % (n)	Used on All Patients % (n)	% Patients, Mean (SD)
Radiograph proximal (n=217)	1% (3)	21% (46)	59% (34)
Radiograph occlusal (n=217)	23% (50)	4% (9)	27% (29)
Dental explorer occlusal lesion (n=216)	14% (30)	44% (94)	64% (40)
Dental explorer on the margin of an existing restoration (n=217)	3% (6)	54% (118)	79% (32)
Laser fluorescence occlusal (n=217)	90% (196)	<1% (1)	3% (13)
Air drying (n=217)	<1% (1)	78% (170)	92% (20)
Drying time in seconds (n=196)	23% (45)	10% (20)	—
Fiber optic proximal (n=217)	69% (150)	3% (6)	14% (28)
Magnification (n=217)	58% (126)	14% (31)	25% (39)

prevention ($p=0.020$). Female dentists ($p=0.046$) and those having a primarily pediatric dentistry practice ($p=0.027$) use FOTI on a smaller percentage of their patients.

Dentists who use magnification on a greater percentage of their patients have a greater number of years since dental school graduation ($p=0.002$)

and provide a higher percentage of patients with individualized caries prevention ($p=0.013$).

DISCUSSION

In this paper, we identified the methods that Brazilian dentists use to diagnose dental caries and

Table 4: Linear Regressions of Use of Each Diagnostic Method, With Practitioner and Practice Characteristics as Covariates

Variable and Categories	B (SE)	SE	p
Radiograph for proximal caries			
Years since dental school graduation	-0.569	0.220	0.010
Advanced degree awarded	11.360	2.884	<0.001
Individualized caries prevention	0.251	0.070	<0.001
Radiograph for occlusal lesions			
Years since dental school graduation	-0.536	0.198	0.007
Advanced degree awarded	7.946	2.591	0.002
Explorer on occlusal lesions			
Years since dental school graduation	0.545	0.265	0.041
Specialty practice/specialized training	-12.168	5.848	0.039
Advanced degree awarded	-10.162	3.469	0.004
Explorer on the margin of an existing restoration			
Years since graduation from dental school	0.459	0.220	0.038
Performing caries risk assessment	-9.037	5.268	0.088
Use of laser fluorescence on occlusal surfaces			
Practice model (private)	5.931	1.996	0.003
Air drying when diagnosing occlusal caries			
Fiber optic transillumination for proximal caries			
Sex (female)	-8.442	4.196	0.046
Advanced degree awarded	5.777	2.493	0.022
Primarily pediatric practice	-11.918	5.359	0.027
Individualized caries prevention	0.142	0.060	0.020
Use of magnification			
Years since graduation from dental school	0.852	0.265	0.002
Individualized caries prevention	0.210	0.084	0.013

B (beta) represents the rate of change of the diagnostic method (one percentage category to the next) as a function of changes in the predictor variable (with dichotomous variables this means comparison between groups, e.g. male to female; for percentage independent variables, this means from one percentage category to the next); it is the slope of the regression line.

which variables are significantly associated with them, because little is known about dental practice patterns regarding caries management in Brazil.

Diagnostic methods used by dentists in most patients were AD (92%), dental explorer (Ex) for occlusal caries (64%) and for the margin of existing restorations (79%), and radiographs (Rx) (59%) for proximal caries. FOTI (14%) and LF (3%) were used in the minority of patients by the participants. Gordan and others⁶ found similar results among PBRN dentists for using dental explorers and radiographs in proximal caries. For FOTI and LF, a systematic review has shown insufficient scientific evidence for diagnostic accuracy of such methods.¹²

The finding that visual-tactile examination was used by dentists in most patients is in accordance with other studies. Most general dental practitioners' from New Zealand preferred conventional visual-tactile (87%) and digital radiography (78%) among several methods for caries detection.¹³ For private dental practitioners from Ankara, Turkey, sharp explorers were one of the most commonly used instruments to detect carious lesions.¹⁴

In fact, Nyvad and others¹⁵ demonstrated that an attentive professional using AD can diagnose most initial carious lesions by visual-tactile inspection. It is a quick and easy method, and when associated with assessment of lesion activity, is the best choice for the diagnosis of caries.¹⁶ However, the use of sharp explorers may cause some damage to the dental surface.¹⁷ In an *in vitro* study comparing ultrastructural defects caused in primary teeth by ball-ended probes and sharp explorers, the findings showed that less damage was caused using ball-ended probes when probing primary dental surfaces.¹⁸ Moreover, professionals tend to over-diagnose the disease when they use a sharp explorer because a "sticking" probe may be entirely due to pit and fissure anatomy.⁶

According to Fontana and others,¹⁹ an explorer should be used very gently to remove debris and plaque, to confirm cavitation when in doubt, to help the assessment of lesion activity and of dental material's integrity and retention. Systematic reviews have showed that visual methods had good accuracy for detecting carious lesions,²⁰ and they should remain the standard for clinical assessment in dental practice.²¹

Dentists in the current study use proximal radiographs for the diagnosis of proximal caries in almost 60% of their patients (Table 3). These findings, although lower than those reported in

other practice-based studies, still show that the majority of dentists use radiographs in their patients for assessment of proximal surfaces as shown by 96% of dentists in the United States⁶ and by dentists in Ankara (Turkey) who used radiographs in almost all their patients.¹⁴ One possible explanation for this finding is that 46% of the dentists participating in the current study work in public health settings. A radiographic imaging unit may not be available in some public health settings. In a Brazilian study that investigated dental radiology services in the public health setting, investigators found that 46% of municipalities from the Midwest region of Minas Gerais State did not have a radiographic imaging unit.²² Another Brazilian study that assessed the weaknesses in public dental service of a city from the South Region, the interviewed dentists reported the lack of X-ray equipment as one of the main criticisms to the public service.²³

Radiographic examination seems especially suitable for detecting cavitated proximal lesions in dentin. However, for enamel or incipient proximal caries lesions, the method presents low sensitivity and high specificity.²⁴ According to Pretty and Ekstrand,²⁵ the reproducibility from bitewing radiographs varies widely and they suggest that radiographs can aid the assessment of dentin proximal lesions, but are not as good as visual inspection for occlusal lesions. Therefore, they argue that radiographic examination is indicated when additional information is needed to aid dentists in the decision-making process. Additionally, it can be used to monitor early proximal lesions.

Another interesting finding is that regression analyses showed an inverse relationship for the use of radiographic imaging and years since graduation from dental school. There are very few studies on radiographic imaging use by Brazilian dentists. Castro and others²⁶ assessed availability of radiographic imaging to dentists in the city of Belo Horizonte and observed that recent graduates, up to 30 years of age, had more X-ray machines in their offices (72%) than those aged more than 30 years. The authors also found that dentists up to 20 years since graduation showed greater knowledge about radiographic techniques and radioprotection compared with dentists with 21+ years since graduation.

The results of the regression analysis showed that some dentists' characteristics were significantly associated with the use of certain caries diagnostic methods: dentists with an advanced dental degree were more likely to use radiographic imaging and FOTI. Dentists who practiced individualized caries

prevention in their patients were more likely to use radiographic imaging, FOTI, and magnification. Dentists with greater number of years since dental school graduation were more likely to use an explorer and magnification. Dentists who work exclusively in private practice are more likely to use LF (Table 4).

One of the most relevant findings of this study is the frequency of the use of a dental explorer on occlusal lesions and on margins of existing restorations in most patients, as previously mentioned. Regression analyses showed a direct relationship for the use of a dental explorer in occlusal caries lesions and years of graduation from dental school and an inverse relationship between dentists who have postgraduation courses and use of the dental explorer for caries diagnosis. Dentists who have a postgraduation course are most likely to practice dentistry based on current evidence, whereas dentists with more years of graduation from dental school may be more accustomed to traditional methods of caries diagnosis, such as the use of a sharp dental explorer. Indeed, Fontana and others²⁷ reported that teaching the use of a dental explorer to diagnose occlusal caries was the gold standard for many decades.

Regression analysis also showed a direct relationship between the use of radiographic imaging to diagnose caries on posterior teeth and dentists with an advanced degree, as well as with dentists who provide individualized caries prevention treatment for their patients. These findings were consistent with Gordan and others,⁶ who found that dentists who provide individualized caries prevention treatment are more likely to use radiographs to assess proximal caries.

Although other methods such as LF, FOTI, and magnification were not used by most dentists, the regression analyses showed that dentists who use LF on occlusal surfaces on a greater percentage of their patients are more likely to work in an exclusively private practice model. It does make sense because most public services in Brazil do not have these adjunct technologies. In a recent systematic review about the accuracy of LF in *in vitro* caries diagnoses, the results showed that the method was accurate (sensitivity, 0.71; specificity, 0.81) in predicting caries or healthy surfaces; however, the authors believe that in clinical practice, LF alone is not enough for an accurate caries diagnosis.²⁸

Dentists who use magnification on a greater percentage of their patients have a greater number of years since dental school graduation. It seems that older dentists use magnification more frequently

than younger dentists and this could be explained because presbyopia is a common deficiency affecting visual acuity that can begin in the 40s and can be compensated with magnification aids.²⁹

The limitations of this study, besides being a cross-sectional design, include that results are from a self-selected group of dentists. Despite the low response rate, the strengths of this study include the similarity for sex and age between study participants and practicing dentists in Araraquara. The study also proved to be feasible as a tool to investigate the current practice of dentistry, and it can be used to compare the results with other dentist populations.

The study findings identified a gap between dentists with more years of clinical experience and the practice of current evidence-based dental care. Future research could assess whether additional training and continuing education courses are indicated to improve the delivery of standard of care in dental offices by dentists who graduated many years ago and who did not complete postgraduate training.

CONCLUSION

In conclusion, most Brazilian dentists from Araraquara reported they most commonly use visual, tactile, and radiographic imaging for the diagnosis of dental caries. Some dentists' characteristics, such as years since dental school graduation and having postgraduation education, were associated with the use of certain diagnostic methods.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee

guidelines and policies of approval of the Research Ethics Committee of the Araraquara School of Dentistry, São Paulo State University (UNESP). The approval code for this study is 78/11.

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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Comparison of Internal Adaptation of Bulk-fill and Increment-fill Resin Composite Materials

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Clinical Relevance

The filling of deep, wide cavities with bulk-fill resin composites is appealing. However, some bulk-fill resin composites result in larger internal resin-dentin gaps than observed for an incremental-fill resin composite.

SUMMARY

Objectives: To evaluate 1) the internal adaptation of a light-activated incremental-fill and bulk-fill resin-based composite (RBC) materials by measuring the gap between the restorative material and the tooth structure and 2) the aging effect on internal adaptation.

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Methods and Materials: Seventy teeth with class I cavity preparations were randomly distributed into five groups; four groups were restored with bulk-fill RBCs: Tetric EvoCeram Bulk Fill (TEC), SonicFill (SF), QuiXX Posterior Restorative (QX), and X-tra fil (XF); the fifth group was restored with incremental-fill Filtek Supreme Ultra Universal Restorative (FSU). One-half of the specimens of each group were thermocycled. Each tooth was sectioned, digital images were recorded, and the dimensions of any existing gaps were measured. Data were analyzed using analysis of variance ($\alpha=0.05$).

Results: FSU had the smallest gap measurement values compared with the bulk-fill materials except QX and TEC ($p \leq 0.008$). FSU had the smallest sum of all gap category values compared with the bulk-fill materials, except QX ($p \leq 0.021$). The highest gap incidence and size values were found at the composite/adhesive interface. All aged groups had greater gap values in regard to the gap measurement and the sum of all gap categories compared with non-aged groups.

Significance: The incrementally placed material FSU had the highest internal adaptation to the cavity surface, while the four bulk-fill

materials showed varied results. Thermocycling influenced the existing gap area magnitudes. The findings suggest that the incremental-fill technique produces better internal adaptation than the bulk-fill technique.

INTRODUCTION

Given their numerous advantages, resin-based composite (RBC) materials have been widely used in dentistry since their development in the late 1950s. Besides having esthetic properties that mimic those of natural teeth, RBC does not require the removal of healthy tissues to achieve retention because of the ability to bond to tooth structure using resin adhesives. As a result, RBC has several indications: direct filling of anterior and posterior caries lesions and tooth defects, esthetic bonding, and as a luting cement for indirect restorations or the bonding of orthodontic brackets.¹

One reason for RBC direct restoration failure is postoperative pain or sensitivity. The hydrodynamic theory proposes that any change in fluid pressure and fluid movement stimulates pain receptors in the pulp that would cause postoperative pain and sensitivity following placement of resin composite restorations.² Poor internal adaptation of a resin composite restoration will create gaps between the material and the tooth structure and allow fluid collection. This fluid will move into the dentinal tubules due to pressure changes created during mastication or temperature fluctuations, causing the patient to feel pain.³ Other possible reasons for RBC restoration failure are material loss resulting in gap formation and inadequate internal adaptation that can impact retention.³

Many factors, including material properties, cavity preparation design, and operative technique, influence the quality of adaptation of RBC restorations. However, polymerization shrinkage and its associated stress are two of the most adverse properties of current materials.³ Many clinical techniques, such as controlling the curing light intensity,⁴ indirect placement of resin restorations,⁴ application of a flowable resin liner,⁵ and incremental layering techniques,⁴ have been introduced to minimize the shrinkage stress and thereby reduce gap formation. However, no method has been shown to be totally effective in abating the effects of polymerization shrinkage.⁶

The incremental, or layering, technique is a common approach used to eliminate gap formation and achieve adequate bonding of composite to

tooth structure.^{6,7} The technique involves placing RBC in multiple increments, with each increment placed to a specific thickness (2 mm or less) in an oblique manner, and polymerized separately. Thus, the technique allows adequate light penetration to cure the material.⁸ Moreover, it decreases the C-factor (the ratio of bonded surface to unbonded free surface).^{6,9} However, this technique has some drawbacks, such as increased chair time and inclusion of voids between the increment layers.⁶

Many efforts have been made to develop RBC materials that can fill larger cavities all at once, utilizing a bulk-fill technique. Unlike traditional RBCs, bulk-fill RBCs are intended to be placed in increments of 4 mm or greater.⁸ When the entire cavity can be filled in one step, this technique is easier, saves time, and results in fewer voids throughout the material.

An increased material thickness can inhibit good light penetration through the material. While the external surface may cure sufficiently, the material may not polymerize well in deeper portions.¹⁰ Over the past two decades, many manufacturers have introduced RBC materials that are claimed to have increased depth of cure and decreased polymerization shrinkage and gap formation, which would lend the materials to a bulk-fill placement technique. Recently, some of these products have gained popularity, and multiple studies indicate comparable physical and mechanical properties among bulk-fill and incremental-fill composite materials.¹⁰⁻¹² These studies support the claim that bulk-fill materials have greater depth of cure and lower polymerization-induced shrinkage stress than the traditional incremental-fill materials.^{13,14}

Therefore, bulk-fill restorative products may be considered viable alternatives to the traditional incremental-fill materials in preparations with high C-factor if increased depths of cure are seen with less internal stress. Reduced polymerization stress would decrease the incidence of gap formation and result in better internal adaptation compared with traditional incrementally placed composites.¹⁵ Further investigation of the internal adaptation between the restorative material and the tooth structure is needed. The purposes of this study were to 1) quantitatively evaluate the internal adaptation among different bulk-fill RBC materials and a traditional RBC placed incrementally by measuring the gap area between the restorative material and the tooth structure and 2) evaluate the effect of aging on the internal adaptation.

Table 1: Artificial Saliva (OHRI Recipe With Mucin and Buffer, pH = 7)						
Material	CaCl ₂ H ₂ O	KH ₂ PO ₄	KCl	NaCl	Tris Buffer	Gastric Mucin
Weight/1 L	0.213 g	0.738 g	1.114 g	0.381 g	12 g	2.20 g
Abbreviation: OHRI, Oral Health Research Institute, Indiana University School of Dentistry, Indianapolis.						

METHODS AND MATERIALS

Tooth Preparation

Seventy extracted, unrestored, and caries-free human maxillary (n=13) and mandibular (n=57) molar teeth were collected and stored in 0.10% thymol (local institutional review board number 1505861672) until they were used in this *in vitro* study. The cusps of each tooth were flattened by grinding perpendicular to the long axis of the tooth using a 400-grit silicon carbide paper under water lubrication. This created a flat exposed dentin surface in the cusp tip areas. The enamel remained intact at the center of the occlusal surface so that all occlusal cavosurface margins of the cavity preparations were in enamel. This step was required to allow the light-curing units to be held at a repeatable distance from the occlusal margin when photo-curing each tooth. Using an ISOMET 1000 precision saw (Buehler, Lake Bluff, IL, USA) with water cooling, the root portion was removed to 1 mm apical to the cemento-enamel junction and parallel to the flat cusp surfaces to simplify the later sectioning procedure for each specimen. The teeth were stored in artificial saliva (pH=7; composition listed in Table 1) at 37°C.

In the central fossa of each tooth, a class I cavity (C-factor=5.0) was prepared with a round-ended straight fissure carbide bur (cylindrical, #1158, SS White Burs Inc, Lakewood, NJ, USA) at high speed in a contra-angle air-turbine hand piece with air/water spray. The teeth, together with the hand piece, were mounted on a Lathe Model 4100 (Sherline Products Inc, Vista, CA, USA) to produce standardized cavity preparation dimensions. The cavity dimensions were as follows: the buccolingual extension was 2 mm (±0.2 mm), the mesiodistal extension was 6 mm (±0.2 mm), and the occlusogingival depth was 4 mm (±0.2 mm). The initial entrance of the bur was made at the mesial pit perpendicular to the long access of each tooth with the depth of 3.5 mm, crossing the central groove (of the lower molars) and the oblique ridge (of the upper molars) whenever necessary to obtain the 6-mm mesiodistal dimension. The bur was changed after every five cavity preparations. The internal angles were rounded, and the dimensions of each preparation were validated using a Michigan-O probe under 3.0× operator loupe magnification with LED

headlight illumination; any required slight cavity modifications were made manually. Preparations with cracks at the margins or observed pulpal exposure were not used in the experiment.

Specimen Preparation

The prepared teeth were randomly distributed to five experimental groups (n=14); each group contained at least two upper molar teeth. Each group was restored with a different RBC system. The materials were selected from commercially available bulk-fill RBC systems, including only those that do not require veneering with an occlusal layer of conventional high-viscosity composite. The materials were a traditional universal composite placed by increment-fill technique (FSU, Filtek Supreme Ultra Universal Restorative, 3M ESPE, St Paul, MN, USA) and four composite materials placed by a bulk-fill technique (TEC, Tetric EvoCeram Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein; SF, SonicFill, Kerr, Orange, CA, USA; QX, QuiXX Posterior Restorative, Dentsply DeTrey GmbH, Konstanz, Germany; and XF, x-tra fil, Voco GmbH, Cuxhaven, Germany) (Table 2).

All prepared cavities were acid-etched and bonded using the same total-etch system (Kerr Gel Etchant and OptiBond Solo Plus, Kerr) to reduce the number of variables, as there were no manufacturer restrictions for the adhesive. Each cavity was etched with 37.5% phosphoric acid for 15 seconds and then rinsed thoroughly with copious amounts of water for 15 seconds. A moist dentin surface was maintained by blotting excess moisture from the dentin with a cotton pellet. Then two layers of the bonding agent were applied with a microbrush, using a light rubbing motion for 15 seconds for each layer. After applying a weak stream of air for three seconds to evaporate solvent, the bonding agent was light cured (DEMI LED, Kerr) with an irradiance of 1615 mW/cm² for 20 seconds. Light output was monitored using a Managing Accurate Resin Curing calibrator (MARC Resin Calibrator, BlueLight Analytics Inc, Halifax, NS, Canada). The curing light tip was fixed perpendicular to the cavity at a distance of 3.0 mm from the cavosurface margins using an adjustable arm clamp (MARC Resin Calibrator, BlueLight Analytics). All of the restorative materials were packed to the cavity floor and walls by using the same blunt plastic

Table 2: *Materials, Manufacturers, and Chemical Compositions of Matrix, Filler Type, and Filler Content by Weight (wt) and Volume (vol)*

Group Code/Product	Manufacturer, Shade, Part Number	Resin Matrix	Filler Composition/Size	Filler Amount, Wt%/Vol%
Traditional increment-fill resin composite				
FSU: Filtek Supreme Ultra Universal Restorative (nanohybrid)	3M ESPE, A2B, 6029A2B	Bis-GMA, UDMA, TEGDMA, Bis-EMA, PEGDMA	Silica, zirconia, zirconia/silica (0.6-10 μm)	78.5/63.3
Bulk-fill resin composites				
TEC: Tetric EvoCeram Bulk Fill (nanohybrid)	Ivoclar Vivadent, universal IVA, ^a 638244WW	Bis-GMA, UDMA, Bis-EMA	Barium glass, ytterbium trifluoride, mixed oxide, prepolymerized fillers (0.04-3 μm)	76-77/53-54
SF: SonicFill (nanohybrid)	Kerr, A2, 34922	Bis-GMA, Bis-EMA TEGDMA, EBPDMA, MPS	SiO ₂ , glass, oxide (0.02-40 μm)	67/83.5
QX: QuiXX Posterior Restorative (hybrid)	Dentsply DeTrey GmbH, universal, 631202	UDMA, TEGDMA, di- and trimethacrylate resins, carboxylic acid modified dimethacrylate resin	Strontium aluminum, sodium fluoride, phosphate silicate glass (NP)	86/66
XF: X-tra fil (hybrid)	Voco GmbH, universal, 1741	Bis-GMA, UDMA, TEGDMA	Barium boron aluminum silicate glass (0.05-10 μm)	86/70
Abbreviations: Bis-GMA, bisphenol-A diglycidyl ether dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, bisphenol-A polyethylene glycol diether dimethacrylate; PEGDMA; poly(ethylene glycol) dimethacrylates; EBPDMA, ethoxylated bisphenol-A-dimethacrylate; MPS, 3-trimethoxysilylpropyl methacrylate, NP, filler size not provided.				
^a Universal IVA for restorations in the "A" range (A2-A3).				

instrument (2 Woodson composite instrument, Hu-Friedy Manufacturing Co LLC, Chicago, IL, USA), except for SF, which was placed using a sonic-activated hand piece. All light-curing times were according to the manufacturer instructions.

FSU Group (Control)

The cavities were restored using an oblique incremental layering technique with five wedge-shaped composite increments from the pulpal floor to the occlusal surface (each increment being not more than 2.0 mm thick).¹⁶ The first increment was placed against the mesial wall and the pulpal floor and then polymerized; material was then placed against the distal wall to the pulpal floor and polymerized. This procedure was repeated to place the third and fourth increments. No increment was placed at any time that would contact both the mesial and the distal walls of the preparation. The last increment filled the remaining part up to the occlusal portion of the preparation (Figure 1). Each increment was cured for 20 seconds using the same curing light and mounting device described above.

TEC Group

TEC was placed in a 4.0-mm bulk increment and then light cured for 10 seconds using the previously described method.

SF Group

SF was placed in a 4.0-mm bulk increment and then light cured for 20 seconds using the previously described method. Material placement was facilitated by using a sonic-activated hand piece utilizing technology that lowers the material's viscosity, allowing greater flow.

QX Group

QX was placed in a 4.0-mm bulk increment and then light cured for 10 seconds using the previously described method.

XF Group

XF was placed in a 4.0-mm bulk increment and then light cured for 10 seconds using the method described above.

Additional light curing from the facial and lingual surfaces was performed following the manufacturer's recommendation for SF, QX, and XF materials.

Each group was divided equally into two sub-groups—aged and nonaged—with seven teeth in each. Nonaged specimens were immersed in artificial saliva at 37°C and stored in the dark for at least 48 hours to ensure complete material polymerization. In the aged groups, all specimens were immersed in artificial saliva at 37°C for 48 hours

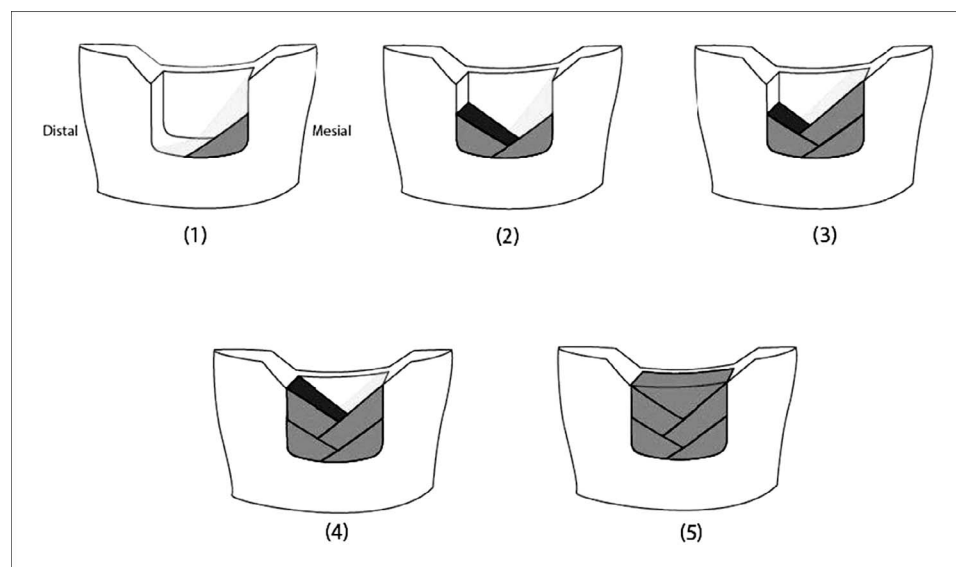


Figure 1. Cross-section view shows the successive resin composite incremental layering technique.

and then thermocycled (SD Mechatronik Thermocycler, SD Mechatronik GmbH, Westerham, Germany) for 5000 cycles between 5°C and 55°C, with a dwell time of 30 seconds and a transfer time of 10 seconds, which corresponded to six months of *in vivo* functioning.¹⁷

After the storage period, all teeth were sectioned vertically in a buccal-lingual direction using an ISOMET 1000 precision diamond blade (Buehler) under water cooling. Four cuts were made with the first cut at the mesial restoration margin, the last cut at the distal restoration margin, and two cuts in between to create three 2.0-mm-thick slices for each tooth. Internal adaptation evaluation and existing gap measurements were conducted on the interface of the inner side of the mesial (labeled as a) and distal slices (labeled as c) and both sides of the middle slice (the mesial and distal sides were labeled as b and b', respectively) (Figure 2).

Each specimen was fixed on a mounting block (Struers Inc, Cleveland, OH, USA) by using sticky wax, leaving the interfaces to be measured exposed. The surfaces were ground flat with water-cooled abrasive discs (500-, 1200-, 2400-, and 4000-grit Al₂O₃ papers, MD-Fuga, Struers) and polished using a polishing cloth with a diamond suspension (1 µm DP-Suspension P; Struers). All specimens were cleaned in an ultrasonic bath and stored in a humidor using in dark, closed containers at 37°C until their next use.

Image Recording and Analysis

The internal adaptation, defined as the lack of any space or gap between the tooth structure and the

restorative material, was evaluated along the cavity pulpal floor of each cavity preparation. Measurements were obtained from a designated area that was 1000 µm long and located at the center of the cavity pulpal floor (Figure 3). The surface of each specimen was gently dried immediately before measuring by using laboratory-delicate task wipes (Kimwipes, Kimtech Science, Kimberly-Clark Global Sales Inc, Roswell, GA, USA). Multiple digital images were taken and saved for each of the a-, b-, b'-, and c-labeled experimental sides (n=280) by using a 1.3-megapixel high-resolution monochrome CCD digital camera and a light reflection microscope (Instron-Wilson-Tukon Model 2100B, Instron, Norwood, MA, USA). The images were obtained using 200× magnification; 500× magnification was used to confirm adaptation failure through the existence of a gap. The images were stitched together by using Adobe Photoshop CS6 to create one panoramic view for each labeled specimen side.

The images were analyzed by using digital image analysis software (ImageJ, ver. 1.459r, National Institutes of Health, Bethesda, MD, USA). A region of interest was determined for each panoramic image, and measurements were obtained. The region of interest was located at the center of each pulpal floor and had dimensions of 1000 µm in length and 500 µm in height. Any gap at the composite/dentin interface was identified and classified into one of the following categories based on its location:

CA: gap at the composite/adhesive interface
AD: gap at the adhesive/dentin interface

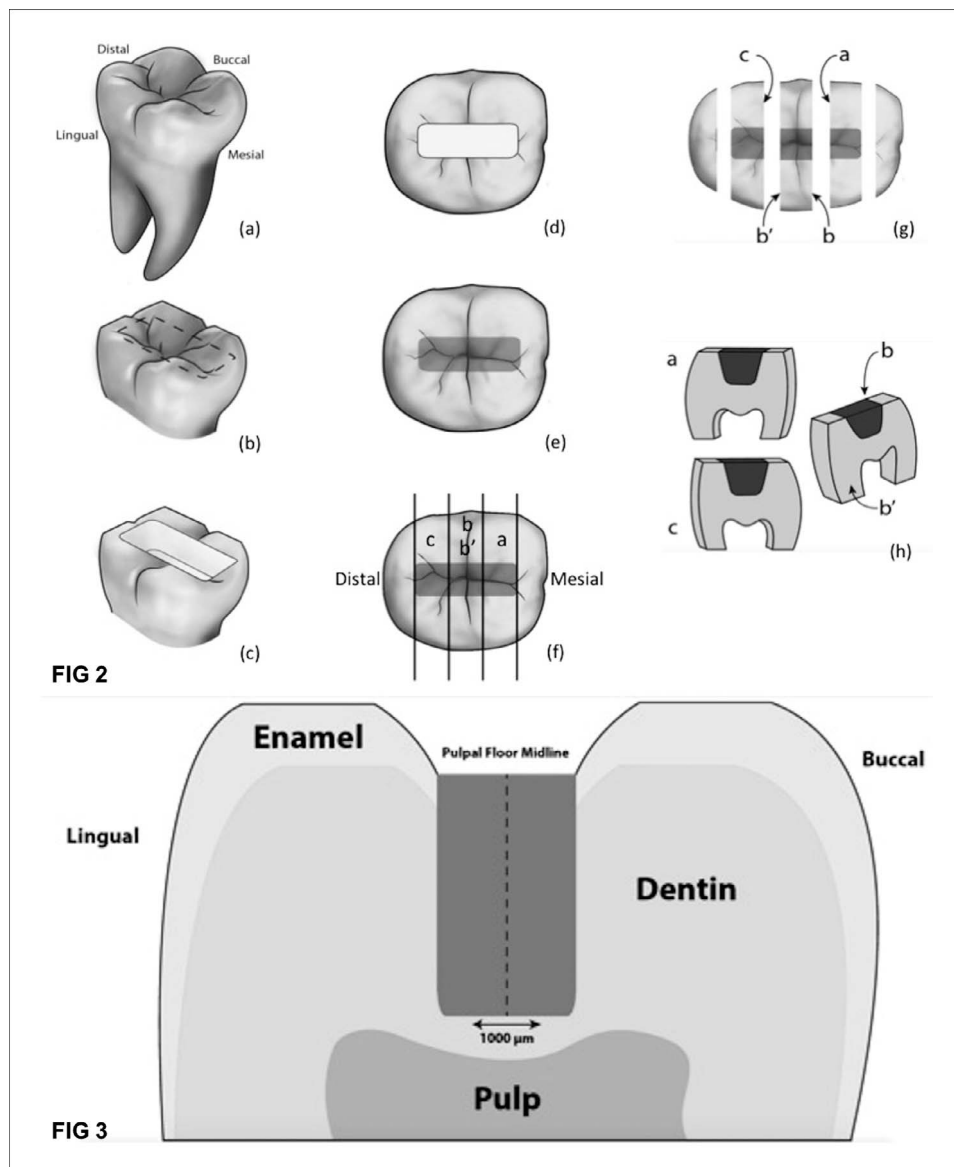


Figure 2. Specimen preparation sequence. (a): Sample lower molar. (b): Cusp tips flattening and root sectioning. (c): Cavity preparation. (d): Occlusal view for cavity dimensions: 6 mm for the mesiodistal extension, 2 mm for the buccolingual extension, and 4 mm for the occlusogingival depth. (e): Each experimental group filled with different resin composite material. (f): Teeth sectioning. (g): Three slices were created from each tooth, and four sides were labeled. (h): Labeling procedure for the inner side of tooth mesial slice (a), the mesial side of tooth middle slice (b), the distal side of tooth middle slice (b'), and the inner side of tooth distal slice (c).

Figure 3. The designated area that the study analysis attained was 1000 μm long and located at the center of the cavity pulpal floor.

CAD: gap at the composite/adhesive/dentin interface (mixed)

Next, each gap boundary was determined, and the gap area was measured (μm^2) using dimensional calibration based on a high-precision-stage micrometer after threshold determination using ImageJ.

The cavity adaptation (%) was calculated for each specimen utilizing the following equation:

$$\text{Cavity Adaptation(\%)} = \left(\frac{\text{sum of adaptation length}}{\text{total length of cavity floor}} \right) \times 100.$$

Any cohesive failures that occurred within the composite-based material or the dentin were documented. Similarly, the occurrence of any internal voids surrounded completely by composite-based material was recorded.

A single trained operator prepared all specimens and completed all laboratory procedures. To ensure accuracy, a second trained operator also collected data and conducted measurements from the same recorded specimen images. There were similar measurements between the two evaluators mainly when gap sizes were relatively small and no differences were encountered that influenced the final results and research conclusion.

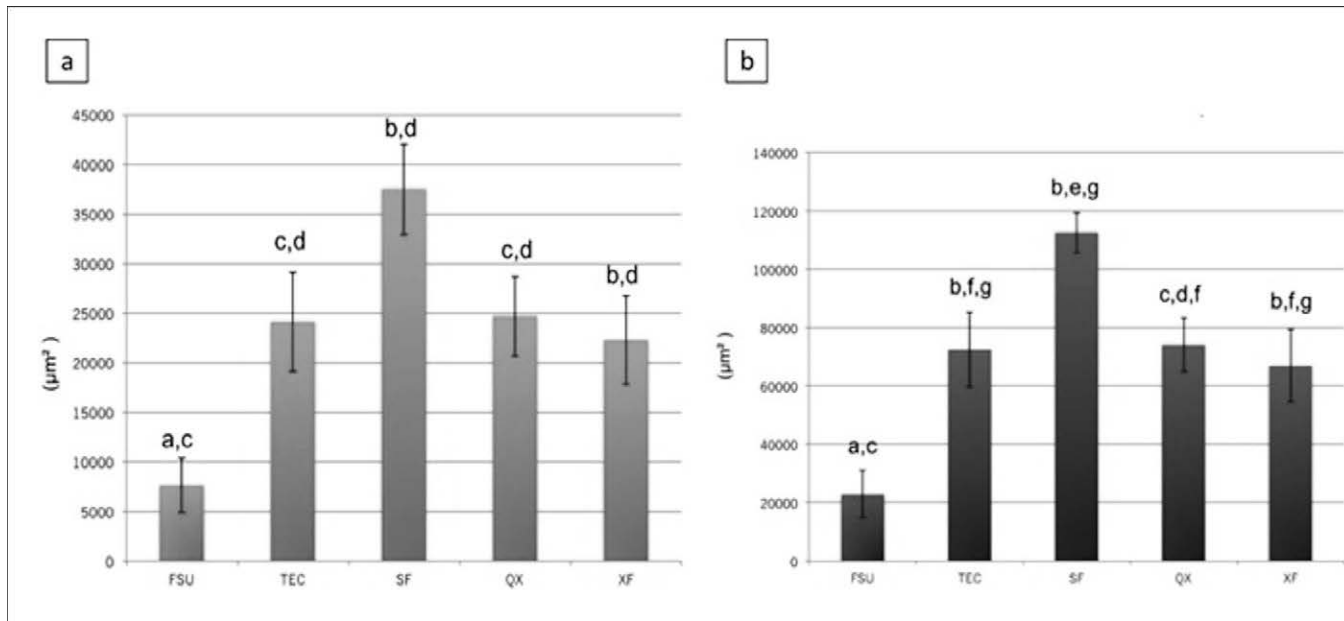


Figure 4. Mean ($\pm$ SD) gap measurement (a) and sum of all gap categories (b) by restorative material. Groups identified with similar letters are not significantly different. Abbreviations: FSU, Filtek Supreme Ultra Universal Restorative; TEC, Tetric EvoCeram Bulk Fill; SF, SonicFill; QX, QuiXX Posterior Restorative; XF, X-tra fil.

Statistical Analysis

Summary statistics were computed for gap area measurement with and without aging of the specimens for each of the five restorative material groups and gap location categories. Mixed-model analysis of variance was performed to examine the effects of aging, restorative material groups, gap location categories, and specimen slice side with a random effect for the correlation between the slices within each tooth. An additional mixed-model analysis of variance was performed to examine the additional effect of gap location categories, with an additional random effect for correlating the gap location categories within each slice. Fisher's protected least significant difference test was used to control for multiple comparisons. Due to non-normality in the data, the dependent variables were ranked (from smallest to largest) prior to analysis.

The sum of all gap categories (CA, AD, and CAD) and the cavity adaptation values were ranked and then used for the analysis process. There was an additional fixed and random effect in gap measurement analysis in addition to the ranking of the dependent variables of the gap measurement values. A 0.05 significance level was used for all comparisons. With a sample size of seven teeth for each aged and non-aged group, the study had 80% power to detect a mean gap ratio of 2.5 for one group compared to another, assuming two-sided tests, and a coefficient of variation of 1.

RESULTS

Gap Measurements

Mean gap area measurements are presented in graphs (Figures 4 and 5). There were significant differences in mean gap area measurement among the restorative material groups ($p=0.0333$). The gap area measurement for the control group FSU was significantly smaller than SF and XF ($p\leq 0.008$). However, no significant differences were found among the other restorative material groups, as illustrated in Figure 4a. Gap area measurements differed according to location category ($p<0.0001$). For all five material groups combined, the gap measurements for all three locations were significantly different from one another, with the smallest measurements for CAD (CAD<AD<CA; all $p<0.0004$). As shown in Figures 5 and 6, there was a significant interaction between restorative material group and gap location ($p<0.0001$). In the FSU group, the gap measurement for CAD was significantly smaller than CA ($p=0.0411$). Gap measurements for both AD and CAD were significantly smaller than CA in the QX, SF, TEC, and XF groups ($p\leq 0.0024$). CAD was significantly smaller than AD in the QX group ($p=0.010$); however, there was no significant difference between CAD and AD gap measurements for the other four material groups (all $p\geq 0.1403$). The gap measurements for the aged group were significantly higher than for the nonaged group ($p=0.0452$).

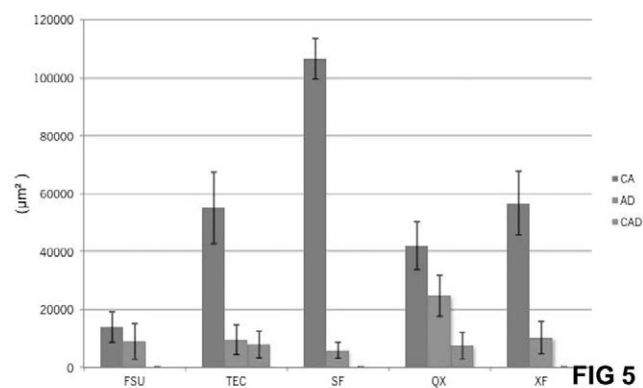


FIG 5

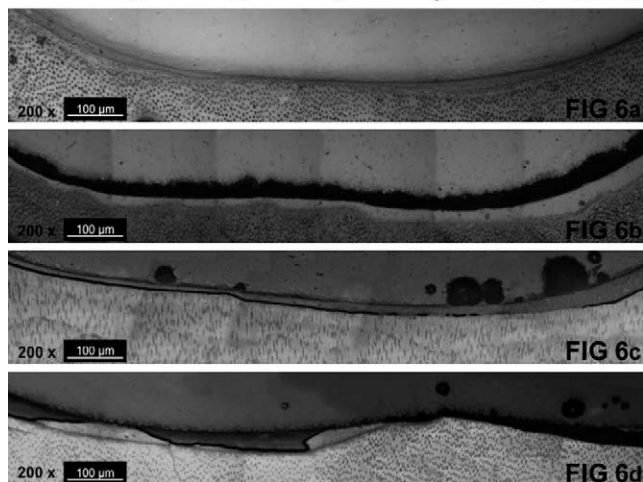


Figure 5. Mean ($\pm$ SD) gap measurement by gap location and restorative material.

Figure 6. Panoramic images representing different gap categories. (a): That obtained from FSU group shows no gap at all. (b): That obtained from SF group shows CA gap type. (c): That obtained from XF group shows AD gap type. (d): That obtained from QX group shows CAD gap type.

Overall, there were significant differences in the sum of all gap categories among the restorative material groups ($p=0.0036$). Individual comparisons indicated that the sum of all gap categories in the control group FSU was significantly smaller than the TEC, SF, and XF groups ($p\leq 0.021$). Similarly, the sum of all gap categories for QX was significantly smaller than SF ($p=0.0257$) (see Figure 4b). The sum of all gap categories for slice side a and side c was significantly larger than b ($p\leq 0.0155$). The sum of all gaps for the non-aged groups was significantly higher than that for the nonaged groups ($p=0.0239$).

In general, there were significant differences among restorative material groups ($p=0.0001$). The control group FSU had a higher cavity adaptation than the SF, TEC, and XF groups ($p\leq 0.019$), and the cavity adaptation for QX and TEC was significantly higher than SF ($p\leq 0.0148$).

Table 3: Incidence of Gap Location Categories Among Different Groups of Restorative Materials

Restorative Material Group	CA	AD	CAD	Total
FSU	7	4	0	11
QX	26	15	3	44
SF	51	5	0	56
TEC	22	6	3	31
XF	27	5	0	32

Abbreviations: CA, gap at the composite/adhesive interface; AD, gap at the adhesive/dentin interface; CAD, gap at the composite/adhesive/dentin interface (mixed).

Gap Location

Table 3 shows the incidence of gap location categories among different restorative material groups. CA gap category incidence was the highest among all the restorative groups followed by the AD gap category. The CAD gap category was presented only in the QX and TEC groups.

All cohesive failures observed in the filling material or the dentin were reported. There were 11 total cohesive failures; nine failures occurred within the composite (all groups except SF) and two within the dentin (FSU and XF). In particular, nine failures occurred in the FSU, QX, TEC, and XF non-aged groups and two in the FSU aged group. Most of the failures occurred in the XF restorative group, with a total of five failures (see Table 4).

Incidence of Voids

The incidence of any internal void that was surrounded completely by composite-based material observed in the panoramic view (from the most inferior border of the composite up to 250 μ m occlusally) was documented. Overall, there were significant differences in the probability of voids

Table 4: Cohesive Failure Among Different Groups of Restorative Materials

Restorative Material Group	Aging Group	Dentin	Composite	Total
FSU	Nonaged	0	1	3
	Aged	1	1	
QX	Nonaged	0	1	1
	Aged	0	0	
SF	Nonaged	0	0	0
	Aged	0	0	
TEC	Nonaged	0	2	2
	Aged	0	0	
XF	Nonaged	1	4	5
	Aged	0	0	

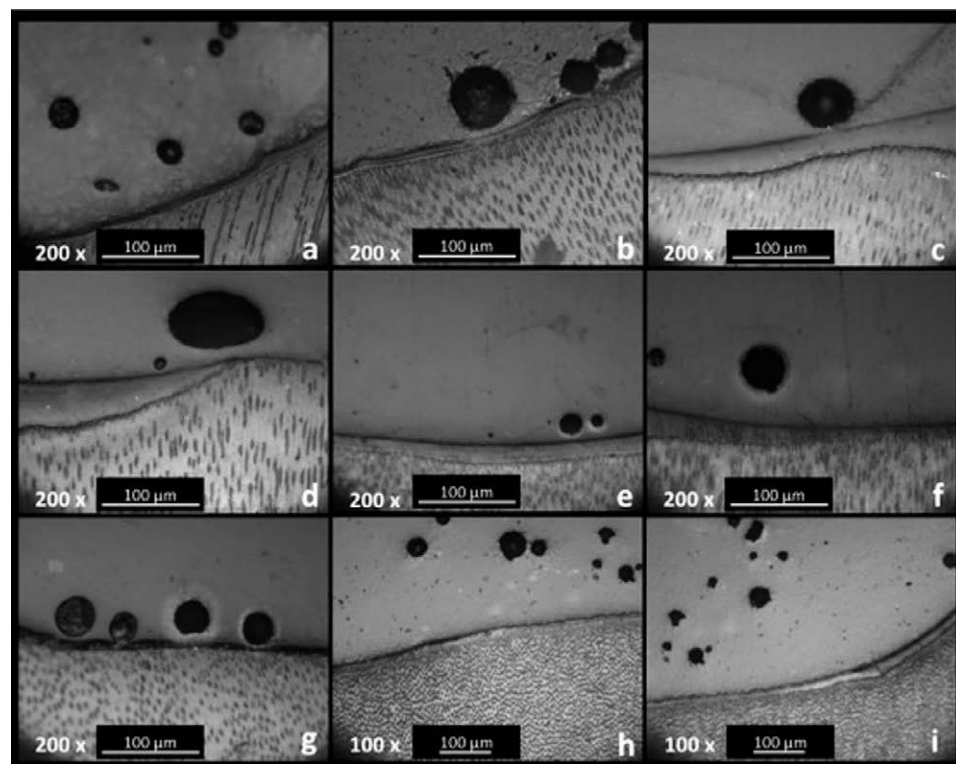


Figure 7. Internal voids. (a) and (b): Samples from XF group. (c) and (d): Samples from FSU group. (e), (f), and (g): Samples from TEC group. (h) and (i): Samples from QX group.

among the different restorative material groups ($p < 0.0001$). The SF group had a significantly lower probability of voids than FSU, QX, TEC, and XF ($p \leq 0.0024$). QX had a significantly lower probability of voids than FSU, TEC, and XF ($p \leq 0.0287$). However, FSU, TEC, and XF did not have significantly different probabilities of voids, as shown in Figure 7.

DISCUSSION

One of the main challenges facing RBC materials is polymerization shrinkage, which may cause the formation of gaps at both marginal and internal tooth restoration interfaces. Many authors have studied this phenomenon by measuring *in vitro* microleakage. However, they have generally evaluated the correlation between polymerization shrinkage and cavosurface marginal microleakage rather than internal adaptation.¹⁸⁻²² Furness and others²³ showed fewer gap-free margins at the pulpal interface when compared with enamel or mid-dentin interfaces after restoring class I cavities with different types of bulk-fill RBC materials. Measuring the internal adaptation is more stringent than marginal microleakage since it is more challenging for the material to adapt to the deepest cavity area compared with the other interface locations.

Longitudinal clinical trials are time consuming and expensive and demand a large sample size that is challenging to standardize. Laboratory studies simulating clinical conditions remain vital as alternatives. However, there are critical factors to be considered in the experimental design to maximize the usefulness of *in vitro* evaluations.

First, tooth substrates vary significantly. Structural defects, such as the presence of internal crazes and enamel cracks, influence the bonding to tooth structure. Teeth with visible defects were not used in this study. Hydrated teeth have shown better bonding than dried teeth,²⁴ so that storing and manipulating extracted teeth inconsistently might affect the results. The teeth in this study were collected under a defined storage protocol. Also, variations in anatomical features, such as cusp height and shape, can affect the final cavity preparation dimensions and C-factor, thus impacting the data. This was the motivation for using the lathe in this study that allowed the secured hand piece to be moved precisely, providing for standardized cavity dimensions.

Second, the physical sectioning method used in this study to visualize the internal adaptation of the restorations is time consuming and might damage the specimens. Nondestructive techniques, such as micro-computed tomography (micro-CT) might be

advantageous. Several studies have used micro-CT after silver nitrate infiltration²⁵⁻²⁷ as well as swept-source optical coherence tomography²⁸ to evaluate the internal adaptation of RBC materials. Nevertheless, these methods present significant challenges, including being expensive, time intensive, technically challenging, and possessing a steep learning curve. Moreover, their results need to be validated by sectioning the specimens and examining them microscopically.

In the current study, the dependent variables of gap measurement, sum of all gap categories, and cavity adaptation (%) were ranked (from smallest to largest) prior to analysis. The size of the gap area may affect the incidence and severity of postoperative pain or sensitivity following placement of the restorative material. Our study demonstrated significantly better internal adaptation with a traditional RBC material placed incrementally compared to bulk-fill RBC materials. All materials tested in bulk placement had significantly larger gap interfaces and less adaptation to the cavity floor with the exception of QX. This result is supported by a recent study that reported that an incremental-fill technique improved the adaptation of a universal composite to the cavity floor compared with a bulk-fill technique.²⁸ This outcome might be related to the reduced material volume and C-factor of each increment, which reduced the generated contraction stresses and is in agreement with previously reported studies on the advantages of incremental filling.^{29,30}

Factors that impact polymerization shrinkage include monomer molecular weight and concentration as well as filler size and concentration.³¹ FSU, TEC, QX, and XF all have higher filler content by weight % than SF. These high-filler resin composites have less matrix monomer available to contribute to the polymerization process. While the space occupied by the filler particles does not contribute to the curing contraction, high filler particle loads may necessitate including low-molecular-weight monomers to ensure a proper handling viscosity. In low-viscosity materials, the motility of the monomers is active such that a greater proportion of monomers contribute to the polymerization reaction, increasing the polymerization shrinkage.³² In the present study, SF exhibited significantly larger gaps and less adaptation to the cavity compared with the other materials tested. SF also had the lowest filler content, which aids in lowering its viscosity during sonic activation. Other authors reported that SF showed excellent adaptation to cavity walls with

smaller gaps and fewer voids than with conventionally lined and layered composite placement techniques.^{33,34}

AD and CAD gap categories could have a significant clinical impact on the postoperative sensitivity due to an exposed dentinal surface. Nevertheless, poor restorative material retention and fatigue degradation could be linked to the CA gap category. The incidence and measurement of the CA gap category was significantly higher than the others, followed by AD. Another finding of interest in the results of this experiment is that the SF group had the highest incidence of CA gap compared with the other groups. It is not clear why this occurred, even though the same bonding system was used for all the experiment groups. It might be due to the relatively higher polymerization shrinkage in SF or a poor chemical reaction between SF and OptiBond Solo Plus, even though both were from the same company (Kerr) and marketed as compatible. Further study will be necessary to evaluate SF's ability to adapt to the cavity pulpal floor using different total-etch adhesive systems.

Artificial aging techniques to examine the alterations at the interface between resin restorations and tooth cavities include 1) aging by water storage, 2) aging by thermocycling, and 3) aging by thermomechanical load cycling.³⁵⁻³⁷ The aging technique used in this study was selected based on a review¹⁷ demonstrating that thermocycling creates stresses similar to those seen during six months of clinical service. It is interesting to note that the aging technique used in this study was a significant factor affecting the resultant gap size measurement, although it did not affect the material adaptation to the cavity. This suggests that thermocycling worsened existing gaps but did not affect actual gap creation *per se*. Several previous studies showed that thermocycling or storage in water might have a slight effect on gap formation; however, thermomechanical load cycling can also efficiently cause artificial aging.^{17,38-40} Further investigation of the effect of the three aging techniques on gap size and bulk-fill material adaptation is recommended.

In our study, internal adaptation was evaluated in four different locations within the same tooth, as three slices obtained from each tooth allowed analysis of four different sides (a, b, b', and c). The sum of all gap categories for slice sides a and c (the mesial and distal slice sides) was significantly larger than b (one of the middle slice sides) ($p \leq 0.0155$). In other words, the gaps located closer to the center of the cavity were larger than those

located close to the cavity sides. This implies that the shrinkage force was greater near the center of the material mass. Of the materials tested in this study, all had at least one cohesive failure within the dentin or the composite material except SF. The XF group had the highest incidence of cohesive failure, all occurring within the composite material. This might be linked directly to the material strength or degree of polymerization.

Voids within the composite material are porosities that remain unoccupied. They are generally deemed undesirable because they can impact the mechanical properties and life span of the composite.⁴¹ They can allow increased sorption in the composite material and contribute to anisotropic behavior of the composite.⁴² Moreover, voids can act as crack nucleation sites, contributing to crack formation and propagation and generating unpredictable behavior of the material.⁴² In this study, SF had a significantly lower probability of voids among the groups ($p < 0.0024$), followed by QX ($p < 0.0287$). The incidence of voids can result from imperfections in material processing or be related to the viscosity of the material during placement and the placement technique. A resin composite material with a high viscosity is more likely to generate voids than a low-viscosity material. As the composite fillers can have void spaces from the manufacturing process, it is challenging for a high-viscosity matrix to penetrate them, especially when the fillers are packed tightly together.⁴³ The current study supports this idea, as it shows fewer voids associated with SF, which had a low viscosity during placement. Furthermore, it has been suggested that using an incremental-fill placement technique may result in more voids due the nature of the layering procedure, which allows air to trap between layers.⁴⁴ In our study, however, although FSU (the incrementally placed group) showed a statistically higher incidence of voids compared with SF and QX, there was no statistically significant difference between FSU and the other two bulk-fill groups (TEC and XF).

CONCLUSIONS

Based on the results of the present study, an incrementally placed resin composite material (FSU) showed less gap formation and better internal adaptation to the cavity floor than the bulk-fill restorative materials. Therefore, an incremental-fill technique seems to have significant advantages in internal adaptation over a bulk-fill technique. The four materials placed using a bulk-fill technique showed various behaviors and results. Moreover,

thermocycling influenced the existing gap quantities, but did not play a role in the material adaptation to the cavity.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Indiana University. The approval code for this study is 1505861672.

Conflict of Interest

The authors of this article 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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Minimally Invasive Adhesive Rehabilitation for a Patient With Tooth Erosion: Seven-year Follow-up

NI Pavesi Pini • LM De Marchi • AL Ramos • RC Pascotto

Clinical Relevance

This case report discusses a full-mouth rehabilitation using direct composite resin and whether this technique is viable for a young patient with tooth erosion. The seven-year follow-up indicates that a conservative approach with an appropriate diagnosis of the patient is a good choice for achieving esthetics, function, and restoration longevity.

SUMMARY

Tooth wear is a multifactorial condition of growing concern. In clinical practice, it is often a challenge for prevention and treatment since many etiological factors may be involved. This case report describes an esthetic rehabilitation of a young patient presenting tooth wear due to erosion. The etiological factor of this case was the patient sucking on lemons, an

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acidic fruit. The main complaint of the patient was the appearance of short maxillary incisors. The treatment involved orthodontic and restorative dentistry techniques. First of all, an orthodontic device was used to increase the vertical dimension of occlusion and create an adequate space for the direct restorations. The posterior teeth were restored with two direct composite resin techniques; the anterior teeth were then restored using a balanced occlusion. The seven-year follow-up of the case is presented. Replicas of the restorations were made and visualized under scanning electron microscopy up to the 12-month evaluation. In the clinical follow-up at seven years, maintenance of the results and restorations can be clearly seen.

INTRODUCTION

Tooth wear is a modern concern for clinicians and has become a challenge to prevent and treat.^{1,2} The etiology of tooth wear is multifactorial, and includes dental erosion as an important factor due to its increased prevalence.^{3,4} According to Bartlett and

others,⁵ more than 25% of the adult population in seven European countries showed tooth wear related mainly to the consumption of acidic fruits or gastric disorders.

Dental erosion is defined as tooth substance loss related to exogenous (foods and soft drinks) or endogenous acids (gastric acids due to regurgitation or reflux disorders) without bacterial involvement.^{6,7} Erosion is a multifactorial condition caused by the interplay of numerous factors, such as acid consumption/production, abrasion, attrition, saliva flow rate, saliva properties, and tooth susceptibility to dissolution, all of which contribute to the erosion process.^{3,8,9}

Patients are often late in perceiving that they suffer from erosion.¹⁰ Erosive lesions are characterized by shallow defects on the smooth surfaces and flattening of the occlusal surface, eventually with exposure of dentin.^{11,12} The teeth can appear yellowish, which is often the first sign of erosion noted by the patients themselves.^{10,11} Another recognized sign is the shortening of the maxillary incisors, indicating advanced lesions, often associated with a loss of vertical dimension of occlusion (VDO).^{10,13} The first approach for the patient with clinical symptoms of dental erosion should be the identification of the source of the acid exposure and elimination of the cause of the disease.¹¹ Restorative therapies are often necessary to restore the teeth.¹³⁻¹⁵

The restorative treatment should be chosen based on the severity of the tissue loss and the extent of existing restorations in the posterior teeth.¹⁶⁻¹⁹ In fact, posterior tooth status typically determines the most appropriate restorative option. Direct restorations are indicated in cases of slight or moderate tooth loss with or without the presence of small restorations.¹⁵ In case of extensive tooth loss and the presence of medium or large restorations, an indirect approach or a combination of indirect and direct restorations should be considered.²⁰ The possibility of direct restorative materials should always be considered since they allow for a minimally invasive treatment that replaces only the lost dental tissues without tooth preparation.^{13,20} Extensive prosthodontic treatment in patients with tooth wear may compromise the survival of the dentition in the long term, which is especially relevant when patients are relatively young.²¹

Studies have concluded that direct resin composite materials represent a viable method for restoring moderate to severely worn teeth since the restora-

tions exhibit a good clinical performance after three years.^{22,23} Thus, the aim of this report is to demonstrate a conservative approach for restoring esthetics and function in a young patient with generalized tooth wear, performing direct restorations using composite resin.

CASE REPORT

A 22-year-old man presented at a clinical appointment complaining about the worn appearance of his teeth and his smile. His main complaint was about his anterior teeth, which appeared to be shorter than normal. An initial analysis of the patient revealed that he did not show his maxillary incisors with his lips at rest, and he presented a change in his smile line, which was not consistent with the plane of the incisors above the canines, causing an inverted smile (Figure 1). The initial clinical examination revealed that the patient suffered from generalized severe dental erosion and attrition involving both the anterior and the posterior teeth (Figure 2).

The areas most affected by erosion included the occlusal surfaces of the maxillary and mandibular posterior teeth and the palatal surfaces of the maxillary anterior teeth. The erosion caused a significant loss of enamel with the exposure of dentin, loss of anatomy, shortening of the teeth, and loss of marginal adaptation of the existing restorations (Figure 3). Although there was extensive dental wear, all affected teeth were vital, even though several of them presented hypersensitivity to air or temperature changes. Also, facial analysis revealed that the patient seemed to have a slight reduction in VDO caused by posterior tooth wear. A cephalometric analysis showed a low mandibular plane angle, reduced display of the upper incisors (related to the upper lip), and a low occlusal plane angle (Figure 4; see black traces). The patient's smile pattern indicated that the anterior teeth presented some extrusion, which compensated for the wear and caused some gingival display, although the patient had zero incisor display at the rest position. However, the cervical gingival margins presented good contour.

An extensive patient history revealed that the patient consumed excessive acidic beverages, including soft drinks, and routinely sucked on lemons. Because of this, no gastroenterological evaluation was requested to further establish the etiology of the dental erosion. Additionally, the patient reported the presence of parafunctional occlusal habits to include nocturnal bruxism without any previous intervention, such as the use of an occlusal guard. The

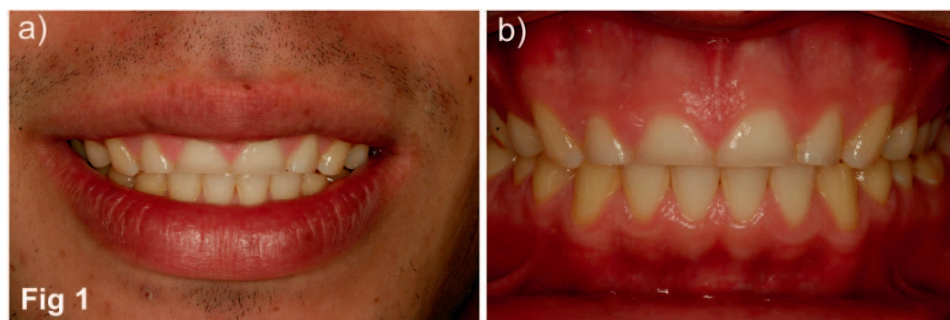


Figure 1. Pretreatment aspect of the patient: extraoral (a) and intraoral (b) views showing the smile and the shortened incisors.

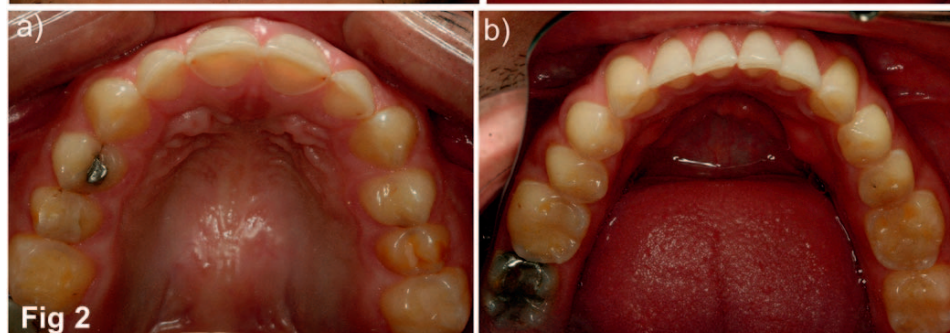


Figure 2. Intraoral view of maxillary (a) and mandibular (b) arches showing the generalized erosive tooth wear.

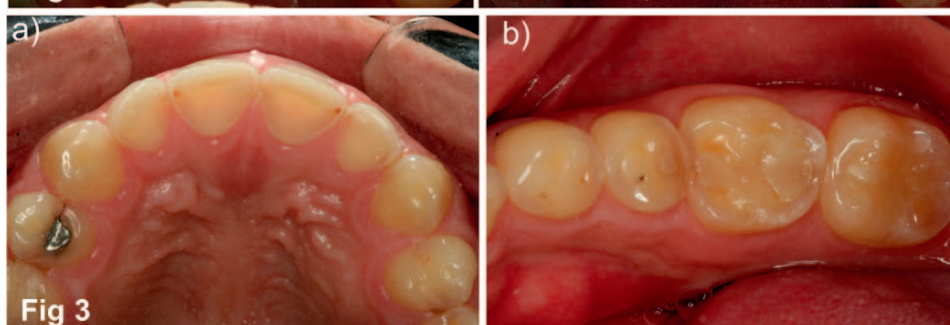


Figure 3. Intraoral view of anterior (a) and posterior (b) teeth showing the damage from tooth wear: exposure of dentin, loss of anatomy, and loss of adaptation of the existing restorations.

problem was extensively discussed with the patient to educate him regarding the importance of his habits in relation to his tooth condition and regarding the necessity of removing the etiological factors to treat and control the sequela of dental erosion.

Clinical examination revealed that to correct the esthetics of his maxillary anterior teeth, the patient's anterior guidance would need to be reestablished with restoration of the eroded posterior enamel and dentin surfaces. The treatment was proposed using composite resin restorations to eliminate further tooth loss. A fixed anterior bite plane was proposed to create anterior interocclusal space for the restorations and to control the parafunctional habit of the patient (Figure 5). Additionally, this fixed appliance induced the extrusion of the posterior teeth, thereby reducing the necessity of extensive restorations and allowing the most conservative treatment possible. This appliance was used for two months and increased the VDO by approximately 1.5 mm, producing adequate

interocclusal space for the restorations. This phase was important to improve occlusion and allow the teeth to passively move until they were once again in occlusion. This phase also created anterior space for teeth, which were stabilized by the appliance.²

When the appropriate VDO was achieved, alginate impressions (Jeltrate 3M ESPE, St Paul, MN, USA) were made of the mandibular and maxillary arches, dental casts were prepared, and the casts were articulated on a semiadjustable articulator in maximum intercuspation to maintain the reestablished VDO (Figure 6). The occlusal posterior restorations were waxed up, and then the casts were duplicated to serve as a mold for fabricating a vacuum-formed matrix template (Figure 7) to reconstruct the posterior teeth with composite resins, a guide to determine the height of the new restorations, and a mold to create the final anatomy of the posterior restorations. All of the teeth were restored using rubber dam isolation (Figures 8 and 9). The teeth were first cleaned with pumice and sandblasted

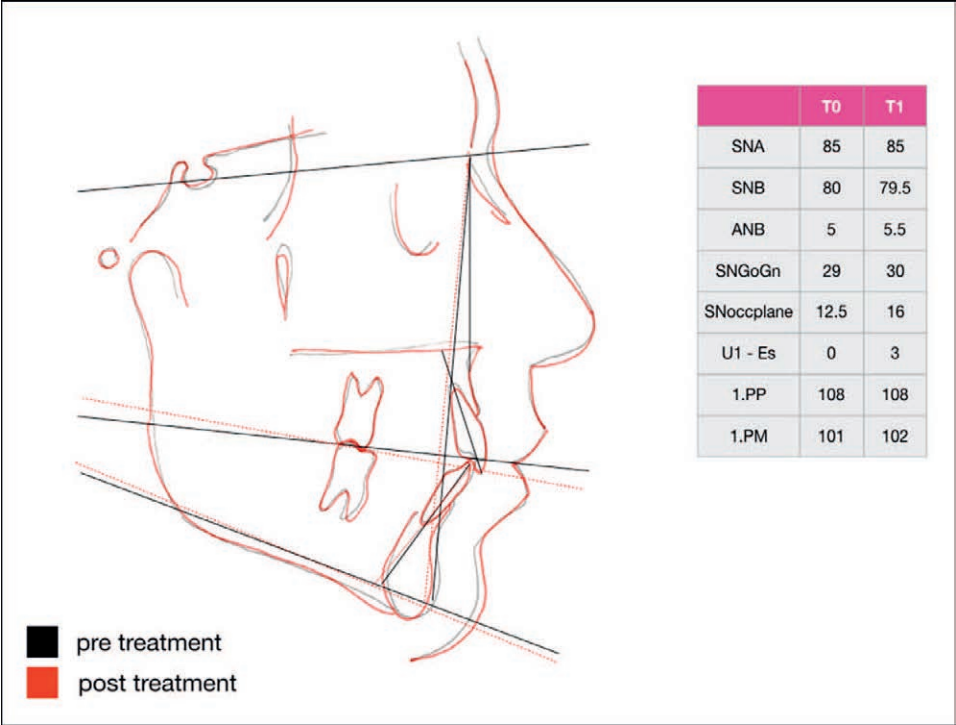


Figure 4. Cephalometric analysis performed before (black traces) and after (red traces) treatment.

using a Rocatec (3M ESPE) to promote better conditions of adhesion under the previous restoration and the eroded, exposed dentin and enamel. Then 35% phosphoric acid (Ultra-Etch, Ultradent Products, Indaiatuba, Brazil) was applied for 15 seconds on dentin and 30 seconds on enamel and rinsed using copious amounts of water. Subsequently, the adhesive (Single Bond 2, 3M/ESPE) was actively applied using brushes, air-dried, and photoactivated for 20 seconds. It is important to floss between the teeth just before curing the adhesive layer to remove any excess adhesive and to avoid bonding the composite to the adjacent teeth. The composite resin used to restore the posterior teeth was a nanohybrid resin (Enamel Plus HRI, Micrium S.P.A., Avegno, Italy), which the manufacturer claims to present a higher refraction index due to its zirconia nanoparticles.

For reconstruction of the molars, the dentin increments (color UD4) were inserted to reproduce the lost cusps. To create a more natural anatomy, a brown pigment (Tetric Color, Ivoclar Vivadent, Barueri, Brazil) was applied with a fine paintbrush between the dentin increments. The restoration matrix was then placed to verify whether more dentin increments were necessary. Once an adequate amount of dentin resin was placed, a thin layer of enamel resin (color GE2) was inserted in the

matrix, which was positioned on the tooth to be restored. The composite resin was photoactivated for 40 seconds through the matrix, the matrix was carefully removed, and excess composite resin was removed from the teeth using a scalpel blade and manual instruments (Microcut, TDV, Santa Catarina, Brazil). The composite was then light cured for an additional 60 seconds (Figure 8).

The procedures used to reproduce the dentin for the molars were repeated to restore the premolars. However, the outer layer of enamel was reproduced using a copy of the occlusal surface of the dental wax-up using a flowable resin (Filtek Z350 Flow, color A2, 3M ESPE). This reproduction of the occlusal surface was cemented on the restorations using a luting cement (Rely X Veneer, color A2, 3M ESPE) (Figure 9). It is important to note that the restorative procedures were individually carried out for each tooth to ensure that the removal of excess adhesive and resin from the adjacent teeth was easily performed with a scalpel blade and that the proximal areas were adjusted using sandpaper strips. After finishing the restoration of one tooth, the next was tooth was restored using the same steps as previously mentioned.

When the posterior restorations were complete, the occlusion was carefully adjusted to verify the appropriate distribution of the occlusal contacts

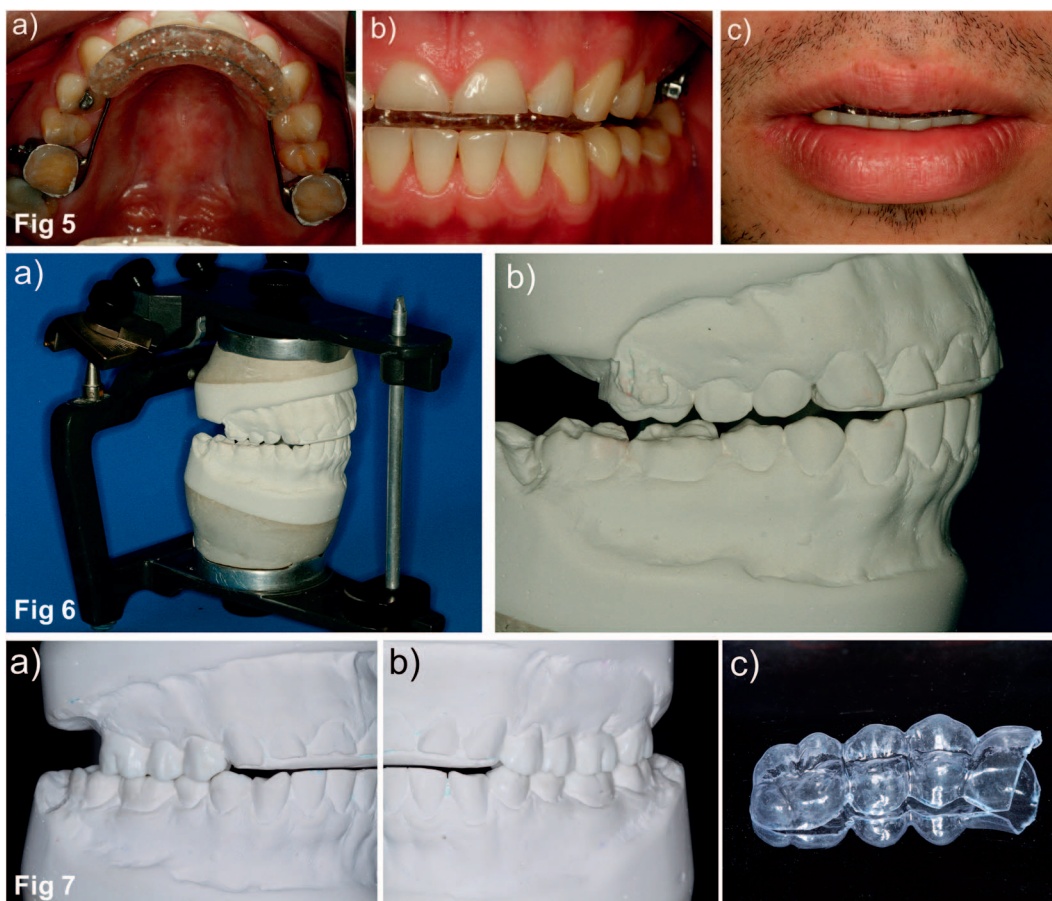


Figure 5. Use of fixed appliance for the patient. (a): Design of the appliance fixed on the maxillary permanent first molars. (b): Interocclusal space created for the future restorations. (c): Lips at rest, demonstrating the loss of VDO. VDO, vertical dimension of occlusion.

Figure 6. Dental casts with the orthodontic appliance for planning the direct restoration (a) casts articulated on a semiadjustable articulator (b and c) demonstration of the provided interocclusal space.

Figure 7. The maxillary posterior restorations were waxed up (a and b), and a matrix template (c) was created to guide the restorative phase.

(Figure 10). Finishing and polishing were performed using extrafine diamond burs (KG Sorensen, São Paulo, Brazil) and silicon rubber (Enhance, Dentsply, Catanduva, Brazil). Strips of sandpaper were used for interproximal polishing (3M ESPE).

After restoring the posterior teeth, the reestablished VDO (Figure 11) was tested for one month to allow for the detection of any possible nonadaptation to the new VDO and occlusion before delivering the anterior restorations. The patient maintained an anterior open bite during this phase and related that he was very comfortable with the new occlusion. No major modifications were required for the posterior composite restorations.

New dental casts were obtained from the patient to perform the wax-up of the anterior restorations. After the wax-up, the dental cast was duplicated,

and a silicone matrix of the anterior teeth was obtained for use as a guide to construct the palatal surface of the restorations and to establish the correct height (Figure 12). The restorative procedures were performed under isolation using a rubber dam stabilized with clamps on the second premolars. The anterior teeth were prepared using 35% phosphoric acid for conditioning the enamel and dentin surfaces as previously described. The adhesive was placed, air-dried, and photoactivated for 20 seconds. The enamel resin was inserted in the silicone matrix in the region corresponding to the palatal enamel. The matrix was then positioned on the teeth and photoactivated. The palatal surface of each tooth was used as the basis for the other increments of composite resin (color GE2, Enamel Plus HRI, Micerium S.P.A). The lateral and central incisors were built using composite resin increments to

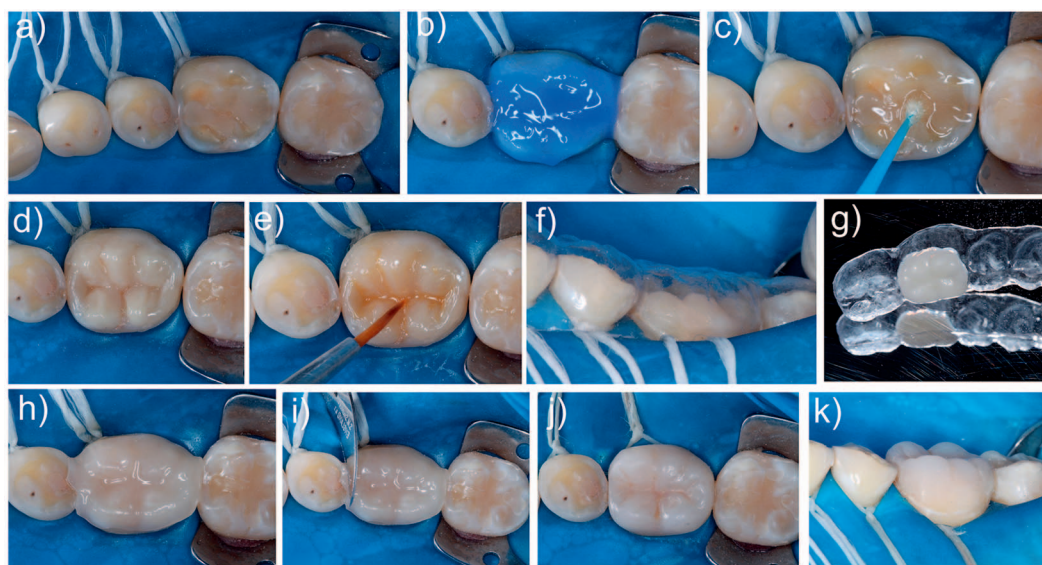
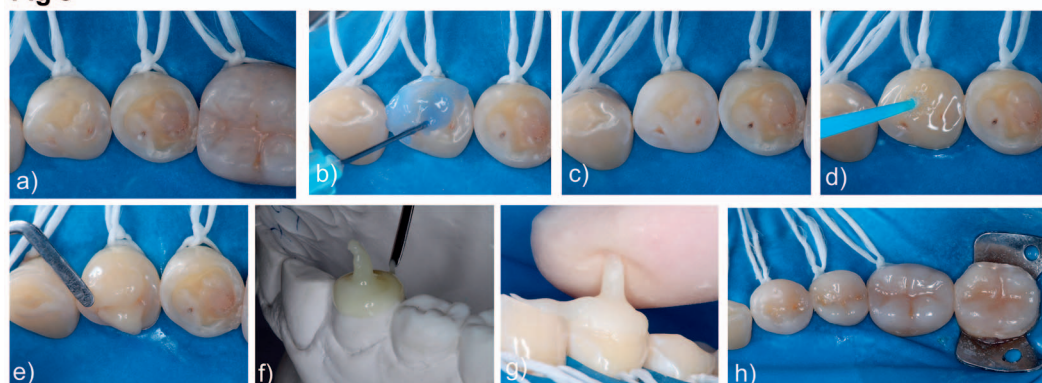
**Fig 8****Fig 9**

Figure 8. Reconstruction of the molars. (a): Teeth after rubber dam isolation and sandblasting. (b): 35% phosphoric acid conditioning. (c): Application of adhesive. (d): Insertion of dentin increments. (e): Pigmentation of the restoration. (f): Placement of the matrix to guide the thickness of dentin and enamel increments. (g): Insertion of enamel resin in the silicon matrix. (h): Restoration after placement of the matrix and light curing. (i): Removal of the excess. (j and k): Final aspect of the restorations.

Figure 9. Reconstruction of the premolars. (a): Teeth after rubber dam isolation and sandblasting. (b): 35% phosphoric acid conditioning. (c): Teeth after conditioning. (d): Application of adhesive. (e): Insertion of dentin increments. (f): Placement of flowable composite under the copy of the occlusal surface. (g): Cementation of restoration. (h): Final aspect of the restorations.

reproduce dentin using color A3 for the middle third and color A2 for the incisal third (Four Seasons, Ivoclar Vivadent). A small increment of translucent resin was placed on the incisal third to reproduce the characteristics of this region (Clear, Four Seasons, Ivoclar Vivadent). Finally, an enamel composite resin (Estelite Sigma, Tokuyama Dental, Encinitas, CA, USA) in color A2 at the middle and color A1 at the incisal third was used to construct the enamel surface. For the canines, color A3 resin was used for dentin (Four Seasons, Ivoclar Vivadent) and for the vestibular enamel (Estelite Sigma, Tokuyama Dental) (Figure 13).

Following the restorations, occlusal adjustment was performed, verifying contacts in protrusive and lateral excursive movements of the maxilla and mandible (Figure 14). Finishing and polishing of the restorations was performed using silicon rubber (Enhance, Dentsply), abrasives disks (3M ESPE), and felt disks (FlexiBuff, São Paulo, Brazil). Strips of sandpaper were used for interproximal polishing (3M ESPE). The final occlusal relationship was satisfactory. The patient's smile was immediately changed in tooth size and shape, giving him an appearance in agreement with his age and gender since he displayed his teeth even with his lip at rest (Figure 15). To maintain the restorations and to



Figure 10. Occlusal adjustments after restorations: maxillary (a) and mandibular (b) views.



Figure 11. Aspect of the maxillary anterior teeth after reestablishing VDO. VDO, vertical dimension of occlusion.

control for his habit of bruxism, an occlusal guard, a hard splint for the maxillary teeth, was delivered to the patient to be used during the night. The use of the hard night guard was also monitored at the seven-year follow-up.

The clinical follow-up was accomplished for seven years. Silicone impressions that were poured using epoxy resin were obtained at 12 months from completion of treatment. The mold of selected teeth, canines, and first molars was visualized under scanning electron microscopy (SEM), which showed wear of the cusp tips of the canines (Figure 16), the palatal cups of the maxillary molars, and the buccal cusp tips of the mandibular molars (Figure 17), which were restored and maintained in the SEM control at six and 12 months. Moreover, the patient was recalled every year, when a polishing was executed to provide maintenance of the restorations. After six years, a satisfactory appearance of the patient was still seen (Figure 18). The last clinical follow-up was completed at seven years (Figures 19 and 20), where the satisfaction of the patient (esthetic success) and maintenance of the restorations and teeth (biological success) can be seen. A new cephalometric radiographic analysis (Figure 4; red traces) was performed to show the changes that were achieved with the treatment.

DISCUSSION

Patients affected by severe dental erosion are frequently predisposed for a full-mouth rehabilitation treatment.^{2,14,16-19,21} Often, tooth wear is diagnosed as a multifactorial condition^{2,9,10} caused by several factors, such as erosion and bruxism in this case report. Currently, with improved adhesive techniques and suitable composite resin materials, a more conservative treatment may be proposed for the patient.^{22,24} A modern approach for the treatment of tooth wear is to prevent the progression of this disease to avoid full prosthetic rehabilitation, causing large amounts of additional removal of tooth.² All treatment plans should include a clinical investigation of the causes of wear;¹¹ the control or removal of those etiological factors, in this case the habit of sucking on lemons and bruxism; and a restorative approach by means of direct composite restorations, followed by a maintenance phase, including the use of a mouth guard and regular checkups.² When planning a treatment, adequate communication with patients is essential to inform them of the importance of their problem and treatment. In most cases, patients may believe that a satisfactory result can be achieved by focusing only on anterior teeth, and thus they will not be interested in a more comprehensive treatment plan.



Figure 12. Planning the anterior restorations. (a): Wax-up. (b): Silicon matrix in position.

Figure 13. Anterior restorations. (a): Teeth after isolation. (b): Placement of the first resin increments in the silicon matrix and light curing. (c): Reconstruction of the palatal face. (d and e): Palatal reconstruction with enamel resin in occlusal and frontal view. (f): Insertion of the dentin resin. (g): Insertion of translucent resin in the incisal third. (h): Immediate aspect of the restoration after insertion of the enamel composite.

Figure 14. Occlusal adjustments of the anterior restorations: lateral extrusive (a and b) and protrusive (b) movements.

Figure 15. Aspect of the restorations after polishing. (a): Intraoral view. (b): Smile view. (c): Lips at rest.

The treatment protocol for this case report applied a sequence adapted from a treatment proposed by Vailati and others¹⁷⁻¹⁹ that consisted of an assessment of the occlusal plane, reestablishment of the posterior occlusion, an increase of VDO, and the return of anterior guidance. Increasing VDO was necessary to compensate for the enamel loss and to gain interocclusal space that was shared equally between the mandibular and maxillary posterior

teeth. Diagnostic wax-ups are important tools to be used for this clinical step. Modification of the protocol applied in the present report included using a fixed occlusal splint prior to the restorative approach that was applied to adjust the interocclusal space and control the parafunctional habits of the patient. Commonly, this step may be performed using provisional composite inlays bonded to the teeth and a removable guard, as proposed by several

reports.^{13,17-19,25} Although this method might be more esthetic and comfortable for the patient, it has the disadvantages of additional lab fees, and it is not a truly reversible approach since it could require some tooth preparation to ensure a minimal thickness of the onlays.¹⁷⁻¹⁹ Moreover, the presence of fixed provisional restorations would not allow for the extrusion of the posterior teeth, with the final rehabilitation performed with extensive restorations. As with the present case, bonding of provisional restorations was dropped in order to perform a less invasive treatment.

The use of a removable guard is traditionally indicated for a fully reversible approach; however, its use requires compliance of the patient. Considering the current lifestyle of most people, it is rather naive to expect that patients will wear an occlusal guard 24 hours a day.¹⁸ The treatment plan indicated for this patient included the use of a fixed orthodontic appliance for two to three months to correct the anterior bite plane. This appliance was fixed to the maxillary molars using orthodontic bands and contained an acrylic plane for disocclusion of the patient. To achieve good conditions of oral hygiene, this acrylic was polished to allow the use of dental floss for the patient. The aim of this appliance was to allow for the extrusion of the posterior teeth, thus increasing the VDO. Consequently, appropriate anterior interocclusal space was created for the indicated restorations. This occlusal stabilization splint is a reversible intervention that may reduce tooth grinding, muscular activity, and myofascial pain of the patient.²⁶ The use for two months was crucial for verifying the adaptation of the patient to his new VDO before the final restorative treatments were performed.²⁵ The expected extrusion of posterior teeth was around 1 to 2 mm, which increased the mandibular plane angle and caused an anterior open bite, providing space for incisor restorations. Cephalometric analysis showed that the upper occlusal plane was increased by 3.5 degrees, while the incisor display related to the upper lip at rest position increased 3 mm (Figure 4). Consequently, the occlusal plane provided a better smile for the patient.

Currently, the use of adhesive techniques and hybrid composite technology in particular has proven its potential in the treatment of moderate tooth wear.¹⁶ Especially for young patients, adhesive restorations represent a more conservative treatment approach, reducing the need for preparation when restoring the morphology of worn teeth.²¹ Retrospective studies evaluating the clinical perfor-

mance of direct restorations in cases of tooth wear and with increasing VDO show that the composite resins are suitable materials for this treatment, with low failure rates in an average of three years of evaluation.^{20,21,23} Additionally, technical improvements of resin restorative materials provide good and predictable clinical long-term results. The use of a vacuum-formed matrix template obtained from the model wax-ups, as reported in this case, allows for the establishment of restorations and a new vertical dimension without using a freehand technique and, as a consequence, an unbalanced occlusion.²³ Attin and others²⁰ evaluated the results of this noninvasive technique in a case series after three and after five and a half years and analyzed several parameters, such as surface texture, anatomical form, marginal discoloration, and integrity, among others. According to their results, all parameters analyzed were classified as minimal or no alterations (alpha criteria) after three years. At the five-and-a-half-year follow-up, most of the restorations presented some alteration (as indicated by an increase of the incidence of bravo criteria), although all of the alterations were easily solved with polishing and simple repair procedures.

As with Attin and others,²⁰ this case report evaluated the longevity of the restorations clinically and by using SEM analysis. The follow-up at six years represented by the clinical evaluation showed the clinical maintenance of the restorations over time (Figure 17). On the other hand, the SEM evaluation up to 12 months demonstrated the stability of the restorations in relation to anatomical form and marginal adaptation, especially for the canines and molars, since there were no visible wear facets or marginal maladjustments.

One of the most common concerns for resin restorations is the wear or degradation of the material over time. Especially in patients with an erosive/bruxism background, the clinical long-term success can be hampered due to a combination of abrasion, attrition, chemical degradation, and material fatigue, even in stress-free areas.²³ In these cases and in posterior restorations, the type of composite resin used is important. With respect to wear, fine hybrid composite resins have behaved well in clinical investigations.^{20,27,28} Additionally, clinical follow-up studies have shown that fine hybrid composite materials exhibit wear similar to heavily loaded occlusal enamel areas.^{27,28} These composites show adequate physical properties that are important for the longevity of extensive composite restorations under masticatory load, including

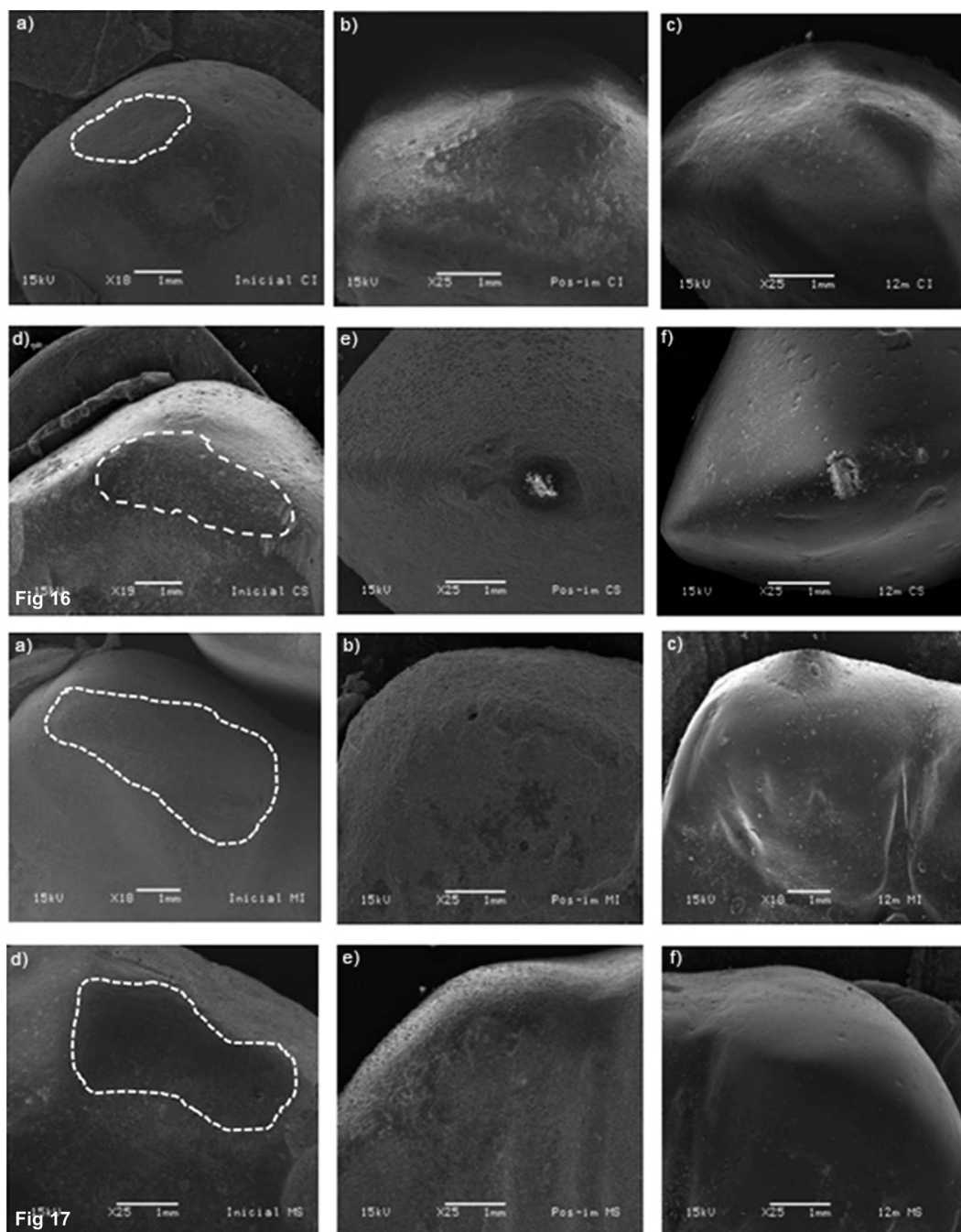


Figure 16. Microscopic impressions of the maxillary (a-c) and mandibular (d-f) canines. (a and d): Initial. (b and e): After restorations. (c and f): After 12 months.

Figure 17. Microscopic impressions of the maxillary (a-c) and mandibular (d-f) molars. (a and d): Initial. (b and e): After restorations. (c and f): After 12 months.

the properties of flexural strength, moduli of elasticity, microhardness,^{29,30} and wear resistance.³⁰

The composite used in this case report to restore the posterior teeth included a zirconia nanofiller. Manufacturers claim that including nanoparticles in

resin composites allows for the production of materials with an increased filler load and better physical and mechanical properties. These nanofilled resins present viscosities and viscoelastic properties comparable to those of universal hybrid composites.²⁹ Randomized clinical trials have shown that there are



Figure 18. Esthetic appearance of anterior teeth after six years: smile (a) and intraoral (b and c) views.

Figure 19. Intraoral view of the restorations during follow-up. (a and f): Immediate. (b and g): After 12 months. (c and h): After three years. (d and i): After six years. (e and j): After seven years.

Figure 20. Esthetic appearance of patient's smile after seven years.

no significant differences between the wear rate of posterior restorations with nanofilled and microfilled resin up to six years of evaluation.^{28,31} In addition to the good mechanical properties, the small filler particles in the composite resin improve the surface

polishing and smoothness of the restoration. These composites also have improved optical properties because the diameter of the particles is a fraction of the wavelength of visible light, resulting in the inability of a human to detect the resin materials.³²

According to the manufacturer, the composite resin Enamel Plus HRI (Micerium S.P.A.) has a refractive index similar to that of a human tooth (1.62). These characteristics and properties indicate the use of this composite for both posterior and anterior restorations, as performed in this clinical report.

The treatment of worn teeth with direct restorations needs a maintenance phase in which the patient uses a protective night guard or therapeutic appliance. In this phase, the night guard seems to be the most effective measure to prevent parafunctional activities and possible occlusal interferences, which are common in patients with bruxism.¹⁶ Additionally, patients are required to return for regular checkups for possible repair of their restorations. Recent data advocate these conservative procedures in cases where the restorations are classified with bravo criteria.^{33,34} Gordan and others³³ conducted a clinical trial with a seven-year recall and validated the success of repairing composite restorations instead of a full replacement as a conservative intervention.

CONCLUSIONS

The incidence of tooth wear represents an increasing concern in the clinical practice and has multifactorial origins. The clinical situation presented in this report showed a direct restorative approach to rehabilitate worn dentition. The use of an occlusal splint was important to control the parafunctional habits of the patient and to create a new occlusion pattern. The use of vacuum-formed and silicone matrices obtained from wax-up models are reliable techniques that can be employed to provide an esthetic and conservative result. This seven-year clinical follow-up indicates that a treatment of dental erosive lesions with direct composite resins is a predictive and conservative option for younger patients.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of approval of the State University of Maringá.

Conflict of Interest

The authors of this article 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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