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Academy of Operative Dentistry • American Academy of Gold Foil Operators • Academy of R.V. Tucker Study Clubs

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On The Cover

"Stained glass in Sainte-Chapelle. "The windows were painstaking restored using cutting-edge techniques, and the work was completed in 2014.This use of advanced technology to restore things to their original state is very similar to the methods of Operative Dentistry" Paris, France. Photo provided by Akimasa Tsujimoto of Tokyo, Japan. Photo taken with a Canon 7D Mark II, Sigma 8-16mm F4.5-5.6 DC HSM, 10mm, f/4.5 at 1/30 sec exposure. © Operative Dentistry, Inc."

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Editorial

Servant Hearts

JA Platt, Editor

There are times in life when we pause, put down the work that lies before us, and reflect on things that have been done by others in our lives. For various reasons, the past couple of months have given me opportunity to do just that. I would like to share some of those reflections here. The following just touches on the lives of a few people who have made significant impact in my life. My desire is that, by taking a minute or two to read it, you might pause and reflect and, perhaps, gain encouragement in your life from what they have done for you.

In November 2015, the American Dental Association honored Dr. Richard V. Tucker with its Distinguished Service Award during its annual meeting of the House of Delegates. ADA President Dr. Maxine Feinberg presented the award stating that "His dedication to excellence in dentistry and to high ethical standards has impacted countless dentists around the world. The fact that there are more than 50 active Tucker Clinical Operating Study Clubs around the globe speaks to Dr. Tucker's leadership in his field."[1] He is the namesake of the academy of study clubs that has committed support to this journal, just another way that Dr. Tucker continues to impact the practice of dentistry. An interesting factoid that may not be widely known is that Dr. Tucker was born in the town of Orofino[1] – get out your Spanish dictionary for that one! The Academy of Operative Dentistry previously recognized Dr. Tucker with its Award of Excellence in 1992.[2] The example of Dr. Tucker continues to provide inspiration around the world.

With the close of 2015 comes further change. Dr. Bruce Matis has served as an Associate Editor for Operative Dentistry for sixteen years. During that time, he took on the major role of interfacing with our corporate sponsors, successfully keeping the subscription rates for this journal among the most attractive available. Bruce has: provided countless manuscript reviews when other reviewers were difficult to find; helped shape the bleaching content published in the journal; consistently contributed unique perspectives during our quarterly Editorial Board meetings; and has been a steady support for the journal editor and staff alike. The lack of his regular presence will certainly be felt by us all. He is another shining example of someone who lives devoted to his commitments, someone who could always be counted on to do what needs to be done. It is one of his qualities that I hope many would recognize and desire to emulate.

Also leaving the editorial staff is Dr. William Browning. He retired from his academic life in 2015 and resigned his Associate Editor position shortly after that transition. Bill came to the journal staff with his move to Indiana University where he held the Indiana Dental Association Endowed Chair of Restorative Dentistry position. Bill's insights and expertise in clinical research provided much needed support in the editorial process. Although his tenure was shorter than some, his contributions had huge impact during his time with us. I wish him well in the years ahead.

These three individuals have gone above and beyond the call of duty. Working with gratitude for what they have and what they have been given, their lives provide examples of service and mentoring that have touched countless numbers of people.

As this New Year begins, take a moment to reflect on the power of the influence that you can have and ask of yourself, "Am I living my life in such a way that others are being served and mentored?"

If not, why not?

Thank you Dick, Bruce, and Bill for all that you have done for our profession and, consequently, for humanity. May each of you continue to find ways to serve in the years that lie ahead!

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Clinical Technique/Case Report

Esthetic Challenges in Rehabilitating the Anterior Maxilla: A Case Report

ME Miranda • KA Olivieri • FJF Rigolin
AA de Vasconcellos

Clinical Relevance

The reestablishment of esthetics and function of anterior teeth can be achieved with correct treatment planning using a conservative technique to condition soft tissues and full metal-free crowns to provide an esthetic smile.

SUMMARY

The rehabilitation of an unesthetic smile in the anterior maxilla is always a clinical challenge, especially when an improper shape and size, old restorations, and unesthetic shading are present. In addition, an irregular gingival zenith contour in the anterior maxilla can affect the smile's harmony. Thus, detailed treatment planning is needed to define a functional and esthetic prosthetic rehabilitation. This study describes a clinical case in which a 55-year-old woman was rehabilitated using Digital Smile Design planning and full ceramic crowns (metal free) in the anterior zone of the maxilla and mandible. To normalize the gingival zenith, a dynamic compression technique was performed using provisional restorations to condition the gingival tissues and harmonize the proportional length of the anterior upper teeth.

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INTRODUCTION

Oral rehabilitation using all-ceramic systems has become widespread all over the world because it is reliable and successful, considering its ability to simulate the optical properties of teeth in relation to color, surface texture, and translucency; low biofilm adherence;[1] wear resistance; and biocompatibility.[2] However, rehabilitation of unesthetic teeth in the anterior maxilla to achieve natural-looking restorations becomes a major challenge,[3] considering the presence of improper shape and size of the existing teeth, irregular gingival contour, and unesthetic shade. In addition, the dental professional and dental lab technician must work together closely to achieve the patient's expectation, as the esthetic outcomes are of utmost importance.[4]

Figure 1. *Anterior view, with periodontal disease and unpleasant esthetics in the anterior zone of the maxilla.*

To obtain better predictability in esthetic rehabilitation using all-ceramic crowns, the design of dental restorations should be previously defined.[5] Digital Smile Design (DSD) is a useful tool that allows a detailed analysis of the patient's dental and facial characteristics through clinical, photographic, and diagnostic wax-up evaluations, enabling the identification of discrepancies in soft and hard tissue morphology.[6]

To provide an optimal esthetic appearance, adequate contour of the gingival zenith for the esthetic teeth is an important aspect that should be evaluated. The recontouring of gingival zeniths may be performed using periodontal surgery or a provisional restoration that conditions the soft tissue.[7,8] The first option may be performed using flapless surgery to remove the gingival tissue to create an appropriate clinical crown length.[7] From a clinical perspective, the second option is more conservative, considering that soft tissue conditioning is achieved using provisional restorations.[8] These techniques aim to determine the location of the crown margin, the final contour of the gingival zenith, and soft tissue architecture.

Therefore, the purpose of this article is to describe a clinical case in which the anterior area of the maxilla was rehabilitated using DSD planning, a dynamic compression technique was performed using provisional restorations to the conditioning of the gingiva, and metal-free ceramic crowns were placed.

CASE REPORT

A 55-year-old woman, in good general health, presented for treatment with the primary complaint of unpleasant esthetics in the anterior zone of her maxilla. An esthetic analysis of her teeth revealed periodontal disease, restorations that were old and

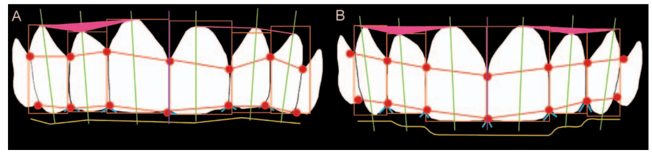

Figure 2. *(a) Initial arrangement of teeth; (b) Modifications and improvements in the anterior maxilla based on esthetic principles obtained using Digital Smile Design.*

not color matched, and an irregular contour of the gingival tissue in the anterior region of the maxilla (Figure 1). No temporomandibular disorders or parafunctional habits were reported.

Taking into account that the patient was positively motivated and wished to improve the esthetic appearance of her smile, a treatment plan was established based on a DSD protocol. For this purpose, impressions were made of the maxilla and mandible using an irreversible hydrocolloid (Hidrogun, Zhermack, Badian Polesine, Italy). Study casts (Kromotypo4, Lascod, Firenze, Italy) were fabricated and mounted in a semiadjustable articulator. In addition, a photographic protocol was performed, allowing a careful analysis of the horizontal reference plane, facial midline, color and smile design, tooth shape and arrangement, and DSD planning.[6]

Many modifications and improvements in the anterior zone of the maxilla based on esthetic principles were considered in the current case using DSD planning (Figure 2a,b). Initially, it was observed that the tooth axis and the gingival zenith contours were not satisfactory. In addition, the interproximal contacts and the height of interproximal papillae were irregular and unesthetic. Considering the dental arrangement, the initial design of the incisal edge and the balance of triangles of the incisors and canines were not satisfactory compared with a harmonic dental arrangement obtained by DSD planning.

With the study casts mounted on the articulator and modifications established with DSD, a diagnostic wax-up was obtained, enabling the observation of an ideal contour, size, shape, and occlusion of the anterior region of the maxilla (Figure 3a,b). The diagnostic wax-up was presented to the patient to confirm the treatment plan. The patient agreed with the treatment plan, which included using zirconia-reinforced ceramic copings for all anterior maxillary teeth, including premolars and anterior mandibular teeth.

Prior to initiating the prosthetic rehabilitation, periodontal treatment was performed, providing an adequate oral health for the patient. It is important

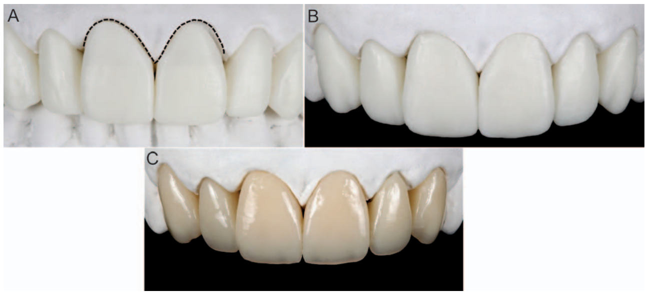

Figure 3. *(a,b) Diagnostic wax-up before and after creating the adequate gingival zenith contour, highlighting an ideal contour, size and shape; (c) Provisional restorations.*

to highlight the necessity of normalizing the gingival contour zenith to provide an optimal esthetic appearance; this was especially true for the left central incisor in this current case. A connective graft was the first treatment option discussed with the patient to reestablish the esthetic appearance for the left central incisor, considering that the gingiva on the right central incisor was too coronal compared to the left central incisor. However, the patient refused this treatment option. Another option to improve the esthetic appearance without surgical procedures was to use a dynamic compression technique with provisional crowns to condition the gingiva.

For this, provisional restorations were made according to the diagnostic wax-up (Figure 3c). This technique consists of a dynamic compression of the gingiva with a concave and a convex approach, performed weekly. Every week, a selective pressure was applied through the addition of light-cured acrylic resin (SNAP, Parkell, Farmingdale, NY, USA) on the cervical region of specific provisional restorations. After 4 weeks, adequate contour of the gingival margin was observed, greatly improving the esthetics of the anterior maxillary teeth.

The teeth were prepared, the provisional restorations were cemented (Figure 4), and the patient was followed for 4 weeks to condition the soft tissues and to achieve a regular gingival zenith contour in the maxillary anterior teeth.

To guide the treatment sequence, a silicone index (Speedex, Coltène/Whaledent Company, Altstatten, Switzerland) was fabricated according to the diagnostic wax-up. After soft tissue conditioning, the provisional restorations were removed, and shade selection was performed (Figure 5), trying to mimic the optical properties of the tooth structure.

For the final impression, retraction cord was used for gingival retraction (Ultrapak no. 0, Ultradent

Figure 4. *Anterior view with provisional crowns.* Figure 5. *Tooth preparation and shade selection.* Figure 6. *Zirconia copings.*

Products, South Jordan, UT, USA), and a double-mix impression technique, with addition silicone (Elite HD, Zhermack), was used to reproduce the teeth and surrounding soft tissue. Working casts were obtained for the laboratory procedures.

To obtain the zirconia copings (Lava System, 3M ESPE, St Paul, MN, USA), a computer-aided design/computer-aided manufacturing system was used (Figure 6). In the sequence, the ceramic (IPS e.max Ceram, Ivoclar-Vivadent, Schaan, Liechtenstein) was fired in different steps over the zirconia copings to build the full ceramic restorations. During the ceramic application and firing, a silicone index was used based on the diagnostic wax-up to guide the

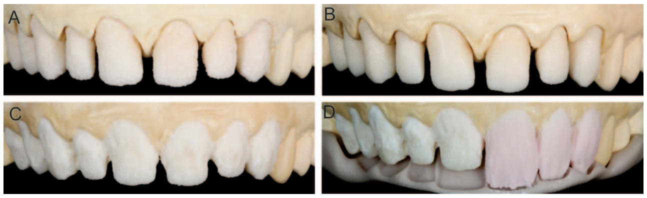

Figure 7. *(a-d) Ceramic firing based on the diagnostic wax-up using a heavy silicone index.*

previously defined esthetic principles related to size and shape (Figure 7a-d).

An interesting aspect related to the maxillary central incisor restorations is the difference in the gingival contour among the anterior teeth. In this case, the metal-free restorations were made according to the dynamic compression technique, with a concave and a convex approach. Therefore, considering a concave approach, the cervical border moves the gingiva down (Figure 8a), and with the convex approach, the cervical border moves the gingiva up (Figure 8b), resulting in a more harmonic gingival zenith aspect.

Before final cementation, a prophylaxis using pumice was performed. A resin cement was used (RelyX 100, 3M ESPE) to cement the final restorations. Careful positioning of the metal-free crowns occurred during cementation, and then the resin cement was polymerized for 40 seconds. During cementation, oral fluids and any hemorrhage process were controlled. Afterward, the excess resin cement was removed. The occlusal and interproximal contacts were assessed, and marginal adaptation was performed according to the established biologic and esthetic parameters. It was possible to observe the difference in gingival zenith contours during the soft tissue conditioning through the provisional restorations and after the prosthetic rehabilitation. The dynamic compression technique was an effective treatment to provide favorable esthetic results in this area with the regularization of the gingival zenith contour (Figure 9a,b). A beautiful and

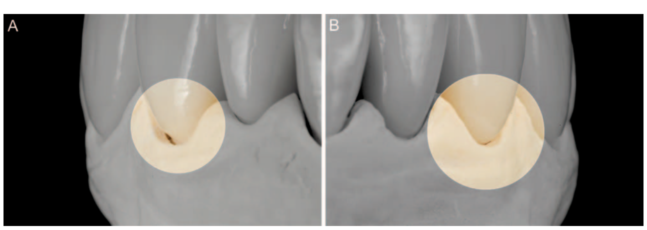

Figure 8. *(a) Provisionals used for tissue conditioning and (b) final ceramic crowns and the improved gingival zenith.*

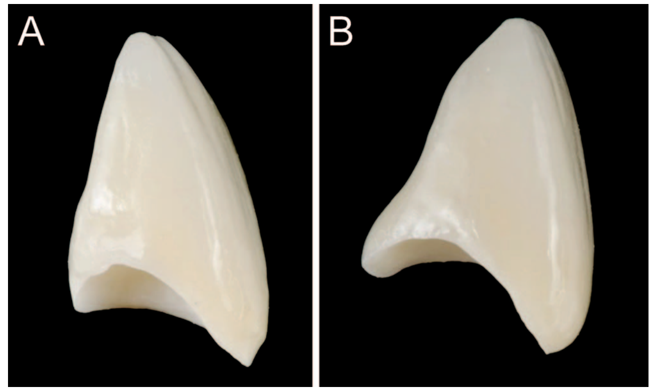

Figure 9. *Highlight to the (a) concave and (b) convex borders of the ceramic restorations.*

pleasant result was obtained, changing the patient's smile (Figure 10a-d).

DISCUSSION

The elevated expectation of patients and dentists for esthetic restorations has resulted in a trend to substitute metal-ceramic restorations with metal-free restorations.[9,10] The ceramic systems offer improved esthetics, biocompatibility, and long-lasting restorations and are an excellent alternative for the rehabilitation of anterior teeth, having been increasingly used with high success rates.[11]

To achieve esthetic and functional harmony, treatment planning is usually realized using wax-ups for diagnosis.[12] However, DSD was used initially in the current case for an esthetic diagnosis and to provide better communication with the patient and technician. When considering these aspects, a digital photography protocol allows better visualization and analysis of issues that are usually observed clinically.[6] In addition, it is possible to establish excellent communication with the patient to realize preferences related to shape, morphology, and size of the teeth and to forward all these aspects to the

Figure 10. *(a,b) Before prosthetic rehabilitation. (c,d) After rehabilitation, presenting a beautiful and pleasant result.*

technician, increasing the predictability of the restorations.[13] With all this information, a three-dimensional wax-up may also be used for the mock-up and to guide the technician during ceramic firing.[14]

A challenge related to the esthetic smile in the present case is asymmetry among the anterior maxillary teeth, taking into account that the gingival contour was modified. The gingival zenith can be defined as the most apical point of the marginal gingiva.[15] However, the quantitative orientation of the gingiva in the mesio-distal and apico-coronal directions has not been reported in the literature.[16] A previous study showed that, in the upper anterior teeth, the gingival zenith of the canine is apical in relation to central incisors and that the gingival zenith of the lateral incisor is approximately 17% below the gingival line when considering the head positioned on the axial orbital plane.[17] These aspects are important as guidelines for obtaining predictable esthetic results.

To provide an adequate gingival zenith and achieve outstanding anterior esthetics with ceramic restorations, different techniques may be used. The periodontal modification may be performed using gingivoplasty, with or without the involvement of osteotomy or osteoplasty.[7] However, the discrepancy of the gingival zenith for the left upper central incisor was treated in the current case through a dynamic compression technique using provisional crowns. This technique consists of conditioning soft tissues in the esthetic area to establish an adequate emergence profile using a concave or a convex approach and provide harmony with the gingiva of the adjacent teeth.[7,8]

Ceramic restorations are widely used in the rehabilitation of anterior and posterior teeth, and many ceramic systems have been developed for clinical use.[18] Zirconia-based dental ceramics are stronger than conventional glass-ceramic restorations and have excellent mechanical strength properties.[19] They can be used to fabricate single crowns and three-unit fixed-bridge frameworks, considering that zirconia flexural strength is approximately 900-1100 MPa.[20] In the present case, zirconia copings were used for all restorations. However, a zirconia core is opaque and lacks translucency.[21] For this reason, IPS e.max Ceram was used over the zirconia copings to improve the esthetic appearance. This system consists of a nanofluorapatite glass ceramic distinguished from all previous ceramic systems by specific features, such as improved translucency and unique opalescent shades that are achieved with the help of opacifiers and ion coloring, while also providing high strength, considering that a very high crystalline content of approximately 70% can be included in the glass matrix to increase the strength without compromising translucency.[22,23] Thus, IPS e.max Ceram allows the creation of natural and lifelike restorations, with adjustable translucency, brightness, and opalescence combinations, which are characterized by improved stability, shape, and color.[24]

CONCLUSION

Successful anterior restorations can be achieved when using a detailed treatment plan and when considering the esthetic and functional parameters. The use of a conservative technique to condition soft tissues is attractive to the patient, and metal-free crowns improve the dental arrangement and shade matching, providing a pleasant smile for the patient.

Acknowledgement

Our appreciation to CDT Cristiano Soares for his beautiful and meticulous work making the ceramic crowns.

Regulatory Statement

This case was conducted at the São Leopoldo Mandic School of Dentistry, in Campinas, 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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Treatment of Enamel Surfaces After Bracket Debonding: Case Reports and Long-term Follow-ups

RH Sundfeld • LM Franco • LS Machado
NIP Pini • FM Salomao • RB Anchieta
D Sundfeld

Clinical Relevance

After bracket debonding and mechanical removal of residual bonded material, the use of enamel microabrasion can be an excellent method for restoring the morphologic characteristics of the enamel surface.

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SUMMARY

After bracket debonding, residual bonded material may be observed on the enamel surface. When not properly removed, this residual material can interfere with the surface smoothness of the enamel, potentially resulting in staining at the resin/enamel interface and contributing to biofilm accumulation. Clinical case reports demonstrate clinical procedures to remove residual bonded material after bracket debonding. A water-cooled fine tapered 3195 FF diamond bur was used to remove the residual bonded material. Subsequently, the enamel surface was treated with Opalustre microabrasive compound. After one week, overnight dental bleaching was initiated using 10% carbamide peroxide in custom-formed trays for four weeks. The enamel microabrasion technique was found to be effective for polishing the enamel surface and for reestablishing the dental esthetics associated with dental bleaching. Longitudinal clinical controls of other clinical cases are presented.

INTRODUCTION

The aim of orthodontic treatment is to correct the malpositioning of teeth, which can affect the pa-

Figure 1. *Example of resin cement remaining after bracket debonding.*

Figure 2. *A 25-year-old male patient who presented with residual bonded material on the maxillary and mandibular facial surface after removal of orthodontic brackets.*

tient's mastication, speech, and hygiene. Consequently, the functional correction can also provide better dental esthetics by providing harmony between the teeth and smile. Nevertheless, there are concerns regarding the adhesion of brackets, including the need for sufficient bond strength, ease of debonding, and the limited risk of permanent damage to the enamel surface.[1]

At the conclusion of orthodontic treatment and after bracket debonding, residual bonding material may remain on the facial enamel surface (Figure 1), which may clinically influence the esthetics of the enamel and smile.[2] When not properly removed, this retained resin bonding material interferes with surface smoothness of the enamel, potentially resulting in staining at the resin/enamel interface and contributing to biofilm accumulation.[3,4]

Several protocols have been proposed for removing the residual bonding material, such as using pliers; using diamond, carbide, or tungsten burs; and polishing with discs, cups or points or with impregnated aluminum abrasive discs.[3,5-9] Ultrasonic removal and bioactive-glass air-abrasion have also been reported in the literature.[6,10] Regardless of how carefully the residual material is removed, however, iatrogenic damage to the enamel after debonding procedures is inevitable.[3,11] No instrument can achieve complete composite removal without affecting the enamel surface.[2,12] Therefore, these techniques result in some superficial damage to the enamel surface, inducing scratches or grooves on enamel tissue, which can affect the anatomical shape and surface smoothness.[8,13,14] Additionally, improper debonding can result in cracks on the enamel surface or fracture of the enamel prisms.[3] As a consequence, tooth sensitivity, increasing risk of caries, and pulp necrosis can occur,[3] especially when dealing with ceramic brackets.[1]

To obtain a smoother and more regular enamel surface, some studies[15-18] have proposed removing residual material by using a diamond bur in a high-speed handpiece under water cooling and subsequent enamel microabrasion. The microabrasion technique is used to remove superficial intrinsic stains and to repair superficial enamel defects. Microabrasion has shown excellent clinical results, both immediately after its completion and after long-term follow-up.[19-22]

The current study presents clinical case reports that describe the steps for removing the residual material after orthodontic bracket debonding, followed by enamel microabrasion and dental bleaching. The effectiveness and longevity of the treatment are evaluated using scanning electron microscope (SEM) images and through the long-term results of previous clinical cases.

CASE REPORT

After bracket removal with orthodontic pliers, a 25-year-old male patient presented to a dental clinic with residual bonded material on the facial surface of teeth in the upper and lower arches (Figure 2). All of the necessary clinical procedures required to remove the material were explained to the patient, who consented to the treatment. An initial impression was made of the teeth before the clinical procedures using a silicone impression material (Express XT Putty and Light body, 3M ESPE, St Paul, MN, USA) in order to analyze the enamel surface under SEM. After professional prophylaxis with pumice and water, the remaining bonding material was scratched with an explorer probe to highlight the remaining resinous material and to guide the operator during its removal (Figure 3). Then, a fine-tapered diamond bur (3195 FF, KG

Figure 3. *Resin bonding material was highlighted with an explorer to guide the operator during its removal procedure.*

Sorensen, Barueri, Brazil) was used to remove the resin remnants (Figure 4) under water-cooling until no residual material could be identified by air-drying followed by scratching the enamel surface with an explorer. After complete removal, a new impression was made as previously described. The upper arch was then isolated with a rubber dam. The operator, dental assistant, and patient's eyes were protected during all clinical procedures.

Opalustre enamel microabrasion compound (Ultradent Products Inc, South Jordan, UT, USA) was applied to the enamel surfaces using a specific rubber cup (OpalCups, Ultradent Products Inc) with enclosed brush bristles specifically developed for this purpose (Figure 5). The cup was coupled with a low-rotation micromotor, and the compound was applied using a very slow speed to prevent splattering. Three applications were performed on each of four teeth for a period of 60 seconds. After each application, the teeth were rinsed with water/air spray. Later, the surfaces were polished with 1200-ppm fluoride paste (Herjos, Vigodent SA Indústria e Comércio, Rio de Janeiro, Brazil) and then washed and dried. The immediate aspect after the microabrasion is represented in Figure 6. A topical application of 2%

Figure 5. *Enamel microabrasion using Opalustre.*

neutral-pH sodium fluoride gel (FGM Products, Joinvile, Brazil) was performed on the treated enamel surfaces for four minutes. A final impression was taken. The same procedures were performed at the next session for the lower arch.

One week after completing the procedures, overnight vital dental bleaching was performed using 10% carbamide peroxide (Opalescence, Ultradent Products Inc) in custom-formed trays for four weeks. The patient was instructed to place a small drop of the bleaching gel into each tooth section, from the second premolar to the second premolar. The final presentation is shown in Figure 7.

Epoxy resin was used to cast the impressions. Before examination, the samples were positioned on aluminum stubs and subjected to a vacuum in a sputter coater (SCD-5 sputter coater, Oerlikon Balzers, Bingen, Germany) for deposition of a thin layer of gold in order to increase the surface reflectance. Qualitative images were obtained from a SEM (JSM 5600LV, JEOL, Tokyo, Japan) operating under 15 kV (Figures 8 through 11).

Figures 12 and 13 represent follow-ups of similar clinical cases in which the patients were treated using the same technique described in the present case on patients after 14 years and 18 years, respectively.

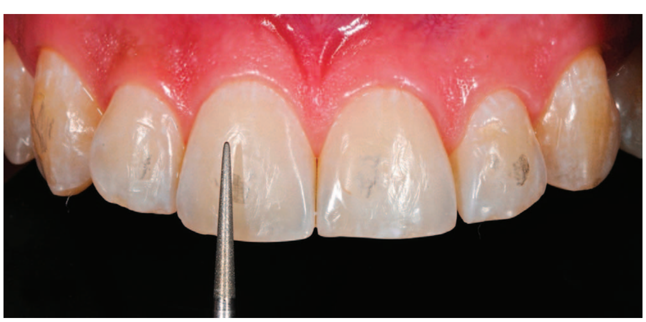

Figure 4. *Residual bonded resin removal using a fine-tapered 3195 FF diamond bur on the facial surfaces of the maxillary arch.*

Figure 6. *Appearance of the teeth immediately after enamel microabrasion.*

Figure 7. *Appearance of the teeth one month after microabrasion and dental bleaching. No residual bonding material was found.*

DISCUSSION

The process of debonding orthodontic brackets should include creating an enamel surface that is as close as possible to its pretreatment condition.[12,23,24] Therefore, the enamel microabrasion technique was used in the current case study to promote a smoother enamel surface after removing the remaining resin with a fine-tapered diamond bur. The present study reports three clinical cases (some with long-term follow-up and SEM images) that showed the effectiveness of the enamel microabrasion technique in creating smooth enamel after removing the resin bonded material with a fine-tapered diamond bur and approximating the original state of the enamel surface.

Possible failure types after bracket debonding are adhesive between the enamel and the adhesive resin, partially adhesive and cohesive in the adhesive resin (mixed), or adhesive between the bracket base and the adhesive resin, with the latter two requiring removal of remaining resin.[11] Although some reports have suggested the use of tungsten carbide burs to remove the resin bonded material,[9,24,25] Alessandri Bonetti and others[2] reported that 20.8% of tooth surfaces still had composite remnants when using a high-speed 12-bladed tungsten carbide bur followed by finishing with graded medium, fine, and superfine Sof-Lex discs. Ulusoy[3] found adhesive remnants on the enamel surface with either 30- or 12-fluted tungsten carbide burs. Øgaard and Fjeld[1] claimed that the use of tungsten carbide burs in a slow-speed handpiece or debonding pliers may result in adhesive material being left on the enamel after debonding. Ryf and others[14] also observed a large amount of composite on the enamel surface after grinding with carbide burs.

Figure 8. *(a and c): SEM images showing enamel facial surfaces of the upper incisors after bracket removal. (b): Clinical aspect of residual bonded material on the facial surfaces of upper incisors after bracket removal.*

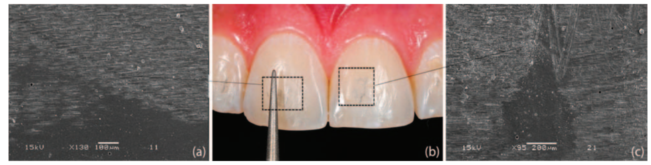

Figure 9. *(a and c): SEM images showing scratches on the facial enamel surfaces of the upper incisors after bracket removal and the application of a fine-tapered diamond. (b): Removal of residual bonded material using a fine-tapered diamond.*

Some practitioners prefer conventional diamond burs for the removal of composite remnants; however, these burs may scratch the enamel because of their shape and sharpness, regardless of the care and experience of the practitioner.[3] The scratches that are left by conventional diamond burs are influenced by the speed and pressure of the bur on the tooth surface.[13] The fine-tapered diamond bur was chosen in these clinical reports because it is able to remove all remaining materials. However, even with the literature advocating the use of different clinical procedures to obtain a more regular and smooth surface after removal of the residual bonded material,[8,11,13,26,27] it has been observed that the enamel does not recover the characteristics of unaltered enamel.

The use of burs results in deep gouges on the enamel surface and an increase in surface roughness.[9] Thus, the finishing of enamel surfaces after removing directly bonded attachments is essential.[9] Eliades and others[8] reported that there was no consistent roughness-reducing effect of finishing with aluminum oxide discs, regardless of the resin removal protocol used. Additionally, those aluminum oxide discs have been reported to leave adhesive remnants on the enamel surface.[28] On the other hand, the use of polishing/silicone brushes is not sufficient for removing the bonded materials[3,14] or

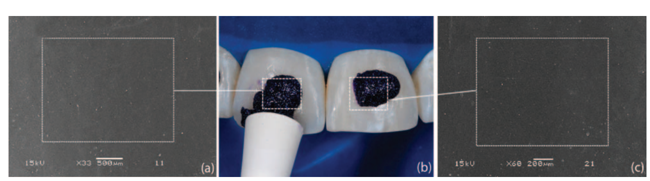

Figure 10. *(a and c): SEM images showing smooth and regular enamel of the upper incisors after the application of Opalustre. (b): Application of the enamel microabrasion compound (Opalustre).*

Figure 11. *(a and b): Clinical and SEM images showing the initial condition of the upper central incisors after orthodontic treatment revealing residual bonded material. (c and d): Clinical and SEM images representing the facial enamel surface and the complete removal of the residual bonded material after application of a fine-tapered diamond bur followed by enamel microabrasion. The technique was able to regain the natural aspect of enamel eliminating scratches/grooves.*

the grooves and scratches created by the burs.[3,8] Polishing systems with good composite polishing properties may leave a lustrous surface and more composite remnants because they become invisible to the naked eye,[14] a condition that hinders removal by the operator.

In the present study, the microabrasion technique was adopted as a finishing procedure. This technique is indicated for removing intrinsic enamel stains, superficial irregularities of hard surfaces, or any coloration that can compromise dental esthetics.[17,19-22,29-31] Application of the microabrasive compound promotes superficial enamel demineralization, followed by the subsequent polishing of the surface. This polishing is possible because the technique combines the erosive and abrasive effects of the microabrasive mixture, which contains low acid concentrations (hydrochloric acid 6.6%) and an abrasive agent (silica), applied mechanically using a low-rotation micromotor.[22] The procedure has been shown to be a safe and conservative treatment,[19,32,33] and the enamel wear is clinically imperceptible.[21,22] Sundfeld and others[16] observed enamel loss ranging from 25 μm to 200 μm for 1 and 10 applications, of one minute each, respectively, when using the Opalustre product. They concluded that this enamel loss may be considered clinically irrelevant compared with the remaining enamel surface because enamel thickness may exceed 1400 μm.[34]

Indeed, as observed in this clinical case report, other studies[15-18] have also verified and demonstrated the versatility of enamel microabrasion after bracket debonding; those studies have indicated that

Figure 12. *(a): Patient with residual bonded resin on the maxillary and mandibular teeth. (b and c): Fourteen years after resin removal, enamel microabrasion, and teeth bleaching. Note the polished, healthy, and shiny enamel.*

this technique is ideal for complete enamel surface finishing because the diamond bur produces grooves that correspond to the size of the abrasive diamond particles.[15] The microabrasion technique provides an enamel surface that is regular, smooth, and lustrous over time[15-17,19] because of the abrasion effect promoted by the technique.[31,35] The simultaneous abrasion and acid erosion of enamel prisms may compact mineralized tissue within the organic area, replacing the outer layer of prism-rich enamel with a densely compacted, prism-free region.[35] The resultant enamel presents a glass-like surface, changing its optical properties and resulting in a glossy surface.[22,36] Furthermore, Segura and others[37] used polarized light microscopy to demonstrate that a surface submitted to this microabrasion technique shows a higher resistance to demineralization and to colonization by *Streptococcus mutans*.

During and after dental bleaching, the teeth did not show sensitivity, corroborating the findings of Brauchli and others [5] and Sundfeld and others.[19,38] Those studies demonstrated that the use of carbamide peroxide-based bleaching agents in custom trays can be prescribed safely after microabrasion if applied on nondecayed or well-restored teeth that do not have exposed dentin at the cervical or incisal regions and under the supervision of a dental professional.

One may claim that the association of debonding + diamond bur + enamel microabrasion would result in an enamel loss that, somehow, could affect the enamel properties. However, after 18 years, the treatment demonstrated in the current case report showed great clinical results, notably polished, healthy, and shining enamel (Figures 12 and 13).

Figure 13. *(a): Patient with residual bonded resin on the maxillary and mandibular teeth. (b and c)" Eighteen years after resin removal, enamel microabrasion, and teeth bleaching. Note the polished, healthy, and shiny enamel.*

Indeed, the association of enamel microabrasion with dental bleaching produced satisfactory esthetics to patients over 18 years of clinical analysis.

CONCLUSION

Enamel microabrasion was effective for creating a more natural enamel surface texture after the removal of resin bonded material when using a fine-tapered diamond bur. Long-term follow-ups and SEM analyses attested to the safety and efficacy of the applied technique.

Regulatory Statement

This study was conducted at the Aracatuba Dental School – State University of São Paulo UNESP.

Conflict of Interest

The authors 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 Research

The Impact of a Customized Tray on In-Office Bleaching Tooth Sensitivity: A Randomized Clinical Trial

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Clinical Relevance

Using a customized tray to cover a 35% hydrogen peroxide bleaching agent increases the absolute risk and intensity of tooth sensitivity for the first 24 hours after each in-office bleaching session.

SUMMARY

Objective: It was recently demonstrated that using a tray over a bleaching agent reduces its pulpal chamber penetration, which can reduce tooth sensitivity. This study evaluated the effect of the sealed technique on the presence and level of sensitivity reported by patients during and after the bleaching procedure performed in office.

Methods: Forty-six patients underwent a bleaching procedure with 35% hydrogen peroxide used in a single application of 45 minutes for two sessions with an interval of seven days. A customized tray was maintained over the bleaching agent during the entire procedure in half of the patients. The sensitivity level was evaluated during and immediately after the bleaching using verbal and visual analogue scales. The shade alteration was evaluated with a bleach guide scale. The peak sensitivity after 24 hours and the presence/level at 24 hours were also evaluated using a verbal rating scale. Relative risks were calculated for all time assessments. Data on the sensitivity level for both scales were subjected to Friedman and Mann-Whitney tests (α=0.05). Data on the shades were analyzed by two-way repeated-measures analysis of variance and Tukey's test (α=0.05).

Results: The use of a customized tray increased the relative risks to the tooth measured 24

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hours after each bleaching session. The sealed technique also increased the level of tooth sensitivity only at 24 hours after the first session. No difference was observed between the bleaching techniques regarding the shade evaluation.

Conclusion: Using a tray over the bleaching agent can increase the level and risk of tooth sensitivity for the first 24 hours after in-office bleaching.

INTRODUCTION

Tooth discoloration is frequently treated by in-office bleaching, a conservative procedure that presents a high level of success.[1,2] In-office bleaching consists of the application of a high-concentration hydrogen peroxide–based agent over the buccal surface of the teeth presenting discoloration. The bleaching ability has been associated with the oxidative effect of free radicals, released by the breakdown of H_2O_2.[3] The peroxide penetrates the enamel by diffusion to reach the dentin tissue, where it oxidizes the darker molecules, promoting a whitening effect.[4] However, the peroxides and their products also reach the pulp tissue and can damage the cells of this tissue.[5-7] Clinically, the effects of peroxide on pulp tissue are observed by tooth sensitivity reported by patients.[8,9]

Some clinical trials have reported that 60% to 100% of patients undergoing in-office bleaching report some tooth sensitivity during the procedure.[10-12] The tooth sensitivity observed is commonly transitory and disappears by 48 hours after the procedure.[11] However, this adverse effect caused by bleaching can lead the patient to interrupt the treatment, compromising the results. Several alterations to bleaching protocols have been proposed in an effort to reduce tooth sensitivity. Prior application of desensitizing agents was attempted.[13-16] Another approach was the preemptive use of anti-inflammatory drugs; however, this protocol also did not alter the risk of tooth sensitivity.[11,12]

A recent *in vitro* study found that covering the bleaching agent with a tray reduced the penetration of peroxide into the pulp chamber.[17] This protocol was evaluated in a previous clinical trial that demonstrated a reduction in the level of sensitivity during the in-office bleaching procedure when the bleaching agent was covered with a customized tray, although no alteration to the relative risk was observed.[18] However, the effect of this technique on tooth sensitivity during the first 24 hours after tooth bleaching was not evaluated in this study, although sensitivity is commonly reported by patients during this period. Furthermore, a small sample size (10 patients per technique) was evaluated. Thus, the aim of this parallel, single-blind randomized clinical trial was to evaluate the absolute risk of tooth sensitivity during and until 24 hours (primary outcome) as well as the intensity of tooth sensitivity and the bleaching effect (secondary outcome) of the sealed protocol for in-office bleaching compared to a conventional technique. The hypothesis of this study was that the sealed protocol reduces tooth sensitivity without altering the bleaching effectiveness.

METHODS AND MATERIALS

The protocol of study was registered at clinicaltrials.gov under no. NCT02067715 and followed the CONSORT statements.[19]

Study Design

This study was a randomized, single-blind, controlled trial with a parallel group and an allocation rate of 1:1. The patients were allocated to receive tooth bleaching with the bleaching agents during the procedure covered by a customized tray (experimental treatment) or without a tray (control). The study was conducted at the clinic of the School of Dentistry of the Federal University of Sergipe (UFS) from March 2014 to September 2014.

Inclusion and Exclusion Criteria

Only patients older than 18 years with good general and oral health were included in this study. The participants were recruited by means of advertisements placed on the buildings of the university. Patients with any of the six maxillary anterior teeth presenting caries, restoration, severe internal tooth discoloration (eg, tetracycline stains), hypoplasia stains, gingival recession, dentin exposure, pulpitis, or endodontic treatment were excluded. Participants who reported the continuous use of drugs with anti-inflammatory activities were also excluded from the study. The participants were required to have all six maxillary anterior teeth with shade 2.5M2 or darker, as judged by comparison with the scale of the Vita Bleach guide (Vita-Zahnfabrik, Bad Säckingen, Germany). One previously calibrated evaluator conducted the initial shade evaluation for eligibility assessment for the study.

Sample Size Calculation

The primary outcome of this study was the absolute risk of tooth sensitivity measured during the 24 hours after the bleaching procedure. The sample size was calculated using the absolute risk of tooth sensitivity (100%) found in a previous study using a single 45-min application of the same bleaching agent of this study (Whiteness HP Maxx, FGM, Joinville, SC, Brazil).[11] The calculation was performed for a superiority trial, binary outcome, considering a power test of 80%, a significance level of 5%, and a decrease of 25% for the experimental treatment compared to the control. Thus, 48 patients were required, and 50 patients were included in the randomization to address the possibility of dropout during the follow-up.

Randomization

The participants were randomly allocated to a conventional protocol of in-office bleaching (control) or an experimental protocol of sealed bleaching. A blocked randomization (block sizes of 2 and 4) with an equal allocation ratio was used to produce a random list for the two comparison groups (www.sealedenvelope.com). A randomized list was computer generated by a person not involved in the study. Sealed opaque envelopes containing the treatment for each patient were numbered following the generated list and were opened by the operator only at the moment of the intervention. The patients were numbered according to the sequence of enrollment.

Baseline Measurements

The tooth sensitivity and shades of the six maxillary anterior teeth were evaluated prior to the bleaching procedures. Dental prophylaxis with pumice and water was performed using a rubber cup. The tooth sensitivity was evaluated using a visual analogue scale (VAS) and a verbal rating scale. The VAS consisted of a 10-cm color scale from green (no pain) to red (worst pain), where the patient set his or her pain level by pointing with a pen to the scale. The distance between the marking and the border of the scale was measured and recorded as the level of sensitivity. The tooth sensitivity was also evaluated using a 5-point verbal rating scale (VRS), where 0 = none, 1 = mild, 2 = moderate, 3 = considerable, and 4 = severe. For the initial evaluation, a slight airstream was applied over the buccal surfaces of the upper maxillary teeth. The patients were excluded if the scores were different from 0 in either scale.

Before starting the study, two evaluators were calibrated to use the Vita Bleach Guide scale. For this purpose, the shade of the maxillary anterior teeth from six volunteers (not included in the study) was recorded. This procedure was repeated to obtain a kappa coefficient higher than 0.85 for inter- and intraevaluator agreement. The shade evaluation was made by comparing the shade tabs with the middle third of the teeth. During the study, in the case of disagreement on evaluation, the evaluators discussed the matter to obtain a consensus. A third evaluator was used in the absence of consensus. The 15 shade tables in the guide were numbered from 1 (highest value—0M1) to 15 (lowest value—5M3) for data analysis.

Intervention

Alginate impressions of both dental arches of all patients included in the study were performed, and stone molds were prepared. Customized bleaching trays were made with acetate. The bleaching procedures were performed by two operators. A light-polymerized resin dam (Top Dam, FGM, Joinville, SC, Brazil) was applied over the gingival tissue corresponding to the teeth to be bleached. A 35% hydrogen peroxide gel (Whiteness HP Maxx) was applied over the buccal surfaces of the teeth and remained in position for 45 minutes, according to the procedure in a previous study.[11] The bleaching tray was carefully positioned over the bleaching agent in the patients allocated to the sealed bleaching protocol. Two bleaching sessions were performed with a one-week interval between them.

Evaluation

The patients reported their level of tooth sensitivity using both the VAS and VRS during the bleaching procedure, and the highest values reported were recorded. The tooth sensitivity was also evaluated immediately (five minutes) after the bleaching procedures using the same scales. Twenty-four hours after the bleaching procedure, the patients were questioned about the level of sensitivity at that moment and the highest level felt until that moment, using only the VRS. The tooth sensitivity measurements were repeated during and after the second session. The shade evaluation of the six anterior maxillary teeth was performed one week after each bleaching session. All evaluations were performed by two evaluators blinded to the allocation assignment.

Statistical Analysis

Data on tooth sensitivity using the VRS were arranged into absolute risk of sensitivity (score 0 vs scores 1-4) and overall sensitivity intensity. The first measure represented the likelihood that sensitivity would occur, and the second was the level of intensity likely to occur. At each moment of evaluation, the percentages of presence of sensitivity between the techniques evaluated were compared using the Fisher exact test. The absolute and relative risk for each technique were calculated, followed by determination of the confidence interval (95%). The data on sensitivity intensity were subjected to the Mann-Whitney rank sum test (between two techniques at each assessment point) and the Friedman repeated measures analysis of variance on rank (between assessment points within each group). Multiple comparisons were performed using the Tukey test.

The absolute values measured (in cm) in the VAS were used in statistical analysis. The data did not show normality (Shapiro-Wilk test; $p<0.05$) and were subjected to the Mann-Whitney rank sum test and the Friedman repeated measures analysis of variance by ranks. The color evaluation data were analyzed by Mann-Whitney rank sum test (comparing the techniques at each assessment point) and the Friedman repeated measures analysis of variance by ranks (comparing assessment within each technique). Multiple comparisons were performed using the Tukey test. The significance level was set at $\alpha = 0.05$ for all analyses.

RESULTS

The mean age (years) of the participants in this study was similar between the groups (conventional technique=22.5±2.0, and sealed technique=23.5±2.0 years; p=0.485; t-test). Four patients (two per technique) did not attend the second session of bleaching and were excluded from the study (Figure 1). Thus, 23 patients were analyzed for each bleaching technique, of whom 12 (52%) and nine (39%) were males for the conventional and sealed techniques, respectively (Fisher exact test; p=0.554).

Tooth Sensitivity

Regarding the absolute risk of tooth sensitivity, a significant difference was observed between the techniques only at 24 hours after the bleaching procedures (Table 1). Covering the bleaching agent with a customized tray significantly increased the risk of sensitivity 24 hours after the first (approximately 50%) and second (approximately 140%) sessions. However, the sealed bleaching presented the highest intensity of tooth sensitivity only at the evaluation performed during the first 24 hours (both peak and at the moment of reporting) after the first session (Table 2). For the conventional technique, comparison of the time assessments showed a significant difference only between the peak during the first 24 hours of the second session and the level measured immediately after this session. A tendency was observed toward increased sensitivity 24 hours after the two bleaching sessions for the sealed technique. The VAS did not show any difference between the techniques or time assessments (Table 3).

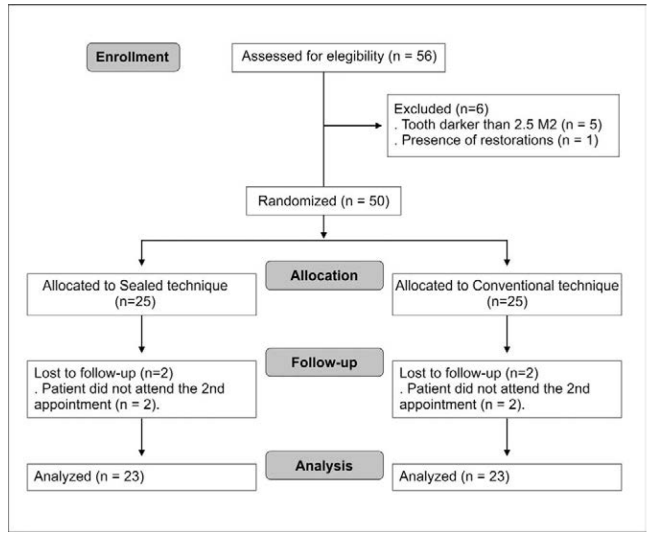

Figure 1. *Flow diagram of the clinical trial.*

Color Evaluation

The results are displayed in Table 4. For both bleaching techniques, the highest shade scores were observed at the baseline, followed by measurement performed a week after the first session. The measurement performed a week after the second session showed the lowest shade scores. No difference between the techniques was found regardless of the time of assessment.

DISCUSSION

Despite the high success rate for in-office tooth bleaching, the tooth sensitivity reported by patients during and after this procedure remains a challenge for clinicians.[8-12] Among the modifications in clinical procedures described in the dental literature, none of the protocols reported are effective in reducing the sensitivity compared to the control.[11-13,15,16] Recently, an *in vitro* study demonstrated a reduction in peroxide penetration (main cause of sensitivity[9]) by the use of a tray over the bleaching agent.[17] However, the outcomes of the present clinical trial did not demonstrate a reduction in the level or risk of

Table 1: *Risk of Patient-Reported Tooth Sensitivity*

Time Assessment	Treatment	Tooth Sensitivity During Treatment (Number of Participants)		p Value[a]	Absolute Risk (95% CI)	Relative Risk (95% CI)
		Yes	No			
During first session	Conventional technique	15	8	1.000	0.65 (0.45-0.81)	1.00 (0.65-1.53)
	Sealed technique	15	8		0.65 (0.45-0.81)	
5 min after first session	Conventional technique	13	10	1.000	0.57 (0.37-0.74)	1.08 (0.66-1.75)
	Sealed technique	14	9		0.61 (0.41-0.78)	
24 h after first session	Conventional technique	13	10	0.047	0.57 (0.37-0.74)	1.54 (1.04-2.30)
	Sealed technique	20	3		0.87 (0.68-0.96)	
During second session	Conventional technique	14	9	1.000	0.61 (0.41-0.78)	1.07 (0.69-1.67)
	Sealed technique	15	8		0.65 (0.45-0.81)	
5 min after second session	Conventional technique	13	10	0.376	0.57 (0.37-0.74)	0.69 (0.37-1.29)
	Sealed technique	9	14		0.39 (0.22-0.59)	
24 h after second session	Conventional technique	8	15	0.001	0.34 (0.18-0.55)	2.38 (1.32-4.29)
	Sealed technique	19	4		0.83 (0.63-0.93)	

Abbrevation: CI, confidence interval.
[a] *Fisher exact test (α=0.05).*

tooth sensitivity when the sealed technique was used. On the contrary, the sealed technique increased the risk of tooth sensitivity 24 hours after the bleaching procedure. Furthermore, the level of sensitivity also increased during the first 24 hours after the first session. Thus, the hypothesis of the present study was rejected.

It was expected that the use of a customized tray over the bleaching agent would reduce the tooth sensitivity reported during the procedure. Some studies have demonstrated that enamel porosity may increase during tooth bleaching.[20,21] More porous enamel facilitates simple air currents reaching the dentinal tubules, where the sensory nerve fiber endings are located. Thus, an air current may induce fluid shifts in the dentinal tubules, and these fluid shifts trigger impulses in the nerve fiber to induce tooth sensitivity.[9,22] Thus, covering the tooth surface during the beaching procedure can avoid the induction of sensitivity by a draft stimulus. Furthermore, it has been speculated that the sealed technique can reduce the dehydration of the bleaching agent and its penetration into the pulp chamber.[17,23] However, in the present study, the same level of sensitivity and risk of sensitivity development were observed during the bleaching procedure compared to the control.

A previous clinical trial found a reduction in the level of sensitivity using the sealed technique, whereas a difference from the control technique

Table 2: *Medians (First/Third Quartiles) of Scores of Tooth Sensitivity Intensity Experienced by Patients for Each Treatment Group at Different Assessment Points Using the Verbal Rating Scale*

Bleaching Session	Time Assessment	Tooth Sensitivity (0-4)		p-Value[a]
		Conventional Technique	Sealed Technique	
First	During	1.00 (0.00/1.00) AB[b]	1.00 (0.00/2.00) BC	0.364
	5 min after	1.00 (0.00/1.00) AB	0.00 (0.00/1.00) C	0.447
	After 24 h	1.00 (0.00/1.00) AB	1.00 (1.00/3.00) A	0.006
	Peak during 24 h after	1.00 (0.00/1.75) AB	2.00 (1.00/3.00) A	0.005
Second	During	1.00 (0.00/2.00) AB	1.00 (0.00/1.00) C	0.991
	5 min after	1.00 (0.00/1.00) B	0.00 (0.00/1.00) C	0.574
	After 24 h	1.00 (0.0/2.00) AB	1.00 (1.00/2.00) AB	0.237
	Peak during 24 h after	2.00 (0.25/3.00) A	2.00 (1.25/3.00) A	0.387
	p-value[c]	0.005	<0.001	

[a] *Mann-Whitney rank sum test.*
[b] *Friedman repeated measures analysis of variance on rank.*
[c] *For the same bleaching technique, distinct letters indicate statistical difference (p<0.05).*

Table 3: *Medians (First/Third Quartiles) of Scores of Tooth Sensitivity Intensity Experienced by Patients for Each Treatment Group at Different Assessment Points Using the Visual Analogue Scale*

Bleaching Session	Time Assessment	Bleaching Technique		*p*-Value[a]
		Conventional	Sealed	
First	During	1.20 (0.08/2.53)	0.80 (0.08/3.78)	0.938
	Immediately after	0.70 (0.00/2.18)	0.30 (0.00/1.08)	0.669
Second	During	0.90 (0.00/3.53)	0.80 (0.00/3.75)	0.875
	Immediately after	0.30 (0.00/1.13)	0.10 (0.00/0.88)	0.954
	p-value[b]	0.151	0.184	

[a] *Mann-Whitney rank sum test.*
[b] *Friedman repeated measures analysis of variance on rank.*

was observed in the evaluation performed at 40 minutes during the bleaching procedure.[18] In contrast to the present study, those authors used only the VAS to analyze the sensitivity caused by the in-office bleaching technique performed in a single session. The high variability of data from the VAS and the smaller number of evaluated patients (10 per experimental condition) increase the chance of bias occurrence.[24] Thus, the sample size included in that study, lower than the sample used in the present study, can help explain the differences between the studies. In the present study, in contrast, the risk and level of tooth sensitivity increased during the first 24 hours after the bleaching procedure compared to the control. Thus, it can be speculated that covering the bleaching agent results in slower peroxide penetration, resulting in delayed sensitivity. In another study, Know and others[17] found a reduction of peroxide penetration into the pulp chamber when a tray was used over the bleaching agent; however, these results were not confirmed by outcomes of the present clinical trial.

Regarding the color evaluation, both techniques used in this study were effective in reducing the scores for shade, and the second session of bleaching promoted an additional bleaching effect. No difference between the bleaching techniques was observed when the bleaching effectiveness was evaluated. One important observation is that the bleaching effectiveness was evaluated only one week after the bleaching procedures. It has been recognized that longer periods of follow-up are necessary to allow the color stabilization.[25] A prior study using the same bleaching protocols,[18] however, did not find alteration between the values of color alteration (delta E) measured at seven and 28 days after the bleaching procedures. Furthermore, this previous study also did not demonstrate a difference on bleaching effectiveness between the sealed and conventional techniques regardless of the time of evaluation.

Unfortunately, despite good results in a preliminary clinical study,[18] this was not confirmed in the present study, mainly because the sealed technique increased the absolute risk and intensity of tooth sensitivity after 24 hours of bleaching. It is important to emphasize that a single 45-minute application of bleaching agent was used for both techniques in the present study. A single 45-minute application facilitates the use of the sealed technique, while replacements of bleaching agent are not necessary. However, a single 45-minute application may result in the highest intensity of tooth sensitivity when compared to three 15-minute applications.[10] Moreover, the sealed bleaching technique has some disadvantages, such as the necessity of fabricating

Table 4: *Medians (First/Third Quartiles) of Scores for Shade Using the Vita Bleach Guide Scale*

Time Assessment	Bleaching Technique		*p*-Value[a]
	Conventional	Sealed	
Baseline	8.8 (7.8/9.3) A[b]	8.5 (8.3/9.3) A	0.766
1 wk after first session	5.7 (4.4/6.7) B	5.7 (4.9/7.3) B	0.716
1 wk after second session	4.7 (3.8/5.3) C	4.5 (4.0/5.2) C	0.834
p-value[c]	$<$0.001	$<$0.001	

[a] *Mann-Whitney rank sum test.*
[b] *Friedman repeated measures analysis of variance on rank.*
[c] *For the same bleaching technique, distinct letters indicate statistical difference* ($p<0.05$).

a customized bleaching tray (similar to the one used for at-home bleaching). Thus, this is more time consuming and makes the technique more difficult to implement. Thus, it is reasonable to affirm that using the bleaching agent without any covering remains the best option for in-office bleaching.

CONCLUSION

Using a customized tray over the bleaching agent in in-office bleaching did not affect the level of sensitivity reported by the patient during the procedures, whereas this technique may increase the absolute risk and intensity of tooth sensitivity for the first 24 hours after in-office bleaching.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Federal University of Sergipe. The approval code for this study is 348.959/2013.

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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Laboratory Research

Effect of Restorative Protocol on Cuspal Strain and Residual Stress in Endodontically Treated Molars

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Clinical Relevance

The use of conventional or resin modified glass ionomers to fill the pulp chamber before cavity filling with an incremental direct composite restoration reduced cuspal deflection and residual shrinkage stress and increased the fracture resistance of endodontically treated molars.

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SUMMARY

Objectives: To evaluate the effect of the restorative protocol on cuspal strain, fracture resistance, residual stress, and mechanical properties of restorative materials in endodontically treated molars.

Methods: Forty-five molars received mesio-occlusal-distal (MOD) Class II preparations and endodontic treatment followed by direct restorations using three restorative protocols: composite resin (CR) only (Filtek Supreme, 3M-ESPE), resin modified glass ionomer cement in combination with CR (Vitremer, 3M-ESPE in pulp chamber and Filtek Supreme in MOD cavity), conventional glass ionomer cement in combination with composite resin (CGI-CR) (Ketac Fil, 3M-ESPE in pulp chamber and Filtek Supreme in MOD cavity). Cuspal strain was measured using strain gauges, and fracture resistance was tested with an occlusal load. Elastic modulus (EM) and Vickers hardness (VH) of the restorative materials were determined at different depths using dynamic microhardness indentation. Curing shrinkage was measured using the strain gauge technique. The restorative protocols were also simulated in finite element analysis (FEA).

The shrinkage strain, cuspal strain, EM, VH, and fracture resistance data were statistically analyzed using split-plot analysis of variance and Tukey test (p=0.05). Residual shrinkage stresses were expressed in modified von Mises equivalent stresses.

Results: Shrinkage strain values (in volume %) were Ketac Fil (0.08±0.01) < Vitremer (0.18±0.01) < Filtek Supreme (0.54±0.03). Cuspal strain was higher and fracture resistance was lower when using CR only compared with the techniques that used glass ionomer. The EM and VH of the materials in the pulp chamber were significantly lower for glass ionomer. The FEA showed that using CR only resulted in higher residual stresses in enamel and root dentin close to the pulp chamber than the combinations with glass ionomers (RMGI-CR and CGI-CR).

Conclusions: The choice of restorative protocol significantly affected the biomechanical behavior of endodontically treated molars. Using glass ionomer to fill the pulp chamber is recommended when endodontically treated molars receive direct composite restorations because it reduces cuspal strain and increases fracture resistance.

INTRODUCTION

Multisurface restorations in permanent premolars and molars are the most frequent type of dental restorations.[1] Posterior direct restorations have been frequently placed in endodontically treated teeth that have a sizable amount of the cusp remaining.[2] Avoiding indirect restorations with cuspal coverage is recommended because they necessitate substantial removal of tooth structure and have a high cost.[2]

Endodontically treated teeth are more susceptible to fracture compared with intact teeth.[3] This has been attributed to structure loss and changes in the mechanical properties of dentin after endodontic treatment.[4] Restoring the strength of endodontically treated teeth requires restorative materials that can resist masticatory forces. Composite resins have been shown to provide fracture resistance when used as direct restorations for posterior teeth.[5] Composite restored teeth are also subjected to residual stresses due to polymerization shrinkage induced during the restorative process or with thermal changes. In a restored tooth, these stresses from different origins can either amplify or compensate each other.[6] Depending on the geometry of the structure, mechanical properties of the materials, and intensity of the applied load, the stress may generate elastic and plastic deformations that can promote failure in the structure.[7]

Masticatory loading can cause deformation of cusps in posterior teeth.[8] Endodontic treatment weakens cusps which results in higher structural deformation under masticatory loads[9] and, in turn, can lead to increased stress concentrations and fracture of the dental structure.[2] Restorative techniques that combine different materials have been suggested to reduce the stress generated at adhesive interfaces.[10,11] Whereas composite resin has been the material of choice for restoring endodontically treated posterior teeth,[1,12] a combination of composite resin and another material with lower elastic modulus (EM), such as glass ionomer, may reduce the shrinkage stress. Moreover, the use of conventional glass ionomer cement or resin modified glass ionomer cement as a substructure will reduce the composite resin volume needed to fill the cavity, which may diminish the residual shrinkage stress.[13] To date, no studies have evaluated the effect of the material combinations on cusp deflection and residual shrinkage stress.

This study evaluated the hypothesis that the use of conventional glass ionomer or resin modified glass ionomer to fill the pulp chamber of endodontically treated molars restored with composite resin will reduce cusp deflection, increase fracture resistance, and improve stress conditions.

METHODS AND MATERIALS

Tooth Selection and Cavity Preparation

Forty-five extracted, intact, caries-free human third molars were used (Ethics Committee in Human Research approval no. 06257012.1.0000.5152). The teeth were selected to have an intercuspal width within a maximum deviation of 10% from the determined mean.[14] The intercuspal width varied between 4.81 mm and 5.98 mm. The roots of the teeth were covered with a 0.3-mm layer of a polyether impression material (Impregum, 3M ESPE, St Paul, MN, USA) to simulate the periodontal ligament and then embedded in a polystyrene resin (Cristal, Piracicaba, Brazil) up to 2 mm below the cementum-enamel junction to simulate the alveolar bone.[15]

The teeth were cleaned using a rubber cup and fine pumice water slurry. Class II mesio-occlusal-distal (MOD) cavities with 4/5 of the intercuspal

Table 1: *Materials Tested in the Study* [a]

Materials	Manufacturer	Material Type	Presentation	Composition	Matrix
Filtek Supreme	3M-ESPE, St Paul, MN, USA	Nanofilled composite resin	Syringe	Silica nanofillers (75 nm), zirconia nanofillers (5-10 nm), and agglomerated zirconia-silica nanoclusters (600-1400 nm)	Bis-GMA, Bis-EMA, UDMA, TEGDMA
Vitremer	3M-ESPE, St Paul, MN, USA	Resin modified glass ionomer	Hand mixed	Fluoroaluminosilicate glass, microencapsulated	Poly (acrylic-itaconic acid) with pendent methacrylate, H_2O
Ketac Fil	3M-ESPE St Paul, MN, USA,	Conventional glass ionomer cement	Hand mixed	Fluorosilicate glass strontium, aluminum, lanthanum, and pigments	polycarbonic acid, tartaric acid, H_2O

Abbreviations: Bis-EMA, bisphenol-A hexaethoxylated dimethacrylate; Bis-GMA, bisphenol-A glycol dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.
[a] *Information provided by the manufacturers.*

width and 5-mm depth were prepared in all specimens with a diamond bur (#3099 diamond bur, KG Sorensen, Barueri, Brazil) with copious air-water spray using a cavity preparation machine.[16] This machine consisted of a high-speed handpiece (Extra torque 605 C, KaVo do Brasil, Joinvile, Brazil) coupled to a mobile base. The mobile base moves vertically and horizontally with three precision micrometric heads (152-389, Mitutoyo Sul Americana Ltda, Suzano, Brazil), attaining a 0.002-mm level of accuracy. The endodontic access was manually performed with a diamond bur (#1016 HL KG Sorensen) in a high-speed handpiece with copious air-water spray.

The composition and manufacturer information of the restorative materials used in this study are listed in Table 1. The specimens were distributed into three groups (n=15). In the composite resin (CR) group teeth were restored with an incremental filling technique using composite resin (Filtek Supreme, Shade A2, 3M-ESPE, St Paul, MN, USA) to fill the pulp chamber and MOD cavity. In the resin modified glass ionomer cement in combination with composite resin (RMGI-CR) group, teeth were restored using resin modified glass ionomer cement to fill the pulp chamber (Vitremer, Shade A2, 3M-ESPE) followed by the same composite resin technique to fill the MOD cavity; In the conventional glass ionomer cement in combination with composite resin (CGI-CR) group, teeth were restored using conventional glass ionomer cement to fill the pulp chamber (Ketac Fil, 3M-ESPE) followed by the same composite resin technique to fill the MOD cavity. Ten restored teeth per group were used for measuring cuspal deflection with strain gauges and afterward for compressive fracture resistance test. The other five restored teeth were used for Vickers hardness (VH) and elastic modulus (EM) measurements using the dynamic indentation method.

Cuspal Deformation

Cuspal deformation was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, Embú, Brazil), which had an internal electrical resistance of 350 Ω, a gauge factor of 2.07, and a grid size of 21.02 mm^2. The gauge factor is a proportional constant between electrical resistance variation and strain. The strain gauges were placed on 10 teeth in the region where a finite element model had indicated the presence of the highest polymerization strains.[17] One strain gauge was placed on the external surface of the lingual cusp next to the height of the pulp chamber. The other strain gauge was placed on the external surface of the buccal cusp next to the base of the Class II MOD cavity. In addition, two strain gauges were fixed to another intact tooth to compensate for dimensional deviations due to temperature effects. The strain gauges were bonded with cyanoacrylate-based adhesive (Super Bonder, Loctite, Itapeví, Brazil), and the wires were connected to a data acquisition device (ADS0500IP, Lynx, São Paulo, Brazil).

For the RMGI-CR and CGI-CR groups, the glass ionomer cements were manipulated as recommended by the manufacturer and used to fill the pulp chamber, thereby creating a flat surface of the pulpal floor level with the gingival wall of the proximal boxes. The conventional glass ionomer was covered with wax for 5 minutes to achieve complete setting. The resin modified glass ionomer was light cured for 40 seconds using a light source with 600 mW/cm^2 output (Demetron Kerr, Orange, CA, USA). Selective etching of enamel was done for 15 seconds, and a two-step self-etching adhesive system (Clearfil SE Bond, Kuraray America, New York City, USA) were used for hybridization procedures in all groups. The average volume of composite per increment used was 24.3 mm^3 (no more than 2-mm thick) defined by a Teflon matrix to standardize before insertion into the cavity. For the CR group, the pulp chamber was filled in two resin increments and the coronal cavity for all groups was filled with eight resin increments (two at the mesial box, two at the distal box, and four at the occlusal box). Each increment was light cured for 40 seconds from the occlusal direction closest to the cavity.

The cuspal deformation data were obtained from the strain gauges through data analysis software (AqDados 7.02 and AqAnalisys, Lynx Tecnologia Eletrônica, São Paulo, SP, Brazil). The strain values were recorded at 4 Hz during the restorative procedure and continued for 10 minutes after curing the last increment.

Fracture Resistance Test

After cuspal deformation measurements, teeth were subjected to axial compressive loading with a metal sphere 6 mm in diameter at a crosshead speed of 0.5 mm/min in a universal testing machine (DL2000, EMIC, São Jose dos Pinhais, Brazil). The load required (N) to cause catastrophic fracture of specimens was recorded by a 500 N load cell hardwired to a computer with control and data acquisition software (TESC 3.04, EMIC). The failure mode of each specimen was analyzed under a stereomicroscope (Leika Ecafix, Tokyo, Japan) at 40× magnification, and then assigned to one of four categories, using a modified classification system based on that proposed by Burke[18]: (I) fractures involving a small portion of the coronal tooth structure; (II) fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; (III) fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, with root involvement that can be restored in association with periodontal surgery; and (IV) severe root and crown fracture, which determine extraction of the tooth.

Vickers Hardness and Elastic Modulus

The remaining five specimens from each group were used for analysis of the mechanical properties (VH and EM) of the composite resin/glass ionomer restorations at eight depths. Each restored tooth was sectioned in the buccal-lingual direction into two halves using a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA). One section per tooth was randomly selected for assessment of the mechanical properties. The specimens were embedded with methacrylate resin (Instrumental Instrumentos de Medição Ltda, São Paulo, Brazil). Before testing, the surfaces were finished with silicon-carbide papers (#600, 800, 1200, and 2000 grit, Norton, Campinas, Brazil) and polished with metallographic diamond pastes (6-, 3-, 1-, and 1/4-μm, Arotec, São Paulo, Brazil). After polishing, the specimens were cleaned using ultrasound for 10 minutes with distilled water. Using a Vickers indenter (CSM Micro-Hardness Tester, CSM Instruments, Peseux, Switzerland), indentations were made every 1.0 mm from 0.5 mm to 7.5 mm, starting from the base of the pulp chamber of the restorations. The indentations were carried out with controlled force, whereby the test load was increased or decreased at a constant speed ranging between 0 and 500 mN in 20-second intervals. The maximum force of 500 mN was held for 5 seconds. The load and the penetration depth of the indenter were continuously measured during the load-unload hysteresis. The universal hardness was defined as the applied force divided by the apparent area of the indentation at the maximum force. The measurements were expressed in VH units by applying the conversion factor supplied by the manufacturer. The indentation modulus was calculated from the slope of the tangent of the indentation depth curve at the maximum force and is comparable to the material's EM.[19]

Post-Gel Shrinkage

Post-gel linear shrinkage was determined using the strain gauge method.[20] Ten specimens were tested for each restorative material. The materials were shaped into a hemisphere on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA) that measured shrinkage strains in two perpendicular directions (X and Y axes). A strain conditioner (ADS0500IP, Lynx Tecnologia Eletrônica) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. The strains measured along the two axes were averaged because the material properties were homogeneous and isotropic on a macro scale. Filtek Supreme (composite resin) and Vitremer (RMGI) were light-cured using a quartz-tungsten-halogen unit (Demetron, Kerr, Orange, CA, USA) with the light tip held at a 1-mm distance from the surface of the composite and monitored for 10 minutes. The radiant exposure was set at 18 J/cm^2 (600 mW/cm^2 ×30 s). Ketac Fil (conventional glass ionomer) was positioned on the strain gauge after mixing and was monitored for 30 minutes. The mean shrinkage strain was used as linear post-gel shrinkage input for the finite element analysis and could be converted to volumetric percentage by multiplying by 3 and 100%.

Residual Stress Calculation: Finite Element Analysis

To calculate corresponding residual stresses in the tooth, a two-dimensional (2D) finite element model was analyzed for the MOD restoration with endodontic access. The geometry of the model was based on a digitized buccolingual cross-section of a third molar with similar dimensions as the teeth selected for laboratory tests. Coordinates were obtained using digital image processing software (ImageJ 1.48, National Institutes of Health, Bethesda, MD, USA). The applied mechanical properties were EM of enamel 84 GPa and Poisson ratio 0.30 as well as EM of dentin 18 GPa and Poisson ratio 0.23.[21] The EM values of the three restorative materials measured in this study were also used for the analysis (Table 4). The Poisson ratios used were 0.24,[22] 0.35,[23] and 0.33,[24] respectively for Filtek Supreme, Vitremer, and Ketac Fil. A plane strain condition was assumed for the tooth cross-sections. Because of this 2D strain condition and consequently 2D finite element model, no distinction was made between the mesial and distal increments.

The finite element analysis (FEA) was performed using MSC.Mentat (preprocessor and postprocessor) and MSC.Marc (solver) software (Version 2010r2, MSC Software Corporation, Santa Ana, CA, USA). One FEA model was generated for each experimental group to simulate the three restorative protocols of the experimental study. Polymerization shrinkage was simulated by thermal analogy. Temperature was reduced by 1°C, while the linear shrinkage value (post-gel shrinkage) was entered as the coefficient of linear thermal expansion. Modified von Mises equivalent stress was used to express the stress conditions using compressive-tensile strength ratios of 37.3,[22] 3.0,[22] and 5.82,[14] respectively for the enamel, dentin, and Filtek Supreme as well as 3.55,[25] and 11.3,[26] respectively, for the Vitremer and Ketac Fil. Stress values were recorded in the integration points of each element and in nodes along material interfaces at either aspect (tooth and restoration).

Statistical Analysis

The cuspal deformation (strain), fracture resistance, post-gel shrinkage, EM, and VH data were tested for normal distribution (Shapiro-Wilk, $p>0.05$) and equality of variances (Levene test), followed by parametric statistical tests. One-way analysis of variance (ANOVA) was performed for cuspal deflection in each cusp, fracture resistance, and post-gel shrinkage. One-way ANOVA was performed in a split-plot arrangement, with the plot represented by restorative protocol and the subplot represented by the depth of the cavity. Multiple comparisons were made using a Tukey test. The data of fracture mode were subjected to a χ^2 test. All tests used $\alpha = 0.05$ as the significance level, and all analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA).

RESULTS

Cuspal Strain (CS)

The values of cuspal deformation (strain) for the three filling techniques are shown in Figure 1 and Table 2. For the lingual cusp, the CR filling technique had the highest cuspal deformation values, followed by the RMGI-CR and CGI-CR techniques, respectively. For the buccal cusp, the CR filling technique also had the highest cuspal deformation values. Buccal deformation was not significantly different between the RMGI-CR and CGI-CR groups.

Fracture Resistance and Failure Mode

The mean fracture resistance and standard deviation for the three restorative techniques are shown in Table 2. One-way ANOVA showed significant difference among groups ($p=0.02$). The CR group had significantly lower fracture resistance than the other two filling techniques that used glass ionomer to fill the pulp chamber. No differences were found between the RMGI-CR and CGI-CR groups. Failure mode distribution is shown in Table 3. No significant differences in failure modes were found among the three groups.

Vickers Hardness

The VH of the three filling techniques at various depths of the restorations are shown in Figure 2A and Table 4. The VH of the CR filling technique was constant through the entire restoration. For the RMGI-CR and CGI-CR filling techniques, the VH was constant on coronal restoration (composite resin portion) and decreased significantly in the pulp

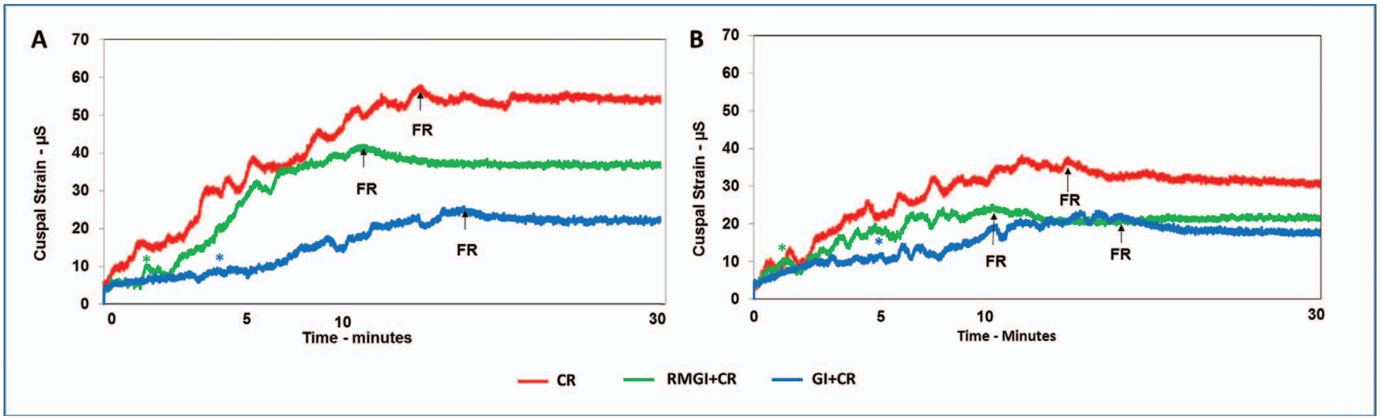

Figure 1. *Cuspal deformation in microstrains (µS) measured with strain gauges. (A): Lingual cusp. (B): Buccal cusp. *Indicates finishing glass ionomer insertion and activation. FR indicates finishing composite curing.*

chamber (glass ionomer–based materials). No differences were found between the VH on the coronal portion of the three filling techniques (Table 4). The VH measured in the pulp chamber was significantly lower for the RMGI-CR and CGI-CR restorative techniques (Table 4).

Elastic Modulus

The EM of the three filling techniques at various depths of the restorations are shown in Figure 2B and Table 4. The EM of the CR filling technique decreased significantly only after the 6.5-mm depth. For the CGI-CR and RMGI-CR filling techniques, the EM was constant in the coronal restoration (composite resin portion). The EM decreased significantly in the pulp chamber for the RMGI-CR and CGIRC techniques (Figure 2B). The EM values measured in the pulp chamber were significantly lower for the RMGI-CR and CGI-CR groups (Table 4).

Post-Gel Shrinkage

The mean values and standard deviations for the post-gel shrinkage of three restorative materials are presented in Table 5. One-way ANOVA revealed statistical difference among the composites ($p<0.001$). Filtek Z350 XT had significantly higher mean volumetric shrinkage value than Ketac Fil and Vitremer.

Finite Element Analysis

Stress distribution for all groups is shown in Figure 3. The filling technique influenced the stress distribution and stress intensity. The CR filling technique resulted in higher stresses in the enamel and in root dentin close to the pulp chamber than the CGI-CR and RMGI-CR filling techniques. For comparison, Figure 4 shows cuspal deformation calculated with the FEA in the same buccal and lingual locations where the strain gauges were placed in the experiments (Figure 1). Experimentally measured cuspal deformation values were similar to the deformation values calculated by FEA.

DISCUSSION

The results of the present study confirmed that the use of conventional glass ionomer or resin modified glass ionomer to fill the pulp chamber reduces the cusp deflection, increases fracture resistance, and improves shrinkage stress distribution in endodon-

Table 2: *Cuspal Deformation (µS) Measured by Strain Gauges and Fracture Resistance [a] Measured by Axial Compression Test (n=10)*

Filling Technique	Mean ± Standard deviation		
	Cuspal deformation, µS		Fracture Resistance, N
	Buccal	Lingual	
Filtek Supreme (CR)	30.9 ± 18.7^B	54.1 ± 23.4^C	943.7 ± 134.1^B
Filtek Supreme + Vitremer (RMGI-CR)	23.2 ± 12.1^A	36.8 ± 17.3^B	1502.8 ± 444.0^A
Filtek Supreme + Ketac Fil (CGI-CR)	19.8 ± 8.6^A	22.2 ± 10.8^A	1882.1 ± 371.4^A

[a] *Different uppercase letters indicate significant difference between the restorative techniques for each mechanical property ($p<0.05$).*

Table 3: *Failure Mode Distribution* [a]

Groups	Failure Mode, %			
	I	II	III	IV
Filtek Supreme (CR)	10	10	80	0
Filtek Supreme + Vitremer (RMGI-CR)	0	0	90	10
Filtek Supreme + Ketac Fil (CGI-CR)	0	20	80	0

[a] Failure modes are defined as follows: (I) fractures involving a small portion of the coronal tooth structure; (II) fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; (III) fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, with root involvement that can be restored in association with periodontal surgery; and (IV) severe root and crown fracture, which determine extraction of the tooth.

tically treated molars restored with composite resin. Therefore, the hypothesis tested in this study was accepted.

The study of mechanical behavior involves examination of the relationship between a body of a given material or combination of materials and the forces acting on it, as well as the consequences of their interaction. Different materials respond differently to the application of these forces. The interactions with materials selection, bonding procedures, and restorative techniques are already complex for vital teeth but are even more complex for endodontically treated teeth. Endodontically treated teeth are weakened by alteration of mechanical properties and moisture content of the dentin,[3] loss of strategic tooth structure through restorative procedures, and caries.[27,28] A direct restoration should recover the stress/strain conditions of the original intact tooth.[21] Therefore, a restorative procedure using materials with mechanical properties distribution similar to an intact tooth is most desirable.

The present study investigated several aspects of the materials and restorative techniques that are involved in the biomechanical behavior of an endodontically treated tooth. To calculate the shrinkage stresses, the polymerization shrinkage responsible for the shrinkage stress had to be determined. The shrinkage component that causes stresses (post-gel shrinkage) was measured using the strain gauge technique.[20] Post-gel contraction is characterized by the development of internal forces in the material, resulting in molecular rearrangement (viscoelastic properties) and their inability to compensate for the polymerization shrinkage by plastic flow and deformation.[29] Contraction of conventional glass ionomers, which also start out as materials that can relieve stress by flow in their uncured stage, were measured by the same strain gauge technique. The post-gel shrinkage of Filtek Supreme (0.54%) was significantly higher than the post-gel shrinkage of Vitremer (0.18%) and the corresponding value for Ketac Fil (0.07%). The low post-gel shrinkage values of Vitremer could be explained by the lower resin component and the prolonged setting reaction in comparison to composite resin. The Ketac Fil had a low post-gel shrinkage value because its initial reaction is based on a relatively slow acid-base reaction that allows more stress relief during setting. Although it was not considered in this study, restorative materials are known to swell because of hygroscopic expansion. Swelling can compensate setting shrinkage, but hydrophilic materials, such as the glass ionomers, may continue to expand,[30] which may have more significance over the lifetime of a restoration than shrinkage. On the other hand, these materials were used only to fill the pulp chamber in the present study, and were not in direct contact with water. The higher shrinkage stress in the CR model may be explained by the higher post-gel shrinkage of the Filtek Supreme in combination with its

Table 4: Elastic Modulus (GPa) and Vickers Hardness (N/mm^2) Averaged from Eight Measurement Points[ba]

Filling technique	Mean ± Standard deviation			
	Elastic Modulus, GPa		Vickers Hardness, N/mm^2	
	Coronal Cavity	Pulp Chamber	Coronal Cavity	Pulp Chamber
Filtek Supreme (CR)	14.4 ± 0.2^{Aa}	13.1 ± 1.1^{Aa}	115.1 ± 1.1^{Aa}	113.5 ± 3.1^{Aa}
Filtek Supreme + Vitremer (RMGI-CR)	14.5 ± 0.2^{Aa}	10.7 ± 0.5^{Bb}	118.6 ± 3.6^{Aa}	59.9 ± 2.0^{Bb}
Filtek Supreme + Ketac Fil (CGI-CR)	14.6 ± 0.1^{Aa}	11.8 ± 0.2^{Bb}	116.8 ± 57.1^{Aa}	57.1 ± 4.9^{Bb}

[a] *Different uppercase letters in columns compare restorative technique for each mechanical property. Lowercase letters in rows compare restoration location for each mechanical property ($p<0.05$).*
[b] *The coronal cavity was filled with composite resin in all groups, but the pulp chamber was either composite resin, conventional glass ionomer, or resin-modified glass ionomer.*

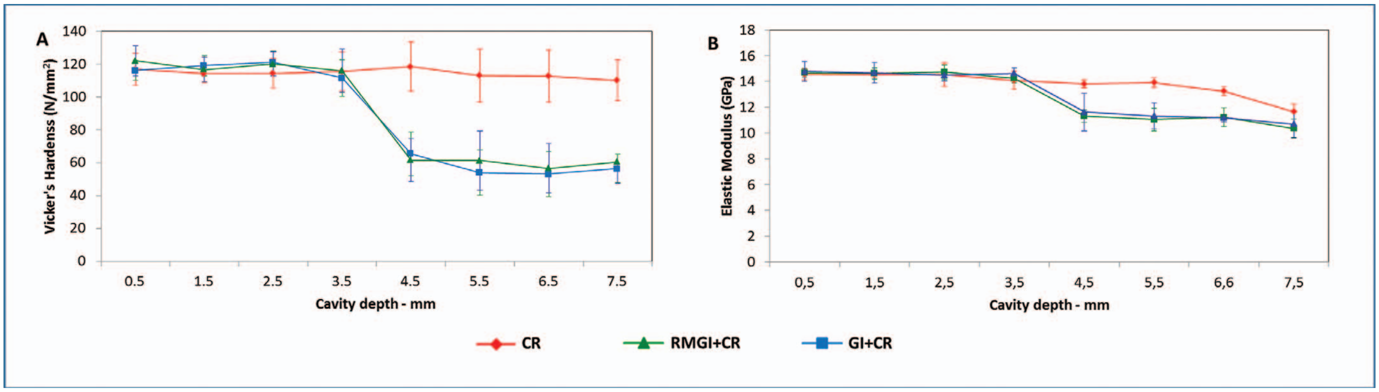

Figure 2. *Mechanical properties of the restorative materials used measured with dynamic indentation. (A): VH at various restoration depths on coronal portion and pulp chamber. (B): EM at various restoration depths on coronal portion and pulp chamber.*

higher EM. The main difference between the models was the material used to fill pulp chamber. Therefore, the residual shrinkage stress was generated in the tooth region where structural dentin was lost, resulting in higher cusp deflection and lower fracture resistance, as will be discussed later.

Microhardness

Hardness has been used as an indicator of degree of conversion (ie, extent of polymerization of monomers to polymers) and curing depth in resin-based dental materials.[31-33] Filtek Supreme inserted incrementally showed constant values of VH at all depths of the restorations, suggesting adequate polymerization and degree of conversion.[14] The Ketac Fil and Vitremer had similar VH, which was significantly lower than that of Filtek Supreme. This may be explained by the different compositions of these materials. Glass ionomer cements are mechanically weaker compared with composite resins because of the weak bonding between the particles of glass and polyacid matrix.[34] Resin-modified glass ionomers essentially consist of conventional glass ionomer components combined with organic photopolymerizable monomers for the initial setting reaction.[35] The VH values of the materials in the pulp chamber were constant for both glass ionomers, demonstrating that their curing process was efficient. The VH of the Filtek Supreme is very similar to the value for human dentin. However, when a correlation is made with the intact tooth, the pulp chamber is similar to an empty, not a load supporting, space. The use of materials with lower stiffness may thus explain the better biomechanical performance of the two groups that used glass ionomer to fill pulp chamber.

Table 5: *Mean (± Standard Deviation) Volumetric Post-Gel Shrinkage* [a]

Materials	Volumetric Post-Gel Shrinkage, %
Filtek Supreme	0.54 ± 0.03[B]
Vitremer	0.18 ± 0.002[A]
Ketac Fil	0.08 ± 0.00[A]

[a] *Different uppercase letters indicate significant difference between the composites (p<0.05).*

Elastic Modulus

The EM represents the relative stiffness of a material and gives information about how occlusal forces will be supported by the materials. The incrementally inserted Filtek Supreme showed constant values of EM up to 6.5 mm depth. At the bottom of the restoration the VH was maintained but EM decreased, demonstrating that VH and EM have no direct correlation.[14] The distance between the light positioned, even with limited access by the cusps was apparently sufficient to cure the very deep region of the cavity but not to attain the same EM.

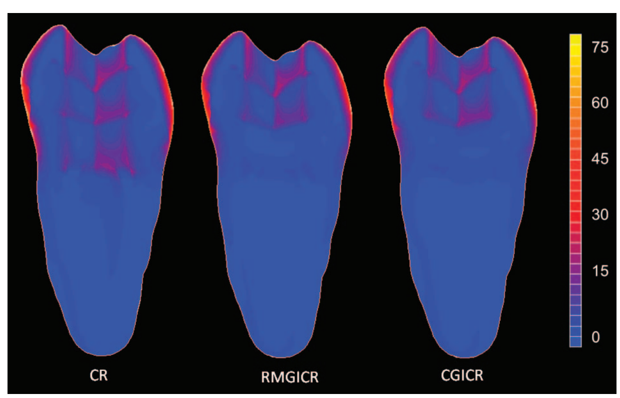

Figure 3. *Stress distribution calculated by FEA (modified von Mises equivalent stresses, MPa).*

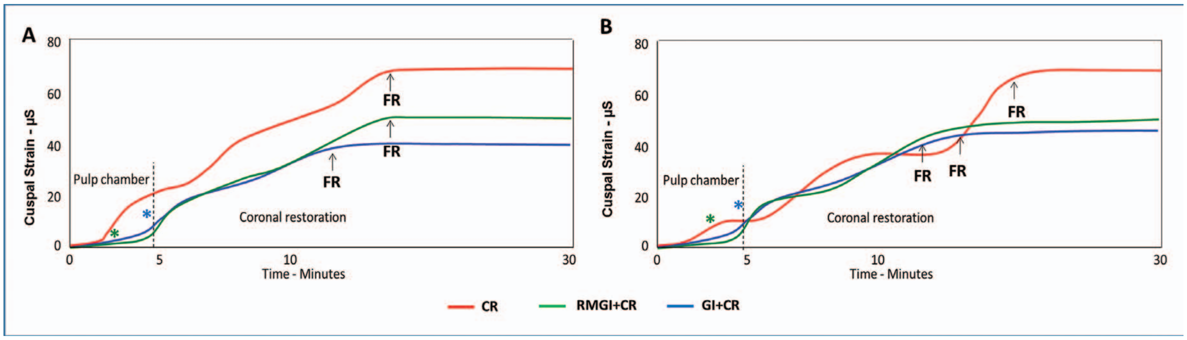

Figure 4. *Cuspal deformation in microstrains (µS) calculated with FEA in the same region where the strain gauges were attached in the experimental test. (A): Lingual cusp. (B) Buccal cusp. *Indicates the CGI and RMGI. FR indicates the end of the restoration.*

Filtek Supreme had the same EM in the coronal restoration in all tested groups, confirming that the biomechanical differences found among the three groups were related to the restorative material in the pulp chamber. The low EM of glass ionomers can be explained by their composition. Particle type and size as well as the flexible matrix of glass ionomers contribute to their relative weakness.[34,36,37]

Cuspal Strains

Cuspal deformation in restored teeth is affected by many factors, including the size of the cavity, the properties of the restorative material, and the filling technique.[14] In this study the size of the cavity was standardized for all specimens. Assuming similar tooth properties, shapes, and sizes, the main variables causing differences in cuspal deformation were therefore the properties of the materials and the filling techniques. We used strain gauges to measure cuspal deformation. Because strains vary across the tooth surfaces, the attachment location is important for the results. FEA was used to identify the areas where the highest strains occurred. The lingual cusp had more cusp deformation than the buccal cusp, irrespective of the restorative protocol. This result can be explained by the amount of remaining tooth structure. Third molars had thinner cervical areas lingually than they had buccally, and, thus, the lingual cusps can be expected to be less stiff and deform more than the buccal cusps. The cuspal deformation values were significantly different among the restorative protocols tested. Using a glass ionomer material to fill the pulp chamber and overlaying it with composite resulted in lower cuspal strain than using composite for the whole restoration. The reduction this gave in cuspal strains can be attributed to the lower shrinkage in combination with the lower EM of the glass ionomers. For the same reason glass ionomers have been recommended as cavity lining to reduce shrinkage stress of the restoration.[28]

Fracture Resistance

The fracture resistance values showed significant differences between the restorative protocols, with significantly lower resistance for the CR group. According to Reeh and others,[27] endodontic procedures have only a small effect on the tooth, reducing the relative rigidity by 5%, which is contributed entirely to the access opening. Restorative procedures and, particularly, the loss of marginal ridge integrity were the greatest contributors to the loss of tooth rigidity. Despite the lower mechanical properties of glass ionomer cement compared with composite resin, placement of a glass ionomer into the pulp chamber resulted in higher fracture strength than restoration with composite alone. A relatively stiffer restoration, in this case with the all-composite resin technique (CR), will transfer and distribute the occlusal loads deeper into the restoration and pulp chamber,[38] making the endodontically treated tooth more vulnerable around the compromised pulpal area. Furthermore, anatomically the lingual cusp seems to be more prone to fracture, which has been attributed to an unfavorable distribution of stresses during mastication.[39] The failure modes observed in this study confirm that most of fractures were concentrated on the lingual cusp (failure mode III). This area was also where shrinkage stresses were more concentrated along the pulp chamber, which may have contributed to this type of fracture.

Validation

The validation and correlation of experimental and computational methods is an important step in a comprehensive research approach and is essential to justify conclusions drawn from *in vitro* analyses.[6] Although FEA was essential to assess the stress conditions, the validity of stress calculations depends on the correct input of material properties, anatomic shape, and restraints of the restored tooth structure.[40] A validated finite element model can be further used to predict mechanical failures or investigate questions that cannot be accessed as well in laboratory tests.[6] Although the calculated stresses could not be validated directly from the laboratory experiments, they could be verified indirectly from the deformation and its consequences.[40] In our study, cuspal strains calculated by the FEA were similar to the cuspal strain data collected experimentally using strain gauges placed on cuspal surfaces (Figures 1 and 4). This close similarity supports the validity of our FEA models and stress results.[38,40,41]

Shrinkage stress is a serious concern, as has been demonstrated clinically by a high incidence of secondary caries in endodontically treated teeth restored with resin composites over a 5-year period.[12] The finding of this study could be important when direct composite restoration is the treatment of choice because of cost or conservative approach. Using conventional or resin modified glass ionomer to fill the pulp chamber under composite restoration may improve the longevity of the endodontically treated molars.

CONCLUSIONS

The restorative protocols significantly affected the deformation, stress, and fracture resistance of endodontically treated molars. Using glass ionomer to fill the pulp chamber under the composite resin restoration resulted in the most favorable conditions by reducing cuspal strain and increasing fracture resistance.

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Regulatory Statement

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

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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Detection of Caries Around Amalgam Restorations on Approximal Surfaces

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Clinical Relevance

In this investigation, the authors evaluated the *in vitro* performance of the International Caries Detection and Assessment System visual criteria, bitewing radiography examination, and a pen-type laser fluorescence device in detecting approximal caries around amalgam restorations in permanent teeth.

SUMMARY

To evaluate the *in vitro* performance of the International Caries Detection and Assessment System (ICDAS) visual examination, bitewing radiography (BW), and the DIAGNOdent 2190, a pen-type laser fluorescence device (LFpen), in detecting caries around amalgam restorations on approximal surfaces. Approximal surfaces (N=136) of permanent posterior teeth (N=110) with Class II amalgam restorations were assessed twice by two experienced examiners using ICDAS, BW, and LFpen. The occurrence of proximal overhangs was also evaluated. The teeth were histologically prepared and assessed for caries extension. Different cutoff limits for the LFpen were used. Intraexaminer and interexaminer reproducibility showed moderate to good agreement for all the methods (weighted κ/intraclass correlation coefficient=0.40 to 0.87). The specificities at D_1 (all visible lesions affecting enamel) and D_3 (lesions extended into dentin) were, respectively, 0.41 and 0.82 for ICDAS, 0.70 and 0.82 for BW, and 0.77-0.89 and 0.88-0.94 for LFpen. The sensitivities were 0.80 and 0.52 for ICDAS, 0.56 and 0.51 for BW, and 0.04-0.23 and 0.01-0.02 for LFpen at D_1 and D_3, respectively. At the D_1/D_3 thresholds, the accuracy and the area under the receiver operating characteristic curve (A_z) values were similar and statistically higher for ICDAS (0.65/0.68 and 0.633/0.688) and BW (0.64/0.68 and 0.655/0.719), respectively; whereas, LFpen presented lower accuracy (0.37-0.44/0.49-0.52) and A_z (0.390-0.454/0.345-0.395) values. The occurrence of overhangs (26.8%) was shown to be irrelevant in determining the presence of secondary caries. The ICDAS and BW methods presented

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the best performance in detecting caries lesions affecting enamel and dentin on approximal surfaces of amalgam restorations.

INTRODUCTION

In dental practice, secondary caries is defined as a lesion that occurs at the margin of an existing restoration, and it is the most common reason for filling replacement.[1-3] Histopathologically, caries lesions around restorations may show lines of demineralized tissue along the cavosurface margin (called outer lesions) and the cavity wall (called wall lesions).[2]

The detection of secondary caries lesions is extremely challenging due to difficulties encountered during the clinical examination, such as stained restoration margins, gaps, crevices, and ditches.[2] Traditional methods for detecting secondary caries include bitewing radiographs and visual-tactile examinations.[1] Bitewing radiographs are important for secondary caries detection because the disease often occurs cervically.[1,4] Nevertheless, radiographs can lead to underestimation of the lesion extension and cannot predict the presence or absence of cavitation of the approximal surface.[5] In addition, restorative materials are radiopaque and can partially or completely hide the lesion.[6]

Enamel translucency, cavitation, consistency or hardness, and the color of dentin and enamel are considered to be the best clinical parameters for determining the activity and extent of secondary caries.[7] However, gray or blue discoloration next to an amalgam restoration presents limitations for caries detection because the discoloration could be due to a large amalgam restoration or the products of its corrosion. This confounding factor associated with the subjective criteria used by dental practitioners can lead to false-positive results for secondary caries.[8,9]

The International Caries Detection and Assessment System (ICDAS) visual criteria were introduced to assist in caries detection.[10] Given that outer lesions from secondary caries are considered similar to primary caries, the broad principles applied to the criteria for primary caries can also be applied to caries around restorations and sealants (CARS).[11] Research has shown that the ICDAS presents good reproducibility and accuracy for *in vitro* and *in vivo* detection of primary caries lesions at different stages of the disease.[10,12-15] To our knowledge, no studies have been published that evaluate the performance of the ICDAS visual criteria in the detection of caries around restorations on approximal surfaces.

New early-caries detection methods, such as laser fluorescence (DIAGNOdent 2095 [LF], KaVo, Biberach, Germany) have received considerable attention as aids in the detection and quantification of demineralized dental tissue beneath restorations.[16-19] In 2006, a new laser fluorescence device (DIAGNOdent 2190 [LFpen], KaVo) was developed to assist the detection of occlusal and approximal caries.[20] The LFpen is able to capture, analyze, and quantify the fluorescence emitted from bacterial porphyrins and other chromophores when the tooth is illuminated by a diode laser with a wavelength of 655 nm.[20] To date, few reports have evaluated the capacity of the LFpen device to detect caries around restorations.[21,22]

The marginal integrity of the restorations on the approximal surface is critical, because cervical overextension of the restoration can lead to plaque accumulation and periodontal inflammation, and underfilled restorations may result in marginal leakage and secondary caries.[23] Studies[24-26] have shown an alarming prevalence of overhanging restorations (57%-64%), which might predispose patients to the development of secondary caries.[7]

Therefore, the purpose of this *in vitro* study was to evaluate the *in vitro* performance of the ICDAS visual criteria, bitewing radiography examination (BW), and the LFpen in detecting secondary caries on approximal surfaces of amalgam restorations in permanent teeth. The association between the presence of overhangs and secondary caries was also evaluated.

METHODS AND MATERIALS

A total of 110 posterior permanent human teeth (56 premolars and 54 molars) with Class II amalgam restorations were selected from a pool of extracted teeth obtained from dental practitioners in the United States. A total of 136 surfaces were included in this study, which included restorations with intact margins, visual signs of demineralization, or cavitated margins on the approximal surfaces. The teeth were cleaned with water and a prophy angle, and calculus and debris were removed using a scaler. The teeth were then numbered and were stored individually in plastic containers at −20°C until use.

The approximal surfaces were photographed at 10× magnification using a stereomicroscope (model SMZ1500, Nikon, Tokyo, Japan) equipped with a digital camera (model DXM1200, Nikon) and imaging software (Nikon ACT-1, version 2.62, Nikon). The occlusal surfaces were also photographed for tooth identification.

The teeth were mounted in plastic dental models (upper and lower arches) (Nissin Dental Products Inc, Kyoto, Japan), using base wax in order to obtain a contact surface, and stored at 100% humidity throughout the study. The surfaces under study were placed next to surfaces with or without restorations in order to simulate the contact point between the crowns, similar to clinical oral conditions. The models were placed in a phantom head (Kilgore International Inc, Coldwater, MI, USA) to simulate clinical examination conditions.

The assessments were independently performed twice by two experienced examiners, observing a one-week interval. The examiners assessed the teeth using the ICDAS criteria for CARS, digital BW, and the DIAGNOdent 2190 device (LFpen, KaVo).

Visual Examination

Before the assessments, the two examiners, who had previous experience with ICDAS, participated in a training session involving ICDAS criteria for CARS. Training consisted of the online ICDAS e-learning program, an evaluation of 20 extracted teeth with amalgam restorations on two occasions with a one-week interval, and a discussion of each code until consensus was reached.

Each surface was assessed by the examiners using the ICDAS criteria proposed for CARS according to the ICDAS Coordinating Committee[27]: 0, sound tooth surface with restoration or sealant; 1, first visual change in enamel; 2, distinct visual change in enamel/dentin adjacent to a restoration/sealant margin; 3, carious defects of <0.5 mm with the signs of code 2; 4, marginal caries in enamel/dentin/cementum adjacent to a restoration/sealant with underlying dark shadow from dentin; 5, distinct cavity adjacent to a restoration/sealant; and 6, extensive distinct cavity with visible dentin.

The examinations were performed in the same room, under good illumination, using a portable dental light, and aid of a three-in-one air syringe, a dental mirror, and a ballpoint probe. The teeth were analyzed moist and then dried from both the buccal and lingual sides.

Radiographic Examination

Digital BW were taken of all teeth using an x-ray unit (Heliodent DS, Siemens Co, München, Germany) and a charge-coupled device (CCD) sensor of a direct digital system (Schick CDR, Schick Technologies Inc, Long Island City, NY, USA) by the same operator at 60 kV and 7 mA, with an exposure time of 0.06 seconds. The radiation source was perpendicularly directed to the sensor and the tooth, following the principles of the parallelism technique, and was placed 2 cm from them.

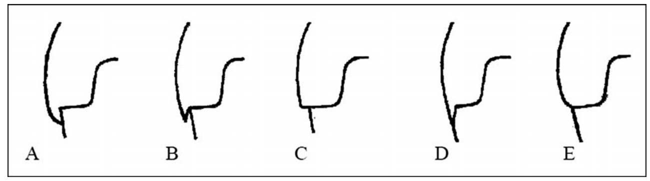

Figure 1. *Definition of overhang.*

The radiographs were viewed using the software supplied by the CCD manufacturer (CDR DICOM 4.5 software, Schick Technologies) on a 15.4-inch computer screen under the same lighting conditions, at a standardized distance and viewing angle. No modification of the original image or screen adjustments was allowed and no image enhancement software was used.[28] The criteria used to indicate enamel or dentin caries lesions were 0, no radiolucency; 1, radiolucency adjacent to the restoration consistent with enamel caries; and 2, radiolucency adjacent to the restoration consistent with dentin caries.

Laser Fluorescence

The LFpen measurements were performed using the wedge-shaped tip (1.1 mm). Before each measurement, the device was calibrated with a ceramic standard and on a sound smooth surface of each tooth, in accordance with the manufacturer's instructions. The approximal surfaces were assessed by each examiner by moving the tip from the buccal toward the lingual side, underneath the contact area. The same procedure was performed moving the tip from the lingual toward the buccal side.[22] Each surface was assessed by scanning the margin and recording the maximum reading (peak value) for each measurement. For statistical analysis, the greater of these values was considered.[22]

Overhang Evaluation

An overhang is a restoration that extends beyond the prepared cavity and does not conform to the proximal contour of the tooth. The examiners evaluated the BW and classified each surface accordingly (Figure 1). Types A, B, and C were defined as overhangs, whereas types D and E were not.[29]

Validation (Gold-Standard)

For validation, the restorative material was removed carefully by one of the examiners using a tungsten carbide bur in a high-speed handpiece under copious water cooling. Care was taken to avoid any contact with the cavity walls and margins. Any remnants of amalgam in the cavity were removed using a sharp excavator.[18]

The teeth were then longitudinally hemisectioned, perpendicular to the approximal surfaces, with a water-cooled diamond blade (Gillings-Hamco, Hamco Machines Inc, NY, USA). Both sides of each section were examined carefully by two experienced examiners using visual examination in a stereomicroscope at 10× magnification; the most severely affected section determined the lesion depth.[18] In cases of disagreement, the results were discussed until a consensus was reached. Each section was scored independently according to the following criteria: 0, no caries, 1, caries lesion limited to the outer half of the enamel, 2, caries extending into the inner half of the enamel or outer half of the dentin, 3, caries limited to the middle third of the dentin, and 4, caries involving the inner half of the dentin.[30]

Statistical Analysis

Data from both examiners were used for statistical analysis. For LFpen measurements, the mean value of the two measurements obtained for each surface was used in the analysis. The cutoff limits for LFpen were based on a previous study[31] for primary approximal caries (0-6, sound; 7-15, caries in enamel; and 16-99, caries in dentin); on a study[21] for approximal caries around composite restorations (0-18, sound; 19-30, caries in enamel; and 31-99, caries in dentin); and on a study[17] for approximal caries around amalgam restorations (0-8, sound; 9-30, caries in enamel; and 31-99, caries in dentin).

The sensitivity, specificity, accuracy, and area under the receiver operating characteristic curve (A_z) of each method were calculated at D_1 ("all visible lesions affecting enamel," considering scores of 1 to 4 as the disease gold-standard) and D_3 ("caries extended into dentin," considering scores of 3 and 4 as the disease gold-standard) diagnostic thresholds (MedCalc for Windows, version 9.3.0.0, Mariakerke, Belgium). Diagnostic accuracy relates the ability of a test to discriminate between and/or to predict disease and health and can be quantified by measures such as sensitivity and specificity, predictive values, likelihood ratios, A_z, overall accuracy, and diagnostic odds ratio.[32] The McNemar test ($p<0.05$) was applied to compare statistically significant differences among the methods. In addition, a nonparametric statistical test for paired data was applied to assess the difference in the A_z by estimating the covariance matrix for the A_z, based on the general theory of U-statistics, and then constructing a large-sample test in the usual way.[33]

The intraexaminer and interexaminer reproducibility was assessed by means of weighted κ (WK) and intraclass correlation coefficients (ICC). The ICC was assessed as poor when the values were below 0.40, fair for values between 0.40 and 0.59, good for values between 0.60 and 0.75, and excellent for values above 0.75. WK values above 0.75 denoted excellent agreement, whereas values between 0.40 and 0.75 indicated good agreement.[34]

The Spearman rank correlation coefficient was determined to compare all three methods with histological scores. The occurrence of proximal overhangs and their possible association with secondary caries was also evaluated using the Fisher exact test. The criterion for significance was set at 5%.

RESULTS

Of the 136 approximal surfaces available for this study, histological examination showed that 52 (38.2%) presented no caries, five (3.7%) presented caries limited to the outer half of the enamel, 18 (13.2%) had caries extending into the inner half of the enamel or outer half of the dentin, 27 (19.9%) had caries limited to the middle third of the dentin, and 34 (25.0%) presented caries involving the inner half of the dentin.

Table 1 presents the cross-tabulation for the ICDAS, BW, and LFpen methods and the corresponding histological results. The analyses were performed twice by two experienced examiners on 136 surfaces, totaling 544 surfaces. The results show a tendency for underestimation and overestimation of the depth of secondary caries lesions. Both BW and LFpen correctly indicated a greater amount of sound approximal surfaces than carious surfaces.

Table 2 presents the sensitivity, specificity, accuracy, and A_z for all methods at the D_1 and D_3 thresholds. At the D_1 threshold, ICDAS presented a statistically higher sensitivity value, whereas LFpen showed lower sensitivity and higher specificity values. Regarding accuracy and A_z values, ICDAS and BW presented statistically comparable results. At the D_3 threshold, both ICDAS and BW presented similar sensitivity, specificity, and accuracy values.

Table 1: *Cross-tabulation of the ICDAS, BW, and LFpen Measurements With the Corresponding Histological Scores*

	Histological Score					
Codes	**0, n**	**1, n**	**2, n**	**3, n**	**4, n**	**Total, n (%)**
ICDAS						
0	85	6	20	12	29	152 (27.9)
1	17	3	12	6	9	47 (8.6)
2	63	7	32	37	25	164 (30.1)
3	11	1	2	14	5	33 (6.1)
4	11	0	2	9	14	36 (6.6)
5	15	3	2	18	32	70 (12.9)
6	6	0	2	12	22	42 (7.7)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)
BW						
0	153	11	46	52	56	318 (58.5)
1	20	1	16	7	5	49 (9.0)
2	35	8	10	49	75	177 (32.5)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)
LFpen						
0	161	8	49	86	117	421 (77.4)
1	23	10	12	21	15	81 (14.9)
2	24	2	11	1	4	42 (7.7)
Total, n (%)	208 (38.2)	20 (3.7)	72 (13.2)	108 (19.9)	136 (25.0)	544 (100)

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).

However, LFpen showed statistically lower sensitivity and higher specificity values.

Table 3 presents the intraexaminer and interexaminer reproducibility assessed by calculating the WK and ICC. For the LFpen, the ICC varied from 0.690 (interexaminer) to 0.878 (intraexaminer A). For intraexaminer reproducibility, the WK values ranged from 0.575 (BW) to 0.819 (overhangs); whereas, for interexaminer reproducibility, the WK values ranged from 0.404 (BW) to 0.673 (ICDAS), indicating good to excellent agreement.

The Spearman rank correlation coefficients for all methods with histology were 0.321 for ICDAS, 0.309 for BW, −0.103 for the LFpen device, and −0.077 for overhangs. A nonstatistically significant correlation was determined between the occurrence of overhangs and the presence of secondary caries ($p>0.05$); whereas, minimal significant correlation was determined for ICDAS, BW, and LFpen ($p<0.05$).

Different overhangs were detected: type A in 3.3% of the radiographs, type B in 1.6%, type C in 21.9%, type D in 5.8%, and type E in 67.4%. Table 4 shows

Table 2: *Sensitivity, Specificity, Accuracy, and Area Under the Receiver Operating Characteristic Curve (A_z) for All the Methods at D_1 and D_3 Thresholds*

	Sensitivity		Specificity		Accuracy		A_z	
Method	**D_1[a]**	**D_3[b]**	**D_1**	**D_3**	**D_1**	**D_3**	**D_1**	**D_3**
ICDAS	0.80 A	0.52 A	0.41 A	0.82 A	0.65 A	0.68 A	0.633 A	0.688 A
BW	0.56 B	0.51 A	0.70 B	0.82 A	0.64 A	0.68 A	0.655 A	0.719 A
LFpen[c]	0.23 C	0.02 B	0.77 C	0.88 A	0.44 B	0.49 B	0.390 B	0.345 B
LFpen[d]	0.04 D	0.01 B	0.89 D	0.94 B	0.37 C	0.52 C	0.454 B	0.395 B
LFpen[e]	0.16 E	0.01 B	0.80 C	0.94 B	0.41 B	0.52 C	0.403 B	0.395 B

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).
[a] D_1: 0 = sound, 1-4 = decayed; [b] D_3: 0-2 = sound, 3-4 = decayed. Significant differences are represented by different small capital letters considering the same column (McNemar test, $p<0.05$ for specificity, sensitivity and accuracy; nonparametric statistical test for paired data for A_z).
[c] Lussi and others (2006): 0-6, sound; 7-15, caries in enamel; 16-99, caries in dentin.
[d] Rodrigues and others (2010): 0-18, sound; 19-30, caries in enamel; 31-99, caries in dentin.
[e] Ando and others (2004): 0-8, sound; 9-30, caries in enamel; 31-99, caries in dentin.

Table 3: *Intraexaminer and Interexaminer Reproducibility for All the Methods*

Method	Intraexaminer Reproducibility		Interexaminer Reproducibility
	Examiner A	Examiner B	All
ICDAS[a]	0.783 (0.708-0.858)	0.657 (0.533-0.761)	0.673 (0.610-0.737)
BW[a]	0.802 (0.701-0.904)	0.575 (0.459-0.691)	0.404 (0.321-0.487)
LFpen[b]	0.878 (0.833-0.911)	0.861 (0.811-0.899)	0.690 (0.622-0.747)
Overhangs[a]	0.819 (0.734-0.904)	0.656 (0.540-0.771)	0.591 (0.511-0.672)

Abbreviations: BW, bitewing radiography; ICDAS, International Caries Detection and Assessment System; LFpen, DIAGNOdent 2190, a pen-type laser fluorescence device (KaVo, Biberach, Germany).
[a] *Weighted κ (95% confidence interval).*
[b] *Intraclass correlation coefficient (95% confidence interval).*

the overhang results and their association with the presence or absence of secondary caries. According to the radiographs, 36 (26.8%) of the amalgam restorations exhibited detectable overhangs and 100 (73.2%) did not present overhangs. Of the total number of amalgam-restored proximal surfaces, 84 (61.8%) presented secondary caries lesions. Of all the proximal surfaces with overhangs (N=36), 20 (55.6%) exhibited secondary caries versus 64 (64.0%) of the restorations without overhangs. No statistically significant difference was determined between overhangs and the presence or absence of secondary caries ($p>0.05$).

DISCUSSION

In this study, the performance of the ICDAS visual criteria, BW, and LFpen in detecting caries around Class II amalgam restorations was compared. Although a previous study[35] had evaluated the prevalence and severity of primary and secondary dental caries in low-income African American adults, to our knowledge, this is the first study to investigate the performance of the ICDAS in detecting caries around approximal amalgam restorations in permanent teeth.

The gold standard used in this study involved microscopic examinations after restoration removal and tooth hemisectioning. Another study also assessed cavities in this manner.[18] Given that it is difficult to validate secondary caries, caution was taken during tooth preparation and examination. However, different histological methods for validating secondary caries are described in the literature, including confocal laser scanning microscopy examination,[17] caries-detector dye application,[36] and histological specimen preparation associated with microhardness evaluation.[21,22]

The LFpen cutoff limits used in this study were proposed by Lussi and others[31] for approximal primary lesions. Other studies[21,22] have also evaluated these cutoff values for secondary caries detection around approximal restorations. The cutoff limits were tested following the principles that secondary caries on approximal surfaces appeared and progressed similar to primary caries.[37] The cutoff limits proposed by Rodrigues and others[21] for the LFpen device using a wedge-shaped sapphire fiber tip to detect caries around approximal composite restorations and the cutoffs proposed by Ando and others for the LF (DIAGNOdent 2095, KaVo) device using a tapered fiber-optic tip (tip A) to detect caries around Class II amalgam restorations in permanent teeth were also evaluated. It is important to emphasize that cutoff limits should be carefully interpreted, because they are used to determine the borderline between health and disease. An attempt was made to establish the optimal cutoff points for this investigation. However, inconsistency was verified between the D_1 and D_3 thresholds, and any value lower than 2.0 showed the optimal balance between sensitivity and specificity in detecting secondary caries in enamel or dentin. This variation

Table 4: *Overhangs Association With the Presence or Absence of Secondary Caries*

Overhangs	Presence of Secondary Caries n	Presence of Secondary Caries %	Absence of Secondary Caries n	Absence of Secondary Caries %	Total, n(%)	*p* Value*
Restored without overhang	64	64.0	36	36.0	100 (73.2)	0.4257
Restored with overhang	20	55.6	16	44.4	36 (26.8)	
Total, n (%)	84 (61.8%)		52 (38.2%)		136 (100)	

* *Fisher exact test ($p<0.05$).*

could be attributed to the distribution of lesion types and the different LFpen readings due to the marginal integrity of the tooth around the restoration. According to Lussi and others,[38] some interference can occur due to the materials and caries when fluorescence is measured approximally, leading to false-positive results. In this work, the surfaces under examination were placed next to surfaces with or without restoration in order to simulate the contact point, similar to clinical oral conditions. A previous study on secondary caries detection confirmed that amalgam restorations did not influence laser fluorescence examinations.[17] Thus, it can be assumed that the LFpen findings could be basically attributed to the cutoff limits evaluated in the present investigation. Superior cutoff ranges are necessary to interpret the LFpen assessments for secondary caries detection.

According to Neuhaus and others,[22] refinishing and cleaning restoration facets by adequate means before LF assessment is indispensable. Thus, all the surfaces of our samples were cleaned before the assessments to avoid false-positive results.

ICDAS and BW were better at detecting secondary caries than the LFpen. Considering all visible lesions affecting enamel, ICDAS showed statistically greater sensitivity than BW. Our results are in agreement with the results presented by Neuhaus and others,[22] who reported high specificities and low sensitivities for BW. According to Sikri and Sikri,[39] the detection of secondary caries by BW is obscured by adjacent superimposing structures. It is known that digital radiography does not fully address the problems associated with conventional radiography,[39] as verified in this investigation. For the detection of lesions extended into dentin, ICDAS and BW showed statistically similar performances, with high specificity and low sensitivity values. Diniz and others[14] reported lower specificity (0.69) and higher sensitivity (1.00) values for ICDAS in detecting occlusal primary caries in permanent teeth.

The LFpen showed poor performance in terms of sensitivity and accuracy at the D_1 and D_3 thresholds for both cutoff limits tested. On the other hand, high specificity values were determined for both thresholds, indicating that the LFpen could be a useful tool for detecting the absence of secondary lesions. Rodrigues and others[21] and Neuhaus and others[22] showed lower specificity and higher sensitivity and accuracy values for secondary caries on crown surfaces at the D_1 threshold as well as higher sensitivity and accuracy values at the D_3 threshold when using the cutoff limits proposed by Lussi and others.[31] Ando and others[17] observed higher sensitivity and accuracy values for the LF device for the D_1 and D_3 thresholds for secondary caries on approximal surfaces when using the cutoff limits based upon the manufacturer's instructions and literature available. These differences could be due to the smaller number of approximal surfaces analyzed, the distribution pattern of caries lesions, with minimal areas of sound surfaces, the LF devices used and their different tips, the simulated contact point between two sound teeth, and the histological validation method used in their studies. Even though the LF method has been evaluated for secondary caries detection on occlusal surfaces around amalgam restorations,[18,36] these studies used a different device (DIAGNOdent 2095, KaVo), and the actual numbers may not be comparable.

The Spearman correlation coefficients were statistically significant for ICDAS, BW, and LFpen. These results showed that there was a positive association between the histological scores and the methods. However, it is important to emphasize that ICDAS and BW presented higher values compared with the LFpen device. Rodrigues and others[21] obtained similar results for BW (0.29) and the visual examination (0.29), but a higher Spearman correlation coefficient for the LFpen (0.54). It should be highlighted that Rodrigues and others[21] evaluated the detection of secondary approximal caries associated with composite restorations, which might explain the differences verified between their work and this study.

Despite the training in visual ICDAS criteria, interexaminer and intraexaminer reproducibility varied from good to excellent, illustrating the need for additional training. Lower reproducibility values were described by Rodrigues and others[21] when assessing caries around composite restoration on approximal surfaces, using different criteria for visual examination. The reproducibility values reported by previous *in vitro* studies[12-14] involving ICDAS criteria for primary caries also varied from good to excellent. Direct visual examination is hard to perform on approximal surfaces, especially around amalgam restorations, in which the presence of ditches, stain, gaps, and crevices may confound clinicians. The ICC values obtained for the LFpen measurements in our study were high for intraexaminer reproducibility, showing excellent agreement. This result corroborates *in vitro* reproducibility results for approximal secondary caries detection.[21-22] For BW, the WK value for interexaminer agreement was lower compared with the other methods, similar to that described by Rodrigues and others[21] but in contrast to Neuhaus and others,[22] who reported higher values for interexaminer reproducibility. These varied results could be attributed to the differences in the examiners' clinical experience in radiographic caries detection.[40]

Overhangs in dental restorations are a major dental health problem, and they are defined as an extension of restorative material beyond the confines of a cavity preparation.[41-43] Overhangs are primarily iatrogenic, caused by poor operator skills and exacerbated by unusual dental morphology.[44] Clinical and radiographic assessments are the most reliable way of diagnosing overhanging margins.[45] In this investigation, no significant correlation between overhangs and approximal secondary caries (p=0.3750) was determined. Similarly, no statistically significant difference was determined between surfaces restored with or without overhangs and the presence or absence of caries (p=0.4257). This is in disagreement with Svensson,[29] who reported 1.6 times more secondary caries on restored surfaces with overhangs compared with restored surfaces without overhangs. These data were derived from a clinical study in which conventional radiographs were taken of 235 patients aged 20-70 years. A total of 1787 proximal amalgam restorations were assessed, and the prevalence of detectable overhangs was 16%; however, a magnifier was used to evaluate the radiographs. In this study, higher percentages of detectable overhangs (26.8%) were observed, even though the digital radiographs were not magnified or altered when assessed.

The LFpen and BW showed good agreement with the histological score in detecting sound surfaces. These results are in accordance with previous studies[17,22] that demonstrate higher specificity values for the LF device and BW in detecting caries around amalgam restorations. Thus, BW and LFpen assessments could be recommended to complement the detection of sound surfaces on approximal amalgam restorations. In contrast, the ICDAS criteria showed a tendency to overestimate the presence of caries around amalgam restorations when no caries were identified by the histological analysis. This result indicates that ICDAS should be used with care when assessing amalgam restorations. Any visual change in the surface around amalgam restorations, such as stained restoration margins, gaps, crevices, and ditches, may lead to false diagnostic outcomes.[2] The examiner using the ICDAS codes might overestimate caries around an amalgam restoration due to the variety of causes of discoloration around it, such as corrosion products or darkly stained areas that are probably from exogenous dietary sources. This is an important observation given that the principles applied to the criteria for primary caries are also applied to CARS.[11] However, it should be noted that the scientific basis for that has not been established and the literature in the area is limited. It should also be stressed that there is difficulty directly inspecting the approximal surfaces once the adjacent tooth and gingival tissue hamper visual access, especially when a restoration is involved, complicating the differentiation between noncarious changes and secondary caries. A temporary tooth separation with an orthodontic rubber ring placed around the contact point for 2-3 days might be indicated when visual inspection is doubtful.

The LFpen showed a tendency to underestimate enamel and dentin carious lesions. This finding must be considered carefully when using the LF device for treatment decision making because carious lesions will be missed and, consequently, they will be left untreated.

CONCLUSION

In conclusion, ICDAS and BW performed better at detecting caries lesions affecting enamel and lesions extended into dentin on approximal surfaces of amalgam restorations compared with the LFpen device at different cutoff limits. LFpen results should be considered with caution when assessing Class II amalgam restorations. In contrast, the ICDAS criteria showed a tendency to overestimate the presence of caries around amalgam restorations when no caries were present, indicating that ICDAS should be interpreted with care when assessing amalgam restorations.

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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 Araraquara School of Dentistry, São Paulo State University. The approval code for this study is 48/08.

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 Bleaching Agents on the Nanohardness of Tooth Enamel, Composite Resin, and the Tooth-Restoration Interface

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Clinical Relevance

Exposure to bleaching agents can result in changes in the tooth-restoration interface.

SUMMARY

This *in vitro* study aimed to evaluate the nanohardness of tooth enamel, composite resin, dental adhesive, and enamel hybrid layer exposed to 35% hydrogen peroxide-based bleaching agents and analyze the tooth-restoration interface using scanning electron microscopy (SEM). This study used 40 crowns of bovine incisors, which were embedded in epoxy resin. A 2 × 2 × 2-mm cavity was prepared in the medial third of the flattened buccal surface of each tooth and restored (two-step etch-and-rinse Adper Single Bond 2 + nanocomposite resin Filtek Z350 XT). The specimens were polished and divided into four groups (n=10), corresponding to each bleaching agent used (TB: Total Blanc Office, pH=7.22–6.33; HPB: Whiteness HP Blue, pH=8.89–8.85; HP: Whiteness HP, pH=6.65–6.04; PO: Pola Office, pH=3.56–3.8), applied in accordance with manufacturer protocols. The nanohardness of the substrates was measured before and immediately after the bleaching procedure and after 7-day storage in artificial saliva with an Ultra-Microhardness Tester (DUH-211S, Shimadzu). Loads used were 100 mN for tooth enamel and composite resin and 10 mN for adhesive and enamel hybrid layer. For SEM analysis, epoxy replicas were prepared through high-precision impressions of the specimens. For nanohardness, the statistical tests two-way analysis of variance and Tukey ($p<0.05$) revealed that the agent with the lowest pH value (PO) was the only one to decrease the nanohardness of enamel and the enamel hybrid layer immediately after its application; however, after 7-day storage in artificial saliva, the nanohardness levels of these substrates returned to their original values. SEM analysis revealed small gaps be-

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tween tooth enamel and adhesive after the exposure to all bleaching agents; however, the most evident gap in the tooth-restoration interface was observed immediately after application of agent PO. No bleaching agent used changed the nanohardness of the composite resin and adhesive layer.

INTRODUCTION

Hydrogen peroxide is the main agent used for dental bleaching, and it is a strong oxidizing agent with low molecular weight. It is able to disseminate through tooth enamel in the inter- and intrarod enamel regions, which are composed mainly of proteins, until it reaches the amelodentinal interface.[1-3] As it disseminates into the tooth structure, free radicals resulting from the decomposition of hydrogen peroxide oxidize the macromolecules of pigments, promoting the cleavage of chemical bonds; turning the long molecular chains into smaller molecular chains, which are not pigmented; making the teeth visually clearer; and thus reestablishing their optical properties.[4,5]

Many patients undergoing dental bleaching treatments have teeth with restorations, and since the tooth-bleaching mechanism involves chemical processes, this could change the physical and mechanical properties of both dental tissues and restorative materials; therefore, it is important to study the effects of bleaching agents on these surfaces.

Nanoindentation is a method used to measure the mechanical properties of both dental tissues and restorative materials. Unlike the conventional microhardness testing procedure based on visual information, the nanoindentation test uses a load displacement curve[6,7] to calculate the mechanical properties of a certain material. Because it uses low loads equivalent to milli-Newtons (mN), this test allows for the evaluation of mechanical properties in extremely thin regions, such as the tooth-restoration interface.

The studies analyzing the effects of bleaching agents on the adhesive interface evaluate mostly the bond strength on dental tissues previously exposed to peroxide; however, little is known about the effects of bleaching agents on existing tooth-restoration interfaces, and this study analyzed the effects of bleaching agents on this interface through the nanoindentation test.

In the attempt to contribute to a broad understanding of the effects of bleaching agents on an existing restoration, the aim of our study was to evaluate the nanohardness of tooth enamel, composite resin, adhesive, and enamel hybrid layer by performing nanoindentation tests and to analyze the tooth-restoration interface through scanning electron microscopy (SEM) to decide whether the composite resin restorations should be replaced after the dental bleaching treatment. The null hypothesis tested was that the different bleaching agents, regardless of the bleaching technique and pH value, would not cause nanohardness alterations on the composite resin-tooth interface.

METHODS AND MATERIALS

Forty freshly extracted bovine teeth were cleaned and stored in distilled water at 4°C until use. The teeth were observed under an optical stereoscope at 50× magnification (MiView USB Digital Microscope, Chinavasion Wholesale, Guangdong, China) in order to visualize the absence of cracks in the buccal enamel surface and were cut at the cemento-enamel junction to separate the crown from the root portion. The crowns were embedded in epoxy resin and the buccal surface of each specimen was polished with 600-grit silicon carbide (SiC) paper (Buehler Ltd, Lake Bluff, IL, USA) under running water in polishing equipment (160 rpm, Buehler Ltd) in order to expose and flatten the enamel surface. The opposite surface of each specimen was also polished to obtain a parallel surface, which is essential for the correct measurement of nanohardness.

After the enamel surface was flattened, a $2 \times 2 \times 2$-mm cavity was prepared in the medial third of each tooth using a high-speed diamond bur (No. 1090, KG Sorensen, Cotia, Brazil) and manual cutting instruments (#14/15, #26, SS White/Duflex, Rio de Janeiro, Brazil). The burs were replaced after preparation of 10 cavities, and the size of each cavity and its depth were measured using a periodontal probe.

For the restorative procedure, each cavity was etched with 37% phosphoric acid (Villevie, Joinville, Brazil) for approximately 15 seconds for enamel and 10 seconds for dentin. The cavities were washed with water spray for 15 seconds, and the excess water was removed with absorbent paper and air-dried. Next, the two-step etch-and-rinse adhesive Adper Single Bond 2 (3M ESPE, St Paul, MN, USA) was applied in two layers, according to the manufacturer's recommendation, and each layer was vigorously scrubbed in the cavity with applicator brushes for 15 seconds, permitting the solvent to evaporate.[8] The adhesive excess was removed using a dry brush, and then the adhesive was light cured for 10 seconds (Elipar Freelight 2, 3M ESPE) with a power density of 1000

Table 1: *Manufacturer, Lot, Composition, and Application Protocol of the Materials Used*

Materials	Manufacturer/Lot	Composition	Application Protocol
Acid Gel	Villevie (Joinville, Brazil)	37% phosphoric acid	15 s on enamel 10 s on dentin
Adper Single Bond 2	3M ESPE (St Paul, MN, USA) #123600553	Ethanol, Bis-GMA, HEMA, colloidal silica, 2-hydroxyethylmethacrylate, glycerol 1,3 dimethacrylate, copolymer of acrylic acids and itaconic acids, UDMA	Two layers 15 s on each layer
Filtek Z350 XT	3M ESPE #1320400385	Bis-GMA, Bis-EMA, colloidal silica, zirconia silica-oxide, silane, UDMA, polyethylene glycol dimethacrylate, TEGDMA, 2,6-di-terc-butyl-p-cresol (BHT), pigments	
TB	Nova DFL (Rio de Janeiro, Brazil) #13060921	35% hydrogen peroxide, thickener, vegetable extracts, amide, chelating agent, glycol, pigments, water	One session Two applications of 20 min each
HPB	FGM (Joinville, Brazil) #160913	35% hydrogen peroxide, thickeners, violet inactive pigment, neutralizing agents, calcium gluconate, glycol, deionized water	One session One application of 40 min each
HP	FGM #130213	35% hydrogen peroxide, thickener, red pigment, glycol, water	One session Three applications of 15 min each
PO	SDI Ltd (Bayswater, VIC, Australia) #122363	Liquid: 35% hydrogen peroxide, water Powder: thickener, catalyzer, pigment, desensitizing agent	One session Three applications of 8 min each

Abbreviations: Bis-EMA, ethoxylated bisphenol A glycol dimethacrylate; Bis-GMA, bisphenol A diglycidyl methacrylate; HEMA, 2-hydroxyethyl methacrylate; HP, Whiteness HP; HPB, Whiteness HP Blue; PO, Pola Office; TB, Total Blanc Office; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

mW/cm^2. The intensity of the light was monitored with a radiometer (LED Radiometer, SDI Ltd, Bayswater, VIC, Australia).

The cavities were restored with nanofilled composite resin Filtek Z350 XT (A2E shade, 3M ESPE), which was incrementally placed using three layers, two oblique and one horizontal, and each layer was light cured for 20 seconds. After the placement of the last layer (horizontal layer), it was covered with a polyester matrix strip and a glass slab that was pressed using a load of 3.5 kg for 10 seconds to standardize the pressure over the glass slab and to ensure better adaptation of the composite in the cavity. Following removal of the glass slab, the composite resin was light cured for 20 seconds. The composition of the materials used is shown in Table 1. After completing the restorations, the specimens were stored in distilled water at 37°C for 7 days.

After this initial storage period, the buccal surface of each specimen was again polished to remove excess filling, if any, on the prepared enamel and to expose the tooth/adhesive/restoration line. Then a decreasing sequence of SiC paper (800, 1200, 2400, and 4000 grit) under running water was used to obtain a smooth and polished surface. Between each polishing stage, the specimens were cleaned using distilled water in an ultrasonic cleaner (Digital Ultrasonic Cleaner CD-4820, Kondortech, São Carlos, Brazil) for 5 minutes to remove any debris. Right after polishing, the specimens were stored in artificial saliva (0.213 g/L $CaCl_2$*$2H_2O$, 0.738 g/L KH_2PO_4, 1.114 g/L KCl, 0.381 g/L NaCl, 12 g/L Tris buffer; pH adjusted to 7.0 with KOH)[9] at 37°C.

The specimens were divided into four groups (n=10) with each group corresponding to one 35% hydrogen peroxide–based bleaching agent used: Total Blanc Office (TB, Nova DFL, Rio de Janeiro, Brazil), Whiteness HP Blue (HPB, FGM, Joinville, SC, Brazil), Whiteness HP (HP, FGM), and Pola Office (PO, SDI).

Bleaching Procedure

The bleaching gels were applied directly to the tooth enamel and restoration 24 hours after polishing, following the protocol of each manufacturer (Table 1), at room temperature without the use of light sources. During this procedure, the gel was stirred using an applicator brush to release possible oxygen bubbles formed. The specimens were washed in distilled water to remove the gel, air-dried, and stored in artificial saliva at 37°C for 7 days.

pH Measurement

The pH value of each bleaching agent was measured with a calibrated pH meter (Hanna HI 2221, Hanna Instruments, Tamboré, Brazil) on the mixture of the bleaching gel (initial) and at the end of the first application (20 minutes for TB, 40 minutes for HPB, 15 minutes for HP, and 8 minutes for PO).

Nanoindentation Evaluation

Nanohardness measurements were performed with a Berkovich tip attached to an Ultra-Microhardness Tester (DUH-211S, Shimadzu, Tokyo, Japan), using a maximum load of 100 mN for tooth enamel and composite resin and 10 mN for adhesive and enamel hybrid layer. For each specimen, three regions were selected visually using an optical microscope coupled to the equipment. Ten indentation measurements were performed in a region (with a 10-μm distance between measurements), in each substrate (tooth enamel, composite resin, adhesive, and enamel hybrid layer), and at three different times (before and immediately after the bleaching procedure and 7 days after the exposure to the bleaching agent and storage in artificial saliva). The average of 10 indentations for each substrate was calculated. The parametric nanohardness values were analyzed using two-way analysis of variance (ANOVA) for repeated measures and the Tukey test ($p<0.05$).

SEM Analysis

To evaluate the tooth-restoration interface, four more specimens were prepared (one specimen for each group) in the same way that the specimens were prepared for the nanohardness test. Replicas of these specimens were created in epoxy resin (Epofix, Struers, Ballerup, Denmark) through a polyvinyl siloxane impression (Express XT, 3M ESPE) for each period of analysis. Three replicas were obtained for each specimen. The epoxy replicas were fixed on stubs and subjected to platinum plating, and the analyses were performed using a Quanta 600 FEG microscope (FEI, Hillsboro, OR, USA) and Sprit software (Bruker, Atibaia, Brazil). Observations were made in the tooth-restoration interface with 1000× magnification.

RESULTS

ANOVA showed a statistically significant interaction between the nanohardness values obtained between bleaching agents and measurement time in tooth enamel ($p=0.005$) and enamel hybrid layer ($p<0.001$).

Tukey test detected a significant decrease of tooth enamel and hybrid layer nanohardness immediately after application of the PO agent only. However, after 7 days of storage in artificial saliva, nanohardness values increased, returning to values similar to those initially presented in these two substrates (Table 2). The nanohardness values of these substrates exposed to TB, HPB, and HP agents did not show statistically significant differences during the three periods of analysis.

No statistically significant difference was found between the nanohardness values obtained in the composite resin and in the adhesive ($p>0.05$). The agent PO presented the lowest pH value (pH3.6–3.8) when compared to other agents (Table 3).

The SEM images of the tooth-restoration interface (Figures 1 and 2) revealed gaps between the enamel and adhesive after being exposed to bleaching agents; however, the most evident gap was observed immediately after the application of agent PO (Figure 2).

DISCUSSION

The hardness of dental tissues is related to mineral gain or loss,[10,11] and in studies using resinous materials, the hardness has been applied to gain knowledge of properties regarding the composition,[12] degree of polymerization,[13,14] and superficial degradation of the material.[15] The nanoindentation test, also known as the ultra-microhardness test, has been introduced as a reliable method to study the changes in the mechanical properties of dental mineralized tissues.[16-18] Since tooth enamel is not a homogeneous tissue, the use of extremely low loads may be related to the property analysis of isolated components of tooth enamel,[19] thus not reflecting the properties of this tissue as a whole. Like the enamel tissue, the composite resin is also not a homogeneous material because it has inorganic particles immersed throughout an organic matrix. According to Masouras and others,[20] the increase of the indentation area guarantees the inclusion of a wider material area, which is most likely to cover resinous matrix and inorganic particles. Accordingly, a 100-mN load was used in this study, as we understood it would be able to promote a visible and significant indentation to obtain readings of tooth enamel and composite resin. This 100-mN load is within the range established by Elfallah and Swain[21] as a low load, which is up to 500 mN. A 10-mN load was used for the nanohardness evaluation of the adhesive and the enamel hybrid layer; this value was established in order to not exceed the thickness of these thin layers.

One of the variables of this study was the bleaching agent. Hydrogen peroxide–based agents at 35% have been used because such agents at higher

Table 2: *Mean Nanohardness Values and Standard Deviations of the Tested Substrates at Different Measurement Times*

Substrates	Bleaching Agents	Measurement Times		
		Initial	Postbleaching	After 7 d
Tooth enamel	TB	314.4 ± 23.65 A	329.3 ± 29.32 A	342.5 ± 25.93 A
	HPB	341.0 ± 25.45 A	342.8 ± 18.52 A	344.3 ± 19.97 A
	HP	327.8 ± 32.10 A	320.0 ± 31.93 A	325.2 ± 31.23 A
	PO	343.2 ± 27.39 A	298.6 ± 25.75 B	347.8 ± 27.38 A
Enamel hybrid layer	TB	470.0 ± 48.9 A	454.0 ± 73.26 A	488.9 ± 68.03 A
	HPB	494.5 ± 84.16 A	479.1 ± 64.61 A	453.3 ± 68.68 A
	HP	408.1 ± 51.37 A	439.7 ± 67.01 A	465.2 ± 60.17 A
	PO	391.4 ± 51.24 A	225.3 ± 30.61 B	376.2 ± 75.64 A
Composite resin	TB	71.0 ± 1.17	70.9 ± 2.4	71.6 ± 1.87
	HPB	70.3 ± 2.13	69.8 ±3.5	70.9 ± 1.44
	HP	71.0 ± 1.07	71.8 ± 1.3	70.7 ±1.87
	PO	70.4 ± 1.64	70.7 ± 2.07	70.5 ± 2.87
Adhesive	TB	20.6 ± 3.61	19.3 ± 2.14	21.2 ± 2.28
	HPB	21.9 ± 2.68	21.0 ± 3.52	19.9 ± 3.55
	HP	22.1 ± 3.12	21.9 ± 2.54	22.7 ± 2.36
	PO	21.8 ± 2.85	23.3 ± 1.92	23.0 ± 1.69

Abbreviations: HP, Whiteness HP; HPB, Whiteness HP Blue; PO, Pola Office; TB, Total Blanc Office.
Different letters in the row indicate a significant difference ($p<0.05$). No statistical differences were found between measurement times and bleaching agents for the substrates composite resin and adhesive.

concentrations would cause more significant changes.[21,22] The four bleaching agents used (TB, HPB, HP, and PO) have differences in their compositions and pH value.

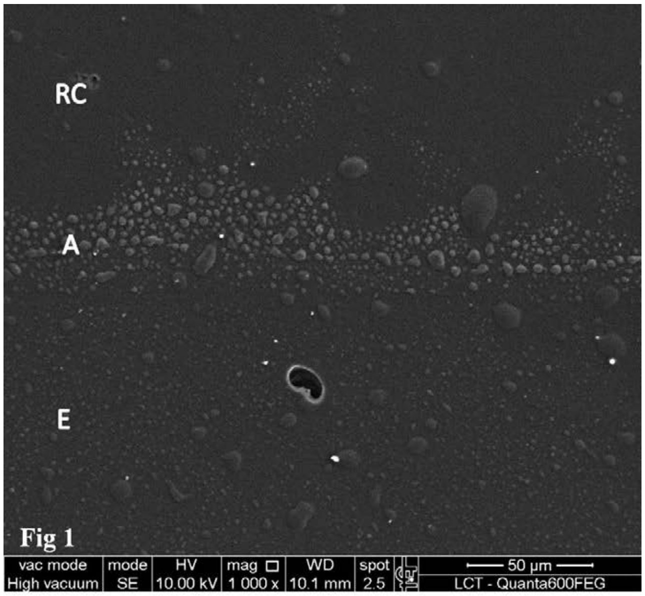
The HPB bleaching agent has calcium in its composition, and this substance was added in the formulation of dental bleaching gels in order to minimize mineral loss of the tooth during the dental whitening procedure.[23-25] The results obtained in the current study revealed that the nanohardness of tooth enamel exposed to this agent remained statistically similar to the nanohardness observed prior to its application. The above-mentioned similar nanohardness could be related to the beneficial effect of calcium addition to bleaching agents because, in fact, no decrease in tooth enamel nanohardness has been observed. However, the nanohardness values of the enamel exposed to TB and HP agents also evidenced no decrease. Since the above-mentioned agents have no calcium in their composition, it is not possible to state that the addition of calcium to the bleaching gel was able to minimize mineral loss during the bleaching procedure.

It is important to know the pH value of dental bleaching agents because it has a strong effect on hydrogen peroxide chemistry. Different oxygen-reactive molecules can be formed, depending on the solution pH value. In a basic environment, only low energy is necessary to start the hydrogen peroxide degradation. According to Malkondu and others,[26] in the pH range of 9.5–10.8, the ionization of buffered hydrogen peroxide produces more perhydroxyl free radicals, resulting in 50% greater bleaching effects in the same period compared to other pH levels. Despite higher pH levels producing more oxidative free radicals, at acidic pH levels, the hydrogen peroxide is more stable, and many bleaching products are formulated at lower pH values to ensure the stability of hydrogen peroxide.[27,28] However, more severe changes in the tooth enamel topography were observed when samples were exposed to low-pH products.[28,29] The bleaching agent PO was the only agent that presented pH values lower than the critical pH of 5.5 (pH 3.6–3.8) and the only one to reduce the nanohardness of tooth enamel and the enamel hybrid layer immediately after its application. These findings support the theory of other

Table 3. *Initial and Final pH Values of Bleaching Agents*

Bleaching Agents	Initial pH	Final pH
TB	7.22	6.33
HPB	8.89	8.85
HP	6.65	6.04
PO	3.56	3.80

Abbreviations: HP, Whiteness HP; HPB, Whiteness HP Blue; PO, Pola Office; TB, Total Blanc Office.



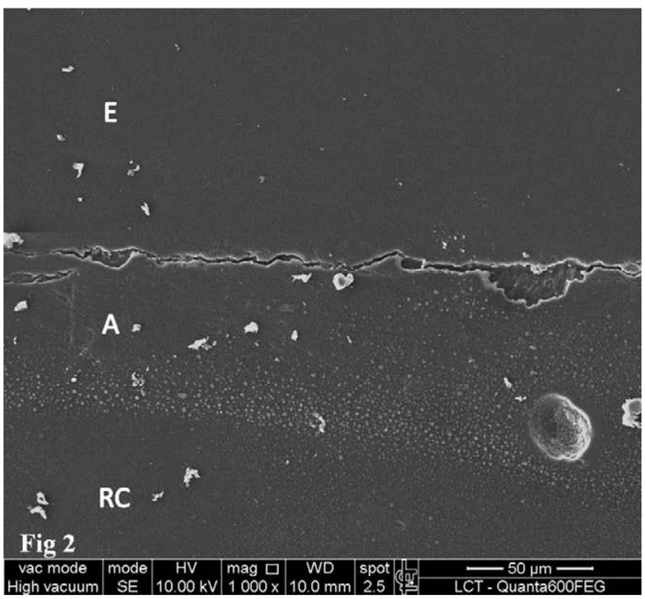


Figure 1. *Scanning electron micrograph of the tooth-restoration interface before being exposed to bleaching agents. No gap was observed. E, enamel; A, adhesive; RC, composite resin. 1000× magnification.*

Figure 2. *Scanning electron micrograph of the tooth-restoration interface immediately after being exposed to agent Pola Office. A well-defined gap may be observed between tooth enamel and adhesive. E, enamel; A, adhesive; RC, composite resin. 1000× magnification.*

authors[27,29-31] that the demineralization of tooth structure is related more to dental erosion due to low pH values of the bleaching solutions than to the effect of peroxide itself. So the null hypothesis tested in the current study was rejected.

Other studies that used the nanoindentation test to evaluate the mechanical properties of tooth enamel exposed to hydrogen or carbamide peroxide presented a decrease of superficial nanohardness of tooth enamel after being exposed to bleaching agents.[17,18,32,33] These results were different from those observed in this study because no changes were observed after the use of the three bleaching agents TB, HPB, and HP. The fact that these studies identified a decrease in nanohardness with the use of all bleaching agents can be explained by the loads used in nanohardness measurement: these were much lower (up to 20 mN) than the load used in this study (100 mN). Thus, lower loads may have evidenced changes that were restricted solely to the surface and that may be less clinically significant.

Although PO caused a significant nanohardness reduction of tooth enamel and enamel hybrid layer, after the 7-day storage in artificial saliva, the superficial hardness value of these substrates increased significantly and returned to the original value. The hardness recovery can be attributed to the storage in artificial saliva because according to Sa and others,[28] artificial saliva is able to promote a certain level of mineralization of tooth enamel surface due to the high level of calcium and phosphate in this solution, which can interact with enamel during the storage and induce mineralization. However, in other studies,[33,34] the storage of specimens in artificial saliva did not increase the hardness of tooth enamel exposed to bleaching agents; therefore, there is still no consensus on the beneficial action of storage in artificial saliva.

The tooth enamel and enamel hybrid layer presented similar nanohardness behaviors in relation to the action of bleaching agents. However, the nanohardness values obtained were different, being higher in the hybrid layer than in enamel. This difference in hardness values can be related to the size of indentation. In the enamel hybrid layer, a 10-mN load was applied, and the indentation depth in this substrate was lower than the indentation depth observed in tooth enamel. According to Zhou and Hsiung,[35] there is a relationship between hardness and indentation depth of crystalline tissues, and hardness level decreases as indentation depth increases.

The results showed that in-office bleaching agents did not change the superficial nanohardness of nanofilled composite resin. The literature has no studies evaluating the superficial changes in this type of composite through the nanoindentation test. The studies found in the literature are related to the superficial microhardness of these composite resins, and the effects of bleaching agents on such restorative material are still controversial. Most studies did not present changes in the superficial microhardness of nanofilled composite resins after exposure to hydrogen and carbamide peroxide *in vitro*[36] and *in situ*.[37] However, a microhardness decrease of this material was also presented in other studies.[26,38] This divergence of results can be explained by the presence of different components in both the organic and the inorganic matrix of composite resins; thus, even materials of the same classification can react differently to a bleaching agent.[39]

Better mechanical properties of the adhesive interface can be related to better adhesion stability and longevity of restorations.[40-42] However, the adhesive interface is the most susceptible to degradation, and its exposure to bleaching agents may affect the longevity of the restoration.[43,44] Aiming to evaluate the mechanical properties of the tooth-restoration interface after being exposed to different bleaching agents, this study was the first to evaluate the effects of bleaching agents on this interface through the nanoindentation test.

The behavior of the two-step etch-and-rinse adhesive Adper Single Bond 2 versus the action of bleaching agents was similar to the behavior of the composite resin because no hardness changes were found. Adhesive hardness is directly related to the bond strength.[42] Lower bond strength is related to a higher susceptibility to adhesive degradation, which depends on the composition and application of the adhesive system.[44] Accordingly, etch-and-rinse adhesives are less susceptible to degradation due to peroxide than self-etch adhesives.[45] Since there were no changes in the adhesive hardness, we can add that there were no demonstrated changes in its mechanical properties; thus, the exposure to 35% hydrogen peroxide–based bleaching agents did not cause adhesive degradation and did not compromise the longevity of the restoration.

However, by analyzing the SEM images of the epoxy replicas, it is possible to visualize the formation of small cracks between tooth enamel and adhesive in the samples exposed to the four bleaching agents used. These results may be related to the results of Dudek and others,[44] who found imperfections mostly between tooth enamel and adhesive by analyzing crack patterns of the specimens subject to shear bond strength testing. Through SEM images, it is possible to evaluate the marginal quality of restorations, which is one of the factors responsible for its clinical success. The presence of cracks in tooth enamel and the adhesive interface can be related to the penetration of bacteria, fluids, and other liquids that can cause sensitivity, marginal staining, restoration detachment, and even secondary caries.[46]

The most evident gap was observed immediately after exposure to the agent with the lowest pH value (PO). Despite the observation of small gaps between enamel and adhesive, it is still not possible to state that the bleaching agents cause deterioration of the marginal integrity of restorations. In clinical practice, it is common to perform dental bleaching treatments on teeth with restorations. The nanohardness evaluation showed that despite the decrease of values on dental tissues, there was a recovery after the storage period. Accordingly, it would be possible to infer that restorations were not compromised after bleaching procedures. However, the observation of small cracks between enamel and adhesive after bleaching procedures shows that there has been some change in this interface; thus, clinical studies are necessary to evaluate possible deleterious effects in teeth restored with composite resin and subject to bleaching treatment; that is, it is not yet possible to predict how the presence of these small gaps can affect the longevity of these restorations.

CONCLUSION

Under the conditions of this study, the bleaching agent with lower pH value was the only one to decrease tooth enamel and enamel hybrid layer nanohardness immediately after its application and the one to promote the most evident gap in the tooth-restoration interface. However, the nanohardness values returned to their original values after 7 days of storage in artificial saliva. None of the bleaching agents used changed the composite resin and adhesive nanohardness.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local ethics oversight committee guidelines and policies of the University of São Paulo, São Paulo, 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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CAD/CAM Polymer vs Direct Composite Resin Core Buildups for Endodontically Treated Molars Without Ferrule

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P Magne

Clinical Relevance

A no-post, full, anatomically shaped high-performance polymer crown can be used as a long-term provisional crown immediately after root canal treatment. Following recovery of the surrounding tissues and confirmation of endodontic status and prognosis, the polymer restoration can serve as the definitive restoration or as a core buildup under an all-ceramic crown.

SUMMARY

Objectives: The aim of this study was to investigate the restoration of broken-down endodontically treated molars without ferrule effect using glass ceramic crowns on different composite resin core buildups.

Methods and Materials: Forty-five decoronated endodontically treated teeth (no ferrule) were restored with a semidirect buildup using an experimental computer-aided design/computer-aided manufacturing (CAD/CAM) high-performance polymer (HPP group) or with light-curing composite core buildups of Tetric EvoCeram with (TECP group) or without (TEC group) a glass-fiber-reinforced post. All teeth were prepared to receive bonded glass ceramic crowns (Empress CAD luted with Variolink II) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the palatal cusp at an angle of 30° and a frequency of 5 Hz, beginning with a load of 200 N (×5000 cycles) and followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. Groups were compared using the life-table survival analysis (log rank test at *p*=0.05). Average fracture loads and number of sur-

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vived cycles were compared with one-way analysis of variance (Scheffé post hoc at p=0.05).

Results: None of the tested specimen withstood all 185,000 load cycles. There was a significant difference in mean fracture load, survived cycles, and survival; the HPP group (fracture load 975.27N±182.74) was significantly higher than the TEC (716.87N±133.43; p=0.001) and TECP (745.67±156.34; p=0.001) groups, and the TEC and TECP groups showed no difference (p=0.884). Specimens in the TECP group were affected by an initial failure phenomenon (wide gap at the margin between the buildup/ crown assembly and the root).

Conclusions: Semidirect core buildup made from high-performance polymer enhanced the performance of all-ceramic leucite-reinforced glass ceramic crowns compared with direct light-curing composite resin buildups. The use of a fiber-reinforced post system did not influence the fatigue strength of all-ceramic crowns.

INTRODUCTION

The reconstruction of severely broken-down and endodontically treated teeth is a challenge in daily practice. Although it is agreed that restorative treatment is critical to the long-term success of endodontic treatment, the possible reconstruction materials and techniques are still being debated.[1]

Meanwhile, it is widely accepted, that the clinically relevant physical properties of dentin are not necessarily affected by the loss of vitality.[2,3] Instead, the risk of fracture of endodontically treated teeth is known to result from structural defects related to decay or tooth preparation requirements (eg, caries removal and endodontic access).[4,5] Additional removal of intact dentin will occur during root canal therapy and preparation for post placement. This will further weaken the tooth and reduce its fracture strength.[6] In spite of the aforementioned issues and the fact that the use of posts does not necessarily reinforce nonvital teeth, direct posts are still frequently used to retain adhesive core buildups.

Optimization of the biomechanical behavior of restored teeth is possible through the preservation of sound cervical tooth structure, which is crucial to create a ferrule effect.[7] Currently, a minimum ferrule of 1.0 mm is deemed necessary to stabilize the restored tooth.[8] In cases where no ferrule effect can be obtained, it was concluded that inserting a fiber post might improve the retention and fatigue resistance of the restoration.[9] However, there is a lack of data to support this claim.

Composite resins, either light polymerized or dual cured, are commonly used as materials for direct buildups. Light-cure buildup materials have several advantages over dual-cure materials. First, they can be bonded, layered, and shaped to ideal form. Second, they present optimal mechanical properties and color stability.[10-12] More recently, dentists and dental technicians, thanks to the development of computer-aided design/computer-aided manufacturing (CAD/CAM) technology, have access to high-performance polymers (HPPs). The polymerization of these materials under controlled and standardized industrial conditions, with optimized pressure and temperature parameters, leads to improved mechanical properties of the resulting restoration compared with manual fabrication.[13,16] Because of their favorable properties, CAD/CAM HPP materials may also have an advantage when it comes to the reconstruction of root-canal-treated molars. Because of their density and homogeneity, along with their dentin-like elastic modulus, it would be reasonable to consider them as a shrink-free core buildup material under bonded ceramic crowns. This concept closely mimics the biomechanical behavior of a natural tooth (biomimetics approach), in which the shock-absorbing dentin (e-modulus ~14 GPa) is covered by stiff and wear-resistant enamel (80 GPa) that preserves shape and function.[17]

The aim of the study was to investigate the restoration of broken-down endodontically treated molars with no ferrule effect using glass ceramic crowns over three different core buildups: an HPP CAD/CAM core buildup, a direct core buildup from light-curing composite with the use of a fiber-reinforced post, and a direct core buildup from light-curing composite without the use of a fiber-reinforced post. The first null hypothesis was that the HPP CAD/CAM core buildup would not lead to different fatigue strength of all-ceramic crowns compared with conventional direct core buildup methods. The second null hypothesis was that the use of a fiber-reinforced post system would not influence the fatigue strength of all-ceramic crowns.

METHODS AND MATERIALS

Upon approval from the Ethical Review Committee of the University of Southern California, Los Angeles (proposal HS-13-00162), and the Ludwig Maximilian University of Munich, Germany, 45 maxillary third molars were collected.

Table 1: *Overview of Properties of Material Used for Core Buildups*

Parameter	Experimental HPP	Tetric EvoCeram
Matrix	Dimethacrylates	Bis-GMA, UDMA, ethoxylated Bis-EMA
Matrix (weight %)	22.0	16.8
Filler	Barium glass fillers (15%), ytterbium trifluoride (9%), mixed oxides (44%), silicium oxide (3), copolymer (7%)	Barium glass fillers, ytterbium trifluoride, mixed oxides
Filler content (weight %)	78	48.5
Prepolymer (weight %)	not available	34.0
Flexural strength (MPa)	167	120
Flexural modulus (MPa)	11,400	10,000
Compressive strength (MPa)	not available	250
Vickers hardness (MPa)	915	580
Water absorption 7 days (μg/mm^3)	28	21.2

Abbreviations: Bis-EMA, ethoxylated bisphenol A glycol dimethacrylate ; Bis-GMA, bisphenol A glycol dimethacrylate; HPP, high-performance polymer; UDMA, urethane dimethacrylate.

In order to evenly distribute the teeth according to size and shape, all specimens (N=45) were organized in groups of three (triplets with similar buccolingual and mesiodistal size and height) and subsequently reassigned randomly to groups that received 1) a CAD/CAM core buildup from HPP (the HPP group), 2) a direct core buildup from the universal composite Tetric EvoCeram (Ivoclar Vivadent, Schaan, Liechtenstein) (the TEC group), or 3) a direct core buildup from the universal composite Tetric EvoCeram in combination with a post (the TECP group) (n=15 each). Each tooth was mounted using a special positioning jig with acrylic resin (Palapress Vario Light Pink, Heraeus Kulzer, Hanau, Germany) embedding the root up to 2.0 mm below the cementoenamel junction. Standardized defects were generated by removing the clinical crown horizontally down to 1 mm above the cementoenamel junction using rotating diamond cutting instruments. The remaining ceiling of the pulp chamber was removed, and root canals were cleaned and shaped using the stepback technique (maximum file 35) and then partially filled and covered by glass ionomer cement (Ketac Molar, 3M ESPE, Seefeld Germany) up to 1.5 mm below the level of the occlusal reduction. According to Schumacher and others,[18] a maxillary first molar has an overall average length of 19.5 mm (±1.8 mm) with an average crown length of 6.2 mm (±0.8 mm) and an average root length of 13.3 mm (±1.7 mm). Therefore the teeth were reconstructed on one average height between 8.5 and 9.0 mm measured from the acrylic resin to the cusps of the crowns.

Teeth from the HPP group received a CAD/CAM fabricated indirect core buildup milled from an experimental HPP material (Ivoclar Vivadent, Schaan, Liechtenstein). Teeth from the TEC group were restored with a conventional direct buildup using the light-curing composite Tetric EvoCeram. In the TECP group, a glass-fiber-reinforced post (FRC Postec Plus system, Ivoclar Vivadent) system was applied before the core buildup, which was also carried out using Tetric EvoCeram light-curing composite. The properties of the two resin materials are presented in Table 1. The following detailed procedures were carried out to create different core buildups.

HPP Group: CAD/CAM Core-Buildup With Experimental HPP Material

Immediate dentin sealing (IDS) was applied: dentin was etched for 10-15 seconds using 37% phosphoric acid (Total etch, Ivoclar Vivadent) before the adhesive system (Syntac, Ivoclar Vivadent) was applied according to the manufacturer's recommendations, except for the fact that Heliobond (Ivoclar Vivadent) was applied in a thick layer without air thinning (requirement of the IDS technique; Figure 1a). Heliobond was then polymerized for 20 seconds and covered with glycerin jelly (Liquid strip, Ivoclar Vivadent) with an additional 20 seconds of light exposure to minimize the oxygen-inhibited layer and

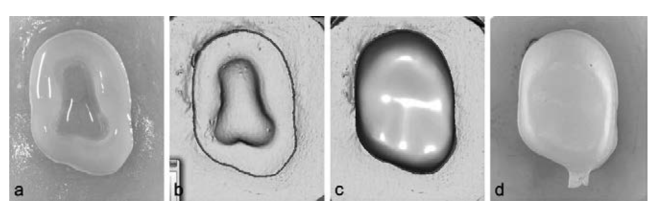

Figure 1. *Fabrication process of CAD/CAM buildup from HPP. (a): Tooth surface after IDS. (b): Data set of scanned tooth. (c): CAD of buildup. (d): Milled HPP buildup after adhesive luting to the tooth.*

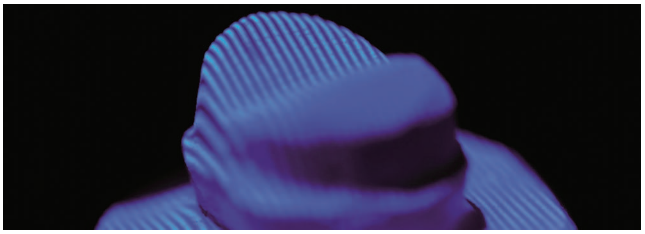

Figure 2. *Digitalization of a prepared tooth using the Cerec AC bluecam.*

secure the thickness of the resin coating.[19,20] A curing lamp (Bluephase, Ivoclar Vivadent) with a light intensity of 1200 mW/cm^2 and a light spectrum between 385 and 515 nm was used.

Specimens were then scanned with a CEREC AC Bluecam (Sirona Dental Systems, Bensheim, Germany), and core buildups with a simplified anatomy were designed (CEREC Software 3.60, Sirona Dental Systems, Figure 1b,c) and milled from an experimental HPP block (CEREC 3 compact milling unit, Sirona Dental Systems). In preparation for adhesive luting procedures, the fitting surface of the milled HPP core buildups was air-abraded (27 μm aluminum oxide, 0.5 bar, 10 seconds, 10-mm distance) then cleaned with phosphoric acid for 10 seconds and in an ultrasonic bath in distilled water for 2 minutes. A silane-containing coupling agent (Monobond Plus, Ivoclar Vivadent) was applied to the fitting surface and dried in an oven (DI-500, Coltene, Altstätten, Switzerland) at 212°F for 60 seconds, followed by wetting with adhesive resin (Heliobond) and air-thinning but not light-curing. On the tooth side, the IDS surface was refreshed by airborne-particle abrasion (27-μm aluminum oxide, 0.5 bar, 10 seconds, 10-mm distance), followed by 30 seconds of etching with phosphoric acid. Then adhesive resin (Heliobond) was applied and air-thinned but not light-cured. The core buildup was then luted using a dual-cure composite resin cement (Variolink II, Ivoclar Vivadent, Figure 1d). After careful elimination of excessive unpolymerized composite resin, each surface was light-cured for 60 seconds (20 seconds per surface, three times). All margins were covered with an air-blocking barrier (Liquid strip) for the last polymerization cycle.

The TEC Group: Core-Buildup With Light-Cure Composite Resin Material (Tetric EvoCeram)

After 10-15 seconds of dentin and 30 seconds of enamel etching with 37% phosphoric acid (Total etch) the Syntac adhesive system was applied according to the manufacturer's recommendations. Composite resin (Tetric EvoCeram) was applied incrementally, each layer (total 4-5 layers) with a maximum thickness of 1.5 mm, and polymerized for 60 seconds (buccal, occlusal, lingual for 20 seconds each).

The TECP Group: Core Buildup With Light-Cure Composite Resin (Tetric EvoCeram) and FRC Post (FRC Postec Plus)

A glass-fiber reinforced post (FRC Postec Plus system) was placed in the palatal root in accordance with the manufacturer's recommendations. The post space was prepared (about 10 mm deep measured from the defect surface) with the FRC Postec Plus Reamers at 1000-5000*g* for a post size 1 (white; 0.7 mm). The post was tried in, and checked for proper fit, then cut 3 mm above the defect surface and cleaned with phosphoric acid etching gel (Total etch) for 60 seconds, rinsed with water, and dried before applying silane (Monobond Plus) for 60 seconds. The manufacturer of the post system recommends the application of Multilink-Automix (Ivoclar Vivadent) in combination with the FRC Postec as a system. Primer A and B were mixed at a 1:1 ratio and applied for 15 seconds into the root canal and on the prepared tooth surface by scrubbing with light pressure. The excesses were removed with a strong stream of air and paper points. Multilink Automix was applied to the post, and the post was rotated to its final position. The excess Multilink Automix was strategically dispensed over the prepared and primed surface of the tooth and light-cured for 20 seconds. The light-curing composite resin (Tetric EvoCeram) was then applied incrementally in a similar fashion as in the TEC group.

Preparation for Glass Ceramic Crowns

All 45 teeth with the different core buildups were prepared to receive a standardized full anatomic glass ceramic crown: occlusal clearance of 2.0 mm, circumferential reduction of 1.0 mm with an axial convergence taper of 12°, preparation height of 7 mm from the level of the embedding resin to the cusp tips, and 5.0 mm at the central groove.

Manufacturing of Glass Ceramic Crowns

A standardized full anatomic crown in the form of a simplified maxillary molar with three cusps was designed using the CEREC system (Figures 2 and 3). The CEREC database was used, and adjustments were made for each individual tooth (Figures 4 and 5) in order to obtain specific dimensions of the crowns: 1.5 mm at central groove, 2.0 mm at cusp

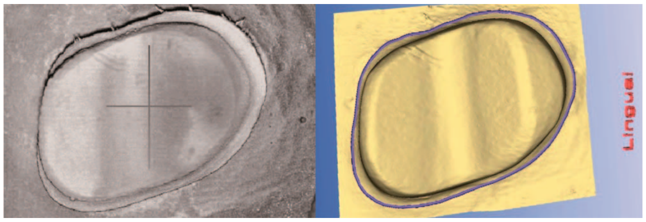

Figure 3. *(Left): Digitalization of a prepared tooth using the Cerec AC blucam. (Right): CAD data set of preparation with determined preparation line.*

tips and 1.0 mm of circumferential thickness. Restorations were milled from leucite-reinforced glass ceramic blocks (EmpressCAD, Ivoclar Vivadent), and all measurements were verified manually using a caliper and confirmed visually by uniform translucency across specimens (Figure 6).

Adhesive Luting of the Glass Ceramic Crowns

The fitting surface of the milled glass ceramic crown was etched with hydrofluoric acid (<5%) (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 60 seconds, cleaned with phosphoric acid for 10 seconds (Total etch) and in an ultrasonic bath for 2 minutes. Silane was applied (Monobond Plus) and heat-dried for 60 seconds. Immediately before cementation, the adhesive resin (Heliobond) was applied to the crown and air-thinned but not light-cured. The tooth was conditioned by air abrasion of the core buildup (27 μm aluminum oxide; 0.5 bar, 10 seconds, 1 cm distance), followed by 30 seconds of phosphoric etching to clean the surface and etch the enamel areas. Adhesive resin (Heliobond) was applied to all surfaces and air-thinned but not light-cured. All crowns were cemented using a dual-cure composite cementation system (Variolink II). After careful elimination of the excess unpolymerized composite resin, the vestibular, occlusal, and palatal surfaces of the crown were polymerized for 60 seconds (20 seconds per surface, three times). All margins were covered with an air-blocking barrier (Liquid strip)

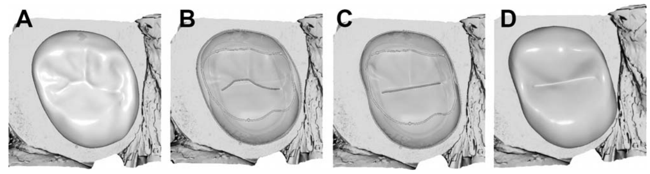

Figure 5. *CAD of crowns using standardized parameters within the Cerec software 3.60. (a): Design suggestion by the software. (b and c): Modifications of the design using the edit mode. (d): Outline of crown with standardized parameters.*

for the last polymerization cycle. Each specimen was stored in distilled water at ambient temperature for at least 24 hours before testing.

Loading Procedure and Configuration

Masticatory forces were simulated using closed-loop servohydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). The masticatory cycle was simulated by an isometric contraction (load control) applied through an artificial composite resin cusp (Z100, 3M ESPE) in the shape of a semicylinder (2.5-mm radius). The low stiffness and toothlike wear of the composite resin cylinder allows realistic simulation of tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials.

All specimens were placed in the load chamber at 30° angulation and situated with a positioning device (sliding table) to create a single contact between the semicylinder and the palatal cusp. The loading point was equidistant to the cusp tip and central groove (Figure 7). The load chamber was filled with distilled water to submerge the specimens during testing. Cyclic load was applied at a frequency of 5 Hz, starting with a warm-up load of 200 N for 5000 cycles (preconditioning stage), followed by stages of 400, 600, 800, 1000, and 1200 and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until fracture or to a maximum of 185,000 cycles.

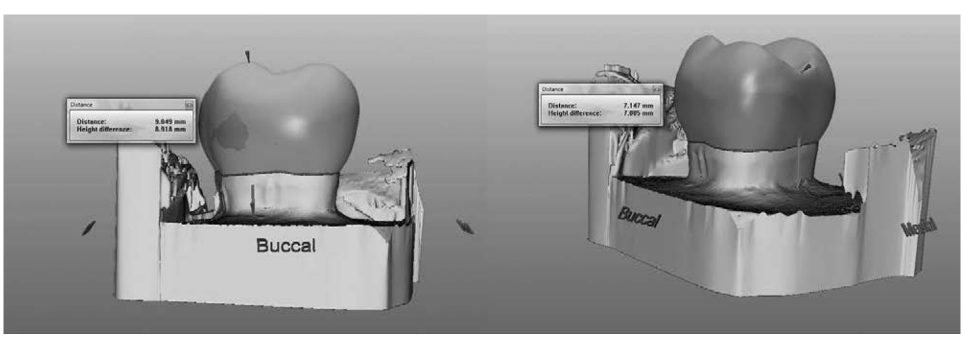

Figure 4. *Standardization of crown design using the Cerec software. Height of cusp tips and marginal ridges could be measured within the software.*

Figure 6. *Translucency confirming homogenous material thickness within specimens.*

Analysis

The fracture load was determined by the load step at which the machine stopped (triggered by the displacement-based, failure-detect module of the testing software). The number of endured cycles and the failure mode were recorded. After a three-examiner agreement under optical microscopy (Leica MZ 125, Leica Microsystems, Wetzlar, Germany) and transillumination, a distinction was made among three fracture modes, considering the reparability of the tooth: catastrophic, that is, tooth/root fracture that would require tooth extraction; possibly reparable, that is, cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure; or reparable fracture, that is, cohesive or adhesive failure of restoration only (Figure 8).

The fatigue resistance of the three groups was compared using the life-table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted. This allowed the calculation of survival probability (%) at each load step. The influence of the different core buildups on the fracture strength was analyzed using the log-rank test at a significance level of 0.05. Differences were localized using pairwise post hoc comparisons with the same test at a significance level of 0.017 (Bonferroni correction for three comparisons). Additionally, the fracture load and number of cycles at which the specimen failed was compared using one-way analysis of variance (ANOVA) followed by Scheffé post hoc procedure at a significance level of 0.05.

Figure 7. *Specimen in load chamber with the loading point equidistant between cusp tip and central groove.*

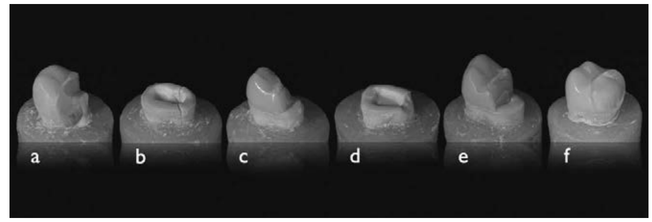

Figure 8. *All specimens were analyzed and classified in one of the three failure modes: (a,b): Catastrophic, that is, tooth/root fracture that would require tooth extraction. (c,d): Possibly reparable, that is, cohesive/adhesive failure with fragment and minor damage, chip, or crack of the underlying tooth structure. (e,f): Reparable fracture, that is, cohesive or cohesive/adhesive fracture of restoration only.*

RESULTS

None of the tested specimens withstood all 185,000 load cycles. Only one specimen from group A (HPP), with a core buildup from the experimental CAD/CAM HPP, fractured during the last interval of 1400 N. As all specimens fractured, the mean fracture load could be calculated. One-way ANOVA and Scheffé post hoc revealed that the mean fracture load for the HPP group with 975.27 ± 182.74 N was significantly higher than that for the TEC group (716.87±133.43 N; p=0.001) and the TECP group (745.67±156.34 N; p=0.001), while the TEC and TECP groups showed no difference (p=0.884). The same results were found when the number of survived cycles was statistically compared (HPP group to TEC group: p=0.001; HPP group to TECP group: p=0.001; TEC group to TECP group: p=0.994). Figure 9 shows the mean values of mean fracture loads and average number of survived cycles and their standard deviations, respectively.

During cyclic loading, initial failures were detected in 26.7% (4/15) specimens of the TECP group. Failure of the specimen was preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root. The gap was always located at the opposing side of the post. Such occurrence was never found in the other groups.

Because clinical detection of such failures appears to be questionable, the analysis of survival was conducted for total failure (TECP) as well as considering initial failure (TECPi). The life-table survival graphs for all groups, including analysis of initial failure are displayed in Figure 10. The log-rank test showed significantly higher survival for the HPP group compared with the TEC (p=0.001)

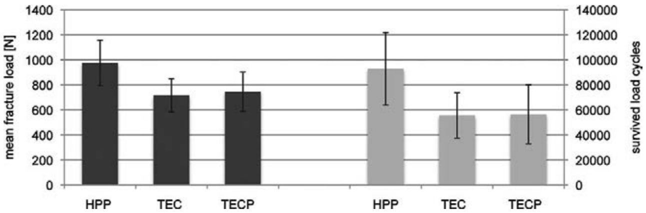

Figure 9. *Mean fracture loads and number of survived load cycles for groups HPP, TEC, and TECP.*

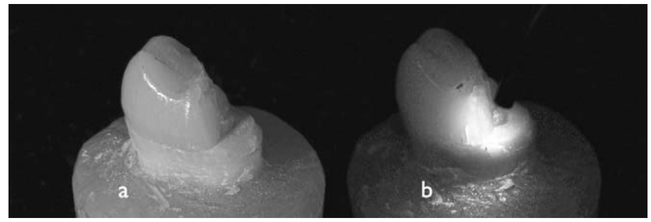

Figure 11. *Specimens were examined using a white-light lamp to make possible cracks visible (same specimen as in Figure 10c, possibly restorable).*

and TECP (p=0.001) groups. No difference could be found between the TEC and TECP groups (p= 0.688). Also, when considering the initial failure, the log-rank test showed significantly higher survival for the HPP group compared with the TECPi group (p=0.001). However, no difference was found between the TEC and TECPi groups (p=0.453).

Analysis of Failure Mode

After three-examiner agreement, the HPP and TECP groups showed the highest rate of catastrophic failures (each 80% vs 53,3% in the TEC group). Possible fractures of the roots were made visible by transillumination in order to classify the specimen correctly (Figure 11). Figure 12 gives the number of specimens and percentage of each specific fracture mode for each group.

DISCUSSION

This study evaluated the performance of leucite-reinforced glass ceramic crowns for the rehabilitation of severely broken-down endodontically treated molars with no ferrule effect. A core buildup from an experimental HPP was compared with direct light-curing composite resin core buildups with and without the application of a fiber-reinforced post system. The first null hypothesis, stating that different core buildups influence the survival rate and fracture load of the restorations, was rejected because HPP was associated with significantly higher fracture loads and survival rates compared with the TEC and TECP groups. Because the TEC and TECP groups were associated with similar survival rates and fracture resistance of all-ceramic crowns, the second null hypothesis, stating the absence of effect of fiber-reinforced posts, was accepted.

In the present study, a closed-loop servohydraulic control system in combination with a stepped load protocol was applied to create a testing method, which allows a physiologic representation of mastication.[21] This stepped load protocol represents a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test. Based on original studies by Fennis and others,[22] this test strategy seems to provide a better simulation of clinical conditions than static load tests. The presented protocol appears to be the best compromise between available *in vitro* fatigue testing methods and clinical reality.

The application of cyclic loads, increasing the load in 200-N steps up to 1400 N and a frequency of 5 Hz using a similar testing machine was already described elsewhere.[23] However, during pilot tests for

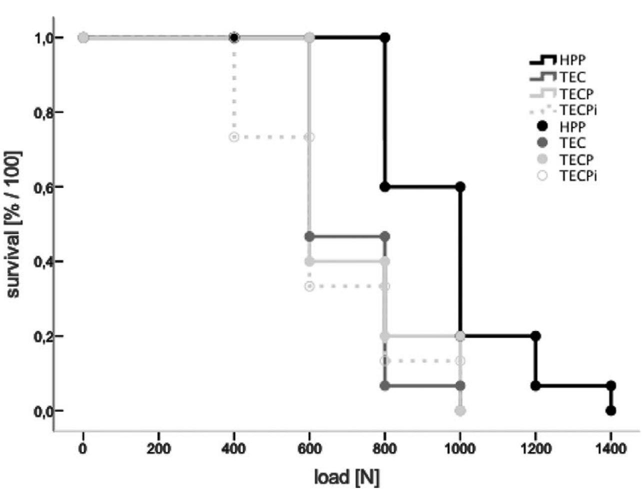

Figure 10. *Life table of survival for groups HPP, TEC, and TECP.*

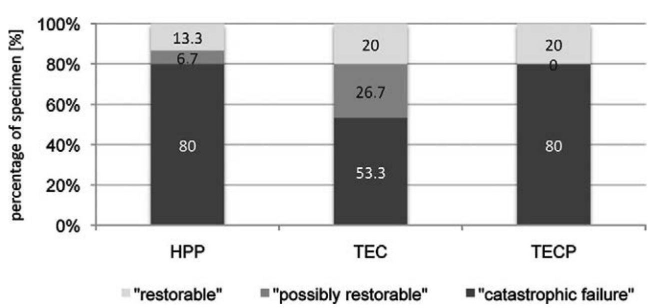

Figure 12. *Percentage of observed fracture mode of specimens for groups HPP, TEC, and TECP.*

the present study, no specimen failed when the load was applied axially and distributed on three opposing cusps of the crown. Therefore, the authors decided to maintain the loading sequence and values but to modify the angle of force to 30° and to concentrate its application to the working cusp using a composite resin cylinder (Z100, 3M ESPE) as an antagonist.[24] This measure increases the stress to the restoration and simulates an extreme load configuration (nonworking contact).

Healthy humans exhibit maximal isometric bite forces in the molar region ranging between 597 N (women) and 847 N (men), but they can also reach up to 900 N.[25] Even higher forces can occur by an accidental bite on a hard foreign body found in a food bolus (eg, stone in a bean/salad, cherry pit). Although it is difficult to draw direct correlations between the load ranges applied in this study and their significance *in vivo*, a study by Sakaguchi and others,[26] using a similar machine, correlated 250,000 cycles at only 13.6 N with 1 year of clinical service. Because of the application of far higher forces in this study, it can be expected that an accelerated life cycle of the restored tooth may have been simulated.

Although *in vitro* studies only partially mimic clinical reality, their chief advantage over clinical studies is the possibility to almost eliminate confounding variables and further enable the testing of samples with well-defined biomechanical status.[27] Because of the high standardization level that can be attained at all preparation steps and restorative steps, the remaining confounding variables are limited to the age, size, and shape of extracted teeth. Therefore, only upper third molars with comparable outer size and geometry of crowns and roots were selected from a larger selection and distributed evenly into each experimental group using the innovative randomly reassigned triplets method (see beginning of the Methods and Materials section). However the different internal and external dimensions of the teeth still has to be considered as a limitation of studies in which natural teeth are used.

Further, after standardized preparation of the different core buildups, standardized crowns were designed using CAD/CAM technology, enabling the use of the same database (maxillary third molar) for each specimen. Adjustments in the edit mode of the software allowed us to create a simplified crown design with highly reproducible anatomy, cuspal inclines, grooves, and a strictly similar thickness parameter for each specimen. All the aforementioned facilitated the loading of the specimen in a strictly identical configuration.

High strength coronal coverage can make the underlying core hypofunctional. Because the overlay of the crown should not be too strong to avoid masking the effect of the core buildups, leucite-reinforced glass ceramic Empress CAD was used. On the other hand, the combination of the experimental HPP (flexural modulus: 11.4 GPa; source: Research and Development-Ivoclar Vivadent) covered with the brittle glass ceramic (flexural modulus: 62 GPa) closely mimics the mechanical properties of a natural tooth, in which the comparably soft dentin (14 GPa) with a shock-absorption property is covered by hard, brittle enamel (80 GPa) that protects the tooth from premature wear.

The combination of shock-absorbing properties of the core buildup and protective crown coverage appears to be the major advantage of this approach. This approach closely mimics the structure and biomechanical behavior of a natural tooth, in contrast to the concepts of endocrowns from polymers or ceramics, where dentists have to choose one of the aforementioned properties. All elements (crown, buildup, and tooth) have to form a cohesive assembly requiring a capable adhesive system and cement, which ideally mimics the properties of the dentinoenamel junction.

The superior performance of the HPP core buildup in this study may have various reasons. First, by using a milled HPP block, polymerization shrinkage will only be limited to the cementation gap instead of the whole buildup itself (Tetric groups).[28] This might be of particular advantage in situations where a negative c-factor (eg, configuration of the pulp chamber) combined with the extreme volume of the buildup may lead to significant shrinkage stresses within the tooth.[29]

The insertion of a fiber post did not seem to influence the load-bearing capacity and survival probability of the restorations (TEC vs TECP groups). This aligns with data on endodontically treated molars with two-wall and one-wall cavities restored with indirect onlay composite resin restorations, in which insertion of a fiber post did not increase the fracture resistance.[30] A unique finding for the TECP group, however, was that in 4 (26.7%) of the specimens initial failure (displayed in Figure 10 as TECPi) could be observed during load cycling. A wide gap at the margin between the buildup/crown assembly and the root could be observed, which intensified over time until total failure. This indicates an adhesive failure at the core buildup/tooth interface, possibly due to the weakness of the self-adhesive system that was used for cementation of the post and core buildup. Such initial failures did not occur when a classic dentin adhesive was used (HPP and TEC groups). This raises questions about whether the manufacturer's recommendation to extend the use of the adhesive system of the post over the entire prepared surface should be modified. A more favorable approach would be to limit the application of the adhesive system of the post to the root canal itself and use a classic adhesive system on the remaining dentin surface to which the core material will be bonded. This renders the already time-consuming procedure of post insertion and buildup even more complicated, material intensive, and error prone without real benefits from a biomechanical standpoint. The post even caused an increased rate of catastrophic failures when comparing the TEC and TECP groups.

As those initial failures only occur under load (cyclic opening of the gap), they would not necessarily be detected clinically by the dentist during regular checkups and may lead to a pump effect, facilitating bacterial infiltration with dramatic clinical consequences.

Another advantage of the HPP core buildup over direct methods is the possibility of applying the immediate dentin sealing (IDS) technique. This means bonding and adhesive are directly applied after preparation to the freshly cut dentin to seal the dentin surfaces. Before adhesive luting, the sealed surface is conditioned by sandblasting, and the bonding can be applied. This technique has been shown to optimize bond strength and protects the preparations and root canals from bacterial infiltration.[31] The effective performance of the IDS procedure was demonstrated by the absence of adhesive failures in the HPP group. On the other hand, the strong adhesion may have facilitated cohesive failures within the remaining tooth substance (80% of nonreparable catastrophic failures). A similar amount of catastrophic failures was found for the TECP group; however, the specimen failed at significantly lower loads and showed unfavorable initial failures. Only in the TEC group, where no post was used, the amount of catastrophic failures was reduced to 53%. This means that the smallest number of unrestorable failures were found with direct core buildups from the light-curing composite without a fiber-reinforced post. In these re-restorable cases it would be possible for the dentist to make a new buildup instead of losing the natural tooth. However, the loads under which the failures occurred were significantly lower. Therefore, the performance of the HPP buildups can be considered superior compared with the other groups; even when the same number of catastrophic failures occurred, those failures happened significantly later and therefore at a significantly higher load.

Regarding these results under extreme circumstances (30° angulation, load on one cusp), the application of indirect CAD/CAM fabricated buildups might be an alternative to known direct methods for core buildups. Also, it demonstrates the potential to replace the application of a fiber-post system. However, further studies should investigate the so-called ideal bond strength, which is strong enough to ensure the long-term clinical success but weak enough to protect the remaining tooth structure in case of fracture under high loads.

From a clinical standpoint, a bacteria-proof sealing of the tooth by a buildup should be achieved immediately after successfully completed endodontic treatment.[32,33]

Novel clinical approaches may result from the findings of the present study. The HPP material may be milled with full anatomy (like an endcrown) and serve as a long-term provisional approach to seal and build up the tooth directly after root canal treatment. After successful recovery of the surrounding tissues and confirmation of endodontic status and prognosis, the polymer restoration could serve as either the definitive restoration or as a core buildup under an all-ceramic crown. As currently only limited data are available regarding the wear behavior of HPPs in occlusion,[34] this study evaluates the behavior of an experimental HPP material as a core buildup under a leucite-reinforced glass ceramic crown. The presented novel concept using HPPs for a long-term provisional and core buildup, respectively, is facilitated by the use of chairside CAD/CAM systems.

CONCLUSION

Within the limitations of this *in vitro* study, when restoring endodontically treated molars without ferrule, the following can be concluded:

1. Indirect CAD/CAM-fabricated core buildup from HPP might offer the potential to enhance the load-bearing capacity and survival of all-ceramic leucite-reinforced glass ceramic crowns.
2. Insertion of a fiber-reinforced post did not enhance the load-bearing capacity and survival of all-ceramic leucite-reinforced glass ceramic crowns on direct core buildups from light-curing composite.

3. The smallest number of unrestorable failures was found with direct core buildups from light-curing composite without a fiber-reinforced post.

Acknowledgements

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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 University of Southern California and Ludwig-Maximilians University, in Munich, Germany.

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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Composite Resin Core Buildups With and Without Post for the Restoration of Endodontically Treated Molars Without Ferrule

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Clinical Relevance

When restoring endodontically treated molars without ferrule, the use of a post must be questioned and may be substituted by the selection of improved buildup materials.

SUMMARY

Objective: The aim of this study was to investigate the restoration of highly damaged, broken-down endodontically treated molars without the ferrule effect using glass ceramic crowns on different dual-cure composite resin core buildups.

Methods and Materials: Thirty (N=30, n=15) decoronated, endodontically treated teeth (no ferrule) were restored without a ferrule with a direct buildup using the dual-curing composite Multicore HB (group MHB) or the dual-curing composite core buildup Multicore Flow in combination with glass-fiber–reinforced composite post (FRC post; group MFP). All teeth were prepared to receive bonded glass ceramic crowns (Empress CAD luted with Variolink II) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the palatal cusp at an angle of 30 degrees and a frequency of 5 Hz, beginning with a load of 200 N (×5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. Groups were compared using the life table survival analysis (log rank test at *p*=0.05). Average fracture loads and number of survived cycles were compared with one-way analysis of variance (Scheffé post hoc at *p*=0.05). Previously published data from the same authors about core buildups made of

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high-performance polymers (group HPP, n=15) and light-curing composite resin without FRC posts (group TEC, n=15) and with FRC posts (group TECP, n=15) using the same experimental setup were included for comparison.

Results: None of the tested specimen withstood all 185,000 load cycles. There was no significant difference in mean fracture load (*p*=0.376), survived cycles (*p*=0.422), and survival (*p*=0.613) between MHB (facture load 859.4 N±194.92) and MFP (796.13 N±156.34). Group HPP from a previous study appeared to have significantly higher performance than all other groups except MHB. All groups with posts were affected by an initial failure phenomenon (wide gap at the margin between the buildup/crown assembly and the root).

Conclusions: HPP and MHB enhanced the performance of all-ceramic leucite-reinforced glass ceramic crowns, and insertion of a fiber-reinforced composite post was not influential when using other materials.

INTRODUCTION

Severely damaged and endodontically treated teeth (ETT) offering only a minimal "ferrule" represent such a challenge in clinical practice that clinicians are tempted to not restore them and rather to rely on implant-supported restorations instead.[1-3] A number of clinicians and patients, however, still have preferences and convictions geared toward preserving the original root and periodontal ligament in order to avoid or postpone more invasive surgical procedures.

Improving the prognosis of restored ETTs requires understanding their biomechanical properties and behavior. Clinically relevant physical properties of dentin do not seem to be affected by root canal treatments.[4,5] However, structural defects of a tooth's hard tissue caused by decay or tooth preparation lead to an increased risk of fracture of ETTs.[6,7] In this context, it could be shown that an endodontic access cavity (removal of the pulp roof), combined with the loss of the marginal ridges (MOD preparation) as important static parameters, result in maximum tooth fragility.[8] According to former traditional prosthodontic techniques, it was generally necessary to retain nonadhesive indirect core buildups by the placement of an indirect cast endodontic post.[9] Unfortunately, this often resulted in further loss of healthy tooth structure.

Today, advanced adhesive procedures are allowing practitioners to save and stabilize valuable tooth structure through bonded composite resin buildups.[10] Posts are still being advocated in combination with adhesive buildups,[11] among which fiber-reinforced posts seem to be the most popular.[12] Although there are attempts to classify the indications for posts, considering important factors, such as crown height, wall thickness, circumferential integrity, and diameter and shape of the canal,[13] there is still no general consensus about the indications for post placement. On the contrary, it has to be questioned whether the technique-sensitive procedure of post placement is worth the risks. For example, for endodontically treated molars with two- and one-wall defects restored with indirect composite resin onlays, the insertion of a fiber post did not increase fracture resistance.[14] Moreover, the removal of natural dentin during the preparation of the root canal for the post seems to reduce the fracture strength of the tooth.[15] Therefore, the main goal for any treatment—and even more so for severely broken-down teeth—must be to preserve as much dental hard tissue as possible. Of special importance is the conservation of cervical tissue to create a ferrule effect, which seems to be crucial to optimize the biomechanical behavior of the restored tooth.[12] As the ferrule effect has proven to generally increase fracture resistance, currently a minimum ferrule of 1 mm is considered necessary to stabilize the restored tooth.[16]

Severely broken-down teeth, however, do not always offer enough tooth structure to create a ferrule effect. It is therefore fitting to investigate other elements (eg, the use of a post and the buildup material itself) that could compensate for the absence of a ferrule. Composite resins, either light-cured or dual-cured, are commonly used with or without posts. The group of dual-cured materials can be further categorized into more viscous (paste-like) or more flowable ones with very distinct material properties. It was demonstrated that the performance of all-ceramic crowns is influenced by the elastic modulus of the core buildup.[17] Previous data by the present authors (same operator in strictly identical conditions) also showed that computer-aided design and computer-aided manufacturing (CAD/CAM) buildups without posts and made from high-performance polymers (HPP) can enhance the load-bearing capacity and survival of all-ceramic crowns. The question remains whether a highly filled dual-cure buildup material used

Table 1: *Overview Over Properties of Materials for Core Buildups*

Parameter	Experimental HPP	Tetric EvoCeram	Multicore HB	Multicore Flow
Matrix	Dimethacrylates	Bis-GMA, UDMA, ethoxylated Bis-EMA	Dimethylacrylates	Dimethylacrylates
Matrix (wt%)	22.0	16.8	13.5	28.1
Filler	Barium glass fillers (15%), Ytterbium trifluoride (9%), Mixed oxides (44%), Siliciumoxide (3%), Copolymer (7%)	Barium glass fillers, ytterbium trifluoride, Mixed oxides	Barium glass fillers, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide, ytterbium trifluoride	Barium glass fillers, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide, ytterbium trifluoride
Filler content (wt%)	78	48.5	86.1	71
Prepolymers		34.0		
Flexural strength (MPa)	167	120	140 (dual curing)	135 (dual curing)
			125 (self-curing)	120 (self-curing)
Flexural modulus	11,400	10,000	18,000 (dual curing)	9000 (dual curing)
			14,000 (self-curing)	7500 (dual curing)
Compressive strength (MPa)	n.n.	250	250	250
Vickers hardness (MPa)	915	580	1000 (dual curing)	510 (dual curing)
Water absorption, 7 days (μg/mm^3)	28	21.2	14.5 (dual curing)	25 (dual curing)

without a post can compete with a flowable material in combination with a glass-fiber–reinforced composite (FRC) post.

The aim of the present study was to investigate the restoration of broken-down endodontically treated molars without the ferrule effect using glass ceramic crowns onto two different core buildups: a core buildup using no post from a high-viscosity and elastic modulus dual-cure material (Multicore HB [MHB]) and a core buildup from a flowable dual-curing composite with the use of a fiber-reinforced post (Multicore Flow+FRC post [MFP]). The null hypotheses were 1) that MHB core buildup would not lead to different fatigue strength of all-ceramic crowns compared to the MFP core buildup and 2) that dual-cure MHB and MFP buildups would not yield different results compared to CAD/CAM HPPs and light-cured composite resin buildups (with or without posts). Previously published data by the same authors using an identical experimental setup were used to test this second hypothesis.[18]

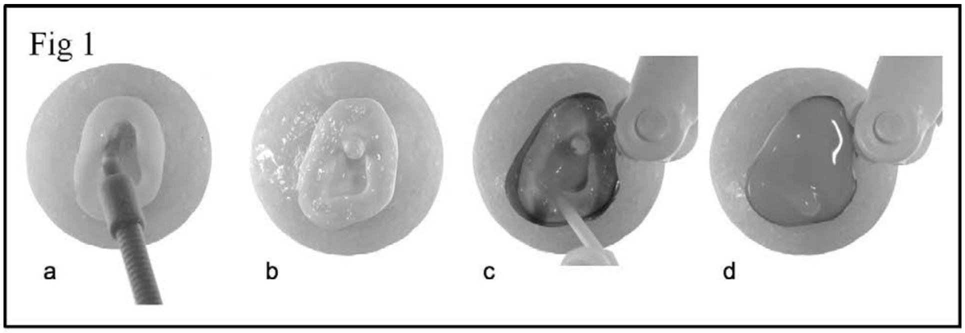
METHODS AND MATERIALS

On approval from the Ethical Review Committee of the University of Southern California, (Los Angeles, CA, USA) and the Ludwig-Maximilians University (Munich, Germany), 30 maxillary third molars were collected. In order to evenly distribute the teeth according to their size and shape, all specimens were organized by the randomly reassigned multiplets (RRM) principle in two groups of 15 teeth, as described elsewhere.[18] All teeth were mounted up to 2.0 mm below the cemento-enamel junction (CEJ) into acrylic resin, and standardized defects were generated by removing the clinical crown horizontally down to 1 mm above the CEJ. The pulp chamber was opened, and root canals were cleaned and shaped using the stepback technique (maximum file 35) and then partially filled and covered by glass-ionomer cement (Ketac Molar, 3M ESPE, Seefeld Germany) up to 1.5 mm below the level of the occlusal reduction.

Teeth from group MHB were restored with a direct buildup using the dual-curing composite Multicore HB (Ivoclar Vivadent, Schaan, Liechtenstein) In group MFP, an FRC post system was applied before the core buildup was carried out using the dual-curing composite Multicore Flow (Ivoclar Vivadent). The properties of the two resin materials are presented in Table 1. The detailed procedures to create the different core buildups are described below.

Group MHB: Conventional Core Buildup With Dual-Cure Composite Resin

Following 10-15 seconds of dentin and 30 seconds of enamel etching with 37% phosphoric acid (Total Etch, Ivoclar Vivadent), the Syntac adhesive system was applied according to the manufacturer's recommen-



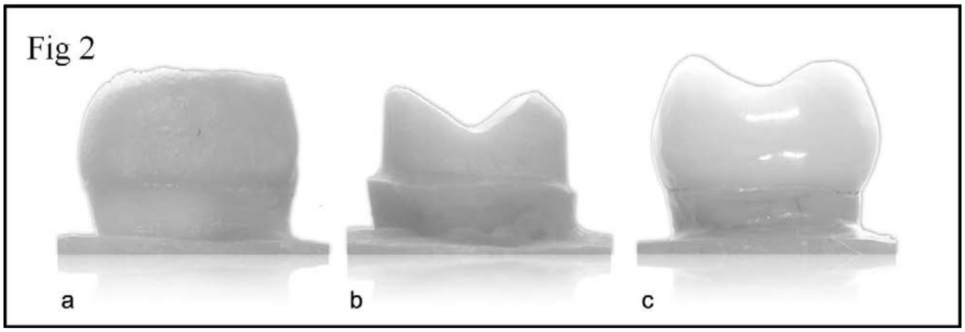


Figure 1. *Group MFP. (a and b): Placement of post (FRC post with Multilink Automix) and application of Multicore Flow (c and d) using a Tofflemire matrix.*

Figure 2. *(a): Core buildup with Multicore HB. (b): Standardized preparation for full ceramic crown. (c): Standardized glass ceramic crown adhesively luted on tooth.*

dations. The base and the catalyst paste of MHB were mixed with a spatula on a mixing pad at a ratio of 1:1. The material was cautiously kneaded to avoid air inclusions before the material was applied in bulk to the tooth and shaped slightly larger than the desired core dimension. Each surface was light cured for 60 seconds (20 seconds per surface, three times; 1000 mW/cm^2; Allegro, Den-Mat, Santa Maria, CA, USA).

Group MFP: Core-Buildup With Dual-Cure Composite Resin (Multicore Flow) and FRC-Post (FRC Postec Plus)

A glass-fiber–reinforced post (FRC Postec Plus System, Ivoclar Vivadent) was placed in the palatal root according to the manufacturer's recommendations. The post space was prepared ($\sim$10 mm deep measured from the defect surface) with the FRC Postec Plus Reamers at 1000-5000 rpm for a post size of 1 (white; 0.7mm). The post was tried in and checked for proper fit and then cut 3 mm above the defect surface and cleaned with phosphoric acid etching gel for 60 seconds, rinsed with water, and dried before applying silane-containing coupling agent (Monobond Plus, Ivoclar Vivadent) for 60 seconds (Figure 1).

The manufacturer of the post system recommends the application of Multilink-Automix in combination with the FRC-Postec as a system. Primers A and B were mixed at a 1:1 ratio and applied for 15 seconds into the root canal and on the prepared tooth surface by scrubbing with light pressure. The excess was removed with a strong stream of air and paper points. Multilink Automix was applied to the post, and the post was rotated to its final position. The excess of Multilink Automix was strategically dispensed over the prepared and primed surface of the tooth and light cured for 20 seconds. A Tofflemire matrix was placed, and the dual-cure core buildup material Multicore Flow was injected to fill the matrix space and light cured for 40 seconds. After 5 minutes, the matrix was removed, and further light polymerization was applied to each surface for 60 seconds (20 seconds per surface, three times).

Preparation for Glass Ceramic Crowns

All teeth were prepared to receive a standardized full anatomic glass ceramic crown: occlusal clearance of 2.0 mm, circumferential reduction of 1.0 mm with an axial convergence taper of 12 degrees (no ferrule), and preparation height of 7.0 mm from the level of the embedding resin to the cusp tips and 5.0 mm at the central groove (Figure 2).

Manufacturing of Glass Ceramic Crowns

A standardized full anatomic crown in the form of a simplified maxillary molar with three cusps was designed using the Cerec system. The CEREC database was used, and adjustments were made for each individual tooth in order to obtain specific dimensions of the crowns: 1.5 mm at the central groove, 2.0 mm at cusp tips, and 1.0 mm of circumferential thickness. Restorations were milled from leucite-reinforced glass ceramic blocks (Em-

Figure 3. *Specimen in load chamber, filled with distilled water to submerge specimen during testing.*

press CAD, Ivoclar Vivadent), and all measurements were verified manually using a caliper and confirmed visually by uniform translucency across specimens. The surface of the crowns was finished by mechanical polishing (OptraFine, Ivoclar Vivadent).

Adhesive Luting of the Glass Ceramic Crowns

The fitting surface of the milled glass ceramic crown was etched with hydrofluoric acid (<5%; IPS Ceramic Etching Gel, Ivoclar Vivadent) for 60 seconds and cleaned with phosphoric acid for 10 seconds (Total Etch) and in an ultrasonic bath for 2 minutes. Silane-containing coupling agent was applied (Monobond Plus) and heat dried for 60 seconds. Immediately before cementation, the adhesive resin (Heliobond, Ivoclar Vivadent) was applied to the crown, air thinned, but not light cured. The tooth was conditioned by air abrasion of the core buildup (27 μm aluminum oxide; 0.5 bar, 10 seconds, 1-cm distance), followed by 30 seconds of phosphoric acid etching to clean the surface and etch the enamel areas. Adhesive resin (Heliobond) was applied to all surfaces, air thinned, but not light cured. All crowns were cemented using a dual-cure composite cementation system (Variolink II, Ivoclar Vivadent). Following careful elimination of excess of unpolymerized composite resin, the vestibular, occlusal, and palatal surfaces of the crown were polymerized for 60 seconds (20 seconds per surface, three times). All margins were covered with an air-blocking barrier (Liquid Strip, Ivocalr Vivadent) for the last polymerization cycle. Each specimen was stored in distilled water at ambient temperature for at least 24 hours before testing.

Loading Procedure and Configuration

Masticatory forces were simulated using closed-loop servohydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). The masticatory cycle was simulated by an isometric contraction (load control) applied through an artificial composite resin cusp (Z100, 3M ESPE) in the shape of a semicylinder (2.5-mm radius). The low stiffness and tooth-like wear of the composite resin cylinder allows realistic simulation of tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials. All specimens were placed in the load chamber at 30-degree angulation and situated with a positioning device (sliding table) to create a single contact between the semicylinder and the palatal cusp. The loading point was equidistant to the cusp tip and central groove (Figure 3). The load chamber was filled with distilled water to submerge the specimens during testing. Cyclic load was applied at a frequency of 5 Hz, starting with a warm-up load of 200 N for 5000 cycles (preconditioning stage), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until fracture or to a maximum of 185,000 cycles.

Analysis

The mean fracture load and average number of endured cycles was calculated, and the fracture mode was evaluated for both group MHB and group

MFP following a three-examiner agreement. A distinction was made between three fracture modes, considering the repairability of the tooth to be, respectively, "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, [chip or crack] of underlying tooth structure), or "reparable" fracture (cohesive or adhesive failure of restoration only).

The fatigue resistance of the two groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted. This allowed the calculation of survival probability (%) at each load step. The influence of the core buildup on the fracture strength was analyzed using the log-rank test at a significance level of 0.05. The fracture load and number of cycles at which the specimen failed were compared using an unpaired *t*-test at a significance level of 0.05.

Supplementary data from a previous study about same design buildups and crowns by the same authors under strictly identical experimental conditions were combined with the present data for additional computation and comparison (life table survival analysis followed by Bonferroni-corrected pairwise comparisons using the log-rank test and fracture/cycles with one-way ANOVA followed by Scheffé post hoc tests).

The previous study included a CAD/CAM-fabricated indirect core buildup milled from an experimental HPP material (Ivoclar Vivadent), a conventional direct buildup using the light-curing composite Tetric EvoCeram (TEC; Ivoclar Vivadent), and an FRC post–supported core buildup using also the light-curing composite Tetric EvoCeram (TECP; Ivoclar Vivadent). The properties of the resin materials are presented in Table 1. The detailed procedures are described elsewhere.[18]

RESULTS

In groups MHB and MFP, none of the tested specimens withstood all 185,000 load cycles; therefore, the mean fracture load could be calculated. The mean fracture load for group MHB with 859.4 N $\pm$ 194.92 was not significantly different from group MFP (796.13N$\pm$156.34; p=0.376). Identical results were found when the number of survived cycles (MHB: 76,515.87$\pm$27,264.25; MFP: 68,339.47$\pm$27,706.96) was statistically compared (p=0.422). Mean fracture loads and average number of survived cycles are displayed in Figure 4.

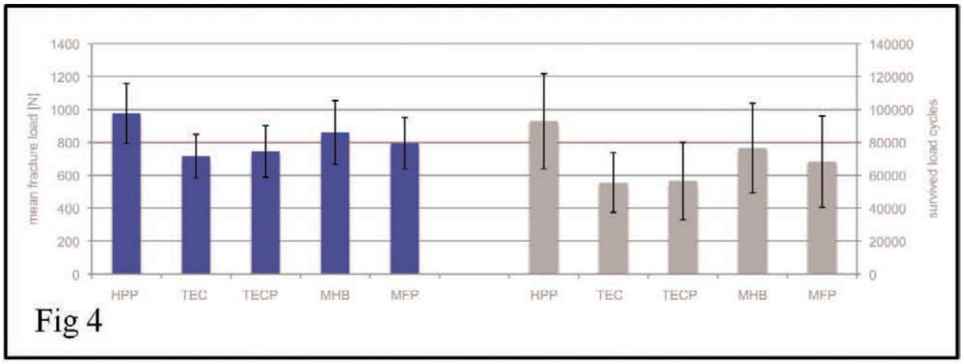
During cyclic loading, initial failures (MFPi) were detected in 20% (3/15) of specimens of group MFP. Failure of the specimen was preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root. The gap was always located at the opposing side of the post. Such occurrence was never found in the other groups. In group MHB, no initial failures could be detected. The life table survival graphs for groups MHB, MFP, and MFPi are displayed in Figure 5. Log-rank test showed no statistically significant differences in the survival of group MHB compared to group MFP (p=0.613) or group MFPi (p=0.221).

When considering previous data (five groups), ANOVA showed significant differences between the groups for fracture load and for survived cycles. HPP was significantly different from group TEC (fracture load: p=0.004; cycles: p=0.005) and TECP (fracture load: p=0.016; cycles: p=0.007) but not from MHB (fracture load: p=0.507; cycles: p=0.541) and MFP (fracture load: p=0.104; cycles: p=0.148). Between groups TEC, TECP, MFP, and MHB, no significant differences were found (Figure 4).

During cyclic loading, initial failures were detected in 26.7% of specimens of group TECP (TECPi) and 20% of specimens of group MFP (MFPi) (Figure 6). Because clinical detection of such failures appears to be questionable, the analysis of survival was conducted for the "total failure" (TECP, MFP) and for the "initial failure" (TECPi, MFPi). For total failure, HPP showed, even after Bonferroni correction, significantly higher survival than TEC (p=0.001) and TECP (p=0.001). Differences between all other groups were not significant. When considering initial failure, however, HPP proved also to survive significantly better than TECPi and MFPi. The life table survival graphs for groups HPP, TEC, TECP, and TECPi are displayed in Figure 7. Table 2 gives the p-values for groupwise comparisons.

Analysis of Failure Mode

Following the three-examiner agreement, groups HPP and TECP showed the highest rate of catastrophic failures (each 80%), followed by MFP (73.3%). Groups without a post, except for HPP, showed the lowest number of catastrophic failure (TEC: 53.3%; MHB: 60%). Figure 8 shows examples of different failure modes, and Figure 9 gives the percentage of specimens of each specific fracture mode for each group.



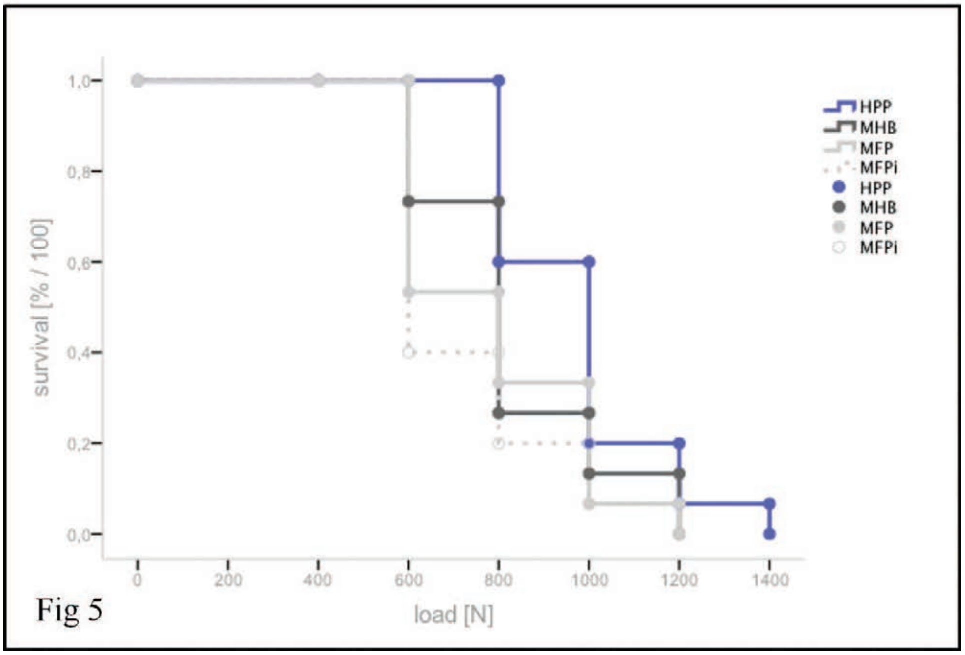


Figure 4. *Mean fracture loads (blue) and average number of survived load cycles (grey) and their standard deviations, respectively (previous data included[18]).*

Figure 5. *Life table survival graphs for groups MHB, MFP, and MFPi. For better comparison, the survival graph of group HPP from a previous study was added.*

DISCUSSION

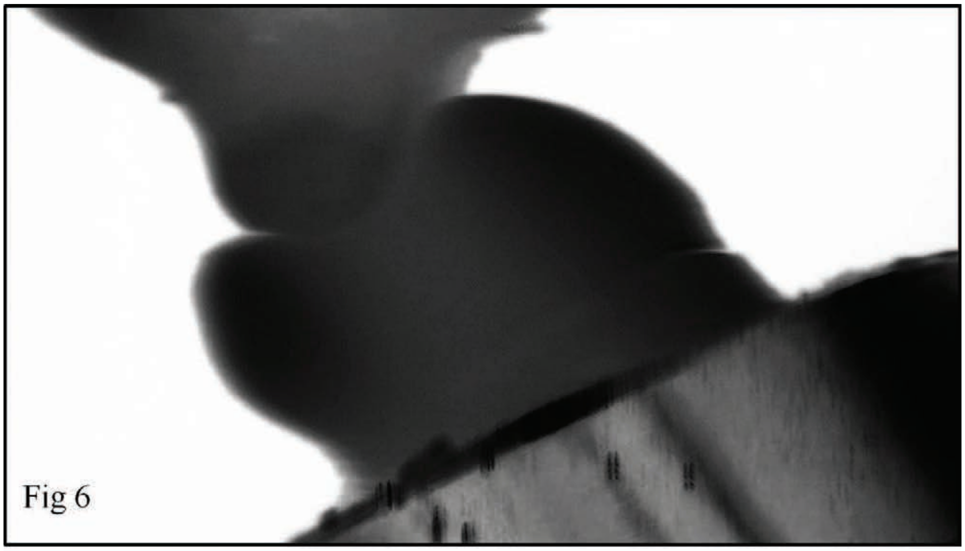
In this study, the performance of leucite-reinforced glass ceramic crowns over two different buildups for the rehabilitation of highly damaged, endodontically treated molars with no ferrule effect was evaluated. A core buildup without post using a high-viscosity dual-cure material (MHB) with a high elastic modulus and a core buildup made of flowable dual-curing composite in combination with MFP were tested. Results were compared with previously published data by the same authors using a strictly identical experimental setup. The first null hypothesis, stating that MHB core buildup would not lead to different fatigue strength of all-ceramic crowns compared to the MFP core buildup, was accepted, as no statistically significant differences could be found between the groups. Because HPP showed higher survival rates and fracture resistance compared to TEC, TECP, TECPi, and MFPi, the second null hypothesis was rejected.

Table 2: p-*Values of Pairwise Comparisons*

TEC	0.0001*					
TECP	0.0001*	0.688				
TECPi	0.0001*	0.453	0.285			
MHB	0.066	0.054	0.12	0.025		
MFP	0.032	0.157	0.303	0.066	0.613	
MFPi	0.005*	0.592	0.77	0.213	0.221	0.512
	HPP	**TEC**	**TECP**	**TECPi**	**MHB**	**MFP**

** Significant difference at the 0.005 level of significance after Bonferonni correction. Statistical analyses were carried out considering either groups TECP and MFP (total failure) or TECPi and MFPi (initial failure).*

The applied stepped load protocol, using a closed-loop servohydraulic system, represents a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test, allowing a physiological representation of mastication.[19] As shown by Fennis and others,[20] this test strategy seems to provide a better simulation of the



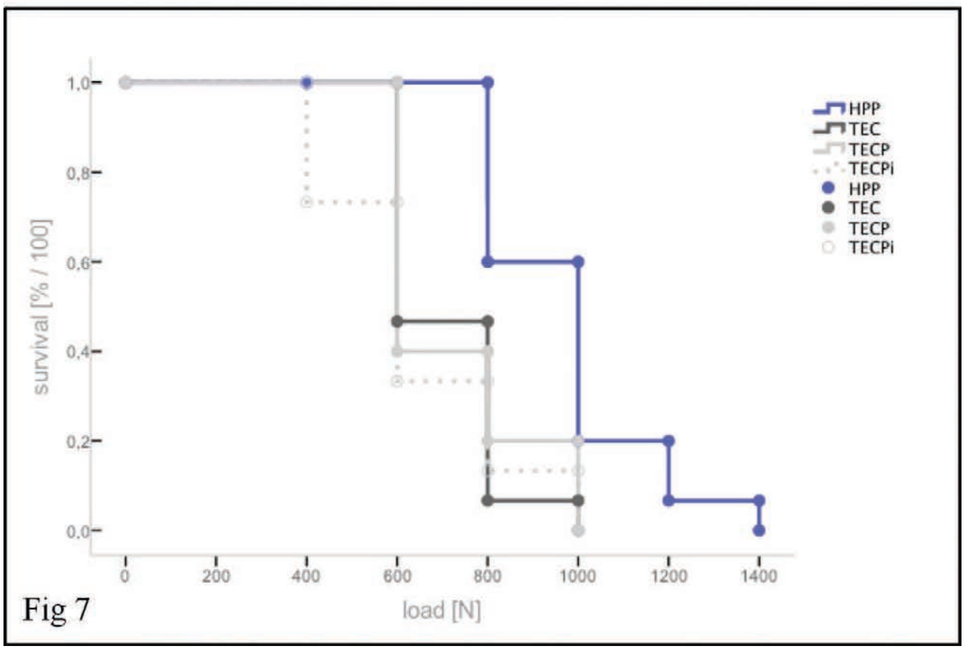


Figure 6. *Initial failure of the specimen was preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root. The gap was always located at the opposing side of the post. Such occurrence was never found in the groups without post. Because clinical detection of such failures appears to be questionable, the analysis of survival was conducted for the "total failure." Image motion blur is due to loading dynamics and water immersion.*

Figure 7. *Life table survival graphs for groups HPP, TEC, TECP, and TECPi.*

clinical conditions than static load tests. Therefore, the presented protocol appears to be the best compromise between available *in vitro* fatigue testing methods and clinical reality. To further challenge the restoration, the previously described load protocol with increasing loads from 200 up to 1400 N and a frequency of 5 Hz[21] was combined with an angle of force of 30 degrees concentrated on the working cusp. This method represents an extreme load configuration (worst-case scenario) and was selected because no specimens failed during pilot tests in which the load was applied axially and distributed on a tripodic contact. The extreme character of the applied method becomes even clearer when the loads are compared with a study by Sakaguchi and others[22] using a similar testing machine. They correlated 250,000 cycles at only 13.6 N with 1 year of clinical service. Therefore, it can be expected that an accelerated life cycle of the restored tooth may have been simulated.

The major advantage of *in vitro* studies over *in vivo* ones is their opportunity to create a high level of standardization with well-defined parameters, such as the biomechanical status of specimens.[23] To achieve a high level of standardization, even when using natural tooth with different age, size, and shape, only maxillary molars were used and distrib-

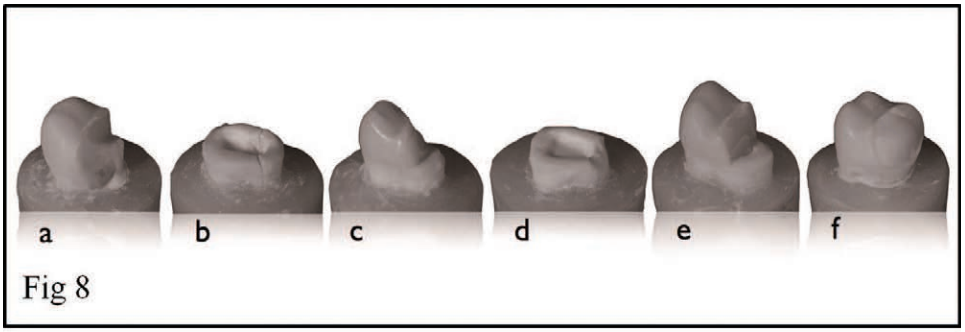


Figure 8. *Failure mode. All specimens were analyzed and classified into one of the three failure modes: "catastrophic" (tooth/root fracture that would require tooth extraction) (a and b), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage [chip or crack] of underlying tooth structure) (c and d), or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only) (e and f). The analysis was carried out in accordance with a previous study.[18]*

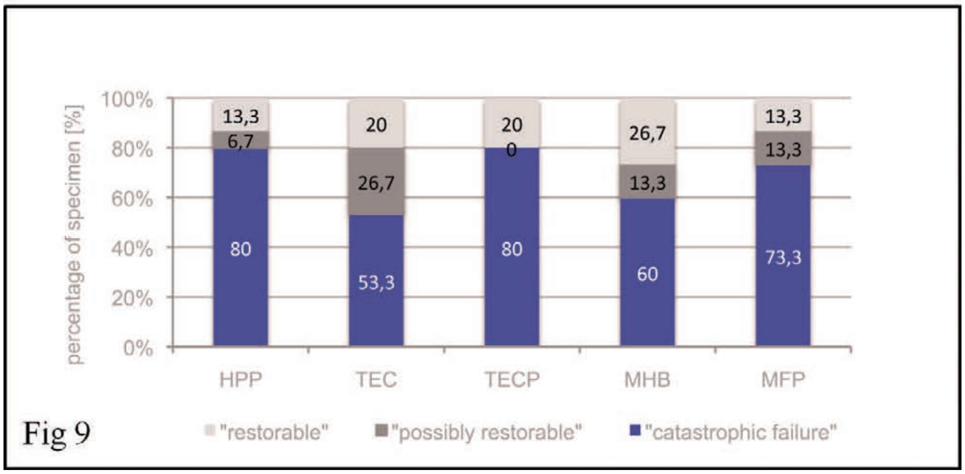


Figure 9. *Percentage of specimens per group for each fracture mode.*

uted into test groups by the RMM method. Further, CAD/CAM technology helped to achieve similar crown design with highly reproducible anatomy, cuspal inclines, grooves, and a strictly similar thickness parameter for each specimen. Using manual techniques to fabricate the crowns, such a level of standardization seems to be hard to achieve. This high level of standardization enabled the loading of the specimen in a strictly identical configuration and, further, comparing the results of this study with previously published data from the authors using the same methodology. In order to avoid masking the effect of the core buildup, high-strength ceramics were omitted as coverage material. Instead, leucite-reinforced glass ceramic was used for the fabrication of the crowns. By the same principle, teeth were prepared without a ferrule in order to avoid making the underlying core hypofunctional.[24]

In view of the present results, the use and effect of FRC posts can be questioned. No significant difference could be observed between groups MHB and MFP/MFPi. These findings are in accordance with a previous study by Scotti and others[14] stating that a fiber-post insertion did not increase the fracture resistance of severely broken-down endodontically treated mandibular molars restored with indirect composite resin overlays. The use of a highly viscous material with a high elasticity modulus (MHB) may have played a significant role in avoiding the technical and sensitive procedure of post placement. Even though there were no statistically significant differences, group MHB showed higher mean fracture load and failure resistance combined with more favorable failure modes when compared to MFP. Additionally, no initial failures could be observed in group MHB, whereas 20% of specimens showed initial failures (MFPi) in group MFP. The initial failure phenomenon, that is, a wide gap at the margin between the buildup/crown assembly, intensifying and preceding total failure, was essentially associated with the presence of a post (including group TECP in the previous study)[18] and never happened in no-post groups (HPP, TEC, MHP). This gap occurred and could be detected only under high oblique loads (>400 N). Due to the flexibility of the FRC post, the gap closes again in the absence of force. As a result, the detection of such initial failures is extremely difficult in the clinical situation, as only low to medium loads are usually applied during clinical examination. However, high loads are very likely to occur during mastication[25] and may lead to a pumping effect, facilitating bacterial infiltration and possibly causing secondary decay. A possible explanation for this phenomenon is that the post acts as a lever (rotation center) and causes the opening of a gap opposite to the load side during oblique loading (30 degrees). In addition, post systems are usually supplied with their own self-etching and/or self-adhesive dentin bonding system. Because initial failures did not occur when the total etch-and-rinse three-step dentin adhesive was used (HPP, TEC, MHB), the efficiency of the simplified adhesives may be questioned. Further studies are needed to evaluate whether initial failures would also occur when limiting the application of the post adhesive system to the root canal itself and using a classic adhesive on the remaining dentin surface to which the core material is bonded. This would further complicate the already time-consuming, material-intensive, and technique-sensitive procedure of post insertion and buildup.

The use of a post in combination with the high-viscosity MHB and the milled HPP material seems to be impractical from the clinical perspective. Therefore, these combinations were not included in this study. Generally, in view of the results, the use of a post should be questioned even in the absence of a ferrule effect. The groups with posts show the least fracture loads and failure resistance, combined with higher rates of unfavorable catastrophic fracture modes (TECP: 80%; MFP: 73.3%). The least catastrophic failures were found with direct no-post buildups (TEC, MHB). This aligns well with the description by Zicari and others[24] stating that shortening the post and the ensuing preservation of tooth structure offers the potential for re-restorability through a failsafe mechanism and thus may reduce the occurrence of catastrophic failures. In addition, clinical data seem to confirm that the absence of a post is associated with increased survival of ETT.[2]

Among groups without posts, HPP showed the highest fracture load and fatigue resistance but also a high percentage of catastrophic failures (80%). The reasons for this behavior have been discussed previously.[18] HPP is an industrially polymerized composite resin, and due to the semidirect fabrication, polymerization shrinkage occurs only within the luting material. Generally, a trend could be recognized that lower load-bearing groups tended to show fewer catastrophic failures. Further research is needed to establish the optimal balance between strength and favorable failure mode. In the present study, the most surprising and favorable combination of strength and failure mode could be observed in group MHB. The monomer matrix of MHB consists of dimethacrylate (13.5 wt%). The inorganic fillers are barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and highly dispersed silicon dioxide for a total of 86 wt%, which exceeds all other buildup materials. Additional contents are catalysts, stabilizers, and pigments (0.5 wt%). The total content of inorganic fillers is 70 vol%. Particle sizes range from 0.04 to 25 μm. Group MHB, together with HPP, showed the highest survival and fracture loads; however, MHB showed only 60% catastrophic failures against 80% in group HPP. The more adhesive failure modes in group MHB, leading to fewer catastrophic failures, might be explained by the different mode of application of the adhesive system. The strong performance of MHB might also come from its high elastic modulus (18,000 MPa) and hardness (Vickers hardness: 1000 MPa), as it was demonstrated that a higher elastic modulus of the core buildup increased the fracture resistance of all-ceramic crowns.[17] Because MHB was hand mixed, its maximum potential may have been diminished by the inclusion of air bubbles and porosities. On the other hand, the lesser mechanical properties of HPP seem to have been offset by the polymerization under industrial conditions. Therefore, a CAD/CAM block of MHB might represent the best performance (combination of mechanical properties and industrial processing). The only shortcoming of MHB, besides its handling, is its high opacity combined with an ocher shade. Some practitioners may view this as an advantage when removing excesses and repreparing. In the present study, MHB was applied directly to the bonded dentin surface. Further research should explore whether the use of MHB should be preceded by the placement of a flowable liner in more complex geometries. A complete evaluation of the previously mentioned materials and techniques should include microleakage/nanoleakage studies, although this was not the scope and was not investigated in the present study.

There are several clinically relevant elements that can be drawn from this *in vitro* study. Omitting placement of a post significantly facilitates clinical procedures without interfering with longevity as long as the right materials are selected. The use of HPP offers several innovative treatment options. For example, a fully anatomically shaped HPP crown can be used as a long-term provisional immediately after root canal treatment (eg, chairside using an intraoral scanner and milling unit) to achieve a reliable bacteria-proof sealing.[26,27] Subsequently, after recovery of the surrounding tissues and confirmation of endodontic status and prognosis, the polymer restoration can serve either as the definitive restoration or as a core buildup under an all-ceramic crown.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following can be concluded when restoring endodontically treated molars without a ferrule:

1. An indirect CAD/CAM-fabricated core buildup from an HPP and a direct core-buildup made from MHB might enhance the load-bearing capacity and fatigue resistance of all-ceramic leucite-reinforced glass ceramic crowns.
2. Insertion of a fiber-reinforced post does not enhance the load-bearing capacity and survival of all-ceramic leucite-reinforced glass ceramic crowns on direct core buildups from dual-cure or light-curing composite.
3. In the presence of FRC posts, failure of the specimen was often preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root (initial failure). This significantly affected the survival rate.
4. The most favorable combination of strength and failure mode could be observed in group MHB using MHB as buildup material.

Acknowledgement

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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 Ludwig-Maximilians University, Germany, and the Ethical Review Committee of the University of Southern California, Los Angeles.

Conflict of Interest

The authors 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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Influence of Adhesive Core Buildup Designs on the Resistance of Endodontically Treated Molars Restored With Lithium Disilicate CAD/CAM Crowns

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HP Maia • M Giannini • P Magne

Clinical Relevance

Lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) crowns with or without composite resin buildup exceeded expectations in restoring endodontically treated molars. The 2-mm buildup provided the highest load to failure and good fatigue resistance, so it can be indicated in cases of high occlusal loading.

SUMMARY

Objective: To assess the influence of adhesive core buildup designs (4-mm buildup, 2-mm buildup, and no buildup/endocrown) on the fatigue resistance and failure mode of endodontically treated molar teeth restored with lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) complete crowns placed with self-adhesive cement.

Methods and Materials: Forty-five extracted molars were decoronated at the level of the cementoenamel junction and endodontically treated. Specimens received different Filtek Z100 adhesive core buildups (4-mm buildup;

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2-mm buildup; and no buildup endocrown preparation) and were restored with Cerec 3 CAD/CAM lithium disilicate crowns (IPS e.max CAD). The intaglio surfaces of restorations (n=15) were conditioned by hydrofluoric acid etching and silane, and prepared teeth were treated with airborne-particle abrasion, followed by cementation with RelyX Unicem 2 Automix. Specimens were then subjected to cyclic isometric loading at 10 Hz, beginning with a load of 200 N (×5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. The chewing cycle was simulated by an isometric contraction (load control) applied through a 10-mm in diameter composite resin sphere (Filtek Z100). Surviving specimens were axially loaded until failure or to a maximum load of 4500 N (crosshead speed 0.5 mm/min). The failure mode was assessed, and fractures were designated as catastrophic (tooth/root fracture that would require tooth extraction) or reparable (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis (log-rank test at *p*=0.05). Surviving specimens were loaded to failure and compared with one-way analysis of variance.

Results: The survival rates after the fatigue test were 100%, 93%, and 100% for 4-mm, 2-mm, and no buildup (endocrown), respectively and were not statistically different (only one specimen failed with a 2-mm buildup under a crown that cohesively fractured at 1,400 N). Postfatigue load to failure averaged 3181 N for 4-mm buildups (15 specimens), 3759 N for 2-mm buildups (12 specimens), and 3265 N for endocrowns (14 specimens). The 2-mm buildups were associated with higher loads to failure than endocrowns and 4-mm buildups, but no differences were found between 4-mm buildups and endocrowns ($p<0.05$.) One endocrown and 2 restorations with a 2-mm buildup survived the load-to-failure test (at 4500 N). Only catastrophic fractures occurred after the load-to-failure test.

Conclusions: The buildup design influenced the performance of endodontically treated molars restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive resin cement. The 2-mm buildups were associated with higher loads to failure than the endocrown and the 4-mm buildup, but all restoration designs survived far beyond the normal range of masticatory forces.

INTRODUCTION

Long-term success of endodontic treatment is highly dependent on the restorative treatment that follows.[1] There is wide general agreement that the ferrule effect is a critical element in the performance of crowned endodontically treated molars (ETMs).[2,3] In dentistry, the ferrule refers to the cervical tooth structure that provides retention and resistance form to the restoration and protects it against fracture. However, in cases when the ferrule is absent, there is no consensus about the optimal buildup design required to rehabilitate these ETMs with extensive loss of coronal structure. Although insertion of a post does not strengthen or reinforce an ETM, posts are frequently used to retain coronal buildup materials, which in turn are used to retain a restoration.

With advances in the mechanical properties of composite resins and bond strength of dentin adhesive resins, it is logical to question whether these materials can be used to develop an internal adhesive ferrule effect without a post. Molars usually have a substantial amount of dentin (including the pulp chamber) available for bonding. In addition to substituting the pulp ceiling, the composite resin core buildup allows clinicians to remove retention from the endodontic preparation and control the restoration thickness. A different strategy to restore ETMs is an endocrown restoration.[4,5] This alternative approach utilizes the surface available inside the pulp chamber and restores both the core and the crown as one component. There is little information about the clinical quality of endocrowns generated with the CEREC (ceramic reconstruction) system; however, it appears to be feasible and at an acceptable level.[6,7]

The aim of this study was to evaluate the influence of a 4-mm buildup, a 2-mm buildup or no buildup (endocrown) on the mechanical performance and failure mode of ETMs restored with lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) complete crowns placed with self-adhesive resin cement. The null hypotheses were that there is no significant difference in the fatigue resistance and failure mode of ETMs among the three different buildup designs tested in this *in vitro* study.

METHODS AND MATERIALS

Once approval was obtained from the ethics committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California review board, 45 freshly extracted, sound human maxillary molars stored in solution saturated with thymol were used. Teeth were mounted in a special positioning device with acrylic resin (Palapress, Heraeus Kulzer, Armonk, NY, USA), and the root was embedded up to 3.0 mm below the cementoenamel junction (CEJ).

Tooth Preparation

A standardized tooth preparation was applied to all specimens. The intact crowns were removed by a horizontal section 1 mm above the CEJ using a diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under water lubrication. A standard-access opening was prepared to simulate root canal treatment in each tooth. Teeth were accessed using slow-speed round and GK269 burs to de-roof the pulp chamber and smooth the internal walls. Canals were located and patency achieved using #10 K-files (Dentsply Tulsa Dental, Johnson City, TN, USA). Coronal flare was created using Gates #3 (Dentsply), and canals were chemomechanically debrided using 04 rotary files (Protaper Niti Rotary, Dentsply) and NaOCl (5.25%) to within 3 mm of the apex. A final rinse with water was performed and canals were dried using paper points. Warm vertical obturation of the canals was then performed using gutta percha to the orifice level and condensed. An additional horizontal reduction of 1.0 mm was obtained (flat preparation following the CEJ, no ferrule) with the aid of a coarse round diamond bur (Brasseler, Savannah, GA, USA). Finally, a glass-ionomer barrier 1.0-mm to 1.5-mm thick (Ketac Molar, 3M ESPE, St Paul, MN, USA) was applied to the base of the pulp chamber.

The teeth were randomly divided into three groups according to restorative technique (n=15 each):

- Group I had 4-mm buildup (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove) + complete crown restorations (1.5-mm thick) (Figure 1A);
- Group II had 2-mm buildup (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove) + complete crown restorations (2.5-mm to 3.5-mm thick) (Figure 1B);
- Group III had endocrown restoration (about 5-mm to 5.5-mm thick) (Figure 1C).

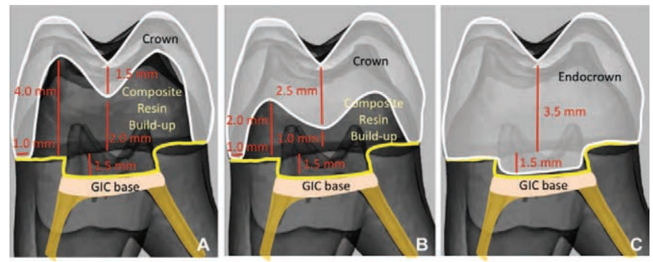

Figure 1. *Restorative techniques. (A) Group I. (B) Group II. (C) Group III.*

Buildups for groups I and II were made using Optibond FL adhesive system (Kerr Corp, Orange, CA, USA) and Filtek Z100 composite resin (3M ESPE) placed in 1.5-mm increments polymerized for 20 seconds each with 1000 mW/cm^2 (Valo, Ultradent Products, Inc, South Jordan, UT, USA).

Design and Manufacturing of Restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). The specimens were fitted with a crown or endocrown of standardized thickness and occlusal anatomy (third maxillary molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the CEREC software (version 3.6, Sirona Dental Systems), the occlusal surface was moved and rotated to make parallel the cusp tips and the preparation surface as well as to align the central groove. All restorations were milled in lithium disilicate ceramic IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) using the Endo mode with the sprue located at the lingual surface, then polished mechanically with a diamond ceramic polisher (CeramiPro Dialite W16DM, Brasseler) and glazed with IPS e.max CAD Cristall/Glaze (Ivoclar Vivadent) according to the manufacturer's instructions. The lithium disilicate crowns require crystallization firing. Thus, after milling and glazing, the IPS e.max CAD ceramic crowns were fired in a ceramic furnace (Austromat 624, DEKEMA Dental-Keramiköfen GmgH, Freilassing, Germany) following the manufacturer's instructions.

Crown Placement

All crowns were cemented with a dual-cure self-adhesive resin cement (RelyX Unicem 2 Automix cement, 3M ESPE). Before cementation, each crown was fit on its respective tooth to check its marginal adaptation. The inner surface of the crowns were then cleaned in a steam cleaner and etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar

Vivadent) for 20 seconds, rinsed, cleaned in an ultrasonic bath in distilled water for 1 minute, and then silanized (RelyX Ceramic Primer, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. The prepared teeth were sandblasted with 27 μm aluminum oxide, rinsed, and dried. The cement was applied to the inner surface of the crowns, which were then seated on the tooth with an approximate pressure of 70 N. Cement excess was removed after a brief light exposure (approximately 2 seconds) with a light-emitting diode curing unit (Valo, Ultradent Products). Air-blocking barrier (KY Jelly, Johnson & Johnson Inc, Montreal, QC, Canada) was used to cover all margins and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with a diamond ceramic polisher (CeramiPro Dialite W16DM, Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier, EC Representative, MDSS GmbH * Schiffgraben, Hannover, Germany), and buffed with a muslin rag wheel.

Testing

Fatigue Testing—Each specimen was stored in distilled water at ambient temperature for at least 24 hours after adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo hydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). Each specimen was placed into the load chamber and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin sphere (Filtek Z100, 3M ESPE) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the sphere contacting the mesiobuccal, distobuccal, and palatal cusps (tripod contact). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 10 Hz, starting with a load of 200 N for 5000 cycles (preconditioning phase to guarantee predictable positioning of the sphere with the specimen), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. After a two-examiner agreement under optical microscopy, a distinction was made between catastrophic failure (crown/root fracture that would require tooth extraction) or reparable failure (cohesive or cohesive/adhesive failure).

Load-to-Failure Testing of Surviving Specimens (in the case where a Major Percentage of Specimens Survived Fatiguing)—After the fatigue test, surviving specimens were axially loaded until failure or to a maximum load of 4500 N with a 10-mm composite resin sphere. The sphere had the same three-point occlusal contacts as in the fatigue test. The cross-head speed was 0.5 mm/min. The maximum post-fatigue load before failure was recorded in Newtons, and mean values were calculated per group. After load tests, the specimens were analyzed for one of the three failure modes as in the fatigue test.

Statistical Analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted. This allowed survival probability (%) to be calculated at each interval.

The postfatigue load-to-failure resistance of the surviving specimens was compared using one-way analysis of variance (ANOVA) (data tested normal) and the Tukey honestly significant difference test for post hoc analyses. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, version 11.0.1, MedCalc Software, Mariakerke, Belgium).

RESULTS

The survival rates after the fatigue test for ETMs with 4-mm buildups, 2-mm buildups, and endocrowns were 100% (15 samples), 93% (14 samples), and 100% (15 samples), respectively, and no statistical differences in survival were found among them (p=0.98) (Table 1). There was only one failure during the fatigue test (a specimen with 2-mm buildup that fractured cohesively, crown and buildup, at 1400 N). All specimens demonstrated limited wear of the crown material (mainly glaze) but marked concave wear faceting on the resin sphere antagonist (Figure 2).

Postfatigue load to failure averaged 3181 N for 4-mm buildups (15 specimens), 3759 N for 2-mm buildups (12 specimens), and 3265 N for endocrowns (14 specimens). One-way ANOVA revealed the higher load-to-failure resistance of 2-mm buildups (2-mm high) compared with the 4-mm buildup and endocrown designs (p=0.02), but no difference was found between the 4-mm buildup and endocrown.

Table 1: *Pairwise Post Hoc Comparisons*[a]

	LD Endocrown	LD 2 mm Build-up	LD 4 mm Build-up
LD Endocrown		.98	.98
LD 2 mm Build-up	<.05		.98
LD 4 mm Build-up	> .05	<.05	

Abbreviation: LD, lithium disilicate.
[a] *Shaded squares = fatigue post hoc tests (log rank test); clear squares = load-to-failure post hoc tests (Tukey honestly significant difference).*

One endocrown and two restorations with 2-mm buildup survived the load-to-failure test at 4500 N. Failure-mode analysis showed that all of the specimens exhibited nonrestorable catastrophic fractures after load-to-failure testing.

DISCUSSION

Today, both composite resin and ceramic materials can be used in the CAD/CAM technique. *In vitro* and *in vivo* research[8-10] tends to favor composite resin blocks over porcelain ones, especially when restoring ETMs. Additional CAD/CAM materials have emerged, such as resin nanoceramics and lithium disilicates. Previous conclusions about CAD/CAM porcelain blocks may not apply to all ceramic materials. Therefore, the biomechanical behavior of those materials and the most appropriate restorative strategy (core buildup vs endocrown) must be investigated to ensure appropriate clinical use.

In the present study, the influence of three buildup designs and restorative material on the fracture resistance of ETMs with extensive loss of coronal structure and no ferrule effect was evaluated. The load-to-failure value of fatigued 2-mm buildup restorations was higher compared with 4-mm buildup restorations and to endocrown (no-buildup design) restorations. Thus, the null hypotheses, which state that there would be no significant difference in the fatigue resistance and failure mode of ETMs among the three different designs tested in this *in vitro* study was partially rejected because the fatigue test alone did not demonstrate significant differences, and neither did the failure mode.

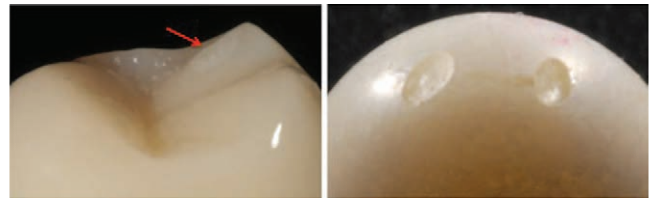

Figure 2. *Photographs of crown (IPS e.max CAD) and antagonist (resin sphere) wear.*

The present testing method allows a physiologic representation of mastication by a servohydraulic control system.[11] It uses a stepped load protocol, which is a compromise between the traditional time-consuming low-load/high-cycle fatigue test and the conventional load-to-failure test (which may be relevant in trauma situations). Although it is not possible to make a direct clinical correlation about the significance of the load range used in this study, Sakaguchi et al.[12] correlated 250,000 cycles at only 13.6 N with 1 year of clinical service using a similar machine. Given the extreme range of load in the present study, the accelerated life cycle of the restored tooth may certainly have been simulated. Careful tooth selection and a CAD/CAM CEREC machine were used in this study to standardize the dimensions and anatomy of occlusal surfaces of all specimens. The load was applied simultaneously at the buccal and palatal cusps by a composite resin spherical antagonist[9,13] to generate the cuspal flexure and stresses that challenged the coronal integrity.[14-16] Posts were intentionally not used in the present study because minimally invasive approaches were studied. Placing a post often involves removing more tooth structure, thereby weakening the tooth and presenting additional risks of root fractures and/or root perforations.[17] Furthermore, it is well known that posts do not bond well to buildup materials. In addition, omitting the post opens the possibility of using endocrown restorations, which may present even greater fracture strength than the conventional crowns supported on posts and filling cores.[4]

As in a previous study,[18] this study demonstrated that no differences in fatigue survival were found among the three types of crowns. However, the load-to-failure test of the fatigued restorations with a 2-mm buildup showed the best results. All restorations survived far beyond maximum masticatory human forces; one endocrown restoration and two restorations with 2-mm buildup even survived the load-to-failure test at 4500 N. The use of endocrown restorations presents the advantage of simplicity. On the other hand, a 2-mm buildup, besides providing the best fracture resistance, helps remove possible retention from the endodontic preparation, offers some kind of positive geometry (ie, will facilitate seating of the restoration), and decreases restoration thickness, which allows the blue light to pass through the indirect restoration to polymerize the underlying resin cement.[19] The 4-mm buildup restoration certainly provides even better provisional stabilization; however, this is at the cost of polymerization shrinkage due to the large amount of composite resin.

After the fatigue test, it was observed that the buildup design could influence the load-to-failure resistance of restored ETMs with lithium disilicate. The 2-mm buildups performed better than endocrowns and 4-mm buildups. The explanation may lie in the fact that in the 2-mm buildup, the restoration is still relatively thick, providing additional resistance; also, the buildup itself acts as a bonded connector (Optibond FL included) with the tooth. Conversely, the combination of those two elements is missing in the 4-mm buildup (which are a well bonded but thinner restoration) and the endocrown (a thick restoration but lacks bonding because of the self-adhesive cement).

Loaded restorations and resin sphere antagonists showed well-defined wear facets, which supports the clinical relevance and validity of this simulation. It is always more realistic to simulate tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials.[13] Wear facets were predominant on the antagonist (resin) sphere compared with the lithium disilicate restoration itself.

Considering the results of this *in vitro* simulated fatigue study on no-ferrule and no-post complete crowns, further research could be carried out to confirm that the use of a post is not required. However, it is difficult to envision how another restorative strategy could yield better results than those obtained with lithium disilicate ceramics without ferrules or posts.

CONCLUSION

It can be concluded that the buildup design influenced the performance of lithium disilicate CAD/CAM complete crowns placed with self-adhesive cement, even though all three buildup designs exceeded all expectations. The use of 2-mm buildups was the most robust approach. Not only did it yield higher loads to failure than endocrown and 4-mm buildup restorations, but it may also be useful to provide enhanced geometry, remove undercuts from the endodontic preparation, and facilitate provisionalization.

Acknowledgements

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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 University of Southern California Health Sciences Campus Institutional Review Board. The approval code for this study is HS-12-00278.

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 Different Light Sources and Enamel Preconditioning on Color Change, H_2O_2 Penetration, and Cytotoxicity in Bleached Teeth

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Clinical Relevance

The use of a light activation source or enamel preconditioning did not affect the outcome of in-office bleaching with 35% hydrogen peroxide. However, the bleaching gel was capable of diffusing through enamel and dentin, causing toxic effects to the pulp cells.

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SUMMARY

This study evaluated the effects of acid etching of the enamel and the combination of different light sources (halogen light, light-emitting diodes [LEDs], and LED/Laser) and the bleaching product on color change, penetration of hydrogen peroxide (H_2O_2), and cytotoxicity over time. The color change (ΔE) and the amount of H_2O_2 that permeated the tooth tissue were analyzed using a spectrophotometer. Cell metabolism and morphology were evaluated using the methylthiazol tetrazolium assay and scanning electron microscopy, respectively. The ΔE values and H_2O_2 permeation were not significantly different under any of the experimental conditions. Tooth whitening significantly reduced cell metabolism, regardless of whether a light source was used. Preconditioning the enamel did not influence the cellular metabolism in any group. In conclusion, combining the bleaching product with different light sources and/or preconditioning the enamel resulted in few significant changes in color, transenamel and transdentinal pene-

tration of H_2O_2, or cytotoxicity and cell morphology.

INTRODUCTION

In order to accelerate and increase the effectiveness of whitening treatment, products with high concentrations of hydrogen peroxide (H_2O_2) have been developed. These products are used with different light sources, such as halogen lights, light-emitting diodes (LEDs), and lasers.[1,2]

The inclusion of these light sources is based on the assumption that the light projected on a whitening product is absorbed and is partially converted into heat, which increases the release of reactive oxygen species and thereby the effectiveness of the technique. Thus, the heat generated by the light source acts as a catalyst in the degradation of the bleaching product, facilitating its diffusion through the dental structure.[3,4]

However, some authors[5-8] have questioned whether these light sources actually catalyze the oxidation-reduction reactions and consequently improve these techniques or whether these claims are simply a marketing strategy designed to sell equipment.

Recently another clinical procedure has been developed to increase the effectiveness of the whitening treatment, and this procedure has yielded promising results. Acid etching of the enamel was initially recommended in the early 1970s[9] for teeth with stains caused by tetracycline, and it is based on the superficial histological changes caused by the action of phosphoric acid. Removal of the aprismatic layer and the increase in surface porosities could theoretically increase the permeability of the substrate for the application of the bleaching agent, thereby optimizing the clinical results.[9-11]

However, despite the esthetic success of this technique, some aspects related to the biological safety of bleaching have been questioned. Several clinical studies have shown that human teeth treated with H_2O_2 exhibit high rates of sensitivity[12-17] and show evidence of pulpal damage.[18,19]

Thus, it can be inferred that although the success of the treatment is directly related to the ability of the bleaching substance to penetrate into the dentinal tubules and react with the darkened molecules,[1] the excessive penetration of the peroxide into the complex pulp-dentin tissue is concerning because it can cause injury in the pulpal tissue.[20]

In this context, the aim of this study was to evaluate the effect of different light sources and acid preconditioning of the enamel on color change and transenamel and transdentinal penetration of H_2O_2 and the response of the pulp cells over time when enamel/dentin discs were subjected to a bleaching procedure with a 35% H_2O_2-based product.

Table 1: *Samples Distribution According to the Treatments*

Groups	Treatments
G1	HP
G2	HP + halogen light
G3	HP + LED
G4	HP + LED/Laser
G5	Ac. + HP
G6	Ac. + HP + halogen light
G7	Ac. + HP + LED
G8	Ac. + HP + LED/Laser

Abbreviations: Ac., 37% phosphoric acid gel; HP, 35% hydrogen peroxide (H_2O_2)-based product; LED, light-emitting diode.

METHODS AND MATERIALS

Specimen Collection and Standardization

The experimental units (enamel/dentin discs) were obtained from bovine incisors.[21] The 5.7 mm-diameter discs were obtained from the middle third of the buccal surface of the teeth.

The dentin surfaces of the discs were regularized using manual rotary motion with aluminum oxide sandpapers of different grades (400 and 600 grit) (T469-SF-Noton, Saint-Gobam Abrasives Ltda, Jundiai, SP, Brazil) until they had a thickness of 3.5 mm (1.3 mm of enamel and 2.2 mm of dentin, ±0.2 mm). To remove the smear layer, a 0.5 M ethylenediamine tetraacetic acid solution, pH 7.2, was applied for 30 seconds; this step was followed by washing with deionized water.

The selected enamel/dentin discs were divided into eight groups as shown in Table 1.

Treatments

Bleaching Treatment—Bleaching was performed with a H_2O_2-based product (35% Whiteness HP Maxx, FGM Dental Products, Joinville, SC, Brazil). The procedure was performed according to the manufacturer's recommendations, and the final product was inserted into a disposable, graduated, 1 mL syringe. Each specimen was treated with 0.04 mL of the bleaching product, which remained in contact with the dental tissue for 45 minutes (three applications of 15 minutes each) during each whitening session. The procedure was repeated

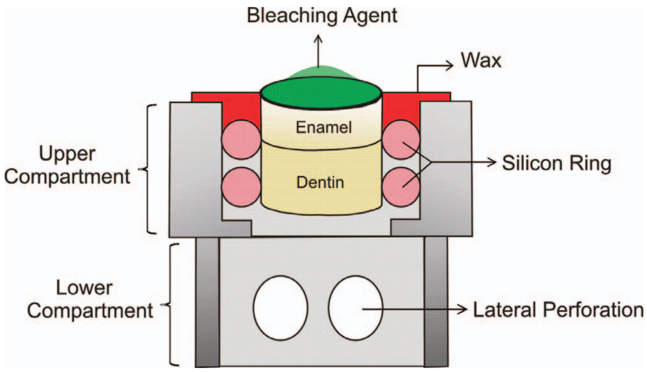

Figure 1. *Artificial pulp chamber.*

three times, with a one-week interval between sessions. The specimens were stored in artificial saliva at 37°C between bleaching sessions.

Light Sources and Acid Conditioning—Irradiation with a halogen lamp was conducted for 20 seconds at each application at a distance of 5 mm from the surface. The Ultralux lamp (Dabi Atlante, Ribeirão Preto, SP, Brazil), which has a light intensity of 500 mW/cm^2 and a wavelength between 450 and 500 nm, was used for this purpose.

LED irradiation was performed using the DB 686 Wireless (Dabi Atlante), which has a light intensity of 500 mW/cm^2 and a wavelength between 440 and 480 nm. Irradiation was conducted for 30 seconds (three applications of 30 s/session) at 5 mm from the enamel upon each reapplication of bleaching gel.

For irradiation of the whitening gel using a LED/Laser, the Whitening Lase II (DMC Equipment Ltda, São Carlos, SP, Brazil) was used. This equipment consists of six LEDs with an intensity of 120 mW/cm^2 and a wavelength of 470 nm and three infrared lasers with a wavelength of 808 nm and a power of 0.2 W. The product was irradiated for three minutes upon each application of bleaching gel (three applications of 3 min/session).

For the groups in which the enamel was conditioned before the whitening procedures, a 37% phosphoric acid gel (Condac 37, MGF Joinville, SC, Brazil) was applied for 30 seconds. The sample was subsequently washed with distilled water and was then dried.

Color Analysis—The selected 96 enamel/dentin discs were divided into eight groups (n=12) and the color analyzed using a reflection ultraviolet-visible spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan) before the first bleaching treatment, six days after each bleaching session, and 14 days after the end of the treatment period. Color evaluation was performed three times for each specimen at each analysis period and the mean values obtained for the evaluated area were subjected to statistical analysis. The CIE L*a*b* color model established by the Comission Internationale I'Eclairage (International Commission on Illumination), which allows the specification of color perception in three-dimensional models, was used. Analyses were performed on the buccal surface of the discs, and these values were compared to the initial reading. The data were submitted to analysis of variance (ANOVA) for repeated analysis (three-way repeated-measures ANOVA) with Scheffe test, with significance accepted at 5%.

Transenamel and Transdentinal Penetration of H_2O_2—To quantitate the amount of H_2O_2 that permeated the dental tissues, 96 enamel/dentin discs (n=12) were assembled in artificial pulp chambers (APCs)[22-27] (Figure 1). Acetate buffer solution (2 mL) was placed inside the APCs. From this moment on, the dentin surface remained in contact with this solution, and the H_2O_2 that diffused through the tooth structure reached the acetate buffer solution and had become part of it. After bleaching, leucocrystal violet dye (0.5 mg/mL; Sigma Chemical Co, St Louis, MO, USA) and peroxidase (1 mg/mL; Sigma) were mixed with 1 mL of the solution (acetate buffer).

This method, which was recommended by Mottola and others,[28] is based on the reaction of H_2O_2 with leucocrystal violet catalyzed by peroxidase. The color intensity of this mixture changes according to the amount of peroxide present. Thus, since the absorbance signal is proportional to the concentration of H_2O_2, it is possible to assess the amount of peroxide that permeated from the enamel surface into the solution contained in the APC. A standard curve of known H_2O_2 concentrations was used for conversion of the optical density obtained in the samples into micrograms of H_2O_2 per milliliter of acetate buffer solution, which represents the total H_2O_2 capable of diffusing through enamel and dentin discs.

The solutions were collected at four different times, as follows: T0, before applying the bleaching gel; T1, 30 minutes after the first bleaching session; T2, 30 minutes after the second bleaching session; and T3, 30 minutes after the third bleaching session.

The Friedman test was used at 5% to analyze the performance of each group over time, and the Kruskal-Wallis test at 5% was used to analyze the performances of the different light sources and pre-etching.

Culture of MDPC-23 Cells—The immortalized odontoblast-like cell line, MDPC-23, was cultured in plastic bottles (75 cm^2; Costar Corp, Cambridge, MA, USA) in Dulbecco's Modified Eagle's Medium (DMEM, Sigma) supplemented with 10% fetal bovine serum (GIBCO, Grand Island, NY, USA), 100 IU/mL penicillin, 100 μg/mL streptomycin, and 2 mmol/L glutamine (GIBCO). The cells were maintained in a humidified atmosphere at 37°C with 5% CO_2 and 95% air. To perform the cytotoxicity assay, 30,000 cells/cm^2 were seeded in each well of sterile 24-well plates (Costar Corp), and the cells were maintained in a humidified incubator with 5% CO_2 and 95% air at 37°C for 48 hours.

Cytotoxicity Evaluation—To evaluate cell toxicity, APCs with the discs in position were sterilized and were placed individually into 24-well plates containing 1 mL of culture medium without fetal bovine serum. Only the dentin surface remained in contact with the culture medium, and the enamel surface received the bleaching gel, as described above. After the specified time had elapsed, the bleaching gel was aspirated and the enamel surface was washed thoroughly with deionized water with concomitant aspiration. After 30 minutes, 500 μL of the extract (culture medium + the components of the bleaching gel that had permeated through the enamel/dentin disc) were collected and were applied to previously cultured odontoblast-like cells (MDPC-23). The cells were maintained in a humidified incubator at 5% CO_2 and 95% air at 37°C for one hour. Next, cell metabolism was analyzed using the methylthiazol tetrazolium (MTT) assay according to ISO 10993-5.[29]

Cell Metabolism Analysis (MTT Assay)—In each group, 10 out of 12 wells were used to analyze cell metabolism (n=10) by cytochemical demonstration of succinic dehydrogenase, which represents the mitochondrial respiration rate of the cells.[30] The cellular metabolic activity was analyzed using the MTT assay.[29] For this protocol, two additional groups were used as controls. In one of them, APC/disc sets were placed in contact with 1 mL of DMEM and no treatment was performed on the enamel surface. Next, the culture medium adjacent to the dentin surface was applied to the cultured MDPC-23 cells; the main absorbance of this group was considered to be 100% of cell metabolism, and the percentage for all samples was calculated based on this parameter. APC/disc sets subjected only to enamel acid conditioning were also used as a control group in order to evaluate if this procedure would interfere with cell metabolism parameters.

For this step, the extracts were aspirated and the cells were washed with 1 mL of phosphate buffered saline (PBS). Then, 900 μL of culture medium (DMEM) containing 100 mL of MTT solution (5 mg/mL; Sigma) was added to the cells. After four hours of contact with the cells, the MTT solution and the DMEM were carefully aspirated and were replaced with 600 μL of acidified isopropanol solution (0.04 N HCl) in each well. Three 100-μL aliquots of each well were transferred to 96-well plates (Costar Corp). Cell viability was evaluated using spectrophotometry at 570 nm wavelength with an enzyme-linked immunosorbent assay microplate reader (model 3550-UV, Bio-Rad Laboratories, Hercules, CA, USA). Two-way ANOVA with Tukey test at 5% was used to evaluate the influence of different light sources as well as the influence of acid etching on cellular metabolism.

Cell Morphology Analysis—Two samples from each group (n=2) were prepared to assess cell morphology using scanning electron microscopy (SEM). For this purpose, sterilized 12-mm-diameter cover glasses (Fisher Scientific) were placed at the bottom of the wells of sterile 24-well plates immediately before seeding of MDPC-23 cells.[31] After the incubation period, the extracts that were in contact with the cells were aspirated, and the MDPC-23 cells that remained adhered to the glass substrate (GS) were fixed in 1 mL of 2.5% buffered glutaraldehyde for one hour. These cells were subsequently rinsed three times with 1 mL PBS (five minutes per rinse), postfixed in 1% osmium tetroxide for 60 minutes, and processed for examination with SEM (JEOL-JMS-T33A Scanning Microscope, Peabody, MA, USA). The samples obtained in bleached groups were analyzed for cell density, cytoplasm shrinkage, and the presence of cell fragments on glass slides in order to determine the toxicity of the bleaching protocols to the MDPC-23 cells. These parameters were compared to those observed in the samples of the negative control group (APC/disc set with no treatment on enamel).[22-26,32]

RESULTS

Color Analysis

The average ΔE values are shown in Table 2. In all groups, a progressive and continuous change in color change (ΔE) values was observed with the bleaching treatment (the capital letters in the columns). The use or lack of use of different light sources did not influence the color change obtained at the different analysis periods ($p>0.05$) (lowercase in the lines). No statistical difference was observed when the techniques were compared under conditions "with" and "without" acid etching ($p>0.05$) ([lowercase]overwritten).

Table 2: *The Average Values (Standard Deviation [SD]) of Color Change (ΔE) in Bleached Teeth with the Use of Different Light Sources and Under Conditions "With" and "Without" Acid Etching on the Enamel*[a]

Time	Without Light	Halogen Light	LED	LED/Laser
Without acid etching				
T0	0.00 (0.00) C a[a]	0.00 (0.00) D a[a]	0.00 (0.00) D a[a]	0.00 (0.00) C a[a]
T1	5.08 (2.61) B a[a]	3.92 (1.43) C a[a]	3.52 (1.47) C a[a]	3.98 (1.34) B a[a]
T2	6.29 (2.83) A a[a]	5.32 (1.62) B a[a]	5.33 (1.57) B a[a]	5.87 (1.23) A a[a]
T3	6.73 (2.97) A a[a]	5.96 (1.50) A a[a]	6.80 (1.73) A a[a]	6.07 (1.03) A a[a]
With acid etching				
T0	0.00 (0.00) D a[a]	0.00 (0.00) D a[a]	0.00 (0.00) D a[a]	0.00 (0.00) D a[a]
T1	5.26 (1.87) C a[a]	4.16 (1.95) C a[a]	4.81 (3.47) C a[a]	4.31 (1.98) C a[a]
T2	7.19 (2.51) B a[a]	6.22 (2.42) B a[a]	6.68 (3.94) B a[a]	5.79 (2.41) B a[a]
T3	7.98 (2.30) A a[a]	7.09 (2.07) A a[a]	8.01 (3.45) A a[a]	7.79 (2.22) A a[a]

Abbreviations: LED, light-emitting diode; T0, before applying the bleaching gel; T1, 30 minutes after the first bleaching session; T2, 30 minutes after the second bleaching session; and T3, 30 minutes after the third bleaching session.
[a] *The different letters (capital in the columns, lowercase in lines, and superscript for the comparison between sessions of the groups with or without the use of acid) indicate statistically significant differences according to Scheffe test ($p<0.05$).*

Transenamel and Transdentinal Penetration of H_2O_2

The mean values of H_2O_2 that permeated through the dental tissue are shown in Table 3. In all groups, similar penetration occurred at T1, T2, and T3, and these values were statistically different from those observed at T0 (uppercase in the columns).

The analysis of the influence of different light sources (lowercase in the lines) on the permeation of H_2O_2 revealed that between the groups that did not undergo pre-etching, the group in which the bleaching gel was combined with the LED/Laser showed the highest values at T1 ($p<0.05$); similar results were observed for the other groups ($p>0.05$). At T2, the lowest average was observed in the group in which the halogen light was used ($p<0.05$). In the groups in which the enamel had been previously etched with 37% phosphoric acid, only the association with the LED and LED/Laser light increased the penetration of peroxide at T1 with respect to those without light.

When comparing the conditions "with" and "without" acid etching (superscript overwritten letters), it was observed that pretreatment of the substrate with phosphoric acid favored the penetration of peroxide only in T1 (bleaching associated with LED) and in T2 (bleaching associated with halogen light). No statistically significant difference was observed for the other times and groups ($p>0.05$).

Table 3: *The Mean (Standard Deviation [SD]) Peroxide Concentration (μg/mL) that Permeated Through the Dental Tissues After Bleaching Treatment, According to the Different Times and Treatments*[a]

Time	Without Light	Halogen Light	LED	LED/Laser
Without acid etching				
T0	−0.42 (0.02) B a[a]	−0.42 (0.01) B a[a]	−0.41 (0.04) B a[a]	−0.41 (0.01) B a[a]
T1	4.66 (0.52) A b[a]	4.51 (0.66) A b[a]	4.65 (0.36) A b[b]	5.43 (0.50) A a[a]
T2	5.41 (0.15) A a[a]	5.11 (0.18) A b[b]	5.44 (0.15) A a[a]	5.38 (0.27) A a[a]
T3	5.09 (0.31) A a[a]	5.11 (0.15) A a[a]	5.10 (0.18) A a[a]	4.94 (0.22) A a[a]
With acid etching				
T0	−0.41 (0.03) B a[a]	−0.42 (0.05) B a[a]	−0.42 (0.02) B a[a]	−0.43 (0.03) B a[a]
T1	4.56 (0.46) A b[a]	4.36 (0.38) A b[a]	5.24 (0.49) A a[a]	5.48 (0.46) A a[a]
T2	5.40 (0.32) A ab[a]	5.42 (0.13) A ab[a]	5.35 (0.29) A b[a]	5.60 (0.21) A a[a]
T3	5.14 (0.34) A a[a]	5.14 (0.15) A a[a]	5.11 (0.20) A a[a]	5.21 (0.14) A a[a]

Abbreviations: LED, light-emitting diode; T0, before applying the bleaching gel; T1, 30 minutes after the first bleaching session; T2, 30 minutes after the second bleaching session; and T3, 30 minutes after the third bleaching session.
[a] *The different letters (uppercase in the columns [Friedman test], lowercase in the lines, and superscript for comparing the conditions "with" and "without" acid etching on enamel [Kruskal-Wallis]) indicate statistically significant differences ($p<0.05$).*

Table 4: *Mean (Standard Deviation [SD]) of the Metabolism of Odontoblast Cells MDPC-23 (%) Subjected to the Bleaching Treatment Combined with the Use of Different Light Sources and Prior Acid Etching of the Enamel*[a]

Control	Without Light	Halogen Light	LED	LED/Laser
Without acid etching				
100.29 (3.13) Aa	63.72 (1.95) Ab	57.22 (4.55) Ab	61.43 (6.04) Ab	59.72 (7.17) Ab
With acid etching				
101.21 (4.68) Aa	57.11 (13.84) Abc	49.87 (9.03) Ac	62.91 (6.94) Ab	45.98 (3.15) Bc

Abbreviation: LED, light-emitting diode.
[a] *The different letters indicate difference statistically significant differences (uppercase in the columns and lowercase in the lines [Tukey test],* $p<0.05$*).*

Cell Metabolism (MTT Assay)

The cell metabolism results obtained from the MTT assay are presented in Table 4. When the conditions "with" and "without" acid etching were compared (uppercase in the columns), a statistically significant difference was observed only when the whitening gel was combined with the LED/Laser ($p<0.05$), whereas pretreating the enamel surface led to a decrease in odontoblast cell metabolism. It is also observed that APC/disc sets subjected only to enamel acid conditioning (control group) did not interfere with cell metabolism parameters. In the comparison among the groups (lowercase in the lines), no significant difference was observed between those that received or did not receive the different light sources; however, a significant reduction of cell metabolism (compared with the control group) was found in all cases ($p<0.05$).

Cell Morphology (SEM Analysis)

In the control group, which lacked bleaching treatment, a large number of cells covered the entire surface of the GS. These pulp cells were fully confluent, with regions of apparent mitosis (asterisk) (Figure 2A). Conversely, regardless of whether light was utilized or pre-etching of the enamel was performed, the bleaching treatment resulted in significant cellular changes (Figure 2B,C). These changes were characterized by cell death, followed by detachment from the GS. The few remaining cells showed significant morphological changes, presenting rounded, thin, and short cytoplasmic extensions (arrow). The remnants of the cytoplasmic membranes of cells that underwent cell death were apparent on the GS (circle).

DISCUSSION

Although tooth whitening is considered a conservative treatment,[33,34] concerns exist regarding its biological safety, especially when highly concentrated products are employed.[18,19,26,35-37] The use of peroxide in high concentrations (35%-38%) produces visible results after the first bleaching session, and this fact has been the main source of appeal for the increase in the use of this technique.[38-40]

In order to accelerate and increase the effectiveness of bleaching, these products have been combined with different light sources[1,3,8] as well as with pre-etching of the enamel.[11,41] The light sources are recommended as "peroxide activators," whereupon part of the energy that results when the light is focused on the bleaching gel is presumably absorbed and is converted into heat;[4] thus, the use of the light would accelerate the decomposition of peroxide hydrogen. Further, in order to increase light absorption, some bleaching products are mixed with specific dyes such as carotene (photosensitive). The orange-red color of the carotene increases the absorption of light,[4] thereby apparently increasing the effectiveness of the bleaching treatment.[41]

In the present study, the ΔE values obtained ranged between 3.52 and 8.01, indicating that the different protocols that were utilized resulted in a high degree of color change in the enamel/dentin discs. These data show that the bleaching treatment with 35% H_2O_2 was effective for tooth whitening regardless of the use of light. Similar observations were reported in several laboratory and clinical studies.[8,42,43]

On the other hand, the results of this study contradict those obtained by Calatayud and others,[44] who reported that the use of light sources favors the achievement of greater color changes. However, it is noteworthy that Calatayud and others performed the color analysis immediately after the bleaching procedure; therefore, this analysis was influenced by the dehydration caused by surgical isolation, the osmotic power of the bleaching gels, and the heat created by the lights.[42,45] To minimize these influences, the color analysis was performed six days after each bleaching session in this study.

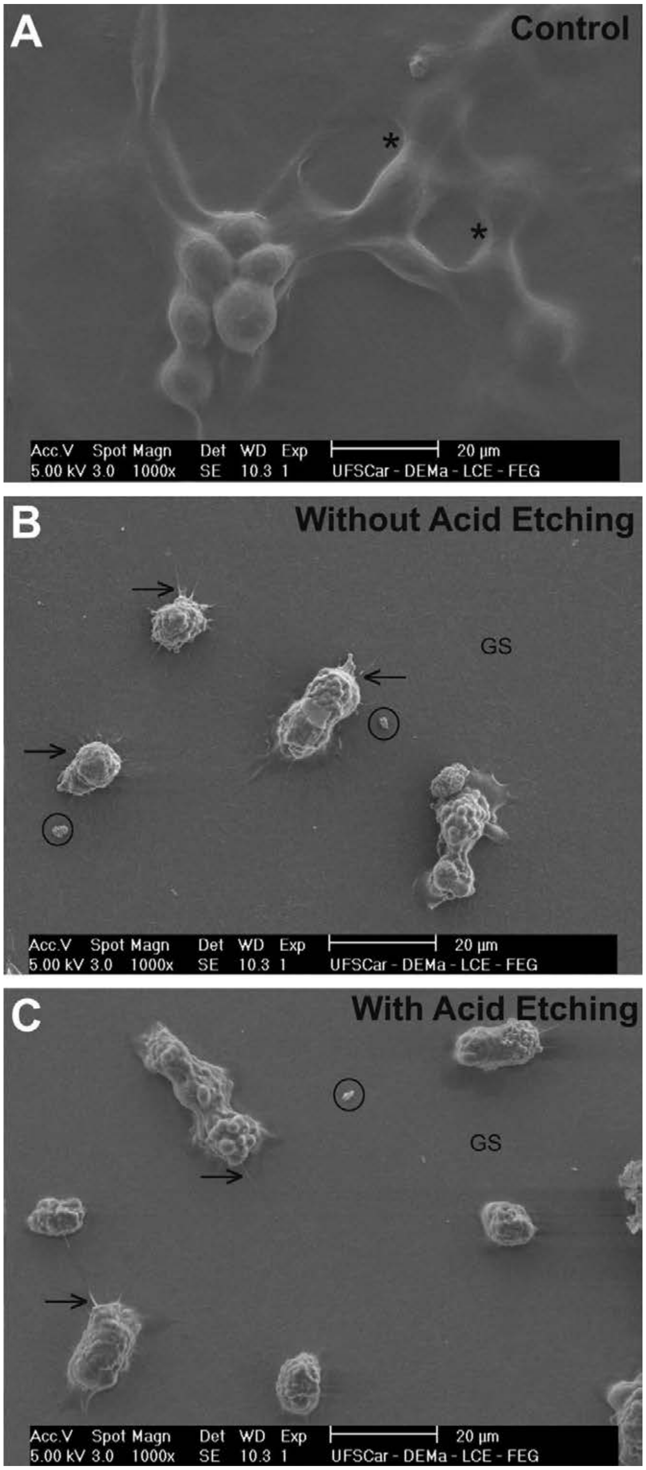

Figure 2. *Representative photomicrographs of cell morphology (1000×). (A) Control; a large number of MDPC-23 cells cover the entire surface of the GS, with apparent cell mitosis (asterisk). (B) Representative image of the groups that were not pretreated with acid etching on the enamel. (C) Representative image of the groups that were pretreated with acid etching on the enamel.*

Similar to the findings of Kanematsu and others,[41] it was observed that pre-etching the enamel using 37% phosphoric acid did not accelerate or increase the effectiveness of the bleaching techniques studied. It is known that phosphoric acid decreases the amounts of calcium and phosphate present in the enamel surface, and this decrease is even greater when the enamel is exposed to bleaching products shortly thereafter.[46] Thus, according to Li and others,[47] the high initial luminance (L*) values are directly related to dehydration and mineral loss, and the regression of these values is related to the process of rehydration and remineralization of this tissue.

Despite these considerations, given the recent questions about the safety of bleaching treatment, a complete study of these techniques should not be limited to the analysis of the color changes that occur in the teeth. Currently, the safety of this treatment is disputed because of the high levels of H_2O_2 detected in the pulp chamber. To address this issue, this study quantified the permeation of H_2O_2 toward the pulp chamber as well as the metabolic rate and morphology of the odontoblast-like cell line (MDPC-23) after different protocols were performed.

In this context, it is determined that H_2O_2 can penetrate the tooth structure and reach the pulp chamber, as observed when the later times were compared to time T0. In general, a pronounced increase in the amount of peroxide was not observed in the pulp chamber when pre-etching of the enamel was performed and different light sources were applied. These results are similar to those of Kwon and others,[3] who did not observe an increase in the amount of peroxide in the groups when bleaching was combined with a light source.

Regarding cytotoxicity, the components of the bleaching agent caused significant toxic effects to the pulp cells (MDPC-23). Nevertheless, in general, the use of different light sources as well as the use of pre-etching on enamel did not influence the cellular metabolism, except in the group in which the whitening gel was combined with the LED/Laser. In this group, a greater reduction of cell metabolism was observed when pre-etching was performed on the enamel. In this context, although the difference was not statistically significant when peroxide penetration was compared between the techniques "with" or "without" pre-etching of enamel, an increase in peroxide penetration was detected at all measured times, and this may have resulted in the reduction in cell metabolism.

Trindade and others[26] demonstrated severe damage to odontoblast cells after 3 × 15-minute applications of 35% H_2O_2, with a 92% reduction in MDPC-23 cell metabolism. In contrast, the mean general reduction of cell metabolism was approximately 43.33% in the present study. This lower percentage of cellular metabolism reduction can be attributed to the reduced contact time with the cell extract (one hour) when compared to that of the previous study (24 hours). The results of this study are similar to those reported by Soares and others.[32] The SEM images revealed numerous dead cells or cells displaced from the GS in all experimental groups that received the bleaching agent. The few cells that remained showed significant morphological changes, suggesting that the whitening procedure should be studied so that the best posology can be indicated for each individual case.

The results of this study cannot be directly extrapolated to a clinical situation because this is an *in vitro* study and it is known that human teeth have higher permeability compared to bovine teeth.[48] Furthermore, the presence of saliva, intrapulpal pressure, and odontoblast extensions can reduce the permeation of H_2O_2.[49-53] Moreover, the lymphatic system and antioxidants that are present in the pulp tissue protect pulp cells against external aggressions.[52,54,55]

However, the data obtained in this study suggest that the bleaching product can induce toxic effects in cells and pulp tissue. In this context, the concerns regarding the combination of bleaching products with different light sources, as well as acid etching of the enamel, appear to be negligible for both color change and peroxide penetration because the weakness of the technique is the biological safety of the bleaching procedure and not the resources employed to enhance its effectiveness. However, future studies should be conducted to elucidate the cellular mechanisms involved in the biological response to tooth whitening, which would eliminate or minimize these effects.

CONCLUSIONS

Under the experimental conditions of this study, the following conclusions can be made:

- The use of different light sources and prior acid etching of the enamel do not influence the change in tooth color obtained by bleaching;
- In general, the use of different light sources or acid etching prior to application of the whitening gel to the enamel does not influence H_2O_2 permeation through the dental tissues at the end of the treatment; and
- The application of 35% H_2O_2 to enamel/dentin discs promoted moderate toxic effects on pulp cells (MDPC-23); the presence of light or preconditioning of the enamel did not influence the cytotoxic effect.

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Regulatory Statement

This study was conducted at Aracatuba Dental School, UNESP–University Estadual Paulista in Brazil.

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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Evaluation of Stain Penetration by Beverages in Demineralized Enamel Treated With Resin Infiltration

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Clinical Relevance

Clinicians are provided useful information about the staining potential of common beverages on resin infiltration–treated enamel surfaces.

SUMMARY

Purpose: To evaluate stain penetration by different beverages in artificially demineralized human teeth treated with resin infiltration.

Methods and Materials: Sixty extracted human permanent molars were demineralized, treated with resin infiltration (Icon), and immersed in four different beverages (coffee, grape juice, iced tea, and distilled water; N=15) for four weeks. After aging, teeth in the distilled water group were stained with 2% methylene blue for 24 hours. All teeth were sectioned, and stain penetration was evaluated under light microscopy. Chi-square test, independent and paired sample *t*-test, analysis of variance with the Fisher least significant difference *post hoc* test, and the Kruskal-Wallis test were used to analyze the results ($p<0.05$).

Results: Resin infiltration–treated surfaces (Icon surfaces) had statistically significant fewer samples with presence of stain penetration compared to untreated surfaces (control surfaces) ($p<0.001$). There was also a significant decrease in depth of stain penetration in Icon surfaces compared to the control surfaces ($p<0.001$). Among tested beverage groups, iced tea showed significantly greater depth of stain penetration (0.134 ± 0.029 mm), followed by grape juice (0.118 ± 0.047 mm), methylene blue (0.022 ± 0.019 mm), and coffee (0.008 ± 0.017 mm; $p<0.001$).

Conclusion: Both Icon and control surfaces exhibit stain penetration by different beverag-

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es (iced tea, grape juice, and coffee). However, resin-infiltrated enamel surfaces allow significantly less depth of stain penetration compared to untreated surfaces. The iced tea group presents greatest depth of stain penetration, followed by grape juice, methylene blue, and coffee.

INTRODUCTION

While the overall prevalence of dental caries in the United States has declined dramatically in the past few decades, dental caries remains the number one chronic childhood disease.[1,2] Historically, addressing the caries challenge has relied on prevention and restoration, with no intermediary means to stop lesion progression.[2] Recently, a technique called resin infiltration (Icon, DMG America, Englewood, NJ, USA) was introduced as a conservative way for arresting dental caries.

The concept of resin infiltration was first developed in Germany and later was brought into the US market in 2009.[2] The resin infiltration technique was developed with the aim of filling the non-cavitated pores of an incipient lesion with a low-viscosity resin by capillary action.[2-4] Since porosities of enamel caries lesions act as diffusion pathways for acids and dissolved minerals, infiltration of these pores with light-curing resins might occlude the pathways and thus arrest caries progression.[5,6] In contrast to the application of sealants,[8] where the diffusion barrier remains on the enamel surface as a covering resin coat, the resin infiltration creates a diffusion barrier within the enamel lesion and thus prevents further caries progression.[4,5] In addition, resin infiltration has been proven to have high penetration depths up to 800 μm into lesion bodies, strengthen demineralized enamel, and withstand new acid challenges.[7,9] Resin infiltration is indicated for arresting incipient caries, postorthodontic white spot lesions, and noncavitated smooth surface lesions.[2]

In clinical dentistry, a commonly encountered problem in dental restorative materials is microleakage. Microleakage is defined as the passage of bacteria, fluids, chemical substances, molecules, or ions in the interface between the tooth and its restorative material.[10,11] Factors that can contribute to microleakage include polymerization shrinkage of restorations, different linear coefficients of thermal expansion from the tooth, water absorption, mechanical loading, and manipulation of materials by operators.[12,13] *In vitro* studies have shown that microleakage may cause marginal discoloration, hypersensitivity, recurrent caries, adverse pulpal response, and accelerated deterioration of some restorative materials.[11] This property has been used by many clinicians and researchers to predict the performance of a restorative material.

A common problem with resin materials is that, after months and years of use and exposure to a variety of different foods and beverages, the materials become stained.[14-16] This discoloration of restorations, which can be due to either extrinsic or intrinsic factors, is a frequent reason for replacement of resin materials.[17,18] Color stability of the infiltrated area can be a particular factor for the long-term clinical success and acceptability of teeth in the esthetic zone.[3,4] Intrinsic factors can involve the discoloration of the resin material itself as well as microcracks and microvoids located at the interface between the filler and matrix acting as penetration pathways for staining agents.[19,20] On the other hand, extrinsic factors for discoloration include staining by adsorption or absorption of colorants as a result of contamination from exogenous sources.[19,20] The degree of discoloration from exogenous sources varies according to individual oral hygiene; eating, drinking, and smoking habits; and the type of chromogenic bacteria.[19] The staining of polymeric materials by colored solution in the form of beverages (ie, coffee, tea, red wine, and cola), mouth rinses (ie, chlorhexidine), and medications has been reported in many studies.[14,19,20,21]

To ensure optimal restoration longevity and esthetics, it is necessary for a restorative material to minimize microleakage, maintain color stability, and be resistant to surface staining. The current body of literature dealing with microleakage in resin infiltration remains scarce. To date, there has been no published study investigating its stain penetration and microleakage potential when under chronic challenges by colored and acidic beverages. Therefore, the purpose of this *in vitro* study was to evaluate the extent of stain penetration by common beverages in artificially demineralized human teeth treated with resin infiltration.

METHODS AND MATERIALS

Preparation of Teeth

Sixty extracted noncavitated human permanent molars were collected, cleaned, and stored in 0.1% thymol solution prior to study to avoid dehydration. Apices of the teeth were covered with utility wax,

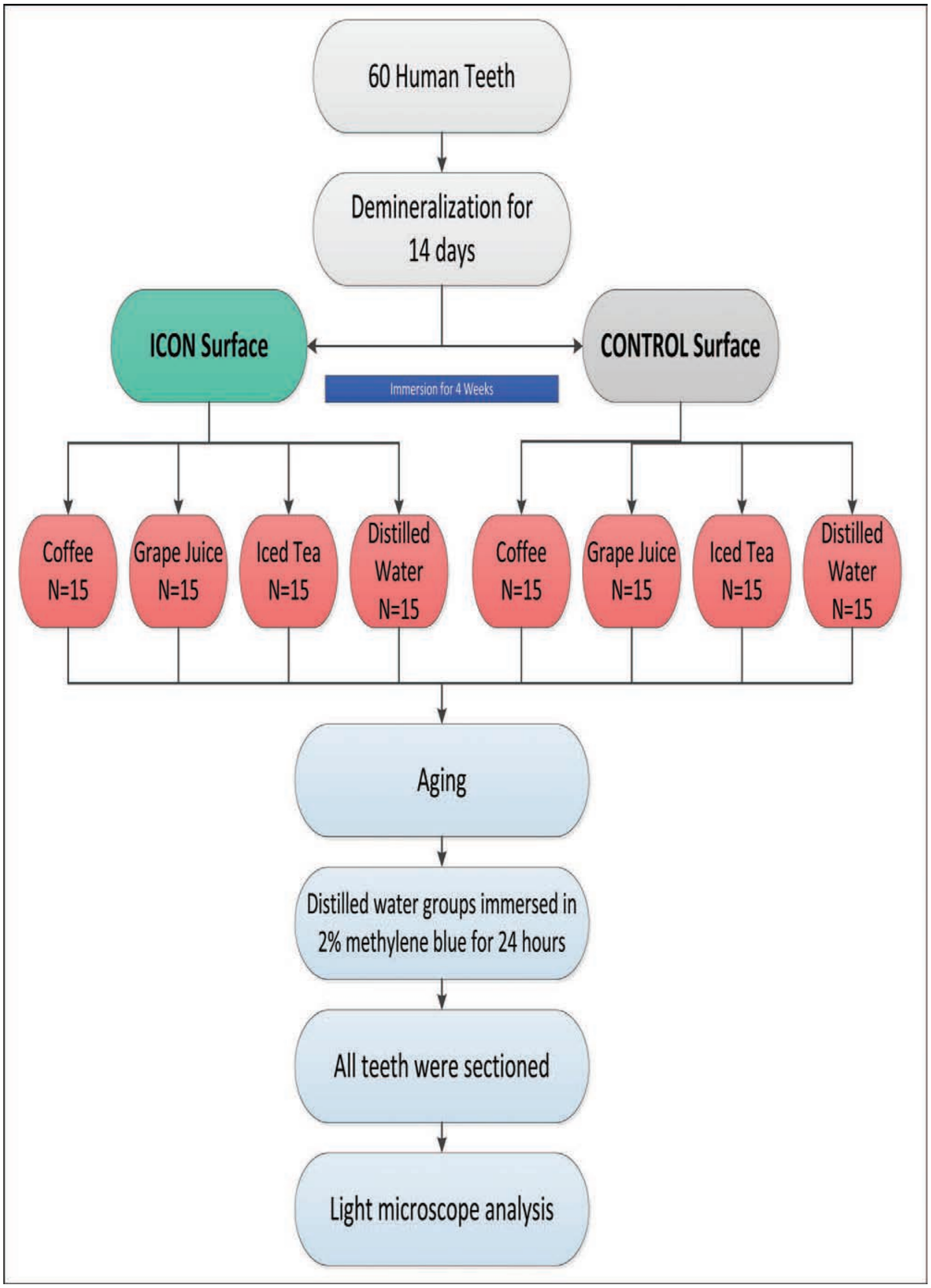

Figure 1. *Study design.*

and root surfaces were coated with acid-resistant varnish (Revlon 730 Valentine, Revlon Consumer Products Corporation, New York, NY, USA). Demineralization was created on the crowns of teeth by storing specimens in 1L of a demineralizing solution (pH=5) containing 100 mL of 1 mol aged lactic acid and 1% carbopol (C907) for 14 days (Loma Linda University demineralization formula). The total volume of solution used was estimated to immerse the entire sample group. Demineralization was confirmed, as clinically detectable white discoloration appearing on the crowns of teeth.[22] Teeth were stored overnight in a 37°C incubator to simulate the oral environment. For the study design, refer to Figure 1.

Resin Infiltration

After all specimens were demineralized, resin infiltration (Icon) was accomplished according to manufacturer's recommendations on randomly selected buccal or lingual surfaces on each specimen. First, Icon-Etch (15% HCl) was applied on the tooth

Table 1: *Summary Table of Beverages*					
Beverage	**Brands**	**Flavor**	**Color**	**pH**	**Sugar Content (Teaspoons in 12 Ounces)**
Coffee	Folgers	Instant coffee	Brown	4.5	0.0
Grape juice	Welch	100% natural grape	Purple	3.4	11.9
Iced tea	Snapple	Raspberry	Red	3.2	7.6
Water	Sparkletts	Distilled water	Clear	7.0	0.0

surface for two minutes followed by water rinsing for 30 seconds. The etching step was performed twice for two minutes each. Next, Icon-Dry (99% ethanol) was applied for 30 seconds followed by air drying. Then, Icon-Infiltrant was applied on the tooth for three minutes followed by light curing for 40 seconds. Excess material was removed with an explorer prior to light curing. A second application of Icon-Infiltrant was applied for one minute followed by light curing for 40 seconds. The contralateral surface of the tooth did not receive any treatment and served as its own control. Polishing was done with aluminum oxide polishing strips (Sof-Lex Finishing Strips Fine/Superfine, 3M ESPE, St Paul, MN, USA). The batch number was not recorded since all Icon material used was from the same box.

Immersion of Specimens in Beverages

On completion of specimen preparation, teeth were randomly divided into four groups (n=15) according to storage solutions: 1) coffee, 2) grape juice, 3) iced tea, and 4) distilled water. Beverages and their respective colors and pH values are summarized in Table 1. Samples were immersed in beverages continuously for four weeks, during which all beverages were replaced with fresh solutions daily. Samples were stored in a 37°C incubator to simulate oral conditions while immersed in these beverages.

Aging, Dye Penetration, and Sectioning

After four weeks of staining, all teeth were put in separate containers for aging. After six months, teeth in the distilled water group were immersed in 2% methylene blue for 24 hours.[10,21] The sectioning was done using a diamond wheel of 0.3-mm thickness (part no. DWH4123, Southbaytech, San Clemente, CA, USA) mounted in a low-speed diamond wheel saw (Model 650, Southbaytech). Five buccal-lingual cuts were made in the center of the occlusal surfaces, resulting in four sections of 1-mm width per tooth. Each section was examined on both sides to evaluate both Icon and control surfaces so that each tooth underwent 16 examinations. The cut surfaces were polished using a roll grinder (Handimet II, Buehler, Lake Bluff, IL, USA) with running water to ensure similar texture and smoothness.

Light Microscope Analysis

A light microscope, at a magnification of 30× (Optometric Tools, Inc, Rockleigh, NJ, USA) connected to a magnescale LH10 (Sony, Tokyo, Japan), was used. All sections were evaluated by a single observer and examined for the following:

a) Presence or absence of stain penetration on both Icon and control surfaces:
   1 = no stain penetration
   2 = stain penetration only on treated enamel surface
b) Rank scale of stain penetration on both Icon and control surfaces:
   Rank 1 = 0 to 0.049 mm
   Rank 2 = 0.050 to 0.099 mm
   Rank 3 = 0.1 to 0.149 mm
   Rank 4 = 0.150 to 0.2 mm
   Rank 5 = 0.2 mm and beyond
c) Actual depth of stain penetration in millimeters for both Icon and control surfaces. The average depth from the three deepest penetration points was recorded in each reading.

Statistical Analysis

The Statistical Package for the Social Sciences (IBM SPSS Statistics, ver 20, SPSS Inc, Chicago, IL, USA) computer software was used for statistical analysis. Descriptive statistics for the presence or absence of stain, rank scale, and actual depth of stain penetration included mean, median, mode, and standard deviation. Inferential statistical tests used in the study included chi-square test, independent and paired sample t-test, analysis of variance (ANOVA) with the Fisher least significant difference (LSD) *post hoc* test, and the Kruskal-Wallis test. The significance level was set at $p < 0.05$.

RESULTS

A total of 960 data points from both the Icon surfaces (n=480), and the control surfaces (n=480) were included in the statistical analysis. Representative

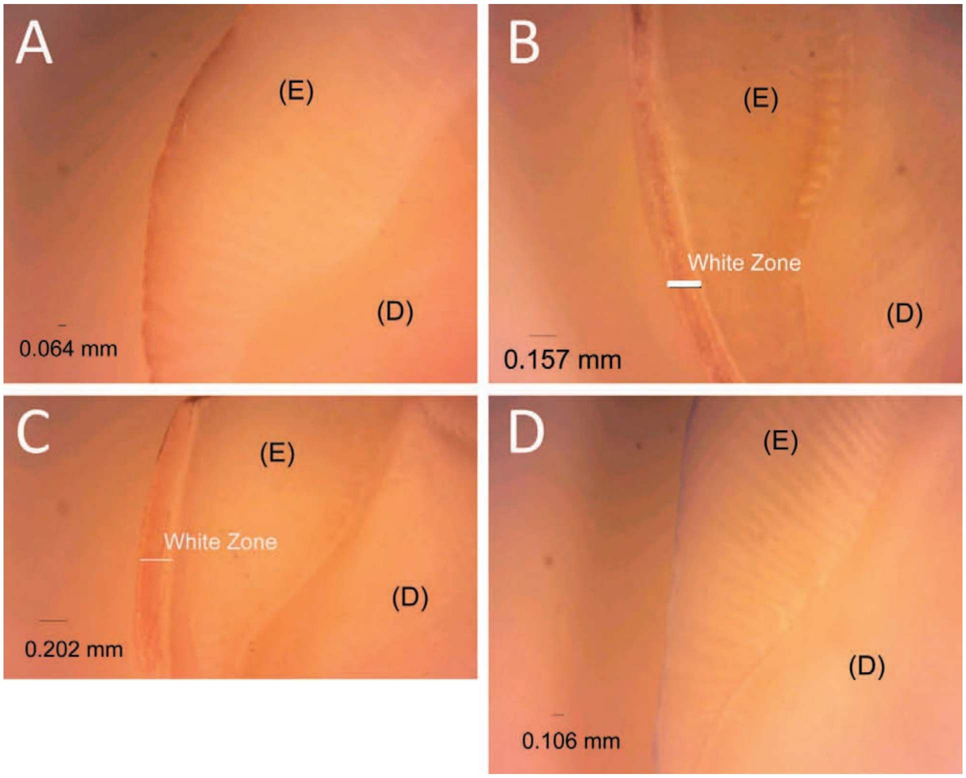

Figure 2. *Slide samples from different beverage group: A) Coffee, B) Grape Juice, C) Iced tea, D) Methylene blue. (E= enamel; D=dentin)*

slide samples from different beverage groups are shown in Figure 2a,b,c,d.

As summarized in Table 2, the majority of data points in the control surfaces (n=421, 87.7%) showed stain penetration on enamel surfaces, and only a small number (n=59, 12.3%) had no stain penetration. A similar pattern was also observed in the Icon surfaces, where the majority of data points (n=340, 70.8%) had stain penetration on enamel surfaces, and fewer (n=140, 29.2%) showed no stain penetration. Nevertheless, according to the chi-square test, the Icon surfaces had significantly fewer data points with stain penetration compared to the control surfaces ($p<0.001$).

When comparing different beverage groups (Table 2), most of the data points in iced tea (n=240, 100%), grape juice (n=239, 99.6%), and methylene blue (n=197, 82.1%) had stain penetration on treated enamel surfaces, whereas fewer data points in the coffee group (n=85, 35.4%) showed stain penetration. Chi-square test indicated that these different stain penetration patterns between coffee group and the rest of beverage groups were statistically significant ($p<0.001$).

Table 2: *Presence or Absence of Stain Penetration and Rank Scale*

	Icon Treatment, N (%)		Beverage Groups			
	Icon Surfaces	**Control Surfaces**	**Coffee**	**Grape Juice**	**Iced Tea**	**Methylene Blue**
No stain penetration	140 (29.2)	59 (12.3)	155 (64.6)	1 (0.4)	0 (0)	43 (17.9)
Stain penetration	340 (70.8)	421 (87.7)	85 (35.4)	239 (99.6)	240 (100)	197 (82.1)
p-value, chi-square test	<0.001		.001			
Rank and depth (mm)						
1: 0-0.049	234 (48.8)	86 (17.9)	180 (75)	8 (3.3)	1 (0.4)	131 (54.6)
2: 0.05- 0.099	64 (13.3)	130 (27.1)	49 (20.4)	45 (18.8)	14 (5.8)	86 (35.8)
3: 0.1-0.149	118 (24.6)	53 (11.0)	5 (2.1)	64 (26.7)	79 (32.9)	23 (9.6)
4: 0.15-0.199	56 (11.7)	93 (19.4)	4 (1.7)	62 (25.8)	83 (34.6)	0 (0)
5: >0.2	8 (1.6)	110 (24.6)	2 (0.8)	61 (25.4)	63 (26.3)	0 (0)
p-value	<0.001, chi-square test		<0.001, Kruskal-Wallis test			

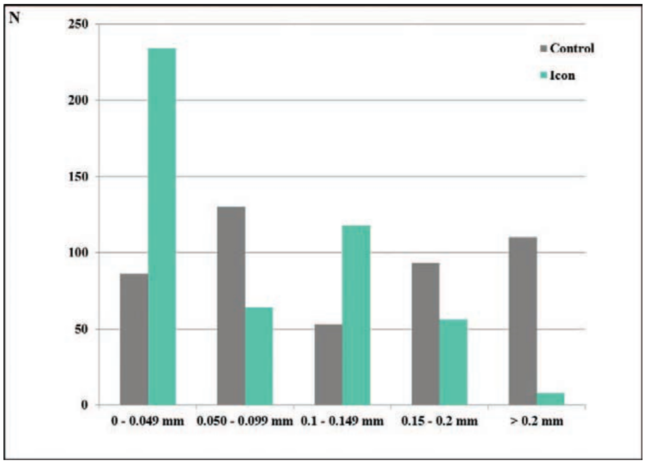

Figure 3. *Bar chart of stain penetration between Icon and control surfaces.*

The results of the stain penetration rank scale are summarized in Table 2. Data points in the Icon surfaces (n=234, 48.8%) had most of their stain penetration in rank 1 (0-0.049 mm), whereas the control surfaces had stain penetration evenly distributed among the five ranks (Figure 3). This indicated that stain penetration in the Icon surfaces tended to be shallower than the control surfaces ($p<0.001$, chi-square test). Among different beverage groups, coffee (n=180, 75%) and methylene blue (n=131, 54.6%) had most of their stain penetration in rank 1. In comparison, both grape juice and iced tea had most of the stain penetration evenly distributed in higher ranks 3, 4, and 5 (Figure 4). This demonstrated that stain penetration in both the grape juice and the iced tea groups was significantly deeper than in the coffee and the methylene blue groups ($p<0.001$, Kruskal-Wallis test).

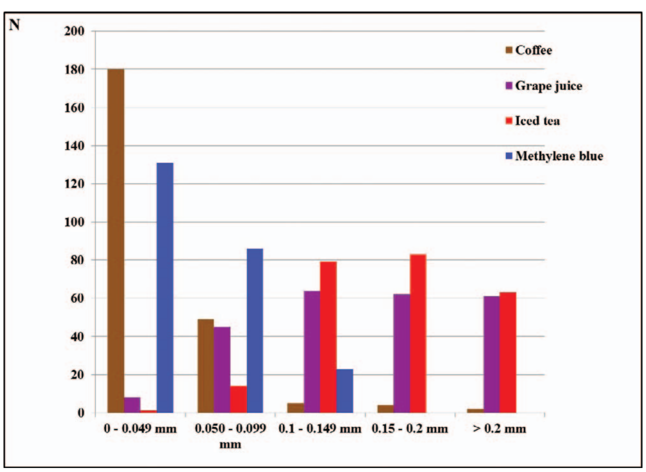

Figure 4. *Bar chart of stain penetration among beverage groups.*

Table 3: *Summary Table of Stain Penetration*

Beverage	Actual Depth (mm) Mean	Standard Deviation	95% Confidence Interval Lower Bound	Upper Bound
Icon surfaces				
Coffee	0.0078	0.01677	0.0048	0.0108
Grape juice	0.1176	0.04737	0.1091	0.1262
Iced tea	0.1339	0.02930	0.1286	0.1391
Methylene blue	0.0216	0.01931	0.0181	0.0251
Total	0.0702	0.06387	0.0649	0.0765
p-value	<0.001, LSD post hoc test			
Control surfaces				
Coffee	0.0469	0.07874	0.0326	0.0611
Grape juice	0.1925	0.06428	0.1809	0.2041
Iced tea	0.2033	0.03556	0.1968	0.2097
Methylene blue	0.0731	0.02845	0.0680	0.0783
Total	0.1289	0.08914	0.1210	0.1369
p-value	<0.001, LSD post hoc test			

In regard to the actual depth of stain penetration (Table 3), the Icon surfaces showed statistically significant less stain penetration depth (0.070±0.064 mm) compared to the control surfaces (0.129±0.089 mm; $p<0.001$, paired sample *t*-test). One-way ANOVA showed that there was a statistically significant difference of actual stain penetration depth between different beverage groups when considering all surfaces together (Icon and control surfaces; $p<0.001$). The LSD *post hoc* test indicated that iced tea presented the greatest depth of stain penetration (0.134±0.029 mm), followed by grape juice (0.118±0.047 mm), methylene blue (0.022±0.019 mm), and coffee (0.008±0.017 mm; $p<0.001$; Table 3). According to the two-way ANOVA, there was also a statistically significant difference of stain penetration depth among different beverage groups (Icon vs. control surfaces; $p<0.001$) (Figure 5). The stain penetration patterns of four beverages in between the Icon and the control surfaces were similar. Iced tea also presented the greatest depth of stain penetration, followed by grape juice, methylene blue, and coffee (Figure 5).

"White zones" were observed microscopically as areas of continuous, white-color bands within the outer one-third of enamel (Figure 2b,c). Interestingly, only the grape juice and the iced tea groups had white zones observed, and stain penetration was confined to the white zones. The *t*-test indicated that there was a statistically significant difference of white zone width between the iced tea and the grape juice groups ($p<0.001$). Iced tea showed greater width of the white

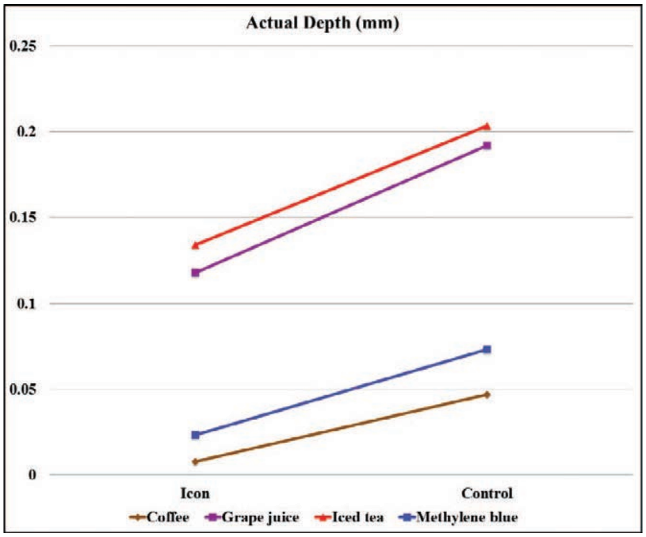

Figure 5. *Actual depth of stain penetration.*

zone (0.255±0.053mm) compared to grape juice (0.217±0.079 mm). In addition, the Icon surfaces overall showed less width of the white zone (0.205±0.053 mm) compared to the control surfaces (0.267±0.065 mm), though the difference was not statistically significant ($p>0.05$, paired sample t-test).

DISCUSSION

According to the results of this study, although most of resin-infiltrated enamel surfaces (70.8%) were susceptible to stain penetration by different beverages, they had statistically significant fewer samples with stain penetration compared to the control surfaces ($p<0.001$). Also, when there was stain penetration, the Icon surfaces showed statistically significant less depth of stain penetration compared to the control surfaces ($p<.001$). This is an important finding, as it is consistent with the manufacturer's claim that Icon can occlude the diffusion pathway when light cured.[1,2,5] Therefore, resin infiltration might help to prevent or lessen stain penetration by beverages.

Previous studies have suggested the potential of erosion from acidic beverages in the development of microleakage.[10,11] In vitro studies have shown that microleakage may cause marginal discoloration along with many other issues in dental restorative materials.[10] Since resin infiltration has been introduced recently in dentistry, there have not been any published studies on microleakage of Icon. According to the results (Table 3), beverages with lower pH, such as iced tea and grape juice (pH=3.2 and 3.4, respectively), showed significantly greater stain penetration than beverages with higher pH (coffee pH=4.5; $p<0.001$). In addition, iced tea, having the lowest pH value among the tested beverages (pH=3.2), had greatest depth of stain penetration on both the Icon and the control surfaces. The acidity of the beverages ranged from pH 3.2 to 4.5 in the present study (Table 1). The acidic environment could have negatively affected the surface integrity of the resin-infiltrated enamel. This detrimental effect can possibly lead to microleakage at the interface between the resin infiltration and tooth structure and thus increase staining potential of the infiltrated surfaces.

Other factors that can contribute to the increase of microleakage include filler loading of the resin matrix and the extent of polymerization shrinkage. Studies have shown that lower filler content of the resin matrix has demonstrated higher polymerization shrinkage and therefore contributes to greater microleakage of the material.[23] Other studies have also shown that resin with the lowest filler content had poor color stability due to more water absorption in the filler-matrix interface, consequently leading to filler-matrix debonding or hydrolytic degradation of the filler.[18,24] Since the infiltrant is unfilled resin, it is likely that the material would have greater polymerization shrinkage and also be susceptible to stain penetration.

In addition, some studies have shown that the degree of water sorption and hydrophilicity of the resin matrix may influence the stain susceptibility of the resin materials.[25-27] The resin matrix used as an infiltrant has hydrophilic characteristics that may allow beverages to absorb into resin matrix and lead to discoloration. Thus, it is not surprising to find that both the Icon and the control surfaces had the majority of samples with stain penetration by different beverages (coffee, grape juice, and iced tea) in this study. Also, some studies[19] have noted that there is more water sorption as the proportion of triethylene glycol dimethacrylate (TEGDMA) increases in the resin matrix. Kalachandra and others[25] found that incorporation of greater amounts of TEGDMA results in an increase in water uptake in Bis-GMA-based resins. Mazato and others[26] explained that the ethoxy group in TEGDMA shows an affinity with the water molecule by hydrogen bonding to oxygen, thereby increasing its surface hydrophilicity. While DMG America has yet to disclose the composition of the Icon infiltrant, based on Meyer-Luckel and Paris's[6] work it is evident that the Icon infiltrant is a TEGDMA-based resin. Therefore, the extent of discoloration and stain penetration from different beverage groups in this study might be attributed to the infiltrant's high-TEGDMA content and its hydrophilic property.

There are only a few reported studies on stain potential and color stability of teeth treated with resin infiltration. Luebbers and others[28] found that artificial lesions treated with resin infiltration were not sensitive to discoloration by sunlight. Our study demonstrated that stain from beverages could not only occur on external surfaces of teeth but also penetrate into the infiltrated surfaces, indicating that both intrinsic and extrinsic factors can influence stain penetration. The beverages (coffee, iced tea, and grape juice) used in this study are consumed regularly in our daily lives and have been recognized as strong staining agents.[14,16] Stain penetration in the iced tea group showed the greatest depth of penetration, followed by grape juice and coffee. The findings from this study were similar to the results of a project conducted by Kuriya and others[29] demonstrating the discoloration potential of teeth treated with resin infiltration. According to the study, all tested beverages (grape juice, iced tea, coffee, and distilled water) affected the color stability of enamel treated with resin infiltration. As immersion time increased, color changes became more intense.

While most of the samples in the iced tea, grape juice, and methylene blue groups had stain penetration into treated enamel surfaces, only a small number of samples in the coffee group showed stain penetration. Even when samples in the coffee group had stain penetration, the depth of penetration was shallower than the rest of the groups. It is interesting to point out that the pH of coffee (pH=4.5) was lower than that of distilled water (pH=7). If acidity was the main factor influencing stain penetration, the depth of stain penetration in the coffee group should be deeper than the distilled water group; however, this was not the case. One of the possible explanations was that coffee's pigments may be larger than the rest of the beverages as well as methylene blue and therefore they remained on the surface and did not penetrate into the resin-infiltrated enamel as much as the other beverages.

White zones were incidental findings observed microscopically only in the grape juice and iced tea groups—the two groups having lower pHs and higher sugar content compared to the other groups. Since the samples used in this study were not sterile, the combination of low pH, high sugar content, and the presence of microorganisms could have caused further demineralization of the enamel surfaces, leading to increased staining potential of the infiltrated enamel. It is worth pointing out that the iced tea group showed a significantly greater white zone width compared to the grape juice group. Since the iced tea group had lower pH but less sugar content than the grape juice group, the pH factor seemed to play a more important role in creating the white zone.

This *in vitro* study was done under controlled laboratory settings utilizing demineralized enamel treated with resin infiltration. The results indicated that some common beverages have stain penetration potential into resin infiltrated enamel and therefore can contribute to discoloration. The study, however, did not simulate any saliva-buffering effect or consider any relevant clinical situations, such as dietary habits, oral hygiene, xerostomia, or other effects caused by systemic diseases and so on. This study did not consider the bacteria type and loading amount in the samples. Thus, future studies are needed to investigate other factors that could potentially contribute to the extent of stain penetration, such as the surface integrity and roughness of the infiltrated surface in relation to stain penetration after an acid challenge, the composition of the white zone, the effect of chromogenic bacteria, and the effect of beverage temperature.

CONCLUSION

Stain penetration by different beverages in resin-infiltrated enamel was evaluated using light microscopy. Based on the findings of this study, the following conclusions were drawn:

- Both the Icon and the control surfaces show stain penetration by different beverages (iced tea, grape juice, and coffee).
- Resin-infiltrated enamel surfaces allow significantly less depth of stain penetration than untreated enamel surfaces.
- The iced tea group exhibits the greatest depth of stain penetration, followed by grape juice, methylene blue, and coffee.

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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 Loma Linda University. The approval code for this study is IRB#5130272.

Conflict of Interest

The authors 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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Push-Out Bond Strength Evaluation of Glass Fiber Posts With Different Resin Cements and Application Techniques

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Clinical Relevance

Conditioning with 37% phosphoric acid prior to self-adhesive cementation of glass fiber posts, applied with an elongation tip, may offer higher push-out strength compared with other cementation methods for improved clinical longevity.

SUMMARY

The purpose of this study was to evaluate the push-out strength of two different adhesive cements (total etch and self-adhesive) for glass fiber post (GFP) cementation using two different techniques (microbrush and elongation tip) of cement application. In addition, this study evaluated the effect of total-etch conditioning before the use of a self-adhesive cement. Sixty premolar specimens with a single root canal were selected, endodontically treated, and shaped for GFP cementation. The specimens were randomly placed into one of six groups according to the cement and technique used: RelyX ARC (ARC): ARC + microbrush, ARC + elongation tip; RelyX Unicem (RU): RU + microbrush, RU + elongation tip; or RelyX Unicem + 37% phosphoric acid (RUE):

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RUE + microbrush, RUE + elongation tip. Each specimen root was cut perpendicular to the vertical axis yielding six 1.0-mm-thick sections. Push-out strength test was performed, followed by statistical analysis using three-way analysis of variance and the Games-Howell test ($p<0.05$). Statistically significant differences between the groups were found ($p<0.05$). The cervical third of the roots had the highest mean push-out strength values, while the apical third had the lowest mean values regardless of the technique used. The elongation technique produced higher mean push-out strength values compared to the microbrush technique. The self-etch adhesive cement had the highest mean push-out strength value in all thirds. The addition of a conditioning step before the self-etch adhesive cementation appears to be effective in enhancing push-out strength with GFPs.

INTRODUCTION

Glass fiber posts (GFPs) can be used in endodontically treated teeth for indications requiring additional support of core materials and future indirect prostheses.[1] GFPs have a lower modulus of elasticity compared to metal posts and therefore have the advantage of dissipating stress along the post length.[1] This characteristic is different from metal posts with a higher modulus of elasticity that concentrate the stress in the apical third of the root.[2,3] With that in mind, it has been reported in the current literature that the use of GFPs may reduce the occurrence of root fractures compared to rigid metal posts.[1-3]

GFP cementation can be performed with various resin cements that can be classified by the polymerization mode (light cure, chemical cure, and dual cure) and conditioning requirements (total etch and self-adhesive). Due to the difficulty associated with penetration of the light to the apical third of the root, purely light-cured cements are seldom used for GFP adhesion.[4-6] Chemically-cured cements have the disadvantage of limited working time and are difficult to use in the hands of a novice.[7] For these reasons, the best option for GFP cementation is a dual-cure cement. In addition to having the advantages of command light-cure cements, dual-cured cements also contain chemical initiators for deep areas where light access is difficult to achieve.[7] However, there have been some problems reported in the current literature related to total-etch dual-cure cements, which require conditioning with 37% phosphoric acid and the application of the elected bonding system in the root canal prior to cementation. For instance, the complexity of multiple steps and technique sensitivity can cause incomplete post seating, microleakage, and debonding.[8,9]

To decrease the numbers of steps and simplify the cementation process, a self-adhesive dual-cure cement was developed. This cement has just one step (no need for conditioning or bonding system), and it has demonstrated similar bonding performance when compared to other resin-based cements.[10-15] However, incorporating all components into one bottle (phosphoric acid, primer, adhesive, and cement) requires a lower acid concentration, which may cause limited demineralization and hybridization of root dentin.[16,17]

According to the current published literature, another potential problem related to GFP adhesive cementation is the technique used for application of the adhesive cement into the root canal.[18-20] To ensure homogeneity of cement distribution, application techniques should pay particular attention to avoid the introduction of trapped air within the cement layer.[18] Defects of any kind within the cement can cause localized high-stress areas that could initiate crack propagation at relatively low applied loads.[19,20]

There have been some modifications of manufacturer recommendations in the current literature that have been shown to improve clinical bond strength.[21,22] One example is modification of the adhesive application technique of self-etching bonding agents to both enamel and dentin. When total-etch conditioning techniques (30-second conditioning with phosphoric acid and water rinse) were used with self-etching adhesive materials, higher bond strength values were obtained *in vitro*.[21,22] This same concept can be considered for cementation of GFPs with self-adhesive cements.

The purpose of this study was to evaluate the push-out strength of two different adhesive resin cements (total etch and self-adhesive) for GFP cementation using two different techniques (microbrush and elongation tip) of cement application. In addition, this study evaluated the effect of a conditioning step before the use of a self-adhesive resin cement. The null hypotheses tested were as follows: 1) there will be no statistically significant difference in GFP push-out strength between the total-etch and the self-adhesive resin cements, 2) there will be no statistically significant difference between the different resin cement GFP push-out strengths among different root thirds, 3) there will be no statistically significant difference between the different adhesive resin cements in terms of application techniques on GFP push-out strength, and 4) there will be no difference in GFP push-out strength in comparing the use of an elective conditioning technique prior to self-adhesive resin cements compared to the use of self-adhesive resin cements alone.

METHODS AND MATERIALS

Sixty human premolar teeth meeting the inclusion criteria with a ≥18-mm single root canal were selected for the study. Exclusion criteria were the presence of resorption, caries, root fractures, or previous endodontic treatment. The teeth were sterilized, numbered, radiographed, and stored in 10% thymol during the study to prevent dehydration.

The root canal systems were accessed through the occlusal surface under a copious amount of water and located using a #15 K-file (Senseus K-Flexofile, Dentsply, Maillefer, Switzerland). Working length of the root system was determined to be 1 mm from the root apex and verified with an apex locator. The root canals were shaped by rotary instruments (ProTaper system, Dentsply) sequenced in order (SX, S1, S2, F1, F2) applying the crown-down technique. Irrigation was performed with 1 mL of 6% sodium hypochlorite (NaOCl) solution (Vista Dental, Racine, WI, USA), using a syringe and a 27-gauge needle throughout progression of file sizes. Final irrigation was done with 17% ethylene diamine tetra acetic acid (EDTA; Vista Dental) for one minute followed by 6% NaOCl solution for one minute. The root canals were obturated using a warm vertical condensation technique performed with gutta-percha cones (Protaper F2, Dentsply DeTrey Gmbh, Konstanz, Germany) and root canal sealer (AH-Plus, Dentsply DeTrey).

A careful demineralization and tubule opening of the root dentin with ultrasonic instrumentation in association with EDTA was performed. Post spaces were prepared to depths of 10 mm, leaving an apical seal of 5 mm of gutta-percha in the canal space. A series of sequential reamers provided for GFP #2 (Rely-X Fiber Post, 3M ESPE, St Paul, MN, USA) were used for this process. The specimens were randomly assigned into one of six groups under three different adhesive cement procedures: RelyX ARC (ARC): ARC + microbrush, ARC + elongation tip; RelyX Unicem (RU): RU + microbrush, RU + elongation tip; or RelyX Unicem + 37% phosphoric acid (RUE): RUE + microbrush, RUE + elongation tip (all 3M ESPE).

All GFP surfaces were cleaned with 70% isopropyl alcohol (Cumberland Swan, Smyrna, TN, USA) and air-dried. The root canal systems were treated with 2% chlorhexidine solution (VEDCO, St Joseph, MO, USA), irrigated with water, and slightly dried prior to the cementation process.

For adhesive cementation, all manufacturer recommendations were followed for each material according to Table 1. After cementation, all teeth were light cured for 60 seconds (Optilux 500, Kerr Corp, Orange, CA, USA) on the occlusal surfaces.

After cementation of the GFPs, the roots of each specimen were cut perpendicular to the vertical axis by means of a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under copious amounts of water. Six 1.0-mm slices for each root were obtained, which were then separated into three different subgroups by specimen area (two cervical, two middle, and two apical; see Figure 1).

The push-out test for each specimen section was performed with a Universal Testing Machine (#8841, Instron, Canton, MA, USA) at a crosshead speed of 0.5 mm/min. The push-out test load was applied in an apical to cervical direction until the post dislodged from the specimen. The push-out strength values were measured at failure and recorded in MPa ± standard deviation.

Statistical Analysis

The push-out strength values were measured at failure and recorded in MPa ± standard deviation. Inferential statistical analysis of the data was evaluated using three-way analysis of variance (ANOVA) and the Games-Howell test (α=0.05) to compare cement types, application techniques, and root thirds (SPSS version 20.0, SPSS, Chicago, IL, USA).

RESULTS

The three-way ANOVA comparing multiple independent and dependent variables showed statistically significant differences among all groups independent of cement type, application technique, or root third (p=0.000; $p<0.05$). The descriptive statistics are given in Table 2, with statistical differences noted by different uppercase letters in columns and different lowercase letters in rows.

In evaluating root thirds, the cervical third displayed the highest push-out strength values,

Table 1: *Groups, Composition, Root Canal Treatment, and Techniques of the Cement Application for All Materials Used in the Present Study*

Adhesive Cement	Cement Composition	Conditioning	Procedures	Cement Application
RelyX ARC (ARC)	HEMA, bisGMA, dimethacrylate resins, methacrylatemodified polycarboxylic acid copolymer, photoinitiator/ water, ethanol	Yes	Etching with 37% phosphoric acid for 15 s Rinsing with 10 mL of distilled water Removing water excess with paper point #80 Irrigation with 2% chlorhexidine Removing water excess with paper point #80 Application of multistep adhesive system	Application of the adhesive cement into the root canal with a microbrush Application of the adhesive cement on the post Insertion of the post into the root canal Light cure for 60 s
				Insertion of the cement with the elongation tip Insertion of the post into the root canal Light cure for 60 s
RelyX Unicem (RU)	Methacrylated phosphoric esters, dimethacrylates, acetate, initiators, stabilizers, glass fillers, silica, calcium hydroxide	No	Rinsing with 10 mL of distilled water Removing water excess with paper point #80 Irrigation with 2% chlorhexidine Removing water excess with paper point #80 Capsule activation	Application of the adhesive cement into the root canal with a microbrush Application of the adhesive cement on the post Insertion of the post into the root canal Light cure for 60 s
				Insertion of the cement with the elongation tip Insertion of the post into the root canal Light cure for 60 s
RelyX Unicem + etching (RUE)	Methacrylated phosphoric esters, dimethacrylates, acetate, initiators, stabilizers, glass fillers, silica, calcium hydroxide	Yes, optional	Etching with 37% phosphoric acid for 15 s Rinsing with 10 mL of distilled water Removing water excess with paper point #80 Irrigation with 2% chlorhexidine Removing water excess with paper point #80 Capsule activation	Application of the adhesive cement into the root canal with a microbrush Application of the adhesive cement on the post Insertion of the post into the root canal Light cure for 60 s
				Insertion of the cement with the elongation tip Insertion of the post into the root canal Light cure for 60 s

and the apical third showed the lowest push-out strength values independent of the cement type or cement application procedure ($p<0.05$) The cervical thirds were statistically higher than both the middle thirds and the cervical thirds.

When comparing the different cement application techniques according to root thirds, statistically significant differences were found ($p<0.05$). In the apical third, ARC with the elongation tip and the microbrush differed significantly ($p=0.000$), RU with the elongation tip and the microbrush differed significantly ($p=0.000$), and RUE with the elongation tip and the microbrush differed significantly ($p=0.000$). In the cervical third and middle thirds, only the RU with the elongation tip and the microbrush differed significantly ($p=0.000$). The ARC and RUE application technique in the cervical and middle thirds did not differ significantly.

When comparing cement types, application techniques, and root thirds, the RU group showed significantly higher push-out strength values in all thirds and application techniques compared to the ARC groups ($p<0.05$). For the RUE, when adding an additional conditioning step (total etch), the push-out strength values obtained were statistically

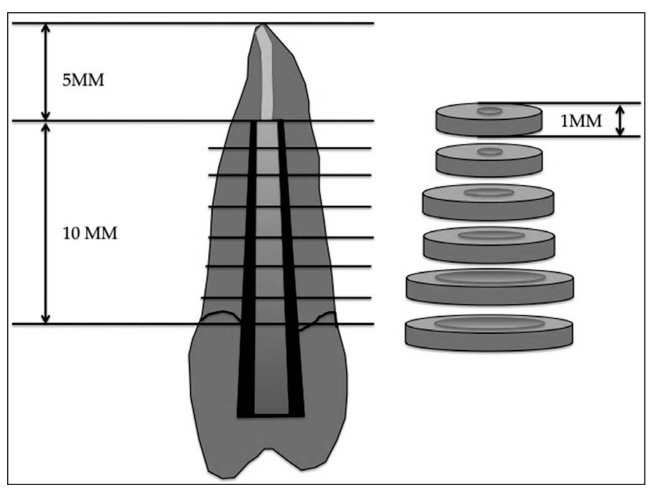

Figure 1. *Sectioning of the cemented glass fiber posts into six slices (two cervical, two middle, and two apical).*

Table 2: *Descriptive Statistics (Mean Group Push-Out Strength [MPa] ± Standard Deviation [MPa]) With Statistical Differences Noted by Different Uppercase Letters in Columns and Different Lowercase Letters in Rows*[a]

Groups	Techniques	Apical Third	Middle Third	Cervical Third
		Study Results		
RelyX ARC (ARC), n = 20	Microbrush n = 10	3.95 ± 1.82 Dc	7.09 ± 2.06 Db	10.44 ± 1.89 Da
	Elongation tip n = 10	5.85 ± 1.53 Cc	8.24 ± 1.70 Db	11.13 ± 2.40 Da
RelyX Unicem (RU), n = 20	Microbrush n = 10	7.23 ± 3.07 Cc	11.32 ± 2.55 Cb	14.81 ± 3.45 Ca
	Elongation tip n = 10	9.42 ± 1.21 Bc	14.97 ± 1.94 Bb	18.68 ± 2.01 Ba
RelyX Unicem + etching (RUE), n = 20	Microbrush n = 10	9.34 ± 3.26 Bc	17.19 ± 3.36 Ab	21.57 ± 3.08 Aa
	Elongation tip n = 10	14.72 ± 3.03 Ac	18.61 ± 2.53 Ab	22.17 ± 2.83 Aa

[a] *Groups connected by the different uppercase letters in columns and different lowercase letters in lines represent statistical different ($p<0.05$).*

significantly higher for both application technique and root thirds.

DISCUSSION

According to Dietschi and others,[1] prefabricated GFPs, due to their lower modulus of elasticity and inherent flexibility, help to distribute stress more uniformly to the entire root surface. In this study, a double-tapered GFP was utilized. Precise fitting of the tapered GFP into the endodontic canal avoids the need for a wider preparation, preserving dental hard structure in the apical third, where the anatomical root form narrows.[23]

The postspace preparation in the root canal system is a critical step, as it can be difficult to completely remove all gutta-percha filling materials. Aggressive removal often leads to an oversize postspace preparation, which has been documented in the current literature as the most frequent cause of adhesive or cohesive failure.[23] In this study, careful removal of gutta-percha and the tubule opening of the root dentin with ultrasonic instrumentation in association with EDTA was performed.[24] Final irrigation was performed with a 2% chlorhexidine solution, which has demonstrated antibacterial properties in the current literature, restricting microbial ingress into dentinal tubules.[25] In the current literature, chlorhexidine also has been shown to have the ability to inhibit matrix metalloproteinases,[26] preserving composite-dentin hybridization over time.[27] GFPs were disinfected with alcohol only prior to cementation. No acid conditioning or sand blasting was performed prior to the cementation of the GFPs due to reports of the structure weakening.[28]

Considering the structural variability of the dentinal substrate inside the root canal, the push-out strength test allows for a more accurate analysis of the overall bonding mechanism and the ability to better simulate a clinical scenario.[29] Considering the push-out strength of the three different resin cements, the null hypothesis was rejected. The results showed that the total-etch adhesive cement (ARC) had lower push-out strength values to dentin when compared with the self-adhesive cement (RU), similar to the findings of previous studies.[12,13,15,30] However, other research has reported higher bond strength values for the total-etch adhesive cement when compared with the self-adhesive cement.[31-33] Conflicting results between the different luting cements can be explained by variability in research methodology and the lack of a systematic review in the current published literature.[8] Additionally, the complexity of a clinical technique utilizing multiple steps can cause inherent problems, including the introduction of operator error and subsequent failure.

The self-adhesive cements are only mildly acidic, resulting in limited demineralization and hybridization of the root system dentin.[34] However, even with limited hybridization,[17] the push-out strengths in this study are statistically higher than that of the total-etch adhesive cements. These results can be explained by the fact that the chemical interactions between the adhesive cement and hydroxyapatite may be more important for root dentin bonding than the ability to hybridize dentin.[13] According to the current literature, this interaction is based on calcium ion chelation by acidic groups from the self-adhesive cements, producing chemical interaction with the dentin hydroxyapatite.[35] Despite the fact that the hybrid layer makes an important contribution to micromechanical bonding, the chemical interaction and the simplicity of application may contribute to the success of self-adhesive cements.[10]

Considering the push-out strength between the different root thirds, the null hypothesis for this study was rejected. The total-etch and the self-adhesive resin cement showed higher cervical third values compared with the middle third, while the apical third presented significantly lower push-out strength values. The results are in agreement with results reported in the current literature.[15,36,37] However, some investigators presented equal bond strength values for the total-etch and self-adhesive cements in different root thirds.[38,39] Additionally, some studies are in disagreement, reporting higher push-out strength values in the apical third for the self-adhesive cements.[38,40]

The lower push-out bond strength in the apical third, compared with the middle and cervical thirds, can be explained. Some explanations are difficulty accessing the narrow and deep areas, incomplete removal of the smear layer before cementation, and poor cement penetration into the dentin in the root canal.[8] Factors that also should be considered are the difficulty of phosphoric acid demineralization in deep areas and maintenance of ideal moisture before cementation.[36] In addition, these regions are most distant from curing light access, likely impacting the degree of conversion of the resin cement. Dual polymerization has better conversion values when light activation is used during polymerization.[8,41] In this study, a tapered translucent GFP was used to improve the light penetration in the apical third of the adhesive cement.[42]

Considering the push-out strength between application techniques, the null hypothesis was rejected. The results obtained in this study found that the push-out strength values are lower for the microbrush technique when compared with the elongation tip technique. Corroborating these results, other studies have found similar results.[43,44] The higher push-out strength values obtained in this study for both adhesive cements, when the elongation tip was used, can be explained by the tip creating a more homogeneous cement application along the entire root surface. Another reason beyond the use of the elongation tip is that the cement is mixed mechanically inside the capsule. This can eliminate human manipulation, which can incorporate air bubbles inside the cement during the mixing and application process with the microbrush technique.

In considering the additional conditioning step for self-adhesive cements, the null hypothesis was rejected. The higher push-out strength values collected for RUE, after the optional conditioning step, can be related to better hybridization of the root dentin. This, acting together with the chemical interaction between the adhesive cement and the hydroxyapatite, can explain the better push-out strength values. The low acid concentration associated with the self-adhesive cements limits decalcification and resin tag infiltration,[16,17] but this can be changed when an additional conditioning step is applied.

The higher push-out strength results achieved for cementation of GFPs with a self-adhesive cement, using an elongation tip application technique and additional conditioning step, should be considered a treatment alternative. A clinical evaluation of these principles are needed to validate the *in vitro* finding to resolve conflicting reports within the current published literature.

CONCLUSIONS

Within the limitations of this *in vitro* study, the results suggest the following:

1. Self-adhesive cement has a higher push-out strength values when compared to total-etch cement in all thirds of the root canal dentin.
2. The cervical third region of the root canal dentin displayed the highest push-out strength values, while the apical third had the lowest results.
3. The cement application technique utilizing the elongation tip had higher push-out strength values when compared with the microbrush technique.
4. The optional conditioning step before self-adhesive cementation obtained the highest push-out strength values regardless of application technique or root area.

Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects oversight committee guidelines and policies of the University of Louisville. The approval code issued for this study was IRB Exempt #14.1063.

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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Departments

ERRATUM

Operative Dentistry would like to clarify author affiliation in "NB Cook, SA Feitosa, A Patel, Y Alfawaz, GJ Eckert, and MC Bottino (*2015*) Bonding Ability of Paste-Paste Glass Ionomer Systems to Tooth Structure: *In Vitro* Studies. Operative Dentistry: May/June 2015, Vol. 40, No. 3, pp. 304-312." The full author affiliation for Dr. Yasser Alfawaz should have read, "Yasser Alfawaz, BDS, MSD, Department of Restorative Dentistry, Graduate Operative, Indiana University School of Dentistry, Indianapolis, IN, USA. Lecturer, Department of Restorative Dental Sciences College of Dentistry, King Saud University, Riyadh, Saudi Arabia."

Faculty Positions

Indiana University School of Dentistry
Tenure-track Faculty position
in the Department of Cariology,
Operative Dentistry and Dental Public Health

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Qualifications: The successful candidate should be eligible for tenure at the rank of associate professor at Indiana University Purdue University Indianapolis. Minimum credentials include a DDS or DMD from a CODA accredited program or equivalent, with preferred credentials to include formal advanced education (MS, MSD or PhD) and credentials in preventive dentistry, operative dentistry, public health, or a related field. Certification by the American Board of Operative Dentistry is strongly desired. Current licensure or eligibility for licensure in the State of Indiana and current experience in teaching and research within all areas noted for this position are required.

Please send a complete electronic application with the following documents:

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Indiana University School of Dentistry is located on the IUPUI campus near the heart of downtown Indianapolis. IUPUI is one of the outstanding urban research universities in the United States and capitalizes on the campus' central location in the state and its position in the research corridor that links IUPUI, Purdue University West Lafayette, and Indiana University Bloomington. IUPUI faculty conduct world-class research in the life sciences with opportunities for interdisciplinary collaborations with the other IU Health Science Schools and the Purdue Schools of Engineering & Technology and Science. The School of Dentistry is the only dental school in the Hoosier state and educates 80% of the dentists practicing in Indiana and offers an extraordinary learning environment in which teaching, research and community service are uniquely combined to prepare tomorrow's dental professionals.

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Please send a complete electronic application with the following documents:

- Signed letter of intent
- Complete curriculum vitae
- Names of three professional references (letters will be required prior to an interview).
- For tenure, three additional professional references of persons who will be able to provide an objective assessment of the candidate's academic contributions and scholarship will be required (letters will be required prior to an interview).
- Documents should be sent to **dsexecaf@iupui.edu** with the subject line reference posting #IN-DENT15007.

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Fatigue Resistance of Y-TZP/Porcelain Crowns is Not Influenced by the Conditioning of the Intaglio Surface

LC Anami • JMC Lima • LF Valandro • CJ Kleverlaan • AJ Feilzer • MA Bottino

Clinical Relevance: In this study, very few Y-TZP frameworks failed, but the porcelain veneers frequently chipped. Cementing with an adhesive resin cement helped veneers survive larger fatigue loads without chipping. Treatment of the intaglio surface of the crowns neither helped nor hurt fatigue resistance.

doi: http://dx.doi.org/10.2341/14-166-L

Digital Smile Design for Computer-assisted Esthetic Rehabilitation: Two-year Follow-up

CTW Meereis • GBF de Souza • LGB Albino • FA Ogliari • E Piva • GS Lima

Clinical Relevance: The use of digital smile design is a useful resource for diagnosis, simulation, and evaluation of esthetic rehabilitation and it can improve communication among the patient, clinician, and dental laboratories.

doi: http://dx.doi.org/10.2341/14-350-S

Use of a Direct Anatomic Post in a Flared Root Canal: A Three-year Follow-up

GM Gomes • RV Monte-Alto • GO Santos • CK Fai • AD Loguercio • OMM Gomes • JC Gomes • A Reis

Clinical Relevance: A standard fiber post does not adapt well to a flared root canal preparation, leaving a large cement space between the post and the tooth structure. Direct anatomic posts provide an alternative technique for restoring these teeth with less chance of debonding.

doi: http://dx.doi.org/10.2341/14-275-T

Effect of Toothpaste Application Prior to Dental Bleaching on Whitening Effectiveness and Enamel Properties

WF Vieira-Junior • DANL Lima • CPM Tabchoury • GMB Ambrosano • FHB Aguiar • JR Lovadino

Clinical Relevance: Dental bleaching promotes physical alteration in enamel, although these alterations might decrease when associated with toothpaste applied prior to the whitening procedures.

doi: http://dx.doi.org/10.2341/15-042-L

Enamel Surface Changes After Exposure to Bleaching Gels Containing Carbamide Peroxide or Hydrogen Peroxide

B Cvikl • A Lussi • A Moritz • S Flury

Clinical Relevance: Bleaching gels with a relatively high concentration of peroxide and shorter application time might be less harmful to enamel. A clinically significant whitening effect can be obtained after a few bleaching treatments.

doi: http://dx.doi.org/10.2341/15-010-L

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Fatigue Resistance of Y-TZP/Porcelain Crowns is Not Influenced by the Conditioning of the Intaglio Surface

LC Anami • JMC Lima • LF Valandro
CJ Kleverlaan • AJ Feilzer • MA Bottino

Clinical Relevance

In this study, very few Y-TZP frameworks failed, but the porcelain veneers frequently chipped. Cementing with an adhesive resin cement helped veneers survive larger fatigue loads without chipping. Treatment of the intaglio surface of the crowns neither helped nor hurt fatigue resistance.

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DOI: 10.2341/14-166-L

SUMMARY

Objectives: The objective of this study was to investigate the effects of treatments of the intaglio surface of Y-TZP frameworks and luting agents on the fatigue resistance of all-ceramic crowns.

Methods: A research design was chosen that attempted to reduce the likelihood of Hertzian cracking and to increase the probability of fracture initiation at the intaglio surface of the framework. Ninety identical preparations were machined in a dentin-like epoxy composite. Each preparation was restored with a Y-TZP framework made by a CAD/CAM system and veneered using feldspathic ceramic. Prior to cementation the intaglio surface of the ceramic was treated using one of four treatments: 1) cleaning with isopropyl alcohol; 2) application of an overglaze; 3) sandblasting with 125 µm aluminum oxide powder; and 4) sandblasting with 30 µm silica powder (CJ). One of three luting cements were used: 1) zinc phosphate; 2) glass ionomer; and 3) adhesive resin cement (PN). All three cements were tested against frameworks that were alcohol cleaned. Only the PN cements were tested

against frameworks that had been sandblasted or glazed. Altogether, six groups of 15 specimens each were tested. Fatigue resistance was evaluated using stepwise loads at 1.4 Hz until failure: 5000 cycles at maximum load of 200 N, followed by 10,000 cycles at maximum loads of 800, 1000, 1200, and 1400 N. The cement thickness and failure modes were analyzed using a stereomicroscope and scanning electron microscopy. The results were analyzed using the Kaplan-Meier and Mantel-Cox log rank tests (5%), a one-way analysis of variance, Tukey multiple comparison test, and Weibull nonparametric test.

Results: The predominant failure mode was chipping of the veneer. The crowns cemented with the adhesive resin cement exhibited chipping failure at higher mean loads than did crowns cemented with cements that usually do not bond strongly with dentin. When the adhesive cement was used, glazing and sandblasting intaglio framework surface treatments exhibited lower mean loads at chipping than did crowns whose intaglio surface was only cleaned with alcohol. Weibull analysis indicated that all specimens had a high ratio of late-to-early failures.

Conclusions: The fatigue experiment produced a pattern of failures that is very similar to that observed in clinical trials of Y-TZP crowns that are veneered with feldspathic porcelain. Crowns cemented with an adhesive resin cement exhibited chipping at a significantly higher mean load than those cemented with luting cements that do not usually form strong bonds with dentin. When cemented with adhesive resin cement, glazing or sandblasting the intaglio surface of the framework significantly reduced the mean fatigue loads at which chipping of veneers occurred, as compared to crowns whose intaglio surface had only been cleaned with alcohol. For this cement glazing or sandblasting the intaglio surface of the crown is not recommended.

INTRODUCTION

The need for more fracture-resistant zirconia has led to the development of tetragonal zirconia polycrystals doped with 3 mol% yttria (3Y-TZP; hereafter this ceramic will be designated Y-TZP). These zirconia-based materials are much more fracture resistant than the feldspathic porcelains traditionally used in dentistry.[1] A major problem with Y-TZP ceramics is that when subjected to localized stress or chemical stimuli they can undergo phase transformations that undermine their fracture resistance.[2-4] That said, clinical trials show few fractures of Y-TZP cores. Clinical trials of Y-TZP crowns that have been veneered with feldspathic porcelain show that chipping of the veneer is the primary failure associated with these restorations.[3-21]

At the same time, the loss of retention of Y-TZP crowns (due to a lack of adhesion between the Y-TZP surface and the tooth) was also shown to be a reason for failure.[9,10,14-16] The adhesion between the Y-TZP surface and cements has been widely studied in *in vitro* research. Sandblasting, silica coating, etching, and glazing are the most commonly used pretreatments. Silica coating by sandblasting improves adhesion between Y-TZP and resin cement[4]; however, it seems to lead to material degradation. The initially present microdefects introduced by the sandblasting seem insufficient to lead to failure. However, the mechanical strength of the ceramic is time dependent as a result of a subcritical crack growth that the material may suffer when subjected to cyclic loading in an aqueous environment.[22] Indeed, aging of the sandblasted Y-TZP has a deleterious effect on the materials' strength.[23-30] The same is observed for a silica or aluminum oxide coated with silica (SiO_2) coating.[23,31,32] Contradicting this theory, studies by Cattani-Lorente and others[33] and Scherrer and others[34] cited that sandblasting with 30-μm silica particles does not promote a deleterious effect on the mechanical behavior of Y-TZP ceramics. In addition to these surface treatments, surface alterations using Y-TZP ceramic with glazing and etching have been tried. Promising results related to the bond strength between Y-TZP and resin cement were observed with glazed and Al_2O_3-sandblasted[35,36] or hydrofluoric acid–etched surfaces.[27,37] However, such a thin glass film is located on the intaglio surface of crowns, which is the area in which tensile stresses are experienced when a crown is mechanically challenged.[38] The presence of this film may trigger the start of crack propagation, since this glass material has a lower tensile strength.

However, there is a lack of evidence in clinical studies related to these intaglio surface treatments, especially in terms of the long-term behavior of the treated crown. The use of luting agents that typically exhibit little adhesion to dentin and ceramics, such as zinc phosphate and glass ionomer, has been studied clinically,[13-15,17] but there are no clinical data comparing the cementation using these agents with adhesive resin cement. Despite the fact that the loss of retention of Y-TZP/porcelain crowns does not appear to be the main cause of failure in clinical studies, laboratory investigation has observed that cementation success is related to the strength of the crown.[39] Moreover, increased cement thickness decreases failure loads for ceramic crowns.[39]

Thus, instead of measuring the fatigue resistance of individual parts of the system, for example, the Y-TZP ceramic alone or the bond strength of the veneer porcelain to the Y-TZP, we investigated the fracture resistance of an entire system under cyclic loading. The system was a CAM-formed Y-TZP crown that was veneered with feldspathic porcelain and cemented to simulated dentin. We applied stepwise loads to standardized Y-TZP/feldspathic ceramic crowns. Stepwise loading challenges the ceramic to a fixed number of cycles at each load, in a set of incrementally increasing loads, until a load is found in which fracture occurs during the cyclic loading. This fatigue test has been used previously in dental research to determine the fracture resistance of Class II resin composite restorations with cuspal coverage[40] and to compare the fatigue resistance of ceramic and composite veneers.[41]

The present study was designed with the following objectives in mind: 1) to investigate the influence of treatment of the intaglio surface of feldspathic porcelain veneered Y-TZP crowns on fatigue resistance and 2) to evaluate the effects of different luting systems on the fatigue resistance of the crown and veneer system.

METHODS AND MATERIALS

The fatigue test used in the present work was adapted from one developed by Kelly and others.[42] The present test used a glass-fiber mesh-filled epoxy composite NEMA class G10 (International Paper, Hampton, SC, USA) to simulate the elastic flexibility of dentin and therefore to produce high stresses along the intaglio surface of the crown. Consistent with the fracture behavior of ceramics that have failed clinically,[38,43,44] this test was designed to increase the probability of fracture initiating from the intaglio surface of the framework. Furthermore, also following the method of Kelly and others,[42] the present design applied the load via a large-diameter indentor that spreads the load widely over the outer surface of the crown. This reduces the chance of fracture initiating at the outer surface (here on the outer surface of the veneer).

The *in vitro* survival rates of Y-TZP/porcelain crowns cemented using different cements and pretreatments were determined by fatiguing the crown under stepwise-increasing loads. Computer-aided machining of the G10 composite dentin analogue material was used to produce 90 identical crown preparations, each 6 mm high with a flat top, 12° of total occlusal convergence, and a 1.2-mm chamfer margin. The design of the specimens was based on the results of a previous simulation using finite element analysis.[45]

After a polyvinylsiloxane impression was made, a digital design of a plaster cast was obtained with the aid of InLab 3.60 software (Sirona Dental Systems, Bensheim, Germany). The InLab Cerec MC XL (Sirona Dental Systems) milled 90 identical frameworks in Y-TZP ceramic (VITA In-Ceram YZ for InLab, Vita Zahnfabrik, Bad Säckingen, Germany). The frameworks were ultrasonically and oven-cycle cleaned and then sintered in a ZYrcomat VITA oven (Vita Zahnfabrik), as recommended by the manufacturer. The 0.7-mm-thick framework was veneered using a feldspathic ceramic (Table 1; VITA VM9 base-dentin, Vita Zahnfabrik) with the stratified technique, simulating a full crown with a flat occlusal surface. Two layers of feldspathic ceramic and their consequent two firings in a vacuum furnace (VACUMAT 6000 M, Vita Zahnfabrik) were performed on each crown. The crowns were polished in a grinding machine under constant cooling. The thickness of the crowns was checked with a digital caliper, ensuring that all the crowns had a 2.0-mm total thickness. All the specimens were cleaned for five minutes in an ultrasonic bath of distilled water, air-dried, and submitted to glaze firing (Programat P100, Ivoclar AG Schaan, Liechtenstein) in order to release any possible residual stresses.

Surface Treatments

The G10 preparations and crowns were numbered from 1 to 90 and then randomized into six groups (n=15) according to pretreatments and cements using the tool at www.randomizer.org, as follows: PN = without surface treatment, resin cement Panavia F; OG = application of a thin glaze porcelain layer, resin cement Panavia F; AO = 125 μm Al_2O_3 sandblasting, resin cement Panavia F; CJ = 30 μm SiO_2 sandblasting, resin cement Panavia F; ZP = without surface treatment, zinc phosphate cement; and GI = without surface treatment, glass ionomer cement.

The G10 preparations were etched with 10% hydrofluoric acid (Dentsply, Petropolis/RJ, Brazil)

Table 1: *Mean Fracture Load (in N) and Standard Deviation (SD), Together with a 95% Confidence Interval, After Stepwise Loading and Cement Thickness (μm) for the Different Groups*[a]

	Load, N				
	Mean Fracture Load	SD	95% Confidence Interval		Cement Thickness, μm
			Lower Bound	Upper Bound	
PN	1093[A]	237	973	1213	205[a]
OG	947[AB]	177	857	1036	271[a]
AO	973[AB]	198	873	1074	250[a]
CJ	920[AB]	147	845	995	201[a]
ZP	867[B]	123	804	929	473[b]
GI	867[B]	180	776	958	226[a]

Abbreviations: AO, 125 μm Al_2O_3 sandblasting, resin cement Panavia F; CJ, 30 μm SiO_2 sandblasting, resin cement Panavia F; GI, without surface treatment, glass ionomer cement; OG, application of a thin glaze porcelain layer, resin cement Panavia F; PN, without surface treatment, resin cement Panavia F; ZP, without surface treatment, zinc phosphate cement.
[a] *Same uppercase or lowercase letters indicate no statistically significant difference.*

for one minute, washed, and dried. For the groups that were to be cemented with Panavia F resin cement, the ED Primer II A & B (Kuraray, Kurashiki, Okayama, Japan) was applied for 30 seconds and then gently air-dried.

All of the crowns were cleaned with isopropyl alcohol and naturally dried through evaporation of the product.

The crowns from the OG group were treated with the overglaze technique, which corresponds to the application of a single thin layer of a glaze porcelain material (VITA AKZENT Glaze and VITA AKZENT Fluid, both from Vita Zanhfabrik) using a brush on the cementation surface. The crowns were then subjected to the glaze-sintering cycle, according to the manufacturer's instructions, at maximum temperatures below the glass transition temperature of the porcelain veneer. The intaglio surfaces were etched with 10% hydrofluoric acid (Dentsply) for one minute, washed, and air-dried. Subsequently, the intaglio surfaces were silanized with Clearfil SE Bond + Bond Activator (Kuraray).

For the sandblasted groups, the sandblasting was performed using 125 μm aluminum oxide particles (Alublast 125 μm, Elephant Dental B.V., Hoorn, The Netherlands) for the group AO or 30 μm aluminum oxide coated with silicon particles (CoJet Sand, 3M ESPE AG, Seefeld, Germany) for the group CJ. The sandblasting was performed at a 15-mm standardized distance from the device's tip to the crown's occlusal surface in a circular motion for 30 seconds for the AO group and for 15 seconds for the CJ crowns, with a constant pressure of 3 bars (Rocatector Delta, 3M ESPE AG). Crowns from the CJ group were also silanized with Clearfil SE Bond + Bond Activator (Kuraray).

Cementation with Panavia F (Kuraray), zinc phosphate–based cement (Zinc Cement, SS White, Rio de Janeiro/RJ, Brazil), and glass ionomer cement (GC Fuji I Capsule [GC Corporation, Tokyo, Japan]) was completed according to the manufacturers' respective recommendations. Each crown was seated using a standardized force of 50 N over the course of five to seven minutes. The excess cement was removed using small brushes, and the cement was light-cured (Astralis 10, Ivoclar Vivadent AG) using four 30 seconds exposures (Panavia F only). All specimens were stored in distilled water for at least 24 hours and a maximum period of seven days before conducting the stepwise load experiment.

Stepwise Load Experiment

The specimens were tested until failure in an adapted fatigue tester (Fatigue Tester, ACTA, The Netherlands) with a 1.4-Hz frequency for 5000 cycles at a minimum load of 5 N and a maximum load of 200 N and 10,000 cycles at a minimum load of 5 N and maximum loads of 800, 1000, 1200, and 1400 N, respectively. The load was applied by a 40-mm-diameter stainless-steel sphere[42] (Figure 1) under distilled water[42] at 25°C. The specimens were checked for cracks and/or failures every 1000 cycles.

Failure Mode Analysis and Cement Thickness

The failure mode of all the specimens was evaluated for a better results comparison. For this purpose, the samples were initially analyzed with a stereomicroscope for localization of the defect that resulted in the failure. The representative specimens were analyzed under scanning electron microscopy (SEM; XL 20, FEI Company, GG Eindhoven, The Netherlands). Three specimens from each group were cut (Isomet 1000, Buehler, Lake Bluff, IL, USA) in 1-mm-thick slices in order to evaluate the thickness of the cement layer. The central slice of each specimen was evaluated via SEM. The cement thickness was the average of the cement layer in the center of the occlusal surface of each slice.

Statistical Analysis

The step during which each specimen failed was used for the survival analysis. After plotting the data

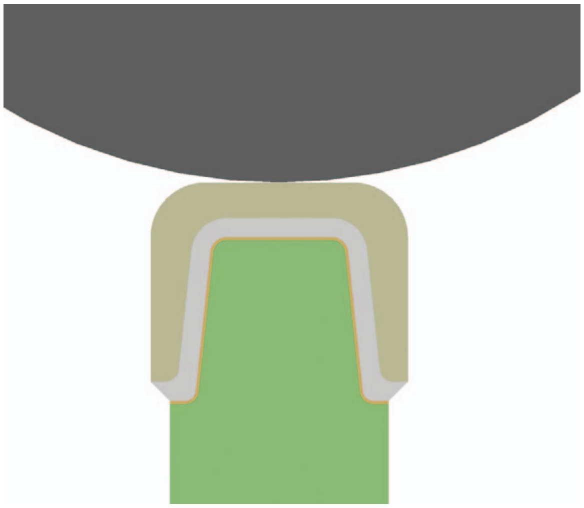

Figure 1. *Schematic drawing of the test. Dark gray: 40-mm steel sphere; light brown: porcelain; light gray: YZ infrastructure; orange: cement layer; green: G10 preparation.*

in a survival function, the Kaplan-Meier and Mantel-Cox (Log Rank) tests were performed and followed by a pairwise comparison ($p<0.05$) (SPSS version 21, SPSS Inc, Chicago, IL, USA). The failure steps and total number of cycles to failure were used for a nonparametric analysis of distribution performed through the two-parameter Weibull analysis using the software Super SMITH Weibull 4.0k-32 (Wes Fulton, Torrance, CA, USA). Data from the occlusal misfit (cement layer) were analyzed by a one-way analysis of variance (ANOVA) and a Tukey test ($p<0.05$).

RESULTS

The predominant mode of failure was chipping of the veneer ceramic without exposure of the Y-TZP framework (Figure 2). In six instances the Y-TZP framework fractured: this occurred in one framework for the OG group, two frameworks for the ZP group, and three frameworks for the GI group.

Figure 3 shows the survival curves from the stepwise load experiments for the different groups. The mean fracture loads (in N) calculated from the survival curves and statistical analyses are summarized in Table 1. According to the Mantel-Cox test (Log Rank, $\chi^2=13.422$, df=5, $p=0.02$), consequently, the tested conditions influenced the fatigue resistance of the porcelain veneered Y-TZP crowns. The pairwise comparison showed that the adhesively cemented (PN) crowns survived at significantly

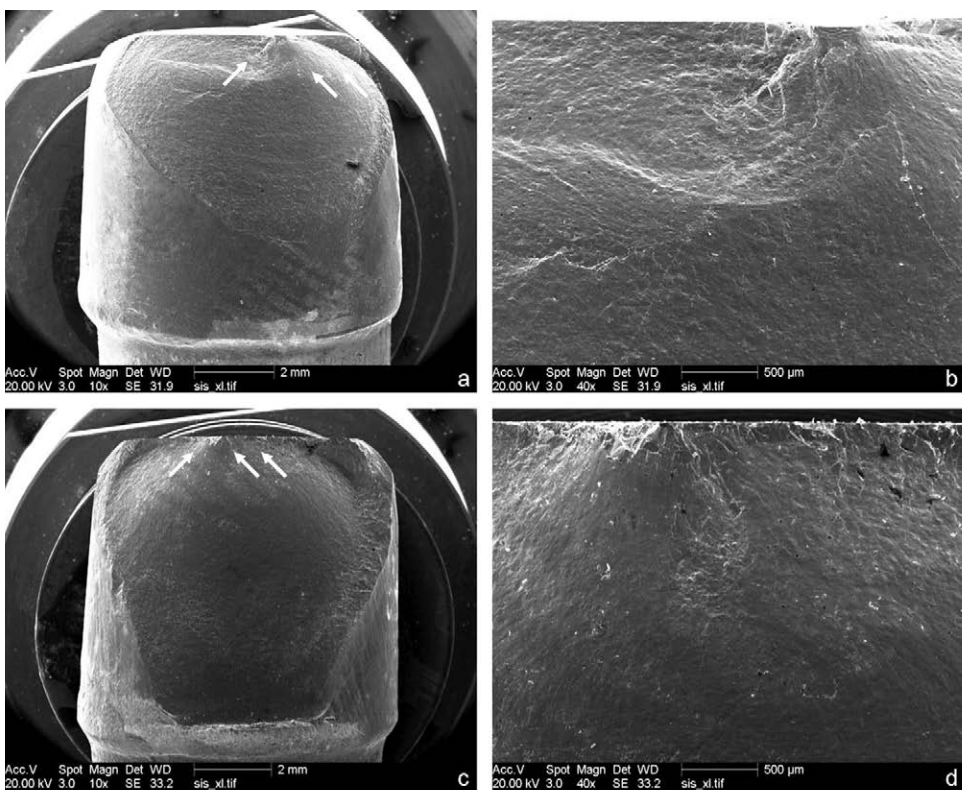

Figure 2. *The predominant mode of failure: chipping of the veneer ceramic. Representative images from groups AO (a,b) and CJ (c,d). The white arrows represent the direction of fracture propagation.*

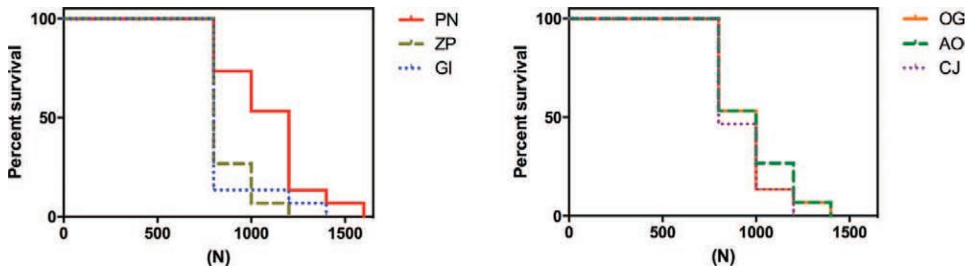

Figure 3. *Survival curves of the stepwise load experiment analyzed according to the steps during which each crown failed.*

higher loads (and, consequently, for more cycles) than the crowns luted with zinc phosphate (ZP) or glass ionomer cements (GI). For crowns whose intaglio surface had been "treated" (ie, glazed or sandblasted prior to bonding), there were no significant differences ($p>0.05$) in the fatigue loads (ie, loads at which chipping occurred) of treated crowns luted with the adhesive resin cement and untreated crowns luted with zinc phosphate or glass-ionomer cement (Table 1).

Table 2 and Figure 4 summarize the Weibull statistics of the stepwise load experiment analyzed according to the maximum load (top) or the number of cycles (bottom) at which each veneer chipped.

The cement thickness was also analyzed. A one-way ANOVA showed differences among the cement thicknesses of the experimental groups ($p<0.0001$). The Tukey test showed that zinc phosphate had the thickest layer compared to all the other groups (Figure 5; Table 1).

DISCUSSION

The failure mode of the majority of specimens during the stepwise load experiment was cohesive failure of the porcelain (eg, chipping) without exposure of Y-TZP. The results of the Kaplan-Meier survival analysis showed statistically significant differences among the experimental groups. The stepwise load experiments showed that the crowns cemented with the adhesive resin cement failed at higher loads than did the crowns cemented with the luting cements that usually exhibit little adhesion to dentin and ceramics.

Zinc phosphate cement has been used for more than a century in dentistry.[46] Despite its low mechanical strength, lack of a chemical bond, and partial solubility to oral fluids, this cement has been

Table 2: *Weibull Parameters, Correlation Coefficients, and the 5% Failure Value (B5%) with their 95% Confidence Interval After Analyzing Stepwise Loading, Depending on the Load-to-Failure (N) and the Total Number of Cycles to Failure*

	Weibull—Load to Failure					
	σ_0	β	r^2	95% Lower	B5%	95% Higher
PN	1175	5.699	0.858	570	698	855
OG	997	8.039	0.678	607	689	783
AO	1033	6.949	0.723	572	673	793
CJ	964	9.217	0.660	618	699	790
ZP	895	13.11	0.455	666	714	765
GI	890	12.61	0.280	661	703	749
	Weibull—Number of Cycles					
	$N_{f,0}$	m	r^2	95% Lower	B5%	95% Higher
PN	26,306	2.023	0.969	3312	6059	11,084
OG	16,895	1.896	0.910	1886	3528	6601
AO	21,204	2.138	0.961	3004	5286	9301
CJ	18,069	2.316	0.922	2933	5011	8563
ZP	13,649	2.574	0.887	2801	4305	6619
GI	12,078	2.267	0.723	2042	3258	5198

Abbreviations: AO, 125 μm Al_2O_3 sandblasting, resin cement Panavia F; CJ, 30 μm SiO_2 sandblasting, resin cement Panavia F; GI, without surface treatment, glass ionomer cement; OG, application of a thin glaze porcelain layer, resin cement Panavia F; PN, without surface treatment, resin cement Panavia F; ZP, without surface treatment, zinc phosphate cement.

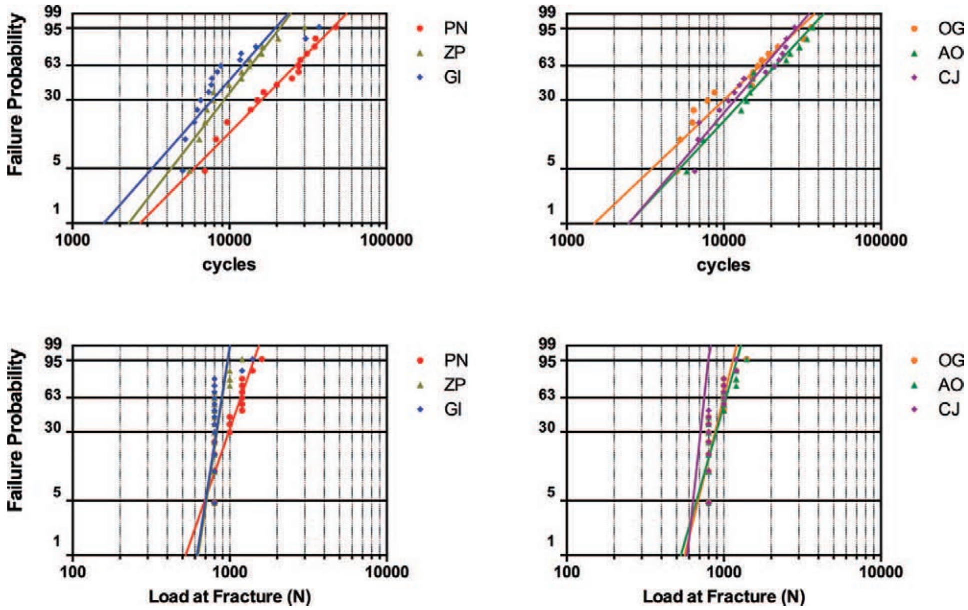

Figure 4. *Weibull probability plots of the stepwise load experiment analyzed based on the number of steps or cycles during which each crown failed.*

used by several other authors.[14,46-50] Both resin cement and glass ionomer cement have better mechanical properties than does zinc phosphate. The superior strength of resin cements may contribute to better bond strength between computer-aided machined zirconia copings and a nickel-chromium (Ni-Cr) alloy[50] and better retention of zirconia crowns to dentin.[51] Notably, the bond strength of resin cement to dentin is greater than that of zinc phosphate or glass ionomer cements to dentin.[50]

Although the bond strength of the adhesive resin cement to the epoxy composite (G10) used in the present experiments was found to be similar to that of the adhesive resin cement bonded to wet dentin,[42] the bond strengths of zinc phosphate cement and glass ionomer cement to the epoxy resin composite have not been measured. It is known that fracture resistance (monolithic test) of feldspathic monolithic crowns can be influenced by their adhesion mechanism to resin cement.[39] A feldspathic crown "bonded" to cement resisted twice the load of "nonbonded" crowns.[39] Apparently, the present work is the first one to observe the influence of luting agents on the fatigue resistance of Y-TZP crowns veneered by porcelain. Consequently, it is not known whether the present results can be extrapolated to Y-TZP bonded to dentin with zinc phosphate or glass ionomer cements. Further studies should be addressed in order to better explore this topic.

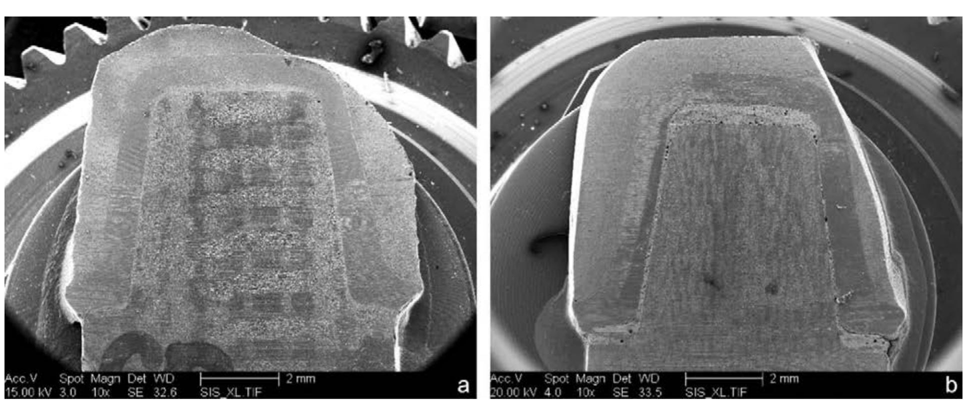

Figure 5. *Representative images of cement thickness from groups PN (a) and ZP (b).*

Results similar to those in the present study have been reported for a study[50] of the fracture resistance of zirconia copings. Namely, when standard copings were luted to a Ni-Cr alloy, lower fracture resistance was found for copings luted with zinc phosphate or glass ionomer cements, and much higher fracture resistances were found for copings luted with an adhesive resin cement.[50]

In this study, the Kaplan-Meier analysis showed that Y-TZP crowns luted with the adhesive resin cement whose intaglio surface had been "treated" (eg, glazed or sandblasted) exhibited veneer failures at fatigue loads that were not significantly different ($p>0.05$) from those exhibited by untreated crowns that had been luted with cements that usually do not form strong bonds to dentin. Sandblasting the intaglio surfaces of Y-TZP frameworks is controversial.[2,19] Very different surfaces can be produced by varying the types and sizes of particles, pressures, area of the jet of sand and projection angle and by using target materials with varying microstructures.[52]

After fatigue, Y-TZP specimens that have been sandblasted with aluminum oxide using parameters similar to those used in the present study exhibit reduced strength.[23,29,30] The same deleterious effect is observed in zirconia that has been sandblasted with silica.[23,31,32] Studies related to the application of overglaze suggest that this treatment is advantageous to the ceramic system as a whole.[27,28,35,37,53-56] Nevertheless, in the present study, the fatigue resistances of the treated Y-TZP crowns (AO: sandblasting with 125 μm Al_2O_3; CJ: sandblasting with 30 μm SiO_2; and OG: application of overglaze) were not significantly different from those of the untreated crowns (PN).

The fatigue behavior of dental materials is generally investigated by a high number of cycles at a low load or by staircase fatigue experiments. A new approach was introduced by Fennis and others,[40] in whose study a stepwise load was applied and resistance to survival was analyzed using log-rank tests. In order to understand the failure mechanism, we analyzed the results with a traditional Weibull analysis using the failure criteria "load to failure" and the "number of cycles to failure." There was a clear difference in the results: for the "load to failure," the Weibull correlation coefficient was between 0.85 and 0.28, while the correlation coefficient of the "number of cycles to failure" was 0.97 to 0.72. The high correlation coefficient of the "number of cycles to failure" showed that the failure mechanism is most likely related to slow crack growth instead of the probability of overload, which is expected for a high correlation with the "load to failure." The Weibull analysis for the "number of cycles to failure" showed values of $m > 1$, which means that most of the failures occurred relatively late.[57]

Interestingly, the m value of the investigated groups was similar ($m=1.9$-2.5), showing that the physics of the failure were similar for all groups. This means that the observed failure mode (eg, delamination of the veneer porcelain) for investigated specimens had the same origin. Recently, Carvalho and others[58] investigated the fatigue resistance of feldspathic glass ceramics, lithium disilicate, and resin nanoceramic crowns in a similar setup. The mean fracture strength of their feldspathic glass ceramics (Vitablocs Mark II blocks) was 1171 N, which is similar to our mean fracture strength. This implies that the strength of the veneer porcelain, or the bond strength between the veneer porcelain and the Y-TZP, is determining the overall fatigue resistance. A closer look at the failure mode analysis showed that the majority of specimens had porcelain cohesive failure (chipping) without exposure to Y-TZP, which corroborates with clinical[3,5-21] and laboratory studies.[58-61]

Although this experiment was designed to test the effect of the surface treatments prior to cementation on the fatigue resistance of Y-TZP infrastructure/porcelain veneer crowns, there were few failures of the Y-TZP framework (six crowns, or 6.67%). This fatigue test produced approximately the same percentage of framework failures as has been seen in clinical trials of Y-TZP crowns. For example, three clinical trials, those of Schmitter and others,[16] Çehreli and others,[62] and Beuer and others,[63] reported 3%, 7%, and 5% framework fractures, respectively. Clinically similar fracture is best simulated by cementing to a preparation with dentin-like elastic properties and avoiding high surface stresses with use of a large-diameter applicator,[42] unlike that used in some recent studies.[60,64]

The thickness of the cement layer was also evaluated. Only the ZP group was significantly thicker than the other groups. This is most likely due to the composition of this cement. According to Jorgensen,[65] the particles of the zinc phosphate powder are only partially dissolved by the acid contained in the liquid, resulting in agglomerated particle formation of up to 100 μm. These clusters can hinder the spread of the cement in the space between the crown and preparation, thereby damaging the adaptation. Despite the differences found between the thicknesses of the cements that usually do not form strong bonds to dentin, the behavior of the specimens cemented with both cements was similar in the fatigue-resistance test, reinforcing the notion that the modulus of elasticity of the cement has more influence on stress formation in the ceramics and in its interface with cement than does the thickness of the cement layer itself.[66] According to Shahrbaf and others,[67] an increase in the elastic modulus of the cement leads to higher stresses in the cement layer for crowns with flat preparations. In this case, the resin cement (elastic modulus of 3 GPa; Yi and Kelly[68]) better distributes the stresses within this layer than do the glass ionomer cements (between 6.3 GPa [Tam and others[69]] and 16.9 GPa [Li and White[70]]) or the zinc phosphate cement (between 13.7 GPa [Craig and others[71]] and 22.4 GPa [Holmes and others[72]]). For crowns with untreated intaglio surfaces, the low modulus of the resin cement may explain the superior fatigue resistances exhibited by crowns cemented with this cement over crowns cemented with zinc phosphate or glass ionomer cements.

In addition to the unknown amounts of adhesion between the dentin analogue and the GI or the ZP luting cements, the main limitations of this study were the brief times in water and the 12° convergence angle of the preparation. The relatively brief storage times in water (between one and seven days) are insufficient to produce the losses in bond strength that have been reported for bonds between Y-TZP and an MDP (10-Methacryloyloxydecyl dihydrogen phosphate)-containing adhesive resin cement. In clinical situations, the water uptake might be slower as a result of the different configurations, but water will eventually reduce the bond strength[73] and most likely the resistance of the survival of the crown. Lower convergence angles of the preparation can be associated with the occurrence of Hoop stresses within the restoration and the reduced resistance of the crown when it is loaded.[74] Finite element analysis is needed to show where these stress concentrations are and what their effects are in terms of the lifetime of the crown.

CONCLUSIONS

The experimental fatigue model that was used produced failures similar to those that are observed *in vivo*. The zirconia frameworks rarely failed, but veneers frequently fractured cohesively. Paradoxically, the experimental model was designed to produce framework fractures that initiate in the inside of the framework near the cement and to minimize surface stresses that could lead to Hertzian fracture at the surface. This experimental model is an excellent candidate for *in vitro* studies of veneered ceramic.

When the intaglio surfaces of crowns were untreated, crowns luted with the adhesive resin cement exhibited veneer failure at higher loads than did those cemented with either the zinc phosphate or glass ionomer luting cements. Furthermore, pretreatments, such as overglazing, sandblasting, or silica coating, did not affect failure load. The Weibull analysis showed that the number of cycles in the stepwise load experiments is related to a failure mechanism that includes slow crack growth.

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Regulatory Statement

This study was conducted in accordance with all the provisions and policies of the Institute of Science and Technology, University Estadual Paulista in Sao Jose dos Campos in Sao Paulo, Brazil.

Conflict of Interest

The authors 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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Digital Smile Design for Computer-assisted Esthetic Rehabilitation: Two-year Follow-up

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Clinical Relevance

The use of digital smile design is a useful resource for diagnosis, simulation, and evaluation of esthetic rehabilitation and it can improve communication among the patient, clinician, and dental laboratories.

SUMMARY

Objective: The esthetics of the smile are related to the color, shape, texture, dental alignment, gingival contour, and the relationship of these with the face.

Purpose: To present a two-year follow-up for an esthetic rehabilitation clinical case in which the method of digital smile design (DSD) was used to assist and improve diagnosis, communication, and predictability of treatment through an esthetic analysis of the assembly: face, smile, periodontal tissue, and teeth.

Clinical Procedure: The smile's esthetics were improved through gingival recontouring, dental home bleaching, and a restorative procedure with thin porcelain laminate veneers using lithium disilicate glass-ceramic (e.max Ceram, Ivoclar-Vivadent) laminates on teeth 4 through 13.

Discussion: The proposed technique had an acceptable clinical performance at the end of a two-year follow-up.

Significance: DSD can be used to increase professional/patient communication and to provide greater predictability for the smile's esthetic rehabilitation.

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PURPOSE

The esthetics of the smile are related to color, shape, texture, dental alignment, gingival contour, and the relationship of these with the face.[1-3] To plan an esthetic rehabilitation, all of these parameters must be considered, and ideally, at the end of treatment, the expectations of patients should be achieved.

Planning through digital smile design (DSD)[4] allows an esthetic analysis of the assembly—face, smile, periodontal tissue, and teeth—through the analysis of extra- and intraoral digital photographs, in which the reference lines of the face and of the anatomical axes are plotted as a guide to establish a proper gingival contour, shape, and dental alignment. This provides greater predictability of treatment because it allows a final dental outline showing the relationship between the preoperative situation and the ideal design, in addition to assisting as a guide to diagnostic wax-up and consequently to the mock-up.[4]

A strategy used to assist in planning and predictability of treatment is making a dental cast following the completion of the mock-up,[5] in which the diagnostic wax-up is performed based only on the esthetic analysis of the teeth shapes and gingival contour. Despite the fact that facial analysis is not considered with this technique, this is the planning strategy performed in most of the cases reported in the literature.[6-9] Although it is a simple technique that does not require specific equipment or software for its achievement,[4] no case reports on the use of DSD were found.

Adequate planning may ensure a conservative, effective, and durable treatment. Sometimes dental bleaching may be a conservative alternative able to produce a good result;[10] however, when looking for a solution to esthetic problems, involving morphologic modifications in relation to tooth color, shape, contour, size, volume, and positioning, a restoring treatment is necessary.[11] Porcelain laminate restoration has proven to be a durable and esthetic modality of treatment.[12-16] The porcelain material commonly indicated for use in veneers is hot-pressed glass-ceramic because of its translucency and potential for use in small thicknesses.[17] This allows for a conservative tooth preparation because, by way of an adhesive cementation technique, the veneers are bonded to the enamel through resin luting systems, allowing such fragments to resist fracture.[18]

All planning techniques and case studies are important and contribute to better outcomes in terms of the final rehabilitation treatment. However, the patient does not always have the ability to imagine the condition presented with the aid of plaster models and waxing implemented in an actual clinical situation. The DSD allows the patient to gain a prediction of treatment, facilitating understanding and allowing his critical analysis and participation in planning. Thus, the purpose of this article is to present a two-year follow-up for an esthetic rehabilitation clinical case in which the method of DSD was used to assist in the diagnosis, communication, and predictability of treatment through an esthetic analysis of the assembly: face, smile, periodontal tissue, and teeth. The DSD method may also help to improve the interaction between professional and patients, allowing their critical analysis in the treatment planning.

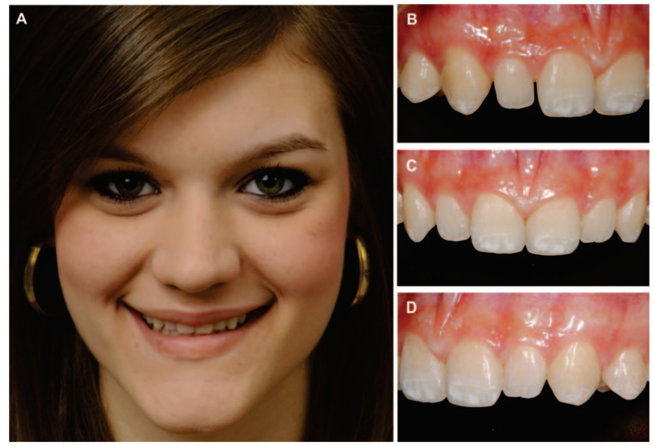

Figure 1. *Pretreatment aspect of the patient. (A) Facial view. (B-D) Intraoral view of the maxillary teeth. All anterior maxillary teeth exhibit enamel hypoplasia, a relatively dark color, and a disharmony of shape and proportion. The gingival margin of the left central incisor is more coronal than that of the right central incisor.*

DESCRIPTION OF TECHNIQUE

A female patient, 19 years of age, was disappointed with her smile because of the appearance of what she called her "childlike smile" and the presence of white spots. The patient further pointed out that she would like her teeth to be whiter. After anamnesis and clinical examination, the presence of white spots on the facial surface of the upper teeth was observed. It was diagnosed as enamel hypoplasia, and there was also a disharmony of shape and proportion of the maxillary anterior teeth and the gingival contour. The pretreatment aspect—facial and intraoral views of the patient—is shown in Figure 1.

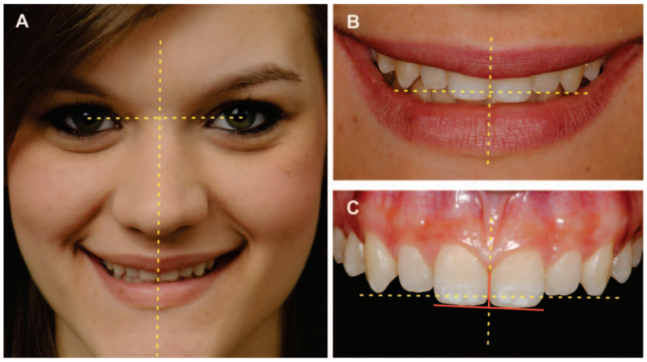

Figure 2. *Digital smile design (DSD) protocol. (A) Determining the ideal horizontal plane and vertical midline on the facial photograph. (B) Transferring the cross to the intraoral photography to establish the vertical midline and occlusal plane. (C) Drawing the three reference lines that allow for the analysis of the relationship among the facial lines, lips, teeth, and gingiva.*

Digital Planning

To obtain better predictability of the proposed treatment and to facilitate communication among the interdisciplinary dental team, in addition to the manufacture of the dental cast and conducting extra and intraoral photographs, the digital planning of the case was accomplished with the help of a presentation software, Keynote (iWork, Apple, Cupertino, CA, USA), by the DSD technique, as described previously.[4]

First, the three photographs required for DSD analysis were performed, as follows: full face with a wide smile, full face at rest, and retracted view of the full maxillary arch with teeth apart. In the photograph of the full-face smile, the horizontal plane and the median sagittal plane were determined according to the interpupillary line and anatomical references such as the glabella, nose, and chin, respectively (Figure 2A). These two lines were transferred to the intraoral photography (Figure 2B) to analyze the smile in accordance with the facial references. The dental midline and occlusal plane were established (red line—Figure 2C), and their relationship with the facial lines (dashed yellow line) was analyzed.

After the facial analysis the dental analysis was performed. A rectangle with the actual proportion of maxillary teeth and tooth outline were accomplished to analyze the shapes and width/length proportions of the pretreatment teeth (Figure 3A). Then a rectangle with the ideal length/width proportion was placed over the teeth to compare the actual pretreatment proportions with the ideal ones (Figure 3B). Furthermore, measurements in the digital photographs were performed and transferred to the dental cast to calibrate the digital ruler and guide the diagnostic wax-up (Figure 3C-F). The final teeth outline and gingival contour were planned (Figure 3G), and the diagnostic wax-up was fabricated using the DSD as a guide (Figure 3H).

Figure 3. *Digital smile design (DSD) protocol. (A) A rectangle is placed over the maxillary teeth, and outlines of the teeth were accomplished to define the shapes and proportions of the pretreatment teeth. (B) A rectangle with the ideal length/width proportion is placed over the teeth to compare the actual pretreatment proportion with the ideal one. (C,D) Measurement of the width of the central incisors on the photograph and cast for calibration of the digital ruler. (E) Measurement of the distance between the horizontal line and incisal edge on the photograph. (F) This measurement is transferred to the cast. (G) Final teeth outline and gingival contour showing the relationship between the preoperative situation and the final design. (H) The diagnostic wax-up is fabricated using the DSD as a guide.*

Treatment Plan

After planning the case and discussing the treatment options with the interdisciplinary dental team, the DSD was used as a tool for communicating with the patient to clearly illustrate the treatment and discuss whether or not it met the patient's expectations. After obtaining patient consent, the treatment plan was defined; this plan integrated the performance of gingivoplasty in tooth 9, dental bleaching, and a restorative procedure with thin ceramic laminate veneers on teeth 4 through 13 in order to improve the esthetics of the smile with minimal reduction of healthy tooth structure.

Gingivoplasty

Initially, gingivoplasty was performed on tooth 9 to raise the gingival margin in the apical direction and to realign the gingival zenith to match the equivalent teeth. After anesthetizing the region, an

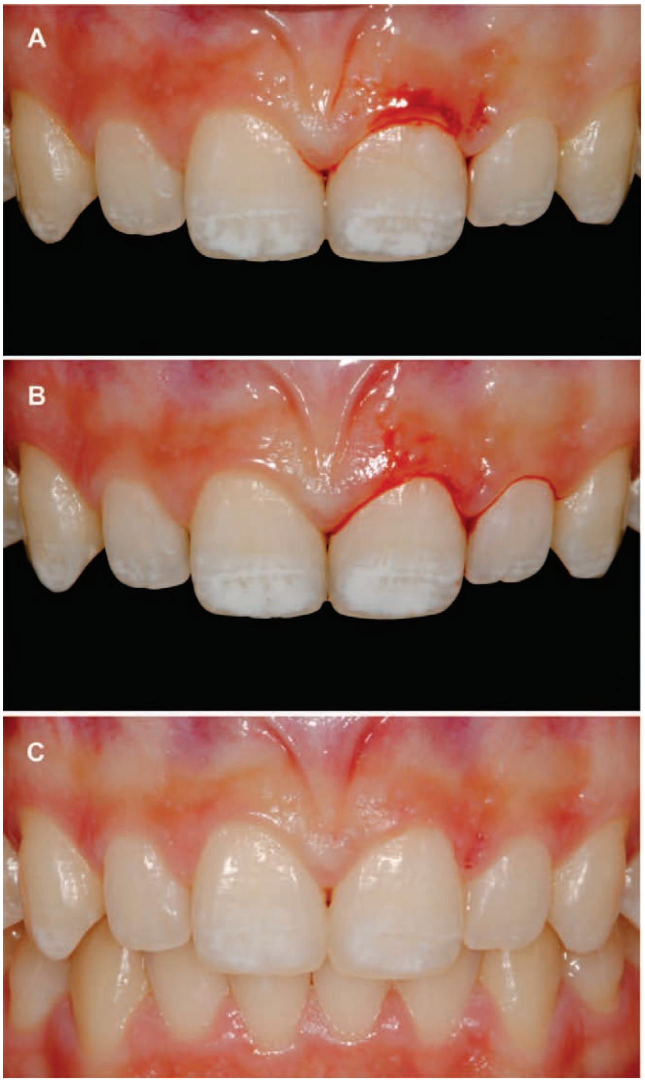

Figure 4. *Gingivoplasty of the left central incisor. (A) The left central incisor after the incision from the margin of the free gingiva. (B) Final aspect of gingivoplasty at the left central incisor. Note the rise in the gingival margin to the apical direction and the realignment of the gingival zenith like the contralateral tooth. (C) Clinical aspect after 24 hours of follow-up. Note the satisfactory aspect of the alignment of the gingival margin and tissue healing.*

internal bevel incision from the margin of the free gingiva was made with scalpel blade 15C, and gingival tissue was removed with a McCall 13-14 curette (Figure 4A,B). One week postoperatively it was possible to observe a satisfactory aspect of the alignment of the gingival margin and tissue healing (Figure 4C).

Dental Bleaching

After healing of the periodontal tissue, dental home bleaching was performed on the upper and lower teeth using 16% carbamide peroxide gel (Whiteness, FGM Produtos, Joinville, SC, Brazil) one hour and 30

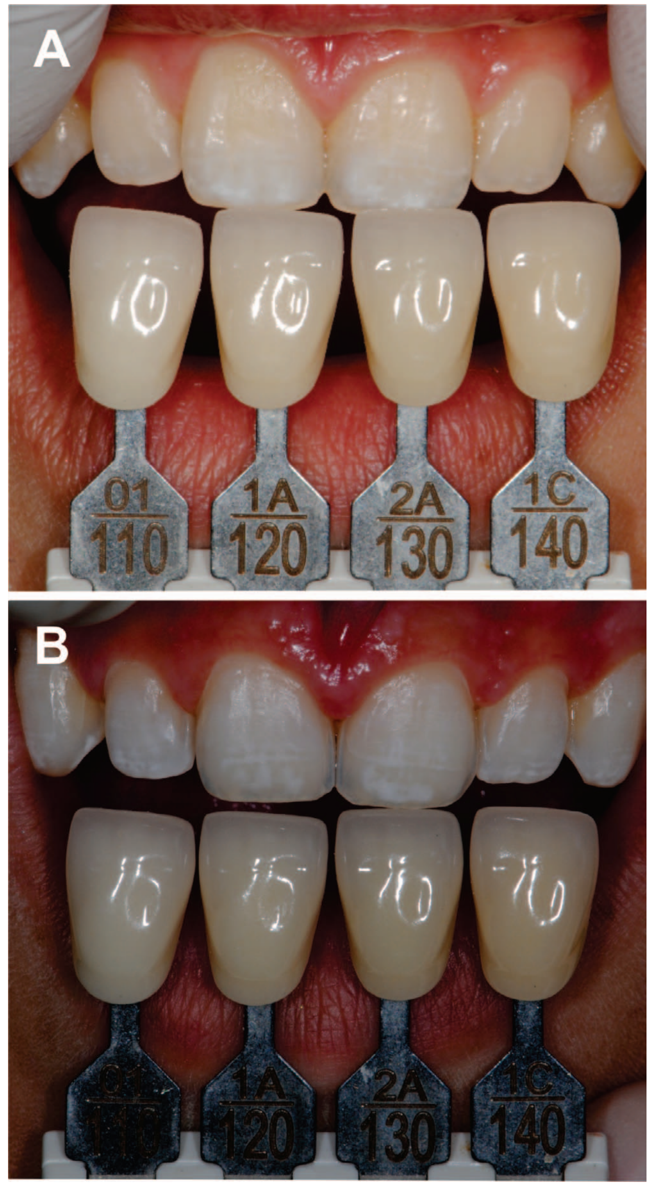

Figure 5. *Dental bleaching. (A) Aspect of the teeth before dental bleaching. (B) Final aspect of the teeth after 21 days of dental bleaching with 16% carbamide peroxide gel.*

minutes per day for 21 days.[19] Figure 5 shows the appearance of the teeth before and after the completion of the dental bleaching, demonstrating that the color registration obtained by the color scale (Vita-Pan 3D master, Vita, Bad Säckingen, Germany) was originally A2 (Figure 5A) and passed to B1 at the end of the dental bleaching process (Figure 5B).

Restorative Procedure with Thin Ceramic Laminate Veneers

Meanwhile, a dental cast of the patient was obtained for preparation of the wax-up and for the construc-

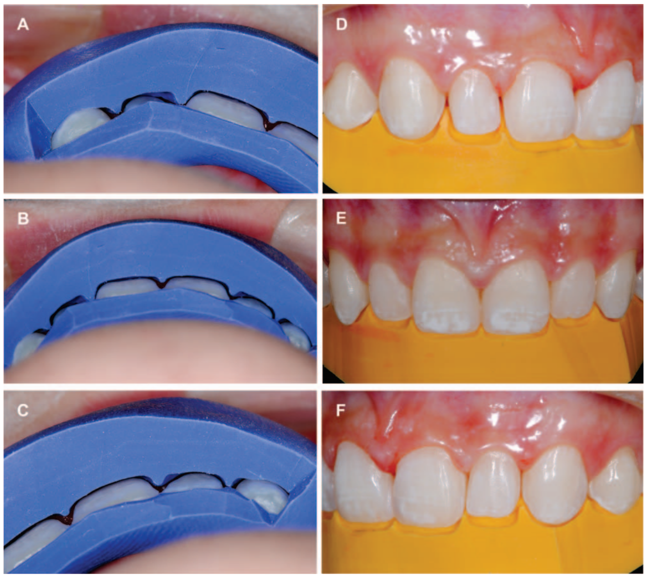

Figure 6. *The silicone matrix used to guide and check the amount of reduction in tooth preparation to the restorative procedure with thin ceramic laminate veneer. (A-C) Occlusal view of the silicone matrix used to guide the tooth preparation on the facial surface. (D-F) Frontal view of the silicone matrix used to guide the tooth preparation on the incisal third.*

tion of the mock-up. This procedure allows a tridimensional intraoral revisualization of the final result prior to tooth preparation, allowing for anatomical changes and adjustments.[20] From the dental cast with wax-up, two silicone (Express XT, 3M ESPE, St Paul, MN, USA) impressions were obtained. One was for guidance and verification of the need for reduction, thus creating a reference for the horizontal and vertical extent of the preparation (Figure 6), and the other was used for the mock-up and the provisional restorations.

Twenty-one days after the completion of dental bleaching, teeth 4-13 were prepared for thin ceramic laminate veneers. The tooth reduction, restricted to a small thickness of the enamel, was performed with diamond tip 2135 (KG Sorensen, São Paulo, SP, Brazil) on the facial surface of the tooth. For the proximal area, metal sandpaper (KG Sorensen) was used to create a separation between the teeth in order to facilitate the definition of the proximal margin, the impression procedure, and the positioning of the veneers. The cervical end was beveled to the subgingival level. The incisal third was prepared, reducing only the buccal surface, maintaining enamel tissue in this region. During this phase, it was important to use the silicone matrix, obtained from the wax-up, to guide the amount of reduction in tooth preparation (Figure 6). To refine the tooth preparation margin, diamond tips F (fine), FF

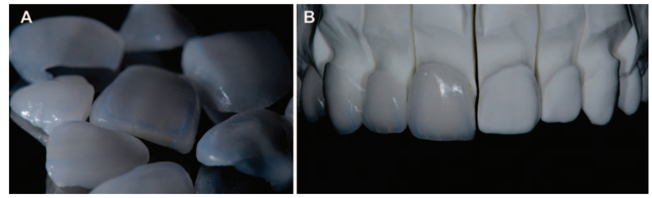

Figure 7. *The thin ceramic laminate veneer. (A) The translucence of the thin ceramic fragments. (B) Positioning the thin ceramic laminate veneer on dental cast to verify marginal adaptation, alignment, shape, and color. Note the difference between the thin ceramic laminate veneer positioned on the dental cast on the right and the thin ceramic laminate veneers not positioned on the dental cast on the left.*

(extrafine) 4138 (KG Sorensen), and abrasive disks (Sof-Lex Pop-on, 3M ESPE) were used to leave all rounded angles. The final amount of reduction was 0.5 mm in the middle third and 0.2 mm in the cervical third.

For the impression of prepared teeth, placement of two cords (UltraPack, Ultradent, São Paulo, SP, Brazil) was used for gingival retraction, with the impression technique a double mixture in two steps with vinyl polysiloxane in heavy and light consistencies (Express XT, 3M ESPE). Then color selection was performed for the ceramic laminate veneers with the help of a color scale (Vita-Pan 3D master, Vita) and the provisional restorations made with a Bis-acryl resin (Protemp, 3M ESPE). The maxillary and mandibular casts were sent to the dental technician for manufacturing of the ceramic laminates (e.max Ceram, Ivoclar-Vivadent, Schaan, Liechtenstein).

Prior to cementing, the ceramic laminates were carefully positioned to verify marginal adaptation, alignment, shape, and color (Figure 7), with satisfactory results. A shade match with the color of the selected cement was established through the try-in pastes, and the translucent cement was selected. For luting, the conditioning of the internal surfaces of the restorations was performed through application of 10% hydrofluoric acid (Porcelain Conditioner, Angelus, Londrina, PR, Brazil) for 20 seconds, washing with water and air-drying, then conditioning with 37% phosphoric acid (Acid Gel, Villevie, Joinville, SC, Brazil) for one minute, washing with water, and air-drying; afterward, a silane (Dentsply, York, PA, USA) and adhesive (Adper Scotchbond Multi-purpose, 3M ESPE) were applied. After isolation of the soft tissues, teeth were conditioned with 37% phosphoric acid (Acid Gel, Villevie) for 30 seconds, and then rinsing and drying were performed. Afterward, the adhesive (Adper Scotchbond Multi-purpose, 3M ESPE) was applied. Resin cement (Variolink Veneer, Ivoclar-Vivadent) was used as a

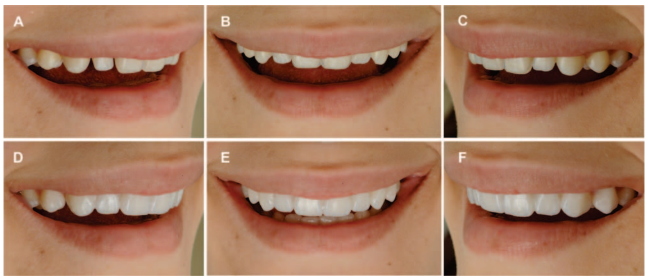

Figure 8. *The patient's smile before (A-C) and after (D-F) treatment.*

luting agent. It was applied to the internal surface of the ceramic laminate which was then positioned and light-cured (Radii Cal, SDI, Bayswater, Australia) on the facial and lingual sides for 40 seconds. The luting of the ceramic laminates was performed following the same sequence for each tooth. After luting of all veneers, the cervical margins were verified, and the excess cement was removed. The finishing and polishing of the cement line were performed with abrasive discs (Sof-Lex Pop-on, 3M ESPE).

Immediate Result and Clinical Follow-up

The intraoral aspects of the patient can be seen before (Figure 8A-C) and after (Figure 8D-F) treatment completion. The facial view after treatment can be seen in Figure 9. The clinical follow-up with the intraoral aspects of the patient can be seen after six months (Figure 10) and after two years (Figure 11) of treatment.

Esthetic match, porcelain surface, marginal discoloration, and integrity were carefully examined for restoration following modified California Dental Association/Ryge criteria[21,22] at the recalls performed at the end of six months and two years. The ceramic laminate veneer after six-month and two-year follow-ups was rated as acceptable (Alpha scores were observed for all evaluation criteria).

POTENTIAL PROBLEMS

Esthetic rehabilitation planning must be performed through thorough evaluation that includes a facial analysis, dental-facial analysis, and dental analysis.[1-3] The dental literature recommends gathering the diagnostic data through forms and checklists;[23] however, nothing indicates how the information ideally should be gathered and implemented. Therefore, many of these diagnostic data may be lost if they are not transferred in an adequate way to the rehabilitation design. The DSD protocol[4] performed in this case allows a thorough analysis of the esthetic principles through the drawing of reference lines on

Figure 9. *The patient's facial view after treatment.*

Figure 10. *The patient's smile after six months of clinical follow-up.*

Figure 11. *The patient's smile after two years of clinical follow-up.*

digital photographs that in a predetermined sequence are transferred to a cast model and serve as a guide for diagnostic wax-ups, thereby preventing loss of diagnostic data.[4,24,25] Although the DSD is a simple technique that does not require specific equipment or software for its achievement, training and handling are required, but because of the simplicity of the technique may not represent a limitation.

In the present case, veneers were made with lithium disilicate glass-ceramic. These ceramics provide excellent esthetic value and demonstrate high translucency, just like natural dentition.[8] However, the final shade of the veneers depends not only on the shade, opacity, and thickness of the porcelain but also on the shade of the underlying tooth and the shade and thickness of the luting composite.[26,27] Therefore, in this case the color of the resin cement was established through the try-in pastes. These pastes simulate the shade effect of ceramic restorations, allowing the choice of an ideal shade of the luting resin that does not compromise the final shade of the veneers. Another limitation of the minimally invasive ceramic veneers is the inability to mask severely stained teeth.[28] However, ceramic veneers had a satisfactory cosmetic result in this case, in which teeth were affected by enamel hypoplasia.

Ceramic laminate can be considered a conservative treatment option for reestablishing aesthetic teeth[9] because it enables minimally invasive veneer preparation designs. These involve less tooth reduction and minimal porcelain thickness.[11] The thin laminate can cause an increased risk of crack formation and fracture in luting due to the stress generated by polymerization shrinkage.[29] As a result of their high mechanical properties, glass-ceramics, with flexural strength of approximately 306 MPa,[30] can be used in clinical situations when higher flexure risk factors are involved,[31] as in minimally invasive ceramic veneers. With this material, it is possible to have thicknesses of less than 0.5 mm with or without preparation of the enamel because of their increased strength and fracture toughness, as well as the presence of sufficient room to achieve the desired esthetics.[31] However, since the thin laminate veneer is a new treatment modality, longitudinal clinical studies are necessary to understand whether the small thickness of the ceramic veneers does not compromise their mechanical strength and long-term clinical behavior.

The preparation technique for porcelain laminate veneers is important for the longevity of the restoration because the high failure rates of these restorations have been attributed to the large exposed dentin surfaces.[18] Although improved new adhesives and resin luting cement have been developed, the bond strength of porcelain to enamel is still superior compared with the bond strength of porcelain to dentin.[32] Dentin substrate has a lower inorganic content, tubular structure, and variations in this structure, along with the presence of outward intratubular fluid movement, may result in the aging of the restoration through hydrolytic degeneration of the interface components, resin, and/or collagen. This can be considered one of the main reasons for resin degradation within the hybrid layer, which contributes to the reduction in bond strengths between dentin/adhesives over time.[33] Therefore, the preparation should be done completely in enamel to maintain an optimal bond with the porcelain laminate veneers[32] and to obtain a greater clinical longevity for this restoration,[18] as was the case in this clinical case.

SUMMARY OF ADVANTAGES AND DISADVANTAGES

The DSD protocol allows for esthetic planning through the drawing of reference lines and the final dental design on extra- and intraoral digital photographs. That protocol widens the diagnostic vision and helps the team members measure the treatment limitations and risk factors such as asymmetries, disharmonies, and violations of esthetic principles. In addition, the DSD protocol provides a greater predictability of treatment and facilitates the communication between the interdisciplinary team members and the dental technician. Because the protocol allows for the viewing of the relationship between the preoperative situation and the ideal design, it serves as a guide to conduct the diagnostic wax-up more efficiently by focusing on developing anatomical features within the parameters provided, such as planes of reference, facial and dental midlines, recommended incisal edge position, lip dynamics, basic tooth arrangement, and the incisal plane. The protocol is also an amazing tool for communicating with patients, because the clinician is able to clearly illustrate the issues and possible solution, thus balancing the patients' expectations as well as increasing their understanding of the treatment plan and discussions of the prognosis. In addition, with the drawings and reference lines, it is possible to perform comparisons between the before and after pictures, which allows for a precise reevaluation of the results obtained in every phase of treatment.[4,34-36] On the other hand, this protocol requires a lot of time and has a relatively high cost, which makes this approach less accessible to all patients.

In this case report, the patient complained about the esthetics of her smile, which presented enamel hypoplasia on the facial surface of the upper teeth, and a disharmony of shape and proportion of the maxillary anterior teeth and the gingival contour. Treatment possibilities using gingivoplasty, dental bleaching, and laminate veneers, as well as their advantages and limitations, were shared with the patient.

With the intention of improving the final esthetic result, gingivoplasty on tooth 9 and a bleaching protocol were established as the first steps of the treatment. During the gingivoplasty, an internal bevel incision was made from the free gingival margin to prevent the exposure of connective tissue and to provide for a comfortable postoperative experience and rapid healing. The dental bleaching in less severe cases of enamel hypoplasia may be a conservative alternative able to generate good results, but it can also increase the risk of highlighting the spots.[10] Nevertheless, the desire to modify the shape, size, volume, and tooth position was key to the choice of the restorative treatment. The dental bleaching was necessary because the final color exhibited by a porcelain veneer will be the result of the interaction among the porcelain laminate, substrate, and luting cement.[26,37]

Although composite resin can be used to mask tooth discolorations and to correct unaesthetic tooth shape and position, this type of restoration still suffers from limited longevity because the material remains susceptible to discoloration, wear, and marginal fractures, thereby reducing the esthetic result in the long term. On the other hand, porcelain veneers have proven to be durable anterior restorations with superior esthetics.[12,13,38] This type of restoration presents lower failure rates with regard to long-term survival and is considered more durable than direct composite veneers as long as the patients are adequately selected, the veneers are prepared following meticulous clinical procedures, and the available materials and techniques are correctly applied.[12,30]

With the intention of performing the minimally invasive veneer preparation designs, the silicone matrix obtained from the wax-up was used as a guide during the tooth preparation.[6] One critical step in the porcelain laminate technique is the achievement of sufficient ceramic thickness, and the guide allows for more enamel preservation and, as a consequence, more predictable bonding, biomechanics, and esthetics. Another strategy used to improve the predictability of the treatment was the mock-up, which allows for a tridimensional intraoral revisualization of the final result. This not only allows us to make adjustments and anatomical changes to obtain the best esthetic, phonetic, and functional outcomes but it also allows for better communication with the patient and laboratory.[20]

The porcelain laminate veneer technique includes the bonding of a thin porcelain laminate to the tooth's surface with adhesive techniques and resin cement.[12] For the longevity of this treatment, the strength and durability of the adhesion formed between the veneers and the tooth complex are crucial.[39] In the present report, the clinician used 'gold standard' materials such as a three-step etch-and-rinse adhesive system and light-cured luting resins. This is a photocured material that has a greater clinical longevity, greater bonding strength to the enamel substrate,[14,18,32] and stability of cement color over time.[40] It is known that the light transmission through veneers affects the degree of polymerization of light-polymerized resin luting agents, and the intensity of light transmitted through ceramic veneers was dictated by the polymerization unit and the type and thickness of the ceramic.[41] The IPS Empress e.max Press ceramic veneer is a translucent material and was used with a small thickness that does not compromise the polymerization process of resin cement,[42] resulting in a greater degree of conversion that will lead to more stable color after polymerization[40] and better esthetic results.

In the present report, the esthetic rehabilitation planning was adequately performed, the patient and technique were adequately selected, and materials were correctly applied, resulting in satisfactory esthetics immediately and after two years of follow-up.

CONCLUSION

This clinical report described the DSD protocol for esthetic rehabilitation. The DSD is a tool that assists with the diagnostics and allows the clinician to better predict treatment outcomes by using analysis of the esthetic principles in extra- and intraoral digital photographs. In addition, implementation of a digital dentistry tool can improve communication among the patient, clinician, and dental laboratories and may become a common technique for all esthetic rehabilitations. The DSD is a simple technique that does not require specific equipment or software; however, training and handling are required.

The treatment using gingivoplasty, tooth whitening, and thin ceramic laminate veneers, when done using appropriate materials and techniques, is a minimally invasive approach and is a feasible option for esthetic rehabilitation, showing satisfactory clinical applicability and contributing to the esthetic result over two-year follow-up.

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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 Federal University of Pelotas in Brazil. Patient consent for use of images was obtained.

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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Use of a Direct Anatomic Post in a Flared Root Canal: A Three-year Follow-up

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Clinical Relevance

A standard fiber post does not adapt well to a flared root canal preparation, leaving a large cement space between the post and the tooth structure. Direct anatomic posts provide an alternative technique for restoring these teeth with less chance of debonding.

SUMMARY

The following case report describes the three-year follow-up after rehabilitation of a flared root canal using a direct anatomic post (a resin composite combined with a prefabricated glass fiber post) associated with metal-free ceramic restoration. The report presents the clinical protocol for the fabrication of the posts, which provide an intimate fit to the remaining root and mechanical properties similar to those of the dental structure. These posts serve as an alternative to conventional metal cores.

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INTRODUCTION

Teeth submitted to endodontic treatment typically have extensive loss of dental structure and require the use of intraradicular retainers and filling cores to hold the final restoration.[1] However, the mismatch between the root canal space and post diameters is a clinically relevant concern.[2] Wide root canals can be the result of carious lesions, previous restorations with excessive post and core diameters, endodontic overinstrumentation, incomplete physiological root formation, internal resorption, developmental anomalies, or even oval-shaped root canals.[3,4]

Although cast-metal cores can be made to adapt well to the remaining root structure, they can produce a wedging action under masticatory forces, resulting in root fractures and condemning the tooth to extraction.[5] Prefabricated fiber posts do not

Figure 1. *Initial smile.*

Figure 2. *One can notice the presence of a fractured provisional restoration of direct composite resin on tooth 21 ISO (8 Universal).*

resemble the individual root canal anatomy and adapt inaccurately, thereby obliging the operator to employ excessive amounts of resin cement to replace lost structure.[6] In this way, several techniques have been suggested to restore weakened root canals, and among them, there is the technique of anatomical shaping of prefabricated fiber posts with a composite resin into the root canal.[7] This technique provides a close adaptation of the post to the root canal, reduces the resin cement thickness, improves the mechanical and retentive properties of restored teeth,[7-11] and significantly reduces the chance of root fracture.[8,12,13] Therefore, anatomical posts seem to be an effective method to improve the biomechanical behavior of flared root canal preparations.

Good laboratory results were observed with this technique.[8-10,13] For instance, Clavijo and others[8] and Silva and others[13] demonstrated that anatomical posts showed similar fracture strength to that of metallic posts and superior performance to those of non-relined fiber posts in flared root canals. Faria-e-Silva and others[9] and Macedo and others[10] showed that fiber post relining resulted in higher bond strength than prefabricated posts without relining in flared root canals. Based on these positive results, the aim of this clinical case was to describe the anatomical shaping of a prefabricated (direct anatomical) post, to discuss the important clinical steps involved in the success of this clinical protocol, and to report the three-year follow-up of this clinical rehabilitation.

CASE REPORT

A 30-year-old female patient sought specialized dental treatment with the complaint of lack of esthetics associated with the upper central incisor (tooth 21 in the ISO system or tooth 8 in the universal numbering system). Under clinical and radiographic examination, we diagnosed the presence of a wide and faulty composite resin restoration (Figures 1 and 2) and a periapical lesion. Endodontic retreatment, fiber post cementation, and an all-ceramic crown were recommended. An initial impression with addition silicone (Express XT [commercially available in the United States as Express VPS], 3M ESPE, St Paul, MN, USA) was done to prepare stone models, a diagnostic wax-up, and a mock-up.[14]

After this, gutta-percha was removed, leaving 4 mm of the apical seal, and the corresponding drill of the Exacto 3 post (Ângelus, Londrina, PR, Brazil) was used for canal preparation (12 mm; Figure 3). In the same visit, the post was anatomically characterized with composite resin for better adaptation into the root canal and retention of the indirect crown.

For this purpose, a glass fiber post 3 was conditioned with 37% phosphoric acid gel (Total Etch, Ivoclar-Vivadent, Schaan, Liechtenstein) for 15 seconds, followed by rinsing and drying. The fiber post was coated with silane (Silane, Ângelus) for one minute, and the surface was gently air-dried (for five seconds). The two-step etch-and-rinse adhesive system (Tetric N-Bond [commercially available in the United States as Heliobond], Ivoclar-Vivadent) was applied and light-cured for 10 seconds (Radii Plus, SDI Limited, Victoria, Australia; 1200 mW/cm^2). The fiber post was covered with a nanohybrid composite resin (Tetric N-Ceram [commercially available in the United States as Tetric EvoCeram], Ivoclar-Vivadent; Figure 4), and the set (fiber post and composite resin) was inserted into the canal (Figure 5), previously lubricated with a hydrosoluble gel (KY, Johnson & Johnson, São José dos Campos, SP, Brazil).

This set was removed and replaced twice, and the excess cervical resin composite was removed. The composite resin was light-cured for 20 seconds with the post inside the root canal. The relined fiber post was then removed (Figure 6), and the composite resin was additionally light-cured for 20 seconds on each surface for additional polymerization.

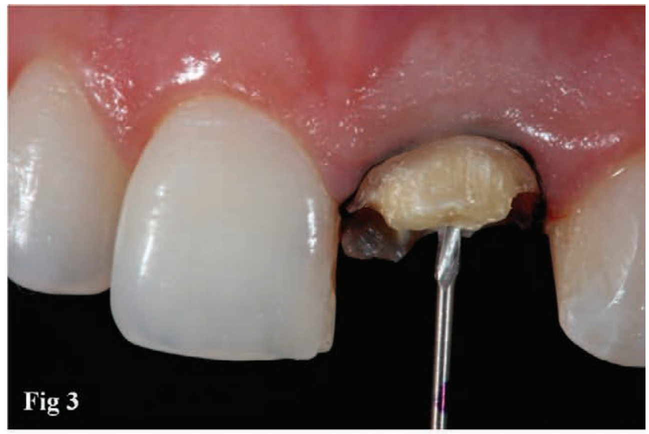
After removal of the retentive areas (Figure 7), the direct anatomic post was inserted into the root canal, and the core was built up with a fiber core (Reforcore, Ângelus) and a nanohybrid composite resin (Tetric N-Ceram, Ivoclar-Vivadent) through incremental filling. Each increment was light-cured for 20 seconds.

The core was then prepared to receive an all-ceramic crown. A ferrule at the coronal end on the buccal and palatal surfaces, 2.0 mm in height and 1.2 mm in depth, was prepared; on the mesial and distal surfaces, the same dimensions were achieved, but the margins ended on resin. Reductions of 1.5 to 2.0 mm were performed on the occlusal surfaces and 1.0 to 1.5 mm on buccal and palatal surfaces. All angles were rounded, and the cervical finish line was continuous, defined, and clear. After preparation, the composite core was finished and polished with Sof-Lex aluminum oxide discs (3M-ESPE; Figure 8). The post was removed (Figure 9), and both the root canal and the relined fiber post were rinsed abundantly with water and air to remove the lubricant gel.

The post was conditioned with 37% phosphoric acid gel (Total Etch, Ivoclar-Vivadent) for 15 seconds. A self-adhesive resin cement (RelyX U200 [commercially available in the United States as RelyX Unicem 2], 3M ESPE) was introduced into the root canal space and on the post surface. The fiber post was seated (Figure 10), the excess resin cement was removed, and the remaining cement was light-cured through the post for 40 seconds. Finally, a temporary restoration was cemented.

In the next session, an impression of the prepared crown was taken with addition silicone (Express XT, 3M ESPE) and sent to a prosthetic laboratory. The all-ceramic crown was fabricated with the IPS e-max System (Ivoclar-Vivadent). After testing and adjustments, the internal area of the crown was conditioned with hydrofluoric acid (IPS Etching Gel, Ivoclar-Vivadent) for 20 seconds and water-rinsed for one minute.

The surfaces of the prepared tooth were etched with 37% phosphoric acid gel (Total Etch, Ivoclar-Vivadent) and rinsed for 15 seconds with an air-water spray. Excess water was removed by gently blowing air, leaving the dentin slightly moist. A dual-cure adhesive system (Excite DSC [commercially available in the United States as Excite F



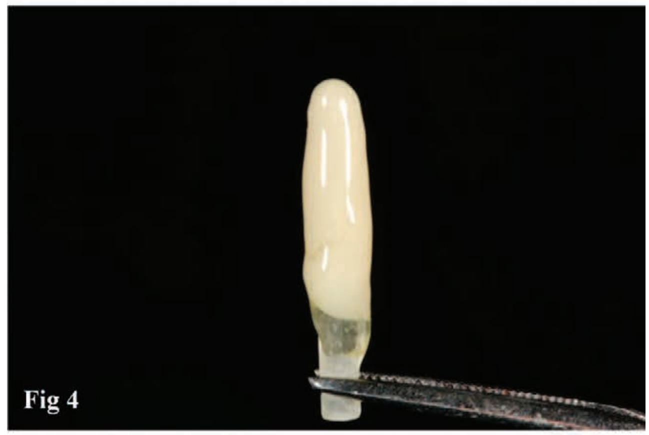


Figure 3. *After removal of the crown, root canal preparation with the corresponding drill of the fiber post selected.*

Figure 4. *After appropriate superficial treatment, the fiber post was covered with a nanohybrid composite resin.*

Figure 5 *The set (fiber post + composite resin) being inserted into the canal.*

Figure 6. *The relined fiber post being removed from the root canal.*

Figure 7. *Removal of the retentive areas of the direct anatomic post.*

DSC], Ivoclar-Vivadent) was applied and light-cured for 10 seconds. The base and catalyst components of Variolink II (Ivoclar-Vivadent) were mixed and introduced into the indirect crown. The crown was seated, the excess resin cement was removed, and the cement was light-cured for 40 seconds on each crown surface. Excess cement was removed with a #12 scalpel blade, and the outcome of the restorative procedure after seven days can be seen in Figures 11 and 12 and after three years in Figure 13.

DISCUSSION

The present case was suitable for the preparation of a direct anatomic post. As a result of the endodontic retreatment, the tooth had a flared root canal with thin radicular dentin. Introducing a conventional fiber post into the canal required a thick layer of luting cement to fill up the spaces between the loosely fitting post and the canal walls. This would have subjected the restoration and tooth to adhesive failure and/or post debonding.[15] Thus, using a post well-fitted to the canal shape allows the use of a thin, uniform layer of cement that increases retention.[7,11]

Some authors[16-19] suggest the restoration of flared root canals with composite resin to reduce canal width. However, the difficulties in providing an adequate curing at the deepest regions of the canal wall may affect the material's properties[20]

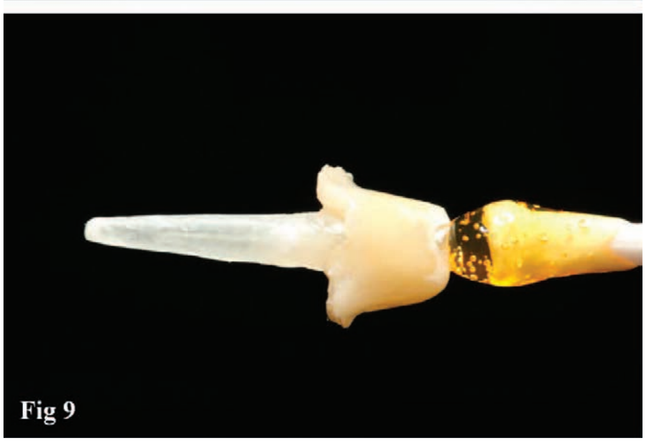


Figure 8. *Coronal preparation of the direct core after finishing and polishing.*

Figure 9. *The direct anatomic post ready to be cemented.*

Figure 10. *The cementation of the anatomic post.*

Figure 11. *Close view of the outcome of the restorative procedures after seven days.*

Figure 12. *Lateral view of the outcome of the restorative procedures after seven days.*

Figure 13. *The outcome of the restorative procedures after three years.*

and its bonding to the adhesive layer. This does not occur with the direct anatomic post, as the composite resin attached to the fiber post is first cured inside the root canal, but it can also be further cured before the luting procedures.

Another suggested protocol is the use of accessory posts to fill in the mismatch around the main glass fiber post and the root canal.[8,21] Contrary to expectations, the thickness of the cement layer is not reduced significantly, as empty spaces still remain between the accessory posts and the root walls. Thus, the likelihood of the resin cement layer presenting large lacunae or bubbles is high,[22] reducing the adhesive performance of this technique.[23]

In the direct anatomical post technique, as performed in this case report, the fiber post is relined in the root canal, replacing the resin cement with composite resin,[7] which has better mechanical and physical properties.[7-10] This technique is relatively easy; only a few additional steps are required beyond those needed to lute a conventional fiber post. Indirect anatomic posts were claimed to have superior mechanical properties,[8] but they have the disadvantage of being more time-consuming and expensive to fabricate as a result of the need for a laboratory step.

The good performance of the anatomical post techniques in laboratory studies[8-10,13,23] can be attributed to the high hydraulic pressure they put on the cement against the dentin walls, resulting in better contact between the cement/post set and the dentin.[9,24] This pressure reduces blister formation in the cement,[24] eliminates sources of flaw-initiating sites; increases the number of tubules filled with the resin cement[25] because of better penetration of resin into demineralized dentin; and results in a more uniform hybrid layer, with greater resin tags and adhesive lateral branches.

Given the tendency to prepare esthetic metal-free restorations, the use of anatomical posts offers a solution when facing flared root canals in daily practice.

CONCLUSIONS

The use of direct anatomical posts in flared root canals is a practical and fast technique that can be applied for direct and indirect esthetic restorations with the aim of both increasing the bond strength between the fiber post and the root canals and minimizing the risk of fractures commonly observed with cast-metal posts.

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 Toothpaste Application Prior to Dental Bleaching on Whitening Effectiveness and Enamel Properties

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Clinical Relevance

Dental bleaching promotes physical alteration in enamel, although these alterations might decrease when toothpaste is applied prior to the whitening procedures.

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SUMMARY

Objective: The purpose of this study was to investigate the effects on the enamel properties and effectiveness of bleaching using 35% hydrogen peroxide (HP) when applying toothpastes with different active agents prior to dental bleaching.

Methods: Seventy enamel blocks (4 × 4 × 2 mm) were submitted to *in vitro* treatment protocols in a tooth-brushing machine (n=10): with distilled water and exposure to placebo gel (negative control [NC]) or HP bleaching (positive control [PC]); and brushing with differing toothpastes prior to HP bleaching, including potassium nitrate toothpaste (PN) containing NaF, conventional sodium monofluorophosphate toothpaste (FT), arginine-based toothpastes (PA and SAN), or a toothpaste containing bioactive glass (NM). Color changes were determined using the CIE L*a*b* system (ΔE, ΔL, Δa, and Δb), and a roughness (Ra) analysis was performed before and after treatments. Surface microhardness (SMH) and cross-sectional microhardness (CSMH) were

analyzed after treatment. Data were analyzed with repeated measures ANOVA for Ra, one-way ANOVA (SMH, ΔE, ΔL, Δa, and Δb), split-plot ANOVA (CSMH), and Tukey post hoc test (α<0.05). The relationship between the physical surface properties and color properties was evaluated using a multivariate Canonical correlation analysis.

Results: Color changes were statistically similar in the bleached groups. After treatments, SMH and CSMH decreased in PC. SMH increased significantly in the toothpaste groups vs the negative and positive control (NM > PA = SAN > all other groups) or decreased HP effects (CSMH). Ra increased in all bleached groups, with the exception of NM, which did not differ from the NC. The variation in the color variables (ΔL, Δa, and Δb) explained 21% of the variation in the physical surface variables (Ra and SMH).

Conclusion: The application of toothpaste prior to dental bleaching did not interfere with the effectiveness of treatment. The bioactive glass based toothpaste protected the enamel against the deleterious effects of dental bleaching.

INTRODUCTION

Because the demand for esthetic dentistry has recently increased, treatment protocols for altering tooth color have been developed, with tooth bleaching becoming an attractive treatment.[1] The whitening mechanism is unclear, although it most likely involves the diffusion of hydrogen peroxide (HP) through the enamel, where it reacts with the chromogens responsible for dental discoloration.[2] HP, as an oxidizing agent, breaks down the pigment molecules and makes them small enough to be removed from the dental structure through diffusion, which indirectly promotes the reduction of light absorption. This reduction in light absorption produces a significant reduction in the yellowness of dentin and an increase in whiteness for the tooth.[3]

Tooth bleaching is currently considered a safe treatment.[4] However, the effects of bleaching agents on dental tissues are not completely understood. *In vitro* studies show that changes in the morphology and properties of dental tissues can happen, such as 1) an increase in permeability and surface roughness[5-7] and 2) a decrease in surface and subsurface microhardness.[8,9] Despite favorable results and effectiveness of bleaching agents, some studies have reported side effects, with the intensity and frequency of these side effects associated with different experimental designs.[10]

Tooth sensitivity from dental bleaching is considered the most common adverse effect.[11,12] This effect starts at the beginning of the procedure and ends after discontinuing the use of the product. To eliminate the adverse effects in the morphology and properties of dental tissues, the use of fluoride remineralization systems during or after treatment has been suggested.[13-15] Additionally, the use of bleaching gel that includes different systems has been discussed; Haywood and others[16] demonstrated that the use of potassium nitrate toothpaste reduced bleaching sensitivity.

Conversely, dentifrices containing arginine or calcium sodium phosphosilicate (bioactive glass) have been studied for preventing and treating dentinal hypersensitivity,[17,18] as these compounds could promote beneficial effects and enamel rehardening,[19,20] resulting in a potential benefit for bleaching therapy.[21,22] However, there are no studies regarding the application of remineralizing compounds associated with dentifrices containing desensitizing agents prior to dental bleaching in the prevention of adverse effects caused by dental bleaching, mainly in relation to enamel properties and the effectiveness of bleaching.

The present study investigated the effects on enamel for toothpastes with different active or desensitizing agents used prior to dental bleaching with 35% HP by evaluating the effectiveness of bleaching, using color analysis, microhardness, and surface roughness on the properties and morphology of enamel. The null hypotheses tested were that the toothpaste application prior to dental bleaching would not affect the whiteness effectiveness and would not protect enamel against any deleterious effects of HP.

METHODS AND MATERIALS

Sample Preparation

Young bovine teeth were stored in a 0.01% thymol solution at 4°C for 30 days until use. Enamel/dentin blocks of 4 × 4 × 2 mm, with 1 mm of enamel and 1 mm of dentin, were obtained from the middle third of the buccal surface using a low speed water-cooled diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA). The specimens were then subsequently serially ground with 600-, 1000-, and 2000-grit SiC papers (Buehler Ltd) and polished with cloths and diamond spray (1, 0.5, and 0.25 μm, Buehler Ltd).

Table 1: *Products, Manufacturers, and Components of Toothpastes According to the Manufacturer's Information.*

Toothpaste	Manufacturer	Active agent	Fluoride	Other components
Sensodyne™ Fresh Impact (PN)	GlaxoSmithKline Brasil Ltda, Rio de Janeiro, Brazil	5% potassium nitrate	Sodium fluoride (NaF) 1426 ppm	Water, hydrated silica, sorbitol, glycerin, cocamidopropyl betaine, xanthan gum, titanium dioxide, sodium sacharin, sucralose, mentha piperita, D-limonene
Colgate™ Fluoridated Toothpaste (FT)	Colgate-Palmolive, São Bernardo do Campo, Brazil	-	Sodium monofluorophosphate (MFP) 1450 ppm	Water, calcium carbonate, glycerin, sodium lauryl sulfate, cellulose gum, tetrasodium pyrophosphate, sodium bicarbonate, benzyl alcohol, sodium saccharin, sodium hydroxide
Colgate™ Sensitive Pro relief Pro-Argin™ Technology (PA)	Colgate-Palmolive, São Bernardo do Campo, Brazil	8% arginine	MFP 1450 ppm	Water, calcium carbonate, sorbitol, arginine bicarbonate, sodium lauryl sulfate, cellulose gum, titanium dioxide, tetrasodium pyrophosphate, sodium bicarbonate, benzyl alcohol, sodium saccharin, xanthan gum, limonene
Colgate™ Maximum Cavity Protection PLUS Sugar Acid Neutralizer™ (SAN)	Colgate-Palmolive, São Bernardo do Campo, Brazil	1.5% arginine	MFP 1450 ppm	Water, calcium carbonate, glycerin, arginine bicarbonate, sodium lauryl sulfate, cellulose gum, titanium dioxide, tetrasodium pyrophosphate, sodium bicarbonate, benzyl alcohol, sodium saccharin, sodium hydroxide
Sensodyne™ Repair & Protect Novamin™ Technology (NM)	SmithKline Beecham Consumer Heathcare, Berkshire, United Kingdom	5% calcium sodium phosphosilicate	MFP 1426 ppm	Glycerin, silica, PEG-8, titanium dioxide, carbomer, cocamidopropyl betaine, sodium methyl cocoyl taurate, sodium saccharin, D-limonene

Between the polishing steps and at the end of this procedure, all samples were placed in an ultrasonic machine for 10 minutes (Marconi, Piracicaba, São Paulo, Brazil) to remove residual particles and smear layers to obtain a standardized enamel surface. The surfaces of the specimens, with the exception of the enamel surface, were protected with acid-resistant varnish (Risqué Colorless, Taboão da Serra, Brazil). Prior to (24 hours) and during the experiment, all prepared specimens were stored in artificial saliva in a 37°C incubator, with artificial saliva renewed every day during the study. The artificial saliva contained 1.5 mM Ca, 0.9 mM P, 150 mM KCL, 0.05 μg F/mL, and 0.1 M Tris buffer, set to a pH of 7.0.[23]

Sample Allocation

Seventy enamel-dentin blocks were allocated into seven groups (n=10). The initial L* value of each sample was used to stratify and allocate specimens into all groups, because the L* value is a significant parameter when making comparisons under the study design,[24] which aimed to reduce the initial variability among the groups. The evaluation method of the L* coordinate is described below.

Toothpaste Treatment

The specimens were submitted to simulated brushing using toothbrush heads (Oral-B Indicator 40 Soft, Gillette do Brasil Ltd, Manaus, Brazil) coupled to an automatic tooth-brushing machine (Equilabor, Piracicaba, Brazil) with a static axial load of 200 *g* and a speed of 5 movements/second, at 37°C.[25,26] One month of tooth brushing was simulated using 825 cycles.

Enamel blocks were brushed with toothpaste slurry (1:3) or distilled water. Information on the toothpastes used, including manufacturers and components, are detailed in Table 1. Additionally, the pH of the toothpastes was determined in triplicate using a pH meter (Procyon, São Paulo, Brazil), and the fluoride concentration (total fluoride, ionizable fluoride, and total soluble fluoride) in

Table 2: *Fluoride Concentration and pH of Toothpastes*

Toothpaste	Fluoride	Manufacturer's information (ppm)	Total fluoride (ppm)	Total soluble fluoride (ppm)	Ionic fluoride (ppm)	pH
PN	NaF	1426	1426.8	1440.1	1416.4	7.26
FT	MFP	1450	1486.8	1081.7[a]	247.8[a]	9.44
PA	MFP	1450	1524.5	1154.5[a]	338.1[a]	9.07
SAN	MFP	1450	1390.7	1127.8[a]	161.0[a]	9.36
NM	MFP	1426	1412.3	1411.3	64.6[a]	9.64

Abbreviations: FT, fluoride as MFP; NM, bioactive glass; PA, 8% arginine; PN, potassium nitrate (with NaF).
[a] *Statistical difference between the fluoride present in toothpastes in relation to the manufacturer's declaration using a one sample* t-test ($p>0.05$).

the toothpastes was determined as previously described,[27] using a specific ORION 96-06 electrode and an EA 940 ion analyzer (Orion, Boston, MA, USA). These results are presented in Table 2. All samples were randomly divided into seven groups according to the treatments (n=10): brushing with distilled water and placebo gel (negative control [NC]); brushing with distilled water and bleaching with 35% HP (positive control [PC]); brushing with potassium nitrate toothpaste containing NaF and bleaching with 35% HP (PN); brushing with conventional sodium monofluorophosphate (MFP) fluoridated toothpaste and bleaching with 35% HP (FT); brushing with arginine-based toothpaste (8% arginine, Pro-Argin Technology) and bleaching with 35% HP (PA); brushing with arginine-based toothpaste (1.5% arginine, Sugar Acid Neutralizer™) and bleaching with 35% HP (SAN); and brushing with toothpaste containing bioactive glass (Novamin) and bleaching with 35% HP (NM).

After each brushing treatment, the specimens were washed with distilled water for 10 seconds and stored in artificial saliva for 24 hours, before each dental bleaching procedure.

Bleaching Procedure

The bleaching treatment was performed using 35% HP (Whiteness HP, FGM, Joinville, Brazil), according to the manufacturer's instructions. The bleaching agent was applied to the enamel surface three times for 15 minutes each. The negative control group was exposed to a treatment with a placebo gel (Proderma, Piracicaba, Brazil), composed of distilled water, neutralized carbopol, glycerin, and triethanolamine, which was buffered to pH 6.0 (which was similar to the initial pH of the commercial bleaching gel used in this study). The specimens were then washed with distilled water and analyzed. The initial and final pH of the bleaching agent was measured in triplicate: initial pH = 5.64; after 15 minutes, pH = 4.87.

Color Measurements

Color reading of each specimen was performed at an ambient light condition (GTI MiniMatcher MM 1, GTI Graphic Technology, New York, NY, USA) in standardized daylight. The color was measured using a spectrophotometer (CM 700d, Minolta, Osaka, Japan). The spectral distribution was measured based on the CIE L*a*b* system, using On Color software (Konica Minolta). L* represents the luminosity (white-black) axis, a* represents the green-red axis, and b* represents the blue-yellow axis. Before measurement, the spectrophotometer was calibrated using white and black reflectance standards, according to the manufacturer's protocol. The differences in the L*, a*, and b* values between initial (baseline) and final (after 24 hours of bleaching) were expressed (ΔL, Δa, and Δb), and any color change was calculated using the following equation: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Surface Roughness

For enamel roughness analysis (Ra), each sample was rinsed in distilled water prior to profilometer measurements. The Ra was analyzed using a profilometer at two times: before (baseline) and 24 hours after bleaching (Surf-Corder 1700, Kosaka, Tokyo, Japan). Three different equidistant directions were measured on the surface of each specimen, with a cutoff of 0.25 mm, a reading length of 1.25 mm, and a velocity of 0.1 mm/s.

Microhardness Analysis

The enamel surface microhardness (SMH) was analyzed after the treatments using a Knoop indenter with a load of 50 *g* and time of 5 seconds in a microhardness tester (HMV-2000, Shimadzu, Tokyo, Japan). Five indentations were made in each sample, 100 μm apart, and the average was calculated to determine the Knoop hardness number (KHN). For the cross-sectional microhardness

Table 3: *Mean (SD) for ΔL, Δa, Δb, and ΔE Based on Treatment Group (n=10)*[a]

Toothpaste	ΔL	Δa	Δb	ΔE
Negative control	0.14 (1.0)[b]	−0.14 (0.3)[ab]	0.72 (0.9)[b]	1.45 (0.5)[b]
Positive control	2.53 (1.0)[a]	−0.45 (0.4)[b]	−5.31 (0.8)[a]	5.96 (1.0)[a]
PN	2.37 (1.0)[a]	0.16 (0.5)[a]	−4.90 (0.8)[a]	5.54 (0.9)[a]
FT	1.85 (0.9)[a]	0.14 (0.4)[ab]	−4.90 (0.6)[a]	5.31 (0.7)[a]
PA	2.48 (1.4)[a]	−0.09 (0.3)[ab]	−5.48 (1.3)[a]	6.18 (1.2)[a]
SAN	2.41 (1.4)[a]	−0.06 (0.6)[ab]	−5.25 (1.3)[a]	5.92 (1.5)[a]
NM	2.42 (1.0)[a]	−0.10 (0.5)[ab]	−4.61 (1.3)[a]	5.27 (1.5)[a]

[a] *Identical lowercase letters indicate no significant difference (p>0.05) among different groups in the same column. Abbreviations: FT, fluoride as MFP; Negative control, unbleached; NM, bioactive glass; PA, 8% arginine; PN, potassium nitrate (with NaF); Positive control, bleaching with 35% hydrogen peroxide (HP); SAN, 1.5% arginine.*

(CSMH) tests, the specimens were longitudinally sectioned through the center, and one-half was embedded in acrylic resin, exposed, and gradually polished as previously described. Three columns of five indentations were made in the central area of the slab using the microhardness tester and a load of 50 *g* for 5 seconds, with measurements occurring 10, 25, 50, 75, and 100 μm from the enamel surface. The mean values at all three measuring points at each distance were then determined.

The indentations can change the topography of the enamel surface and modify the light reflectance pattern, with negative impact on color and roughness analysis. Therefore, the SMH was evaluated only at the final time point, and the experimental groups were statistically compared with control groups.

Statistical Analysis

After exploratory analysis using the SAS software (Release 9.1, 2003, SAS Institute Inc, Cary, NC, USA), the data were subjected to one-way analysis of variance (ANOVA) (SMH, ΔE, ΔL, Δb, and Δa), ANOVA using models for repeated measures (Ra), and split-plot ANOVA (CSMH) followed by the Tukey test, at a 5% level of significance. The analysis of fluoride concentration in toothpaste was performed using a one-sample *t*-test.

A power calculation of the color variables with the following parameters was performed: $\alpha = 0.05$ and a power setting of 0.8. The power calculation computed a sample size of a minimum of nine considering the difference values proposed by Alghazali and others[28] being 1.9 ΔE* units for assessment of perceptibility and 4.2 ΔE* units for clinical acceptability of color differences.

The relationship between the physical surface properties (Ra, SMH) and color properties (ΔE, ΔL, Δb, and Δa) was performed using a multivariate Canonical correlation analysis. The correlations were tested separately by the approximate *F* test and associated with Wilks' lambda, Pillai's trace, Hotelling-Lawley trace, and the Roy 's greatest root ($\alpha<0.05$).

RESULTS

When considering Table 2, the FT, PA, SAN, and NM groups presented a slightly alkaline pH. Overall, all groups showed that the total fluoride present in toothpastes was statistically similar to what the manufacturer declared ($p>0.05$). In relation to total soluble fluoride, only PN and NM showed no difference between the values that the manufacturer declared ($p>0.05$). Furthermore, the PN group demonstrated higher values for ionic fluoride concentration, which was similar to the manufacturer's information ($p=0.85$).

Based on color analysis (Table 3), the positive control statistically differed from the negative control for the ΔL, Δb, and ΔE values ($p<0.001$), with increasing L* values and decreasing b* values; the Δa values did not differ between the negative and positive controls. The toothpaste groups demonstrated a statistical difference for ΔL, Δb, and ΔE values compared with the negative control (unbleached). However, the Tukey test did not demonstrate a statistical difference between the toothpaste groups and the positive control, indicating that these toothpastes did not act directly on the ΔL, Δb, and ΔE values of the specimens during dental bleaching. The PN demonstrated Δa values that differed statistically from the positive control ($p<0.05$), although the ΔL, Δb, and ΔE values were similar to toothpaste groups and positive control.

From the means of roughness values (Table 4), the results of the positive control showed increased Ra values compared with the initial values and the

Table 4: *Mean (SD) for Initial and Final Roughness Values (Ra) Based on Treatment Group (n=10)[a]*

Toothpaste	Initial Ra	Final Ra
Negative control	0.11 (0.02)[Aa]	0.10 (0.02)[Ac]
Positive control	0.11 (0.01)[Ba]	0.14 (0.01)[Ab]
PN	0.11 (0.02)[Ba]	0.15 (0.01)[Ab]
FT	0.11 (0.01)[Ba]	0.14 (0.03)[Ab]
PA	0.11 (0.02)[Ba]	0.13 (0.01)[Ab]
SAN	0.11 (0.01)[Ba]	0.23 (0.02)[Aa]
NM	0.11 (0.02)[Aa]	0.11 (0.02)[Ac]

[a] Means followed by different letters (uppercase in rows and lowercase in columns) are different by PROC-MIXED ANOVA and Tukey test (p<0.001). Abbreviations: FT, fluoride as MFP; Negative control, unbleached; NM, bioactive glass; PA, 8% arginine; PN, potassium nitrate (with NaF); Positive control, bleaching with 35% hydrogen peroxide (HP); SAN, 1.5% arginine.

negative control ($p<0.001$), although no statistically significant difference was found between the PN, FT, and PA groups ($p>0.05$). Nevertheless, the negative control did not increase or decrease the surface roughness, with no statistically significant differences between times ($p>0.05$). In the toothpaste groups, the NM treatment did not affect the enamel roughness, with no statistical difference compared with the negative control or between times ($p>0.05$). In the groups comparison, NM showed lower Ra values that statistically differed from the other groups ($p<0.001$). Furthermore, the SAN group increased in surface roughness, which was statistically different from the initial values, the other toothpastes, and the control groups ($p<0.001$). All groups (with the exception of NM) showed statistically significant differences in relation to the negative control ($p<0.05$) and their respective initial Ra values ($p<0.05$).

In the positive control group, bleaching caused a statistically significant loss of SMH (Table 5, SMH results) compared with the negative control. In contrast, although bleached, the toothpaste groups increased in SMH, which was also statistically different from the negative control (unbleached) and positive control ($p<0.001$). FT promoted a slight increase in KHN values compared with the negative control while statistically differing from the SAN and PA groups (intermediary values). However, these groups did not differ from the PN group. The highest microhardness values were found in the NM group, which showed statistically different values compared with the positive and negative controls and the other experimental groups ($p<0.001$).

The results of CSMH (Table 5) showed that bleaching (negative control) reduced the microhardness of the positive control, up to a depth of 100 μm, whereas this depth was not statistically different between all groups ($p>0.05$). There were no statistically significant differences between the toothpaste groups and the negative control at all depths ($p>0.05$). All toothpaste groups presented improved CSMH values compared with the positive control at 10 μm, whereas only the FT, SAN, and NM groups were statistically different from the positive control at depths of 25 and 50 μm ($p<0.05$). PA and PN did not statistically differ from the negative and positive controls at depths of 25 and 50 μm ($p>0.05$). Finally, no experimental group differed from the positive or negative controls at depths of 75 and 100 μm. No differences were found among the toothpaste groups at all depths ($p>0.05$).

The results showed a high correlation between $\Delta E \times \Delta L$ ($r=0.74$, $p<0.0001$) and $\Delta E \times \Delta b$ ($r=-0.94$, $p<0.0001$). The Canonical correlation was based on the determination of orthogonal canonical variables, as these variables must be linearly independent. The

Table 5: Mean (SD) for Enamel Surface Microhardness (SMH) and Cross-sectional Microhardness (CSMH) Values Based on Treatment Group (n=10)[a]

Toothpaste	SMH	CSMH				
		10 μm	25 μm	50 μm	75 μm	100 μm
Negative control	350.5 (14.5)[d]	395.6 (10.6)[Aa]	395.3 (13.2)[Aa]	402.8 (13.2)[Aa]	396.3 (12.5)[Aa]	395.7 (12.2)[Aa]
Positive control	304.0 (20.7)[e]	339.1 (17.6)[Cb]	359.3 (18.4)[Bb]	361.4 (21.0)[Bb]	369.2 (18.5)[Bb]	378.8 (16.2)[Aa]
PN	395.5 (19.7)[bc]	386.6 (15.0)[Aa]	382.2 (21.1)[Aab]	395.1 (15.9)[Aa]	385.4 (9.7)[Aab]	382.1 (12.1)[Aa]
FT	376.7 (9.0)[c]	387.6 (14.9)[Aa]	390.1 (17.7)[Aa]	385.0 (15.4)[Aa]	382.0 (16.5)[Aab]	387.3 (13.0)[Aa]
PA	406.3 (17.6)[b]	379.6 (15.3)[Aa]	382.8 (15.4)[Aab]	382.7 (20.8)[Aab]	393.1 (19.2)[Aab]	387.0 (16.9)[Aa]
SAN	409.5 (16.3)[b]	386.6 (15.5)[Aa]	387.1 (9.7)[Aa]	387.9 (11.8)[Aa]	387.1 (13.2)[Aab]	386.9 (11.6)[Aa]
NM	436.3 (17.6)[a]	394.0 (11.9)[Aa]	393.7 (12.5)[Aa]	391.8 (10.0)[Aa]	387.3 (7.5)[Aab]	388.0 (8.2)[Aa]

[a] Means followed by different letters (SMH, lowercase in column; CSMH, uppercase in rows and lowercase in columns) are statically different (p<0.05). Abbreviations: FT, fluoride as MFP; Negative control, unbleached; NM, bioactive glass; PA, 8% arginine; PN, potassium nitrate (with NaF); Positive control, bleaching with 35% hydrogen peroxide (HP); SAN, 1.5% arginine.

correlation showed the necessity of eliminating the ΔE variable from the ultimate analysis. The data showed a significant canonical correlation (canonical axis) relating the physical surface variables and color variables (F=3.59; p=0.0025; p value of Wilk's lambda=0.0025). The variation in the color variables (ΔL, Δa, and Δb) explained 21% of the variation in the physical variables (Ra, SMH). The r values of color variables that influenced the physical surface properties were ΔL (r=0.2297), Δa (r=0.1509), and Δb (r=–0.4179).

DISCUSSION

The null hypotheses tested in this study were partially accepted because the bioactive glass-based toothpaste protected the enamel against the deleterious effects of HP, and no toothpaste affected the effectiveness of bleaching. In the present study, enamel blocks were obtained from bovine teeth. These specimens were used because their physical and chemical properties are very similar to those of human teeth, and young bovine teeth are considered a practical model for evaluating bleaching procedures.[29]

The effect of remineralization agents has been confirmed in previous investigations.[13-15,21-22] Fluoridation regimens with toothpaste or gel have been shown to be effective in increasing the enamel microhardness and preventing microhardness loss during bleaching.[14,15] Other studies have shown a similar beneficial effect for products with Pro-Argin[21] or bioactive glass (Novamin)[22] when used in conjunction with dental bleaching. Nevertheless, there are no studies that have evaluated the effects of different toothpastes prior to bleaching.

This study proposed the use of an active control with NaF (PN), because it has been proven with *in vitro* results,[30] which is important because fluoride is currently used as a remineralizing agent.[31] Additionally, the MFP toothpaste acts as a non-active control of arginine-based toothpastes (PA and SAN) and toothpastes containing bioactive glass (NM), because the sodium monofluorophosphate requires enzymatic hydrolysis to release free fluoride[32]; therefore, minimal effects have been described with *in vitro* studies. This current study model allows for the investigation of nonfluoride remineralization systems (PA, SAN, and NM) and a comparison with an efficient fluoridating agent (PN). Additionally, the fluoride concentration analysis (Table 2) showed that the actual fluoride present in the studied toothpastes was very similar to what was declared by the manufacturers. However, the MFP toothpaste has a small amount of free fluoride that acts on the enamel surface explaining the small increase in SMH found in the current study when comparing the FT group with the control groups.

From the results of the SMH and CSMH evaluations, bleaching with 35% HP led to a slight but significant decrease in superficial and cross-sectional enamel microhardness (with an exception at a depth of 100 μm) without prior application of toothpaste. This decrease in microhardness is possibly due to the acidity of the bleaching gel. The lower pH of the bleaching agent may cause demineralization of the enamel.[33] This finding is in accordance with a number of previous studies[8,9] that demonstrated a decrease in microhardness during dental bleaching. In the current study, the toothpaste treatment of bleached surfaces prevented a reduction in microhardness, with an observed increase in SMH, indicating an obvious protective effect of NM, arginine-based toothpastes (PA and SAN) or potassium nitrate toothpaste containing NaF, in this order.

When comparing the therapeutic effects of the arginine treatments (SAN and PA) prior to dental bleaching with the negative, positive, and toothpaste controls, there was an increase in SMH values. Arginine is an aminoacid,[34] with a slightly alkaline pH (Table 2). Based on the mechanism of action proposed by Kleinberg,[35] the combination of arginine and calcium carbonate may provide an alkaline environment that encourages endogenous calcium and phosphate ions to precipitate on dental tissues. Therefore, inorganic electrolytes contained in saliva (calcium, phosphate, fluoride) may be important participants in the remineralization/demineralization process associated with dental bleaching. However, there is a previous study that discussed the acid solubility of the arginine-carbonate deposits.[36] When calcium carbonate dissolves slowly, the released calcium is bioavailable to remineralize the tooth and the carbonate dissolution may give a slight rise in the local pH. This process might happen during the bleaching procedures, as the initial pH of the bleaching gel used in the current study was 5.64, which decreased after 15 minutes of application. This decrease to a lower pH is potentially related with enamel demineralization.[33] Thus, carbonate dissolution may have mediated less variation of pH in the bleaching gel, decreasing the effects of loss of CSMH and SMH in the SAN and PA groups. Although the arginine-carbonate technology has been reported to be useful as a therapeutic agent when applied after dental bleaching,[21] more studies are required to investigate the role of the arginine-carbonate complex on the enamel properties associated with this treatment, especially *in situ* and *in vivo* studies.

A previous study suggests that the NM particles react with the enamel surface to increase the concentration of Ca and P ions, resulting in the repair of the demineralized surface.[22] It is important to note that NM is regarded as a highly biocompatible material and that it has the potential to prevent demineralization and increase remineralization.[19,37,38] In this current study, it is likely that the bioavailable NM on the enamel surface after toothbrushing reacted with saliva to release calcium (Ca^{2+}), phosphate (PO_4^{3-}), and sodium (Na^+) ions.[38] This process could allow for the deposition of free calcium and phosphate, together with nonreacted particles of bioactive glass, which would form a protective layer on the enamel surface. Burwell and others[19] reported that this precipitate could result in the formation of carbonate enriched hydroxyapatite, a mineral similar to that found in natural teeth, which might be potentiated with the association of fluoride. This mechanism would explain the higher SMH values or surface roughness results of this treatment group.

According to the results of this present study, the sole use of bleaching agent (positive control) increased the enamel surface roughness, as previously described.[5,7] One concern remains with regard to the roughness change due to abrasive toothpastes. However, the brushing protocol applied in this current study (1 month, 825 cycles) may be considered minimal compared with the protocol used for simulating 1 year of brushing (10,000 cycles).[26] This current study determined that brushing created minimal or no significant abrasive effects, with the only abrasive effects noted in the SAN group. Although the stated composition of the abrasive in toothpastes is similar between the FT, SAN, or PA and NP and NM groups, the degree of abrasiveness is associated with the size and characteristics of the particles, which can be different in different toothpastes, even if they use the same component.[39] The NM group did not suffer effects from the HP and tooth brushing, which was not different from the unbleached group, indicating that there was less mineral loss, possibly due to the protective effect previously described. Regardless of the dental bleaching effects, it may be considered that the level of abrasion or increase in surface roughness are clinically less relevant than other wear processes that could occur in the oral environment.

The alteration of physical properties is likely due to the demineralization effects that are caused by the diffusion of HP and the acidic pH of the bleaching gel.[33,40] Furthermore, changes in the topography can promote a surface alteration (increase in roughness) associated with a modification of light reflectance,[41] because the observed color of the tooth is a combination of optical phenomena, including the light reflected from the enamel surface, transmitted light, and the degree of light absorption of the dental substrates.[42]

The application of toothpastes prior to dental bleaching presented an effect on the enamel properties in the present study; however, the toothpastes did not affect the effectiveness of the bleaching treatments, because all bleaching groups demonstrated increasing L* values and decreasing b* values while also presenting ΔE values that were statically similar to the positive control (only bleached). These results support a safe indication for toothpastes, especially for those that contain potassium nitrate, which was proposed by Haywood and others[16] for controlling sensitivity during dental bleaching.

In the present study, the variable correlation was statistically confirmed using multivariate Canonical correlation analysis, which demonstrated a correlation of 21% between the color and physical properties. These findings indicated that specimens with low Δb and high ΔL and Δa were associated with a rougher surface and an increase in microhardness. Therefore, the present results showed that dental bleaching (increased L* values and decreased b* values) promoted an increase in roughness. In addition, the direct correlation of 21% was not high due to the roughness variable, whereas the negative control (unbleached) and bioactive glass-based toothpaste group (NM) did not present with alterations in the surface roughness. Conversely, the correlation of high microhardness could be associated with the study model design and with the presence of toothpaste use. Thus, dental bleaching, when not associated with toothpaste treatment, promoted mineral loss and a decrease of microhardness (positive control). The correlation analysis is an important method for evaluating hypotheses, principally those that are associated with different physical properties of enamel. Within this context, the bleaching procedure promoted simultaneous changes in reflectance color, roughness, and enamel mineral loss. The multivariate correlation analysis is a breakthrough for the study of properties and their relationship in *in vitro* models. The evaluation of physical properties and the correlation between the results of this study are very important for improving the bleaching procedure to develop a safer and more effective approach.

It can be concluded that bleaching with 35% HP resulted in morphologic changes and a significant loss of microhardness of enamel. Therefore, toothpaste treatment could decrease these changes to the enamel properties. Among these compounds, arginine-based toothpastes and potassium nitrate toothpaste (with NaF) increased superficial microhardness and did not affect dental bleaching. The toothpaste containing bioactive glass did not provide an increase in surface roughness. Furthermore, NM promotes an enhancement of the microhardness values compared with unbleached enamel, demonstrating a potential benefit for bleaching therapy.

CONCLUSION

The application of toothpaste prior to dental bleaching did not interfere with the effectiveness of treatment. The bioactive glass-based toothpaste protected the enamel against the deleterious effects of the whitening procedure.

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Conflict of Interest

The authors 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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Enamel Surface Changes After Exposure to Bleaching Gels Containing Carbamide Peroxide or Hydrogen Peroxide

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Clinical Relevance

Bleaching gels with a relatively high concentration of peroxide and shorter application time might be less harmful to enamel. A clinically significant whitening effect can be obtained after a few bleaching treatments.

SUMMARY

Objective: This study evaluated the differences in enamel color change, surface hardness, elastic modulus, and surface roughness between treatments with four bleaching gels containing carbamide peroxide (two at 10% and one each at 35%, and 45%) and two bleaching gels containing hydrogen peroxide (two at 40%).

Methods: Enamel specimens were bleached and color changes were measured. Color change was calculated using either ΔE or the Bleaching Index (BI). Then, surface hardness, elastic modulus, and surface roughness of the enamel specimens were evaluated. All measurements were performed at baseline and directly after the first bleaching treatment for all carbamide peroxide– and hydrogen peroxide–containing bleaching gels. In addition, final measurements were made 24 hours after each of a total of 10 bleaching treatments for carbamide peroxide bleaching gels, and 1 week after each of a total of three bleaching treatments for hydrogen peroxide bleaching gels.

Results: After the last bleaching treatment, respective ΔE scores were 17.6 and 8.2 for the two 10% carbamide peroxide gels, 12.9 and 5.6 for the 45% and 35% carbamide peroxide gels,

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and 9.6 and 13.9 for the two 40% hydrogen peroxide gels. The respective BI scores were –2.0 and –2.0 for the two 10% carbamide peroxide gels, –3.5 and –1.5 for the 45% and 35% carbamide peroxide gels, and –2.0 and –3.0 for the two 40% hydrogen peroxide gels. Each bleaching gel treatment resulted in significant whitening; however, no significant difference was found among the gels after the last bleaching. Whitening occurred within the first bleaching treatments and did not increase significantly during the remaining treatments. Surface hardness significantly decreased after the last bleaching treatment, when 10% carbamide peroxide was used. Furthermore, significant changes in the elastic modulus or surface roughness occurred only after treatment with 10% carbamide peroxide.

Conclusion: All six bleaching gels effectively bleached the enamel specimens independent of their concentration of peroxide. Gels with low peroxide concentration and longer contact time negatively affected the enamel surface.

INTRODUCTION

Modern dentistry focuses not only on the treatment of dental diseases but also deals increasingly with the esthetic demands of patients. Whitened teeth lead people to have a better assessment of a person's social competence, intellectual ability, psychological adjustment, and relationship satisfaction.[1] Remarkably, more than one-third of people in the United States and about every fifth person in the United Kingdom are dissatisfied with the color of their teeth, which explains the widespread use of tooth whitening products.[2,3] Tooth whitening products usually contain carbamide peroxide or hydrogen peroxide in different concentrations, carbamide peroxide releasing about 33% of its content as hydrogen peroxide (the active bleaching agent).[4] During ionization of hydrogen peroxide, free oxygen ions are released and cause oxidation of discolored organic pigments in dental hard tissues, thereby resulting in whitening of teeth.[5,6] The efficacy of different tooth whitening products is mostly affected by the final peroxide concentration and the contact time of the bleaching agent with the dental hard tissue.[6]

Three types of bleaching products exist, according to the concentration of peroxide in the tooth whitening product: over-the-counter home-use bleaching gels with a concentration of up to 10% carbamide peroxide, dentist-dispensed home-use bleaching gels with a concentration of up to 20% carbamide peroxide, and professional in-office bleaching gels with a concentration of up to 45% carbamide peroxide or 40% hydrogen peroxide.[6,7] Home-use bleaching gels have the advantages of being self-administered; requiring no, or only short, chair-side time; and being cheaper than an in-office bleaching treatment.[5,8] In-office bleaching treatments, on the other hand, have the advantages of being performed under the dentist's control, requiring less total bleaching time, and avoiding soft tissue exposure and risk of material ingestion.[9,10]

Efficacy of tooth whitening products can be verified visually by a dental shade guide or quantitatively by a spectrophotometer. Spectrophotometers allow for an objective assessment of tooth color and thus provide data that can be used in statistical calculations. The measured colors of a given dental shade are presented by CIELAB values according to the Commission Internationale de l'Eclairage (International Commission on Illumination). Color differences can be calculated using the formula $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]/2$, where ΔL, Δa, and Δb are differences in lightness (L, achromatic coordinate), green-red coordinate (a), and blue-yellow coordinate (b), respectively.[11,12] For a tooth color change to be clinically visible, ΔE has to be higher than 3.7, with the prerequisite of a positive shift in the lightness coordinate and a shift in the blue-yellow coordinate.[13,14] To facilitate communication with the patient, a recently marketed spectrophotometer with a simplified color index (Bleaching Index [BI]; VITA Zahnfabrik, Bad Säckingen, Germany) has been designed, which indicates whitening of teeth in an easy way using decreasing numbers.

Despite the widespread success of tooth whitening products regarding their efficacy in whitening teeth, there is no general consensus about possible negative effects on enamel. On the contrary, it is controversial in the literature whether bleaching gels adversely affect enamel. Several studies using carbamide peroxide with concentrations from 10% to 35% showed a decrease in surface hardness,[15,16] demineralization of enamel,[17] alterations in the surface roughness,[7,18] and even damage to the enamel surface.[19] Other studies using the same concentrations of carbamide peroxide and hydrogen peroxide, however, showed no impact on enamel[20] with respect to microhardness,[21] surface roughness,[5,22] or other deleterious effects on enamel.[23]

Discrepancies in the literature may be due to different study designs, for example, differences in peroxide concentrations, contact time, and tooth color analyses. Furthermore, most studies usually consider single factors that could be affected by bleaching and are mostly focused on either home-use bleaching gels or in-office bleaching gels. The aim of the present study was to evaluate the change in tooth color (ΔE) and bleaching efficacy (using the BI) of six home-use and in-office bleaching gels as well as their impact on surface microhardness, elastic modulus (EM), and surface roughness of enamel. Furthermore, the recently introduced BI was compared with the CIELAB system in order to investigate its usefulness.

METHODS AND MATERIALS

Preparation of Enamel Specimens

Ninety-six extracted human incisors without caries, erosion, cracks, cavities, or restorations were selected, cleaned, and stored in 1% chloramine T trihydrate solution. Before the extraction, the patients were informed about the possibility that their teeth would be used for research purposes and consent was obtained. Before preparation of enamel specimens, the teeth were rinsed thoroughly under running tap water. The crowns of the incisors were separated from their roots using a diamond blade saw (IsoMet Low Speed Saw, Buehler, Lake Bluff, IL, USA) and embedded in acrylic resin as previously described.[24] The embedded crowns underwent a standardized grinding and polishing procedure on a polishing machine (LabPol 21, Struers, Ballerup, Denmark) with silicon carbide paper discs of grain size 18, 8, and 5 μm (Struers) for 60 seconds each and a Struers polishing cloth with a 3-μm diamond abrasive (LaboPol-6, DP-Mol Polishing, DP-Stick HQ, Struers). All grinding and polishing procedures were carried out under water cooling with ultrasonication for 1 minute in tap water between every grinding and polishing step. Enamel specimens were assigned to one of the six bleaching gels (n = 16) according to their baseline color in order to provide identical initial conditions in all groups. For storage before and between experimental procedures, a mineral solution (1.5 mmol/L $CaCl_2$, 1.0 mmol/L KH_2PO_4, and 50 mmol/L NaCl, pH = 7.0)[25] was used to simulate the oral environment.

Experimental Procedures

The carbamide peroxide–containing gels designed for home-use bleaching that were tested in the present study were Opalescence PF 10% and Home Whitening 10%, and those designed for in-office bleaching were Opalescence Quick 45% and Home Whitening 35%. The hydrogen peroxide–containing gels designed for in-office bleaching that were tested in the present study were Opalescence Boost PF 40% and Power Whitening YF 40%. The manufacturer of the Opalescence bleaching gels was Ultradent Products Inc. (South Jordan, UT, USA), and the manufacturer of the Home Whitening and Power Whitening bleaching gels was WHITEsmile (Birkenau, Germany). Determination of color values (ΔE), bleaching efficacy (with the BI), surface hardness (measured as the Vickers hardness number [VHN]), EM, and surface roughness were carried out at baseline (m_0), that is, before the bleaching treatments and directly after the first bleaching treatment (m_1) for all bleaching gels. Measurements were also obtained 24 hours after each of a total of 10 bleaching treatments for carbamide peroxide–containing bleaching gels (m_2–m_11), and 1 week after each of a total of three bleaching treatments for hydrogen peroxide–containing gels (m_2–m_4). A flowchart of the experimental procedures is given in Figure 1.

Bleaching Procedures

Enamel specimens were bleached according to manufacturers' instructions. Before bleaching treatments, specimens were rinsed thoroughly with tap water and dried with oil-free air. Enamel specimens were covered with a 1-mm layer of the bleaching gel according to the group: 1) for 8 hours 10 times with Opalescence PF 10%, 2) for 4 hours 10 times with Home Whitening 10%, 3) for 30 minutes 10 times with Opalescence Quick PF 45%, 4) for 30 minutes 10 times with Home Whitening 35%, 5) for three sessions of 20 minutes each, repeated three times, with Opalescence Boost PF 40%, and finally 6) for three sessions of 15 minutes each, repeated three times, with Power Whitening YF 40%. After application, the 1-mm layer of bleaching gel was evenly distributed on the enamel surface using plastic paraffin film (Parafilm M, Neenah, WI, USA), and the specimens were kept at 37°C and 100% humidity for the required bleaching time. After each bleaching treatment, the bleaching gel was removed and the specimens were washed thoroughly with tap water and dried with oil-free air. During the time when specimens were not treated or measured, they were stored in the aforementioned mineral solution.

Measurement of Color Values

Enamel specimens were evaluated with a spectrophotometer (VITA Easyshade Advance 4.0, VITA Zahnfabrik, Bad Säckingen, Germany) at each time point (m_0–m_11, respectively). The spectrophotom-

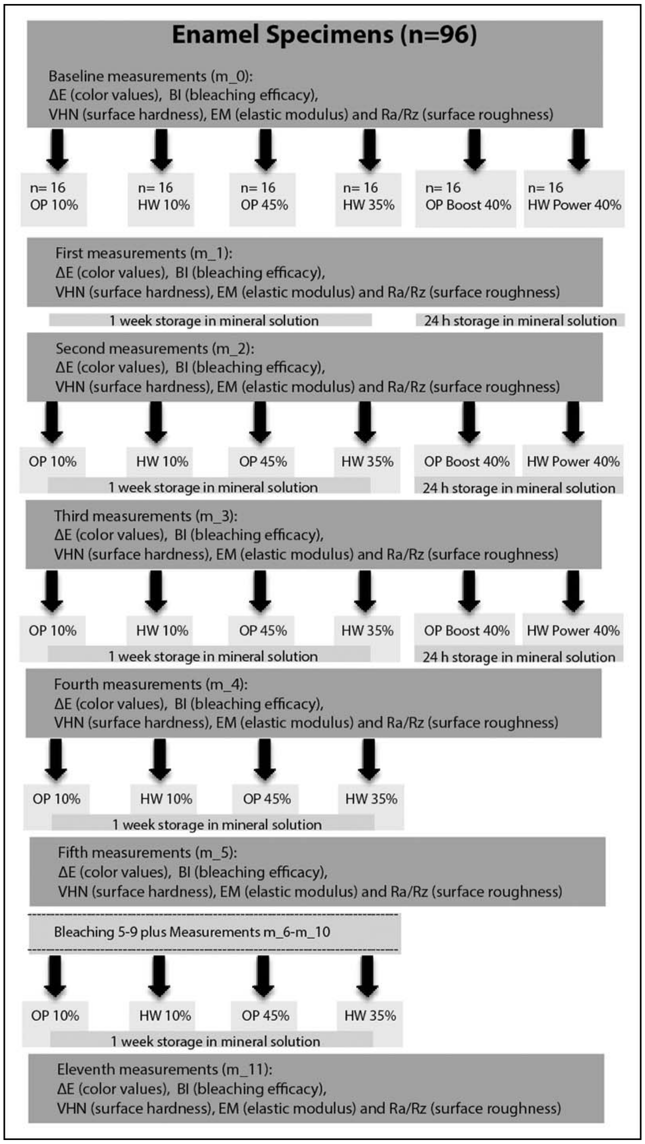

Figure 1. *Flowchart of the experimental procedures.*

eter was always placed at the center of the enamel specimen to ensure reproducibility. For each enamel specimen, the spectrophotometer generated a BI value as well as CIELAB values according to the Commission Internationale de l'Eclairage (CIE), where L represents the lightness in a specimen, a represents the saturation of green and red, and b represents the saturation of blue and yellow.[11,12] ΔE was then calculated using the formula $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]/2$.

Measurement of Surface Hardness and Elastic Modulus

Surface hardness (VHN) and elastic modulus (EM; gigapascals) of the enamel specimens were measured with a hardness indentation device at a force of 50 mN with an indentation time of 30 seconds (Fischerscope HM2000, Helmut Fischer GmbH, Sindelfingen, Germany). Four indentations were made on each specimen, and the mean value of the four VHN and four EM values per specimen were then calculated for each time point (m_0–m_11) for statistical analysis.

Measurement of Surface Roughness

Surface roughness (the average surface roughness [Ra; µm] and the arithmetic mean height of the surface profile [Rz; µm]) of the enamel specimens was profilometrically determined using a surface roughness meter (Perthometer S2, Mahr GmbH, Göttingen, Germany). Three measurements were performed per specimen over a transverse length of Lt = 1.750 mm, with a cutoff value of 0.250 mm and a stylus speed of 0.1 mm/s. The specimen was turned 45° for each of the three measurements to ensure that a representative area of the specimen was investigated; this resulted in three Ra and Rz values per specimen at each time point (m_0–m_11). Using the three Ra and Rz values, a mean value per specimen was calculated for each time point (m_0–m_11) for statistical analysis.

Statistical Analysis

Power analysis and sample-size calculation were performed at alpha = 5% and beta = 20% with a power of 80% using NCSS PASS (Power Analysis and Sample Size Software; NCSS, LLC. Kaysville, UT, USA). Statistical analysis was performed using SPSS version 21.0 (SPSS Inc, Chicago, IL, USA). The nonparametric Mann-Whitney U test for paired samples was used to test for differences in ΔE, BI, VHN, EM, and Ra/Rz between the bleaching gels after the last bleaching treatment only, and for each bleaching gel after each bleaching treatment (with Bonferroni correction for multiple comparisons).

RESULTS

Measurement of Color Values

The mean CIELAB values for lightness, saturation of green-red and saturation of blue-yellow at baseline and after the last bleaching treatment, as well as color change and BI value after the last bleaching treatment are given in Table 1. All six bleaching gels resulted in an increase in lightness (higher L), a reduction in yellowness (lower b), and clinically significant changes in ΔE and BI. When comparing the ΔE and the BI value of the six bleaching gels

Table 1: *Mean CIELAB Values (Minimum; Maximum) According to the Commission Internationale de l'Eclairage International Commission on Illumination for Lightness (L), Saturation of Green/Red (a), and Saturation of Blue/Yellow (b) at Baseline and After the Last Bleaching Treatment As Well As the Color Change (ΔE) and the Bleaching Index (BI) During the Whole Bleaching Procedure of Enamel Specimens Using Six Different Bleaching Gels*

	Baseline			After the Last Bleaching Treatment			ΔE	BI
	L (Lightness)	a (Green-Red)	b (Blue-Yellow)	L (Lightness)	a (Green-Red)	b (Blue-Yellow)		
Carbamide peroxide–containing gel								
OP 10%[a]	74 (67;81)	–2 (−4;1)	18 (13;25)	78 (68;90)	–4 (−4;1)	15 (10;22)	17.6	–2.0
HW 10%[a]	72 (64;87)	–2 (−3;0)	20 (14;33)	75 (64;92)	–2 (−4;–1)	18 (12;24)	8.2	–2.0
OP 45%[b]	71 (60;76)	–2 (−4;4)	19 (13;28)	75 (63;83)	–2 (−4;0)	16 (9;25)	12.9	–3.5
HW 35%[b]	71 (64;82)	–2 (−3;–2)	18 (13;26)	74 (67;80)	–3 (−3;–1)	17 (12;21)	5.6	–1.5
Hydrogen peroxide–containing gel								
OP Boost 40%[b]	74 (69;80)	–3 (−3;–1)	18 (11;26)	76 (67;84)	–3 (−4;–2)	14 (9;20)	9.6	–2
PW Power 40% [b]	76 (66;87)	–2 (−4;0)	20 (12;32)	76 (66;84)	–3 (−4;–2)	16 (9;29)	13.9	–3

Abbreviations: HW 10%, Home Whitening 10%; HW 35%, Home Whitening 35%; OP 10%, Opalescence PF 10%; OP 45%, Opalescence Quick 45%; OP Boost 40%, Opalescence Boost PF 40%; PW Power 40%, Power Whitening YF 40%.
[a] *Home-use bleaching.*
[b] *In-office bleaching.*

after the last bleaching treatment, no statistically significant differences were found between the gels ($p = 0.145$ and $p = 0.433$, respectively).

When comparing the color changes between baseline and every single bleaching treatment, there was a statistically significant difference over the bleaching procedure for each of the six bleaching gels. Opalescence PF 10% and Home Whitening 10% each resulted in a statistically significant increase in ΔE between baseline and after each of the 10 bleaching treatments ($p<0.001$); however, after the first bleaching treatment, no statistically significant differences occurred up to the tenth bleaching treatment. When evaluating the BI, statistically significant whitening occurred between baseline (m_0) and after the third bleaching treatment (m_4; p=0.003) for Opalescence PF 10% and between baseline (m_0) and the second bleaching treatment (m_3; p=0.001) for Home Whitening 10%. However, no further statistically significant whitening effect occurred up to the tenth bleaching treatment.

Treatment with Opalescence Quick PF 45% and Home Whitening 35% also resulted in statistically significant increases in ΔE between baseline and after each of the 10 bleaching treatments ($p<0.001$), however after the first bleaching treatment, no statistically significant differences occurred up to the tenth bleaching treatment. When evaluating the BI, statistically significant whitening occurred between baseline (m_0) and after the second bleaching treatment (m_3; $p<0.001$) for Opalescence Quick PF 45%, and between baseline (m_0) and the fourth bleaching treatment (m_5; p=0.001) for Home Whitening 35%. However, no further statistically significant whitening effect occurred up to the tenth bleaching treatment.

Treatment with Opalescence Boost PF 40% and Power Whitening YF 40% resulted in statistically significant increases in ΔE between baseline and after each of the three bleaching treatments ($p<0.001$); however, after the first bleaching treatment, no statistically significant differences occurred up to the third bleaching treatment. When evaluating the BI, statistically significant whitening occurred between baseline (m_0) and directly after the first bleaching treatment (m_1; $p<0.001$) for Opalescence Boost PF 40%, and between baseline (m_0) and 1 week after the first bleaching treatment (m_2; $p<0.001$) for Power Whitening YF 40%. However no further statistically significant whitening effect occurred up to the third bleaching treatment.

To summarize, each gel resulted in a statistically significant color change over the entire bleaching procedure; however, no statistically significant differences were found between the different gels after the last bleaching treatment. Color changes occurred within the first two to four bleaching treatments for carbamide peroxide–containing gels and within the first bleaching treatment for hydrogen peroxide–containing gels. No significant improvement in whitening of the enamel specimens occurred during the remaining bleaching treatments. An overview of the ΔE and BI values of the different bleaching gels is given in Figures 2a and 2b, respectively.

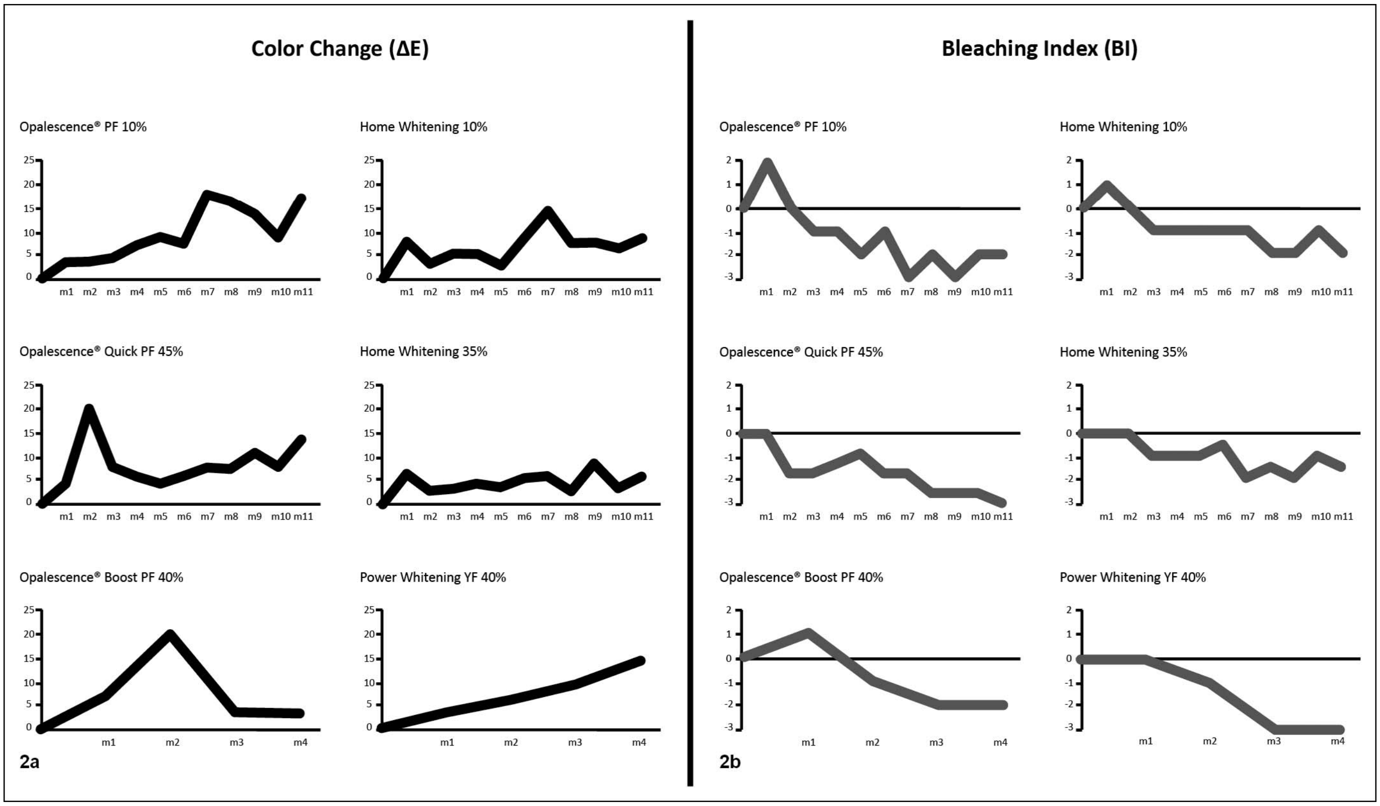

Figure 2. *(a): Color change (ΔE) and (b) bleaching efficacy (according to the BI) of enamel using six different bleaching gels.*

Measurement of Surface Hardness, EM, and Surface Roughness

Surface microhardness, elastic modulus, and surface roughness at baseline as well as the change in these parameters after the last bleaching treatment are shown in Table 2. Comparisons among the six bleaching gels after the last bleaching treatment showed statistically significant differences in ΔVHN

Table 2: Mean Baseline Surface Microhardness (Measured as VHN), Baseline Elastic Modulus (EM), Baseline Surface Roughness (Ra/Rz), and Changes in Parameters After the Last Bleaching Treatment of Enamel Specimens Using Six Different Bleaching Gels

	Baseline			Changes After the Last Bleaching Treatment		
	VHN	EM	Ra/Rz	ΔVHN	ΔEM	ΔRa/Rz
Carbamide peroxide–containing gel						
OP 10%[a]	626	98	0.002/0.120	–69	–1.8	0.001/0.026
HW 10%[a]	579	95	0.026/0.249	–35	+1.9	0.000/0.000
OP 45%[b]	602	98	0.011/0.097	–23	–1.24	0.001/0.010
HW 35%[b]	614	95	0.033/0.311	–56	+1.49	0.000/0.010
Hydrogen peroxide–containing gel						
OP Boost 40%[b]	540	97	0.029/0.175	+20	–0.91	0.001/0.026
PW Power 40% [b]	550	95	0.015/0.172	+44	–0.12	0.001/0.023

Abbreviations: HW 10%, Home Whitening 10%; HW 35%, Home Whitening 35%; OP 10%, Opalescence PF 10%; OP 45%, Opalescence Quick 45%; OP Boost 40%, Opalescence Boost PF 40%; PW Power 40%, Power Whitening YF 40%. Ra, average surface roughness; Rz, arithmetic mean height of the surface profile; VHN, Vickers hardness number
[a] Home-use bleaching.
[b] In-office bleaching

between Opalescence PF 10% and both of the hydrogen peroxide–containing gels (Opalescence Boost PF 40% and Power Whitening YF 40%, p=0.003). No statistically significant differences were found among the six gels with respect to ΔEM or ΔRa/Rz.

When comparing each gel over time (between baseline and after the last bleaching treatment), Opalescence PF 10% and Home Whitening 10% showed a statistically significant decrease in VHN (p<0.001 and p=0.014, respectively) whereas Power Whitening YF 40% showed a statistically significant increase in ΔVHN (p=0.024). Furthermore, treatment with Opalescence PF 10% resulted in a statistically significant increase in surface roughness (p=0.041), while Home Whitening 10% resulted in a statistically significant increase in elastic modulus (p=0.014). All other bleaching gels showed no statistically significant changes in ΔVHN, ΔEM, or ΔRa/Rz.

DISCUSSION

The current study investigated six bleaching gels containing different concentrations of carbamide peroxide or hydrogen peroxide and, consequently, different final concentrations of hydrogen peroxide.[4] The bleaching gels were compared with respect to their whitening efficacy and their influence on the surface of enamel specimens. Because of the different concentrations of peroxide, they also differed in recommended application time. All enamel specimens were characterized before the first bleaching treatment and after each single bleaching treatment with regard to color and surface changes (ie, surface hardness, EM, and surface roughness).

The present study showed that all bleaching gels were effective in whitening the enamel as indicated by ΔE and a decrease in the BI. No statistically significant difference in bleaching efficacy was found among the different gels, which is consistent with studies showing that the bleaching gels containing a higher concentration of hydrogen peroxide need fewer bleaching treatments to produce similar bleaching effects.[6] Nevertheless, it is interesting that a significant change in enamel color, independent of the bleaching gel, occurred after the first bleaching and showed no further significant increase, whereas more bleaching treatments were generally needed to obtain a significant change in BI. For the carbamide peroxide–containing gels (from 10% to 40%), two to four bleaching treatments were needed, whereas for the hydrogen peroxide–containing gels, only one bleaching treatment was needed to demonstrate statistically significant decreases in BI values.

These results indicate first that the number of bleaching treatments can be dramatically decreased, which is consistent with a study by Polydorou and others[21] showing that a bleaching time of approximately 24 minutes is sufficient to reach a clinically significant level of bleaching.[13] A reduced number of bleaching treatments would be beneficial for patients and dentists; treatment time and costs would be reduced, as would the danger of negative side effects resulting from fewer application times.[26,27] Second, our results show that the recently introduced BI is comparable to ΔE in the CIELAB system; both indicated a significant whitening effect. The benefit of using the BI compared with assessing changes in tooth color to investigate the efficacy in whitening teeth is that the BI distinguishes between improvements in tooth color (negative values indicating a whitening) and a worsening of tooth color (positive values indicating a darkening). The ΔE values, however, merely indicate a change in color and do not indicate whether the tooth got lighter or darker. To obtain this information, one has to analyze the single components of ΔE.[11,12] Furthermore, because patients are more interested in the whitening of their teeth than in changes in the single components, BI might be easier to use.

Another purpose of the present study was to investigate the influence of the six bleaching gels on the enamel surface. More specifically, we examined whether the bleaching gels had a negative effect on surface hardness, EM, and surface roughness. Interestingly, the bleaching gels with a relatively high concentration of carbamide peroxide (Opalescence Quick PF 45%, and Home Whitening 35%, resulting in approximately 15% and 11% hydrogen peroxide,[4] respectively) and the bleaching gels containing 40% hydrogen peroxide (Opalescence Boost PF 40% and Power Whitening YF 40%), which were all used with a shorter application time, did not show any negative effects on these enamel characteristics. In fact, one of the 40% hydrogen bleaching gels (Power Whitening YF 40%) caused a significant increase in surface hardness, which is consistent with the study by Polydorou and others.[21] On the other hand, the bleaching gels with the lowest concentration of carbamide peroxide (Opalescence PF 10% and Home Whitening 10%), resulting in a final concentration of approximately 3% hydrogen peroxide,[4] caused a significant decrease in surface hardness after the bleaching treatments. Furthermore, treatment with Opalescence PF 10% resulted in an increase in surface roughness, and treatment with Home Whitening 10% resulted in an increase in elastic modulus. Our results with respect to microhardness partially contradict those of an in situ study in which bleaching with different concentrations of carbamide peroxide resulted in reduced enamel hardness values, suggesting demineralization.[28] The reason why the changes in the present study occurred in the low, but not the high, concentration bleaching gels might be the increased contact time of the low concentration gel. For example, the two 3% hydrogen peroxide products had to be applied for 40 hours or 80 hours, respectively, whereas the 40% hydrogen peroxide products had to be applied for 135 minutes or 180 minutes, respectively.

In the current study, the enamel specimens were stored in a mineral solution between bleaching treatments and measurements.[25] The mineral solution contained $CaCl_2$, KH_2PO_4, and NaCl in order to simulate the oral environment, and remineralization could have been the reason why four of the six bleaching gels did not exhibit decreased surface hardness. Using the bleaching gels for longer times might have disrupted the balance between demineralization caused by the bleaching gel and remineralization caused by the mineral solution to result in decreased surface hardness. This explanation, however, needs further investigation, taking into account the differences between mineral solutions and human saliva. Mineral solutions containing $CaCl_2$, KH_2PO_4, and KCl are, however, supersaturated with respect to enamel, and precipitation of mineral can occur, while human saliva contains proteins hindering this precipitation.[29] Furthermore, the interindividual differences in human saliva and the possibility that the acquired pellicle might have a protective effect on the enamel might also be relevant to investigate in future studies.

CONCLUSIONS

- Bleaching gels containing carbamide peroxide from 10% up to 40% or hydrogen peroxide at 40% effectively whitened enamel.
- A clinically significant whitening effect was obtained within the first few bleaching treatments.
- The simplified BI might be useful in communications between clinician and patient.
- Use of bleaching gels with a relatively high concentration of carbamide peroxide or hydrogen peroxide and a shorter application time might be less harmful to the enamel surface.

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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 Department of Preventive, Restorative and Pediatric Dentistry, School of Dentistry, University of Bern, in Bern, Switzerland.

Conflict of Interest

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

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