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Indiana University School of Dentistry, Room S411
1121 West Michigan Street, Indianapolis, IN 46202-5186
Telephone: (317) 278-4800, Fax: (317) 278-4900
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Guest Editorial

Resin Infiltration Technique for Proximal Caries Lesions in the Permanent Dentition: A Contrarian Viewpoint

SM Hashim Nainar

Minimal intervention dentistry has been promoted as the contemporary science-based paradigm in operative dentistry.[1] The FDI task group reviewing minimal intervention dentistry cautioned in 2012 that one of the procedures, resin infiltration technique, while promising, needed more clinical evidence for conclusive findings.[1] The aim of this brief commentary is to consider the use of resin infiltration technique for proximal caries lesions in the permanent dentition.

Resin infiltration technique was first described in the 1970s for conservative management of noncavitated smooth surface caries lesions but did not find acceptance following preliminary reports indicating dismal clinical application in proximal surfaces of premolars *in vivo*.[2,3,4] The resin infiltration technique has recently been reinvigorated and suggested for proximal caries "lesions extending radiographically into inner enamel or the outer third of dentin" with the intent to avoid the first restoration and its consequent retreatments.[5]

It has been recently remarked that resin infiltration may not be appropriate for proximal caries lesions in primary molars, the better alternative being remineralization for enamel lesions and conventional restorations for those lesions into dentin.[6] In a similar vein, promotion of remineralization may be a better option than resin infiltration for proximal lesions in permanent enamel for the following reasons:

1. There is slow progression of enamel caries lesions with "an average of four years for a lesion to progress through the enamel of permanent teeth."[7]
2. The resin infiltration technique may further undermine the structural underpinning of enamel caries lesions with its relatively intact surface layer and more demineralized subsurface area.[8] It has been shown that, compared to sound enamel, there are large reductions in elastic modulus (up to 83% lower) and hardness (up to 91% lower) in natural proximal noncavitated caries lesions in premolars, whereas the intact surface layer of enamel of the caries lesion had the least reduction (34%) in mechanical properties.[9] The surface layer of enamel has, however, been identified as a barrier impeding resin infiltration into the body of the caries lesion.[10] Resin infiltration technique therefore requires acid conditioning (15% HCl for 2 minutes) in order to remove the enamel surface layer and enhance penetration of the resin infiltrant.[10] This acid conditioning thus results in the removal of the residual strongest component of an already weakened tooth structure within the caries

*SM Hashim Nainar, BDS, MDSc, University of Toronto, Division of Pediatric Dentistry, Faculty of Dentistry, Toronto, ON, Canada

*Corresponding author: 124 Edward St., Toronto, ON M5G1G6, Canada; e-mail: hashim.nainar@utoronto.ca

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lesion. The importance of the surface layer is also alluded to by a study in bovine enamel using 37% phosphoric acid for 5 seconds instead, which found that subsequent infiltration with various resins increased "both microhardness and demineralization resistance of enamel caries lesions."[11]

3. Removal of the surface layer of enamel during resin infiltration technique also renders moot the potential for remineralization.[12] Promoting remineralization of the carious enamel without resin infiltration would result in the healed tooth structure being more resistant to acid dissolution than normal enamel.[13]

Definitive restorations in permanent teeth for proximal lesions that are not amenable to remineralization may be a better option than resin infiltration for the following reasons:

1. The dentino-enamel junction may be considered the Rubicon of treatment threshold for surgical intervention since a compilation of data regarding proximal caries lesions in permanent teeth "found an increasing proportion of cavitated lesions with increasing radiographic depth."[14] It has been reported that in bitewing radiographs of permanent teeth, 11% of the lesions in the inner half of enamel had cavitation, with the proportion of cavitated lesions increasing on breaching of the dentino-enamel junction to 41% for lesions in the outer half of dentin and 100% for lesions in the inner half of dentin.[15] This concept is prudently reflected in clinical practice with ~90% of dentists in a practice-based research network reporting that regardless of caries risk, they would restore a proximal lesion involving the outer one-third of dentin in a lower premolar tooth.[16]
2. Subsequent to 2-minute etch treatment, resin infiltration initially increased the microhardness of caries lesions in bovine enamel; however, there was a reduction in microhardness following acid challenge, likely due to either resin shrinkage or dissolution of the remaining mineral within the body of the lesion.[17] Definitive restorations, though seemingly more drastic, may therefore be more pragmatic than resin infiltration since longitudinal caries data (birth to 32 years of age) have shown caries rate to be constant over the years.[18]

Robinson, who pioneered the resin infiltration technique in the 1970s, reported in a 2011 review that the contemporary technique lacked resolution of some methodological concerns and therefore recommended that it be restricted to "accessible and relatively superficial lesions."[19] Use of the resin infiltration technique for proximal lesions in the permanent dentition therefore warrants further research prior to its application in clinical practice.

Conflict of Interest

The author of this manuscript certifies that he has 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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Literature Review

Contemporary Issues in Light Curing

RB Price • AC Shortall • WM Palin

Clinical Relevance

Clinicians should not take for granted what appears to be the easy task of light curing. Evidence-based steps are provided that will help clinicians improve their light curing technique.

SUMMARY

This review article will help clinicians understand the important role of the light curing unit (LCU) in their offices. The importance of irradiance uniformity, spectral emission, monitoring the LCU, infection control methods, recommended light exposure times, and learning the correct light curing technique are reviewed. Additionally, the consequences of delivering too little or too much light energy, the concern over leachates from undercured resins, and the ocular hazards are discussed. Practical recommendations are provided to help clinicians improve their use of the LCU so that their patients can receive safe and potentially longer lasting resin restorations.

*Richard B Price, DDS, MS, PhD, Dalhousie University, Dental Clinical Sciences, Halifax, NS, Canada

Adrian C Shortall, DDS, BDS, FDS RCPS, FFD RCSI, University of Birmingham, College of Medical and Dental Sciences, School of Dentistry, Birmingham, UK

William M Palin, PhD, University of Birmingham, School of Dentistry, Biomaterials Unit, Birmingham, UK

*Corresponding author: 5981 University Avenue, Halifax, NS B3H 4R2, Canada; e-mail: rbprice@dal.ca

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INTRODUCTION

Premature failure of resin restorations has great health and financial implications. According to the most recent ADA Survey of Dental Services Rendered,[1] at least 146 million resin-based composite (RBC) restorations and sealants are placed annually in the USA. Worldwide more than two hundred sixty one million direct RBC restorations are placed annually.[2] Several reports indicate that the median longevity for posterior resin-based restorations placed in dental offices is only about 6 years[3-5] with the primary reasons for replacement being secondary caries and bulk fracture of the resin.[2,3,5-7] A recent study[8] of 2,318 Class II resin composite restorations and 1,691 Class II amalgam restorations placed in the student clinic at an American dental school reported that the RBC restorations were 10 times more likely to fail prematurely and require replacement than amalgam restorations. The authors speculated that improper positioning of the curing light may have contributed to these failures.

Appropriate light curing of the entire restoration is a basic requirement when placing RBCs; however, the role of the dental light curing unit (LCU) is an often misunderstood and undervalued part of the procedure in many dental offices.[9,10] There is a need for training and guidance in this aspect of primary dental care.[9,11-13] The energy and spectral require-

ments of the RBC must be matched to the output from the light curing unit (LCU) to ensure optimal polymerization but limit excessive temperature increases within the pulp chamber.[14,15] There is ample indirect evidence that undercured resins are a significant cause of restoration failure due to fracture, secondary caries, or excessive wear of the restoration.[13,16-30] Additionally, when dental RBCs are not optimally cured (and thus do not reach a sufficient degree of monomer conversion), they are more likely to leach toxic substances.[31-42] At the same time, since light curing delivers energy that causes a temperature increase in the tooth and surrounding oral tissues,[13-15,43-51] arbitrarily increasing exposure times in an effort to prevent under-curing may damage the pulp and surrounding tissues.

Contemporary LCUs deliver a wide range of spectral emissions and irradiance levels.[10,15,36,51,52] These differences among LCUs are often not detectable by the eye,[53] nor accurately by a dental radiometer, but they can affect the polymerization of the RBC. According to Jandt and Mills,[50] light emitting diode (LED) LCUs have become the gold standard for photopolymerization of resin based dental materials. Using the current literature, this article will present evidence to help clinicians understand the important issues to consider when choosing and using a curing light, so their patients can receive safe and potentially longer-lasting resin restorations.

Definitions: The following radiometric terms will be used in this article:[54]

Term	Units
Radiant Flux or Power	Watt (W)
Radiant Energy (Power x Time)	Joule (J)
Irradiance (sometimes incorrectly called power density)	Watt/Area (W/m^2)
Radiant Exposure (Irradiance x Time) (sometimes incorrectly called energy density)	Joule/Area (J/m^2)

1. THE LIGHT CURING UNIT (LCU)

a) A Single Irradiance Value?

Previous studies[23,24] have reported that a quartz-tungsten-halogen (QTH) unit must deliver a minimum irradiance between 300 to 400 mW/cm^2 to adequately polymerize a 1.5-to 2-mm thick increment of resin composite. The light output from a LCU is usually reported in terms of a single irradiance value.[55-58] However, this output is not uniformly distributed over the end of the light tip,[10,59-64] and so providing only a single value may be very misleading.[62,65] Conventional methods of measuring the light output from a LCU, such as using a thermopile or an integrating sphere, measure the total power emitted and then divide this power by the tip area to provide an average irradiance value at the tip. These methods do not detect how uniform the light beam is and do not show if there are 'hot spots' across the tip end of the LCU. For example,[62] one LED unit delivers an average tip-end irradiance of 1129 mW/cm^2, but the beam profile shows that at the light tip there are 'hot spots' delivering an irradiance in excess of 4,500 mW/cm^2 and 'cold spots' delivering less than 100 mW/cm^2. If the light is held steady, this may result in some of regions of the resin receiving an inadequate amount of energy when light curing.

b) Spectral Emission

The spectral emission from the LCU and the spectral requirements of the RBC should be matched both to ensure optimal polymerization[50,52,66] and to minimize intra pulpal temperature increases.[15] If the LCU is a QTH unit, the spectral emission is sufficiently broad to adequately polymerize any dental RBC material. Most LED units produce a very narrow spectral emission[10,15,50,59,64] and are usually optimized to activate the commonly used camphorquinone photoinitiator that has highest absorption at ~468 nm.[50] Because some RBCs use alternative photoinitiators that require shorter wavelengths (~410 nm), it is possible to use a LED unit that is not ideally matched to the RBC.[15,52,66,67] Recently, "polywave" LED units (with 2 or more spectral peaks) have been introduced that use two or more different colors of LED, meaning that their spectral output ranges from blue (~460 nm) to violet wavelengths (~410nm) of light. These lights can polymerize RBCs containing both conventional and alternative photoinitiators. However, in some of these "polywave" LED units the spectral emission is not uniformly distributed across the light tip, further compounding the effects of beam inhomogeneity.[59] Thus, some areas of the resin may not receive the required wavelengths. Until the manufacturers of dental LCUs address the problem of beam inhomogeneity from their LCUs, the light tip should be moved around by a few millimeters when light curing.[10] This movement should compensate for the non-uniform irradiance and spectral distributions from the LCU, however the light exposure

time will have to be increased at the risk of overexposing some of the oral tissues, unless carefully managed.[10]

c) Effect of Distance

In some LCUs, the irradiance may be high close to the tip but declines rapidly as the distance from the tip end increases.[26,63,64,68-70] Most Class II resin restorations fail at the gingival portion of the proximal box.[71] This is the region that is the most difficult to reach with the LCU and is furthest away from the light source.[68,72] Consequently, the resin here will receive the least amount of light and may be undercured.[13,26,63,64,68,69] Manufacturers should provide data that reports the output or performance of the LCU not only at 0 mm distance from the tip, but also at clinically relevant distances.[70] Some manufacturers and researchers are now starting to provide this information.[13,26,43,56,63,64,68-70] Ideally, the LCU should deliver a well collimated beam of light with minimal reduction in irradiance over clinically relevant distances (up to 8 mm from the tip).

d) Monitoring the LCU

Dental LCUs should be monitored on a regular schedule.[10,50,53] A South African study reported a 100% satisfaction level by dentists with the performance of their LCUs, although nearly half of their units delivered an inadequate output when tested.[12] Whilst it is recognized that the output from QTH units diminishes as the light source and filter age, it is less known that the output from LED units can also decline with age or as a result of misuse.[10,50] Every study of LCUs in use in dental offices has reported that many of these LCUs deliver less than 400 mW/cm^2, most likely due to inadequate maintenance.[12,53,73-77] The introduction of higher power LCUs has not reliably solved the problem of inadequate light output because many light guides on LCUs are either damaged or covered with resin contaminant.[73-76,78,79] Although hand-held dental radiometers are affected by beam inhomogeneity and are inaccurate,[10,80-83] they can be of practical benefit when used to monitor the time-based performance of the same LCU/light guide combination over time.[10,79] Depth of cure scrape tests carried out by the dentist[18] can also be used to evaluate the performance of their light. These two evaluative methods can be used to monitor the LCU and adjust exposure durations to help ensure optimal and predictable light curing results.[18]

e) Infection Control Methods

The LCU can be a source of cross contamination among patients.[78,84,85] Best practice from a cross-infection viewpoint is met by LCUs that have removable, autoclavable light guides and easily disinfected surfaces. Autoclaving light guides may produce "boiler scale" across the light tip of the LCU that reduces the light output.[86] Also, some disinfection solutions may reduce the light transmitting ability of glass-fibered light guides.[87] Since surface disinfectants may degrade the LCU plastic case, lenses, reflectors, fiberoptic light guide, and electronics over time,[78,87,88] care needs to be taken to use the appropriate disinfectant recommended by the manufacturer. LCUs with textured, non-watertight (non-blistered) activation buttons are particularly difficult to clean and can retain microbes between the button and the LCU body. A barrier to prevent cross-infection must be used to cover LCUs with these types of buttons. These plastic barriers will reduce the irradiance from the LCU, so the light exposure time must be increased accordingly.[89-92]

2. RECOMMENDED LIGHT EXPOSURE TIMES

Both light and resin manufacturers' recommendations for light exposure times are often based on a "best case" scenario using a new LCU, a known material thickness, and ideal laboratory conditions where the LCU is stabilised directly over the RBC.[13,24,93,94] Even under these "best case" conditions, some exposure times are deemed to be too short by some dental researchers using objective test methods.[15,18,24,94-97] The manufacturer's instructions usually take no account of the diversity of clinical situations, where the dentist may be using a LCU in a location where it is difficult for the operator to hold the LCU steady, close, and normal to the RBC surface throughout the entire light exposure time.[13,98] Also, curing depths within the RBC will vary significantly depending on the material composition, shade, and light output characteristics of the LCU.[15,52,60,66,99,100] Although some manufacturers recognize this fact, for example one manufacturer recommends light exposure times of 5 to 40 seconds[55] to effectively light-cure different shades and types of their own RBCs, dentists may choose one exposure time and then use it for all shades and situations. Depending on the situation, this may deliver either too much or too little energy to the RBC.

Furthermore, many LCUs are marketed as requiring only a short exposure time,[58] some as short as one second, because they deliver such a high irradiance.[57] This advice incorrectly assumes that

similar material properties can be achieved when the same radiant exposure is delivered, regardless how high the irradiance or how short the exposure time, but this is not always the case.[18,94-97,101] There is concern that rapid light curing of dental resin may increase polymerization contraction stress and decrease the bond strength of resins to the tooth.[28,102-106] Current information indicates that the effects of using different light exposure modes are highly dependent on the specific material used, the LCU, and the clinical situation.[94,97]

3. OPERATOR TECHNIQUE

Operator technique will affect the radiant exposure delivered to the RBC.[11,13,107,108] To maximize the amount of energy delivered, the operator should wear appropriate eye protection. They can watch what they are doing to ensure that the LCU is held both close to and perpendicular to the restoration.[98] Positioning the light tip at 45° to the surface of the restoration will result in a 56% reduction in the amount of energy received by the restoration.[98] A recent study using correctly functioning LCUs tested the ability of 20 dental professionals to deliver adequate energy to simulated restorations in a dental mannequin. Having established 10 J/cm^2 as the minimum radiant exposure required for the bottom of 2 mm thick specimens of Filtek Supreme A2B (3M ESPE, St. Paul, MN) to reach 80% of the top hardness value,[98] the radiant exposures delivered by 20 operators were measured. Using the same LCUs for the same exposure times, there was a large variation among the radiant exposures delivered by the operators with 27% of clinicians delivering less than 10 J/cm^2 to the same simulated Class I restoration, and 82% delivering less than 10 J/cm^2 to the same posterior Class V restoration.[107] Recent studies have shown that this variability can be reduced and radiant exposure improved by providing immediate feedback on how much irradiance and energy was delivered together with instruction on how to avoid mistakes using a patient simulator.[11,98] A similar study from Germany[108] has shown that using proper technique that includes correctly positioning the patient to improve access and ensuring that the LCU is optimally positioned throughout the light curing process, are critical factors for delivering sufficient energy to a restoration.

4. CONSEQUENCES OF DELIVERING TOO LITTLE ENERGY

Delivering too little light energy to the RBC may account, at least to some extent, for the high incidence of early failure of large posterior direct resin-based restorations provided in dental offices due to secondary caries and bulk fracture.[3,5-8] Indirect evidence suggests that the poor clinical performance of many resins seen daily by dentists (e.g., recurrent marginal caries, bulk fracture, bulk and marginal discoloration, loss of anatomical form, and lack of retention) may be related to the failure to deliver sufficient light to adequately cure the resin. Numerous laboratory studies have been published showing impaired mechanical and physical properties,[13,16,17,19-22] weaker bonding to the tooth,[25,26,29] increased bacterial colonization of the resin,[30] and reduced color stability[109,110] in RBCs that have received insufficient curing energy. One clinical study that placed light-cured RBC restorations in denture teeth[20] verified that a purposely undercured resin restoration showed significantly increased and clinically unacceptable occlusal wear after only 2 years.

5. POTENTIAL TOXICITY OF UNDERCURED RESINS

Inadequately polymerized RBCs will have a lower degree of monomer conversion and consequently greater potential to leach toxic substances.[31-42] One study evaluated the cytotoxic potential of RBCs on primary human gingival fibroblast cultures.[39] For each resin, as the percentage of monomer conversion increased, cellular toxicity decreased. Another study assessed the release of bisphenol A (BPA) from an orthodontic adhesive that was light cured at various distances from the light curing tip and correlated the release of BPA to the degree of resin conversion.[41] They found that resins exposed at the 5 and 10 mm away from the LCU tip were significantly less well cured and released significantly more BPA compared to those cured at 0 mm from the light tip. In a recent study, three nano-hybrid RBCs were exposed to light for varying amounts of time. A strong inverse correlation between the degree of conversion and elutable substances from the RBCs was found.[40] The authors emphasized the importance of an adequate light exposure (20 s or 40 s), because shorter exposure times (5 s or 10 s) resulted in a lower degree of conversion and eluted greater amounts of toxic substances in these RBCs. These studies show that for health reasons alone, the RBC should be adequately light cured.

6. HAZARDS OF DELIVERING TOO MUCH ENERGY

Clinicians are taught to avoid unnecessary trauma to the pulp and would not prepare vital teeth

without adequate water coolant to reduce the intrapulpal temperature rise.[111] Light curing a restoration delivers energy to the tooth and surrounding oral tissues that can also cause a temperature increase in these areas, but this temperature rise is often overlooked. The temperature rise that can be tolerated by human dental pulp has been reported to be between 5.5 °C to 11 °C,[112,113] but the effect of heat on the pulpal tissue has only been examined in healthy young dental pulps, or in animal teeth. Heavily restored teeth or teeth traumatized by caries may react differently, but these factors have yet to be determined. When the first generation LED lights were marketed, they were advertised as 'cool' lights that produced less of a temperature rise in the pulp compared to QTH lights.[114-117] This was only true because of the very low power output from the initial versions of these LED units. As the power output from LED units has increased, the potential for generating damaging temperature values in pulp and oral tissues has also increased.[13,43,44,46,47,50,51,118] Leprince et al.[15] assessed the effects of light source characteristics and irradiation time on temperature increase in the pulp chamber of an extracted molar tooth. They reported that the temperature rise increased with longer exposure times and as the LCU light output increased. Where the pulp is at greater risk, such as in deep cavities with little overlying dentin, consideration should be given to the choice of LCU and light exposure program. Also, intrapulpal temperature rise can be minimized by directing a stream of air across the coronal part of the tooth using a syringe or a high-volume suction tip.[119]

Pulpal temperature rise is not only related to the irradiance from the LCU, but also the exothermic polymerization reaction of the light activated resin.[13,45-47,118] Flowable resin composites can generate a higher polymerization exotherm with a greater intrapulpal temperature rise compared to their restorative analogues because of their greater resin content.[47] Thus, the potential for an unacceptable temperature rise is even greater when using flowable resins with high output power LCUs.

In 2012, three clinical cases were reported where a LED curing light burned the lips of patients.[120] Because the patients were anaesthetized, the soft tissue burns were only recognized after the treatment had concluded. It was also reported that the presence of a rubber dam offered no significant protection to soft tissue. The authors recommended that the LCU should be activated over the RBC material only; furthermore, they recommended placing gauze under the rubber dam to reduce heating the soft tissues underneath the rubber dam. This may be difficult to achieve when the cavity margin is close to the gingival tissues such as in a Class V, or the proximal box of a Class II restoration.

7. OCULAR HAZARDS: BLUE LIGHT HAZARD

The dentist has a duty to protect both the patient and employees from harm. Personnel who use LCUs on a daily basis may be at risk for ocular damage from the LCU. While it is well known that UV-A radiation can cause corneal injury or photokeratitis as well as cataractogenesis and transient or permanent opacification of the lens,[121] the blue light from LCUs is particularly damaging to the retina. This Blue Light Hazard is greatest at 440 nm,[122] which is within the output range from dental LCUs.[10,15,51,62] While the natural aversion response of the eye to bright light usually limits single exposures to less than 0.25 seconds, the relatively narrow-band of blue light radiation from LED units does not always evoke this protective aversion response.[123]

Blue light is transmitted through the ocular media and absorbed by the retina. While high levels of blue light cause immediate and irreversible retinal burning, chronic exposure to low levels of blue light may cause accelerated retinal aging and degeneration. This chronic photochemical injury to the retinal-pigmented epithelium and choroid can accelerate age-related macular degeneration (ARMD).[123,124] Most countries follow international guidelines on optical radiation, such as those from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and American Conference of Governmental Industrial Hygienists (ACGIH) for the maximum cumulative permissible exposure to light within an 8-hour period.[122,123] The ACGIH threshold limit for the blue-light hazard is harmonized with the ICNIRP guidelines and the weighted blue-light hazard function, should not exceed 100 J/cm^2-sr over a total viewing time of 167 minutes in an 8 hour day.[122] Previous studies in the 1980's that assessed the hazards from QTH curing lights found that these units had little potential to cause ocular injury.[125,126] However, most lights studied in the 1980's delivered less than 400 mW/cm^2 over a broad spectral range between 400 and 500 nm. Contemporary QTH, high power plasma arc (PAC), and LED curing lights may deliver much higher irradiances, (up to and greater than 5,800 mW/cm^2) and in some lights the peak spectral emission is close to 440 nm.[57-59,62,101,125,127,128] A

recent study[129] found that with these LCUs, the ACGIH limits[122] may be reached during an 8 hour workday. If an operator, not wearing orange protective glasses, looked at the light tip for the first second of each curing cycle before looking away, it would take as little as seven light exposure cycles to exceed the maximum daily exposure to the tested PAC light.[129] It should be noted that the maximum recommended exposure time in the ACGIH guidelines is for individuals with normal photosensitivity; patients or dental personnel who have had cataract surgery or who are taking photosensitizing medications have a greater susceptibility to blue light, and retinal damage may occur with shorter exposure times.[122,123] Some blue light filtering glasses ('orange blue-blockers') have been shown to reduce the transmission of light below 500 nm to less than 1%.[125,130,131] When blue light filtering glasses are used, instead of looking away from the bright blue light from the LCU, the operator can safely watch what they are doing when light curing. This will improve the amount of light delivered to the restoration.[11,98,108] Unfortunately, despite the fact that most manufacturers of dental curing lights supply this protective eyewear, these items are not universally used.[132]

EVIDENCE-BASED ADVICE TO CLINICIANS WHEN USING A CURING LIGHT

The following recommendations are provided to help clinicians improve their use of the LCU so that their patients can receive safe and potentially longer lasting resin restorations.

1. Know the properties of your LCU. Does the LCU deliver a homogeneous light output, or will you need to move the light tip around as you cure the resin? How much does the irradiance decrease as the distance from the tip increases, will you need to increase your exposure time in deep preparations? Does the spectral emission from the LCU match the sensitivity of the RBC being used? Is the exposure mode appropriate for the RBC being used, could excessive polymerization contraction stress be generated? Could the high LCU output cause thermal damage to the pulp or soft tissues if not used carefully?
2. Use appropriate infection control on the LCU and adjust exposure time accordingly.
3. Monitor the performance of your LCU and keep a logbook of the output from each LCU from the date of purchase. To guide any adjustments in exposure duration, the dentist can carry out depth of cure scrape tests using different shades of their RBC light-cured at clinically representative distances.
4. Maximize the output from the LCU by examining the light tip for damage and remove remnants of previously cured RBCs. Clean or replace tip as necessary.
5. Protect the eyes of everyone in the operatory who could be exposed to the bright light, with appropriate orange (blue light blocking) safety glasses.
6. Learn how to use the LCU to maximize energy delivered to the RBC. Place the central axis of the tip of the LCU directly over and normal to the RBC surface; the emitting end should be parallel to the RBC surface being exposed. When using a LCU with an inhomogeneous light output, move the light tip around and increase the exposure time. This should also be done where undercuts are present that prevent straight-line access to the RBC. Additionally, in this situation, use supplementary bucco-lingual curing (but beware of overheating).
7. Develop a technique to prevent uncured resin from adhering to the tip of the LCU and thus reducing the light output. For example, begin the exposure with the tip approximately 1 mm away from the RBC. Then, when the top surface of the RBC is hard (after 1 second), move the tip of the LCU as close as possible to the surface of the RBC.
8. Protect the oral mucosa from the light with gauze and air-cool or wait several seconds between each light curing cycle when using a powerful curing light that has the capacity to produce a damaging temperature rise.

CONCLUSIONS

Evidence has been presented to help clinicians understand that the LCU is a vital, yet often misunderstood and undervalued, item of equipment. The choice of LCU and how it is used are important factors in determining whether the patient will receive a safe and potentially longer-lasting resin restoration.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Clinical Technique/Case Report

A Simplified Clinical Technique for a Routine Indirect Restoration Impression on a Challenging Patient Using a Dry Field Illuminator

NM Santucci • ET Santucci • M Geissberger

Clinical Relevance

Quality impressions require a dry oral environment. This can be difficult on medically compromised patients. During impression taking, simultaneous isolation along with check and tongue retraction, can be achieved using a dry field illuminator.

SUMMARY

Detailed and accurate impressions are made when the oral environment is dry during the impression process.[1] Maintaining a dry field on medically, physically, or emotionally compromised patients can be very challenging. If not achieved, it may compromise dental care and accurate outcomes. This article describes a technique that can be used to make a final impression for an indirect restoration in a protected, isolated, and dry environment, using a dry field illuminator.

*Noelle M. Santucci, DDS, MA, assistant professor, University of the Pacific, Dugoni School of Dentistry, Department of Integrated Reconstructive Dental Science, San Francisco, CA, USA

Eugene T. Santucci, DDS, MA, associate professor, University of the Pacific, Dugoni School of Dentistry, Department of Integrated Reconstructive Dental Science, San Francisco, CA, USA

Marc Geissberger, DDS, MA, professor and chair, University of the Pacific Dugoni School of Dentistry, Department of Integrated Reconstructive Dental Science, San Francisco, CA, USA

*Corresponding author: 2155 Webster St, San Francisco, CA 94115; e-mail: nsantucci@pacific.edu

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INTRODUCTION

From pediatrics to geriatrics, one can find patients whose medical, physical, mental, or emotional status renders dental treatment challenging. [2,3] Temporomandibular dysfunction, enlarged or overactive tongue, dental phobia or anxiety are just a few of the challenges that may compromise routine or complex dental care.[4,5] Children with special needs may exhibit uncontrollable or limited mandibular activity, and older adults with dementia may demonstrate behavioral problems that can limit the doctor's ability to deliver dental care in an efficient, comfortable, and skillful fashion.

Examples of limiting physical conditions include restricted maxillary/mandibular incisal opening, microstomia, masticatory myalgia resulting from prolonged or exaggerated opening, and temporomandibular joint tenderness, especially in patients with a history of temporomandibular dysfunction.[5] An

enlarged, overactive tongue or impingement of the coronoid process against the buccal surfaces of the maxillary posterior teeth can also limit access and visibility.

Patients who are taking certain antipsychotic medications may experience sialorrhea as a side effect.[6] Excessive salivation that is not well controlled, may compromise the success of direct composite restorations or render moisture control very difficult while taking an impression. A patient's medical history may limit the use of parasympatholytic medications, such as propantheline. These medications, which control excessive salivary flow, are contraindicated in patients with glaucoma.[7] The patients themselves may be averse to taking long-acting medications that produce excessive xerostomic effects, thereby precluding their use.

The aforementioned conditions can make, what would seemingly be a routine dental restoration, very difficult and can limit the doctor's ability to deliver dental care.

Techniques suggesting the use of bite-blocks and high-speed suction when providing direct or indirect restorative care fall short when dealing with these complicating factors as they do not allow for adequate moisture control, tongue and cheek protection, accessibility to or sufficient space around the operating field, uninhibited visibility, or adequate illumination. [8] Both patient and operator comfort can be challenged.

Studies have shown a high degree of patient acceptance of rubber-dam use while undergoing dental treatment.[9,10] Yet past emotional reactions to dental procedures can bring on feelings of anxiety. Rubber-dam placement can be a source of apprehension to some patients.[10] It could trigger the claustrophobic feeling that overcomes a patient with rubber-dam isolation techniques.[10] This distress could induce excessive salivation or the fear that they will not be able to maintain a sufficient airway.[10] Patients who exhibit anxiety-related habits, such as protective tongue movements toward the treatment area, pose a risk of injury during dental procedures. Patient perception that a procedure is lengthy can lead to the onset of muscular fatigue and inappropriate mandibular opening. Repeated interruption of the dental procedure to allow the patient to rest the muscles can be frustrating to the doctor and the patient by contributing to a lengthier appointment time. As practitioners, our hope is that, with time, patience, and education, the patient may learn to relax, discontinue the risky maneuvers, and continue to be treated safely. Unfortunately, treatment must still be rendered in the interim.

Traditional rubber-dam isolation is a technique that has been promoted by such organizations as the Centers for Disease Control and Prevention (CDC).[11] It serves as a barrier against blood-borne pathogens, helps minimizing aerosols, and helps attain optimal results in adhesive dentistry.[12] Gilbert et al have shown "greater shear bond strengths and reduced microleakage"[13] with the use of the rubber dam compared with use of cotton-roll isolation alone. Traditional rubber-dam isolation can also improve patient management while serving as a barrier for the tongue and other soft tissues. The rubber dam enhances treatment area visualization by isolating the operative field, keeping it dry, and decreasing the time needed to perform a dental procedure. Perceived drawbacks to the rubber dam include patients' dislike of its use, a potentially time-intensive and inconvenient placement, and ease of dislodgment of the rubber dam or the clamp in patients with active tongue movement.

Some variations to the traditional rubber dam have been developed. One such device is the Quick Dam (Auckland Co, Cary, NC, USA). This device does not require clamps but is supported by a flexible ring located at its border, which is then supported intraorally. One study compared it to the traditional rubber dam and found that "saliva control was not as positive for posterior teeth."[14]

Other time-saving techniques described in dental journals and developed by dental colleagues include a custom prosthesis to enhance moisture control. Fabrication of this device requires a preoperative alginate impression, denture base material, and additional laboratory time.[15]

Dry angles used as isolation devices are thin enough to insert into a patient's mouth and serve as a retraction device of the soft tissues, such as the tongue and buccal mucosa. It also prevents the high-volume evacuation (HVE) from suctioning the soft tissues. Its ability to absorb water for moisture control is short lived, and it needs to be changed frequently. One advantage, however, is that its thinness allows for a less encumbered access to the operative site, though it does not offer any oral-pharyngeal protection.

Some techniques use bite-blocks and HVE when dealing with complicating factors that affect restorative care. The advantage of HVE is that it can reduce microbe-containing aerosols that could potentially be

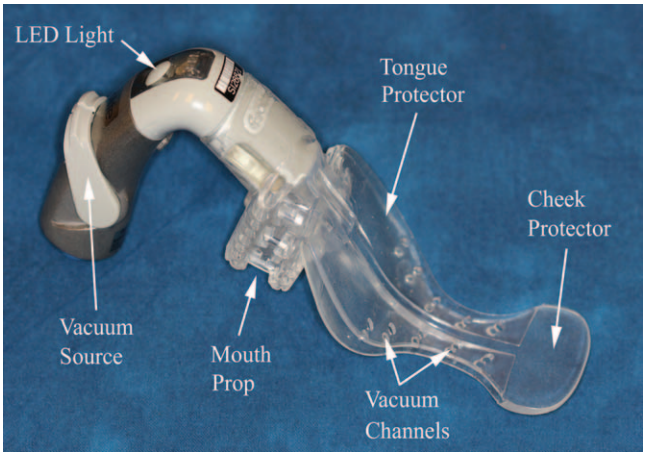

Figure 1 *The isolite appliance and its components*

Figure 2 *Small, medium and large mouth piece.*

hazardous to the doctor or assistant.[16] The technique falls short because it does not promote tongue and cheek protection while allowing for operator space, visibility, illumination, and patient comfort.[17]

Cotton-roll isolation is a method of moisture control in the placement of restorative materials and orthodontic brackets when used in conjunction with the rubber dam to retract it further from the operative sight.[18,19] Other studies show that there is an increase in the long-term survival rates of restorations if placed with the rubber dam versus cotton rolls alone.[20]

The newest devices for isolation and moisture control are dry field illuminators. One such device is the Isolite i2 Dry Field Illuminator (Isolite Systems, Santa Barbara, CA, USA) (Figure 1). This device combines several features, including a portion that retracts the cheek and tongue simultaneously, a bite block to help patients keep their mouth open comfortably, suction, and an intraoral light source for illumination, all in one instrument. An advantage of such devices over conventional rubber dams is the ease of insertion and removal as needed throughout a dental procedure. This allows a patient who may otherwise be apprehensive about the use of a rubber dam to know that at appropriate moments during a restorative procedure the device could be removed and reinserted easily.

This article proposes a technique using a dry field illuminator to address the challenges posed by the physical, medical, or emotional characteristics of the patient while performing a crown preparation, making a final impression, and fabricating a provisional restoration. This system allows the doctor to provide added comfort for the patient, help control excessive salivation around the operative site, maintain maximum operative space, increase illumination, and significantly reduce the risk of patient injury posed by a large tongue or excessive tongue movement during the restorative session.

DESCRIPTION OF MATERIALS AND TECHNIQUE

A 56-year-old male patient presented with a medical history that included systemic degenerative arthritis, resulting in a restricted maxillary/mandibular incisive opening. His dental history indicated difficulty in completing routine dental procedures because of masticatory muscle fatigue and limited incisive opening. This was further complicated by his large tongue. The patient also had an uncontrolled posturing habit directed toward the treatment zone.

The goal of the appointment was to complete the crown preparation, the impression, and the provisional crown on the mandibular left first molar in a perfectly dry, visible, and protected environment with a dry field illuminator appliance in place. This tooth had been previously endodontically treated, and a light-cured core buildup material had been placed.

Before seating the patient, the dry field illuminator appliance was assembled. The parts of the dry field illuminator appliance include a High Volume Evacuator (HVE) source with evacuation channels, a light-emitting diode (LED), and a mouth prop (Figure 1).

The vacuum hose is attached to the HVE port on the cart. Before attaching the mouthpiece to the evacuation/LED system, a proper-sized mouth prop must be selected. The single-use, disposable, nonlatex, Isolite i2 mouthpiece with vacuum channels and sublingual vestibular aspiration comes in pediatric, small, medium, medium-large, large, and

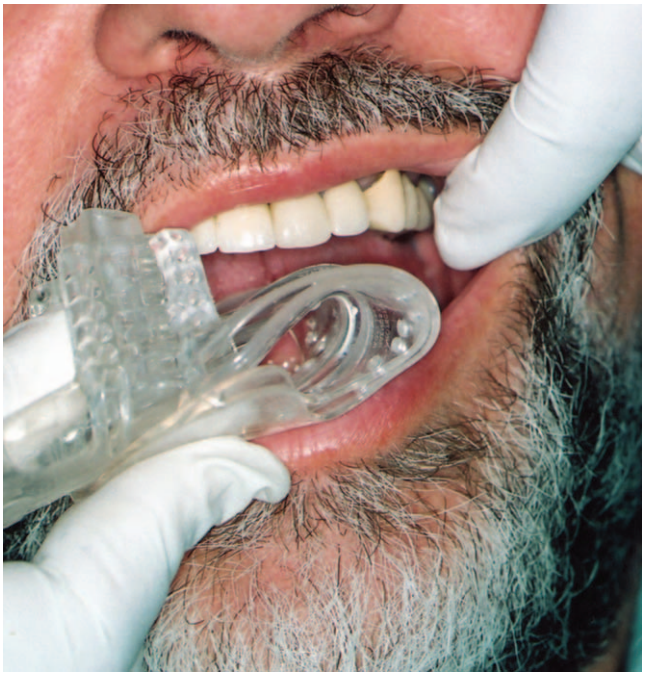

Figure 3 *Inserting the dry field illuminator.*

extra-large sizes (Figure 2). It is recommended to choose the largest size that allows for a comfortable but maximum opening and soft-tissue protection for the patient. Practicing inserting and removing the dry field illuminator makes the process routine.

First, fold the protective tongue flange against the bite-block portion and insert the bite block to the contralateral side of the proposed treatment area (Figure 3). While the patient rests against the bite block, the flange can be positioned so that the tongue is behind the flange and the vacuum channels rest against the lingual side of the teeth to be prepared. The terminal portion of the flange will rest behind the retromolar pad and come anteriorly into the buccal vestibule for cheek retraction and field accessibility during the restorative procedure (Figure 4).

Customized sculpting of the mouthpiece is possible to further improve compliance, especially in situations where impingement on maxillary or mandibular structures, such as tori, exists. This customizing can be easily accomplished with utility scissors.[2] A series of pretreatment exposures of the patient to the mouthpiece is most beneficial for those patients who present with emotional reactions to new dental procedures.

When core buildups are required, the light source in the dry field illuminator appliance can be changed

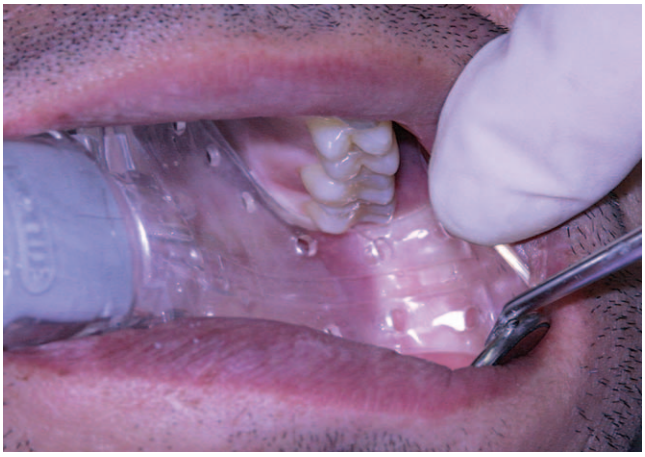

Figure 4 *Positioning appliance in the buccal corridor.*

to the "cure safe" mode so as not to disturb the setting time properties of the composite core materials.

In a study presented at the World Congress of Minimally Invasive Dentistry in San Francisco, California, on August 13, 2004, Dr. Michael J. Melkers showed that the dry field illuminator appliance compared very favorably with rubber-dam isolation in reducing the relative intraoral humidity.[4,21] Proper isolation when placing routine direct composite restorations is critical as saliva contamination can affect the properties of self-etching adhesives, can significantly lower bond strength when etched dentin is contaminated with saliva, and can deteriorate the bond strength of luting cements.[22,23]

After the successful administration of the appropriate anesthesia, the opposing arch impression, temporization template, and pretreatment shade were secured. Consider using a fast-setting alginate substitute for the opposing model on patients with limited incisal opening, increased salivation, or exaggerated swallowing reflex.

With the dry field device in place and the proper suction level attained, the crown preparation can begin. An entire preparation can be completed with the isolation device in place, but it can also be removed at any time to evaluate the need for further occlusal reduction and to ensure that the preparation meets all the appropriate preparation criteria necessary for the new crown to restore proper form, function, and esthetics. Gingival retraction can also be completed with the isolation device in place.

Use of a standard complete arch stock or custom impression tray may be difficult with patients who

Figure 5 *Adapted stock tray.*

have limited opening and may require their modification or use of a sectional tray.[24] With the dry field illumination technique, the clinician will need to adapt either a stock tray or a previously fabricated custom tray (Figure 5). In modifying the tray it is important to include as many teeth as possible in the impression. Including the contralateral cuspid is ideal to improve model stability during the laboratory mounting process.

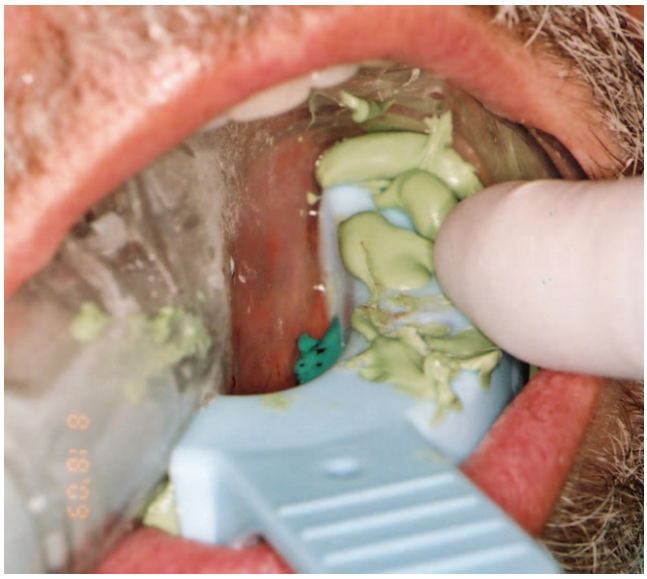

Figure 6 *Final impression using modified stock tray and dry field illuminator.*

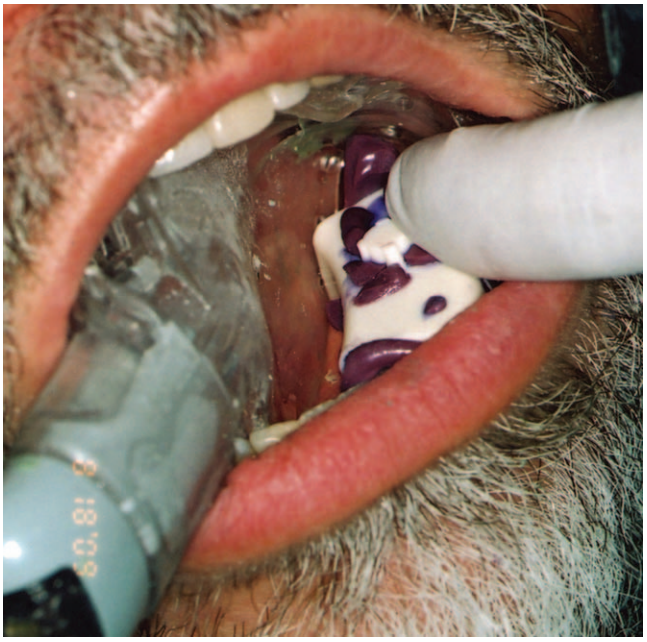

Figure 7 *Provisional restoration fabrication with dry field illuminator in place.*

Polyvinylsiloxane was used for the final impression, following product guidelines. To ensure that the final impression was made in a dry, protected field, it was made with the dry field illuminator appliance in place (Figure 6). The tongue and cheek isolation facilitated by the appliance encourages a superior final impression while helping to prevent displacement of the tray by the tongue while the material is setting. It also facilitates the fabrication of the provisional crown using the previously acquired template (Figure 7).

After the removal of the isolation device, the occlusal adjustment of the provisional and interarch bite registration was completed. The registration should include as many teeth on the prepared side as well as half of the buccal surfaces of that quadrant to help the laboratory technician mount the cast in proper relationship to the opposing model. This is analogous to their mounting a split cast. Cementation of the provisional was accomplished with the dry field illuminator appliance in place.

Except for the occlusal adjustment, at the crown cementation appointment, evaluation of contacts, internal fit, and margins as well as final cementation can be performed with the dry field illuminator in place. This ensures a dry field and unrestricted access during final cementation (Figure 8).[25]

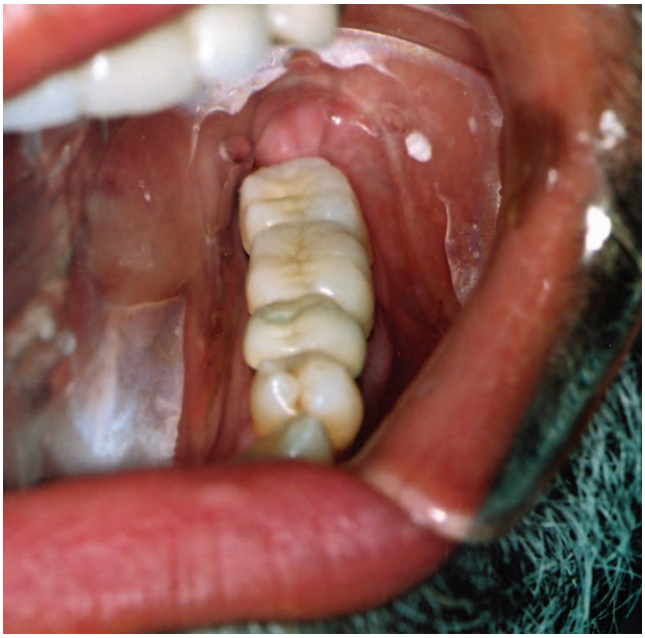

Figure 8 *Final cementation completed.*

POTENTIAL PROBLEMS

This technique presents two potential challenges. First, a full-arch final impression is not possible. A good laboratory technician, however, can use the opposing cast and bite registration to mount the cast made from the modified impression tray onto a semi-adjustable articulator. This is similar to the spilt cast mounting for a removable appliance. The second challenge for the dental practitioner is the need to remove and reinsert the appliance at various times during the restorative procedure. Once the clinician becomes proficient with its use, however, the insertion and removal process becomes a minor issue. The time savings and patient safety will override the inconvenience of reinserting the appliance at the various clinical steps.[2] In fact the patients may enjoy the brief periods of rest when the appliance is removed intermittently.

Prolonged interincisal opening does not appear to be a problem because of the bite-block feature of the dry field illuminator. We surmise that the flexibility of the mouthpiece promotes a more relaxed disposition of the patient, which is also instrumental in decreasing episodes of masticatory myalgia.

BENEFITS

The overriding benefit to the use of the device is isolation and protection of the soft tissues; illumination of the treatment area during preparation; and moisture control during impression making, provisional fabrication, and final cementation.[25–27] Use of a dry field technique reduces relative humidity intraorally to prevent contamination of the restoration sight, which is very important during placement of adhesive restorations.[28] Additional advantages include decreased mirror fogging; decreased dental aerosol spray, which can be further reduced by the staff incorporating an additional HVE at the operative site if needed; and increased patient safety because of the protection of the oropharyngeal airway.[27] These features could also contribute to improved ergonomic postures for the doctor and staff.[16] The critical reason for using the dry field illuminator is to create a dry oral environment to ensure a better quality, obtain a more detailed impression, and minimize the need to remake the impression.[1]

CONCLUSION

Rubber-dam isolation has been shown to improve the quality of treatment, increase the speed of the dental procedure, and save time by 40% to 50%.[29] For patients where rubber-dam placement is impossible, the use of the dry field illuminator is a viable alternative by combining illumination, retraction, mouth support, oropharyngeal protection, illumination, and suction all in one instrument.

In the authors' experiences, the technique presented has proven effective for the preparation, impression making, provisionalization, and delivery of routine indirect dental procedures in patients who present with physical, medical, or emotional characteristics that would greatly interfere with the delivery of quality care. The use of the Isolite i2 Dry Field Illuminator or a similar device can be easily incorporated into any dental practice for use in a multitude of other dental procedures, including clinical examinations, direct restorative procedures, sealants, and periodontal treatments while hand scaling or using the ultrasonic scaler.[25] The initial expense of the appliance is quickly recouped because of its ease of use and effective isolation, suction, tissue retraction, and illumination, all of which contribute to time savings at chairside.[2, 26,27] A dental practitioner whose patients previously required increased chair time to complete routine dental procedures due to medical, physical, or emotional challenges may find this impression technique with the use of the dry field illuminator an invaluable addition to his or her dental practice armamentarium.

In the case described, what would have been a very stress-filled appointment was converted to one where excellent dental care was provided in a totally well controlled, isolated, protected, and comfortable dental environment.

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Proximal Box Elevation With Resin Composite and the Dogma of Biological Width: Clinical R2-Technique and Critical Review

C Frese • D Wolff • HJ Staehle

Clinical Relevance

Advancements in material technology and clinical techniques led to increasing indications for minimally invasive treatment approaches with direct resin composite restorations. Proximal box elevation, an example of an elaborate clinical technique, provides a two-step procedure for the restoration of deep and undermining defects in the proximal area.

SUMMARY

Provided that moisture control is possible, today's resin composite materials can be applied successfully in the restorative treatment of extensively decayed teeth. This suggests that restorative margins will be increasingly located below the cementoenamel junction, probably invading biological width. The recently introduced technique of proximal box elevation (PBE) offers the possibility of performing a stepwise elevation of deep proximal cavities to create more favorable preparation margins for direct or indirect restorations. Clinical instructions for the restoration of extensively damaged teeth are given through this presentation. A two-step R2-technique will be shown, and a critical review of the dogma of biological width will be presented.

*Cornelia Frese, Dr. med. dent., senior dentist, University Hospital Heidelberg, Department of Conservative Dentistry, Heidelberg, Germany

Diana Wolff, Dr.med.dent, University of Heidelberg, Department of Conservative Dentistry, Heidelberg, Germany

Hans Joerg Staehle, Prof.Dr.med., Dr.med.dent., head of department, University of Heidelberg, Department of Conservative Dentistry, Heidelberg, Germany

*Corresponding author: Im Neuenheimer Feld 400, Heidelberg, 69120, Germany; e-mail: cornelia.frese@med.uni-heidelberg.de

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INTRODUCTION

With current adhesive technology and modern composite resin materials it has become possible to restore even severely damaged teeth. Thus, minimally invasive techniques are used to save a maximum amount of sound tooth substance.[1] Even extensive and undermining tooth defects can be restored using direct composite resin materials. In general, it is recommended that the cervical margin

of the restoration should be placed within an intact enamel layer. However, provided that moisture control is possible, composite resin restorations can be applied successfully in deeper cavities, even when restorative margins are located below the cemento-enamel junction (CEJ).[2] A new operational range is thus opened up as the composite resin is located subgingivally adjacent to the junctional epithelium and alveolar bone crest. Modern application techniques allow for the creation of planned and nonirritating composite resin margins in this area.[3,4] A recently described technique, proximal box elevation (PBE), offers the possibility of a stepwise relocation of deep proximal margins to uplift cavity outlines for direct or indirect restorations.[5,6] Step one (PBE) involves a meticulous layering technique for margin relocation above the CEJ. Step two allows the practitioner to decide on whether to place a direct or indirect restoration under improved clinical conditions.

Before restoring extensively decayed teeth, the distance between the future restorative margin and the alveolar crest should be evaluated carefully, for example, by bone sounding. An adequate space for restorative margin placement can be achieved by surgical (crown lengthening procedure) or orthodontic treatment (forced eruption).[7]

The physiological dimensions of the dentogingival junction, with its inherent parts of epithelial attachment, connective tissue attachment, and sulcus depth, were first described by Gargiulo and others in 1961[8] and reevaluated by Vacek and others in 1994.[9] Gargiulo and others described the ideal dimension of the dentogingival junction to be 2.73 mm and Vacek and others determined it to be 3.25 mm.[9] Based on these reports, a distance of 3 mm and more is recommended between restorative margins and the alveolar crest to avoid detrimental effects on neighboring soft and hard tissues.[10-13] In restorative terminology this distance is generally called "biological width."

Violations of the biological width resulting from intracrevicular placement of restorative margins can result in severe gingival inflammation,[4] loss of periodontal attachment, and bone resorption.[11,15] Furthermore, marginal overhangs of direct and indirect restorations are related closely to elevated plaque accumulation, microbiological diversification, and increasing chronic inflammation of soft and hard tissue.[16]

Clinical observations in our department revealed that plain, smooth, and nonirritating margins on deep occluso-proximal resin composite restorations invading biological width are free of gingival and periodontal inflammation, provided that there is distinct oral hygiene training and use of accurately fitting interdental brushes. This fact leads to the hypothesis that subgingival composite resin restorations fabricated using a two-step R2-technique may violate the area of biological width without inducing chronic inflammation.

Together with the clinical procedure presented here, a stepwise introduction is given to the restoration of extensively damaged teeth by applying a direct composite resin restoration, using the two-step R2-technique (step one: PBE; step two: direct composite resin restoration). Furthermore, a critical review is given on the consistency of the dogma of biological width.

CLINICAL TECHNIQUE

Patient Presentation

A 75-year-old female psychologist visited the Department of Conservative Dentistry, Clinic for Oral, Dental and Maxillofacial Diseases, University Hospital Heidelberg, with a restoration loss on the mandibular right premolar #45. A review of her medical history revealed no medical disease. She was a nonsmoker and took no medications. She stated that she felt no pain on tooth #45. Clinical examination revealed positive vitality, no tooth mobility, and probing depths of 2 mm.

Intraoral evaluation revealed carious decay on the cervical margin of the cavity reaching beyond the CEJ. The proximal margin was partly covered by overgrowing gingival tissue (Figure 1). Radiographic examination of tooth #45 revealed that there was no periapical translucency and that the distance between the cavity margin and the alveolar bone crest was between 0.5 mm and 1.0 mm (Figure 2). As the proximal cavity margin was already beyond the CEJ invading biological width, it was assumed that after caries removal it would be located at the level of the alveolar crest. It was explained to the patient that the gold-standard treatment would be placement of an indirect partial or full crown in combination with surgical or orthodontic pretreatment. Alternatively, it was clarified that if the marginal ridge was still intact, a direct restoration with composite resin could be an option. However, it was also explained that the outcome of this procedure would be less predictable than that of an indirect restoration. The patient favored a restoration with direct composite resin to avoid surgical or orthodontic interventions.

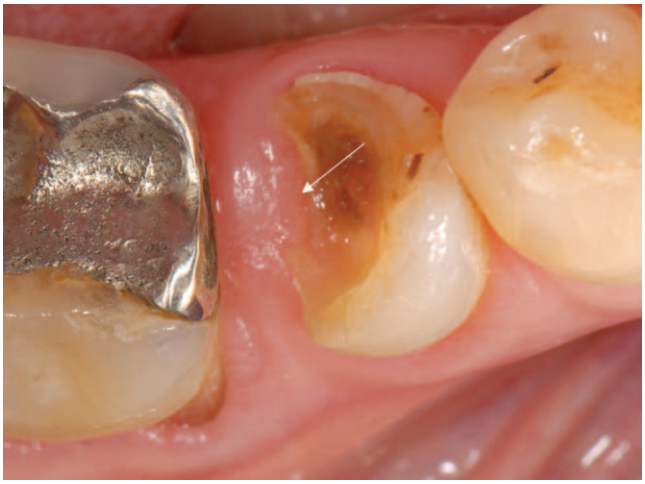

Figure 1. Preoperative view of tooth #45 with occluso-proximal decay and loss of restoration a few weeks before R2-technique was performed. Gingival overgrowth is seen on proximal cavity margin (arrow).

Description of the R2-Technique

Step One (PBE)—All materials used are listed in Table 1. After local anesthesia, the excessive gingiva was removed using an electrosurgical unit (Elektrotom MD 62, KLS Martin GmbH & Co KG, Tuttlingen, Germany). Caries was removed with a bur (H1SEM 204.018-23, Komet, Gebr. Brasseler GmbH & Co.KG, Lemgo, Germany), and any sharp angles were rounded. At this point, it was clear that the proximal cavity margin was close to the alveolar crest, making the application of a partial or circular matrix impossible (Figure 3). For hemostasis, a retraction cord was placed and an astringent paste was applied for 2 minutes and rinsed carefully (Astringent Retraction Paste, 3M ESPE, Seefeld, Germany) (Figure 4). Afterward, direct composite resin was applied to perform a PBE in accordance with the protocol of Frankenberger and others[5] and Roggendorf and others [6] (Figure 5). Tooth #45 was etched for 15 seconds with 37% phosphoric acid, a filled ethanol-based adhesive system (Optibond FL, Kerr, Orange, CA, USA) was applied and the adhesive was light-polymerized for 20 seconds (Bluephase C8, Ivoclar, Vivadent, Schaan, Liechtenstein). A thin layer of flowable composite resin (Tetric Evo Flow, Ivoclar Vivadent) was placed on the cavity margin. On top of the nonpolymerized layer of flowable resin, another layer of viscous composite resin was applied (Tetric Evo Ceram, Ivoclar Vivadent). The viscous material was molded and gently pressed into the flowable resin (Snowplough Technique, Figure 6 detailed description vide infra).[17] Final polymerization of both the flowable and the viscous composite resin was then completed with light at 800 mW/cm^2 (40 seconds). Because of the

Table 1: *Table of materials used for R2-technique*

Material	Manufacturer
Electrosurgical unit	Elektrotom MD 62, KLS Martin GmbH & Co KG, Tuttlingen, Germany
Rotary instruments H1SEM 204.018-23, #128-130	Komet, Gebr. Brasseler GmbH & Co.KG, Lemgo, Germany
Astringent retraction paste	Astringent Retraction Paste, 3M ESPE, Sefeld, Germany
Adhesive system	Optibond FL, Kerr, Orange, CA, USA
Flowable composite	Tetric Evo Flow, Ivoclar Vivadent, Schaan, Liechtenstein
Restorative resin composite	Tetric Evo Ceram, Ivoclar Vivadent, Schaan, Liechtenstein
Rubber dam	Hygienic Dental Dam, Coltene Whaledent, Langenau, Germany
50 μm Al_2O_3 powder	Kaltenbach & Voigt, Biberach, Germany
Sectional matrix system	Palodent, Dentsply DeTrey, Konstanz, Germany
Proximal contact instrument	OptraContact, Ivoclar Vivadent, Schaan, Liechtenstein
Polishing kit	Astropol HP, Ivoclar Vivadent, Schaan, Liechtenstein
Interdental brush	CPS 14 Z, Curaden International AG, Amlehnstrasse 22, 6010 Kriens, Schweiz

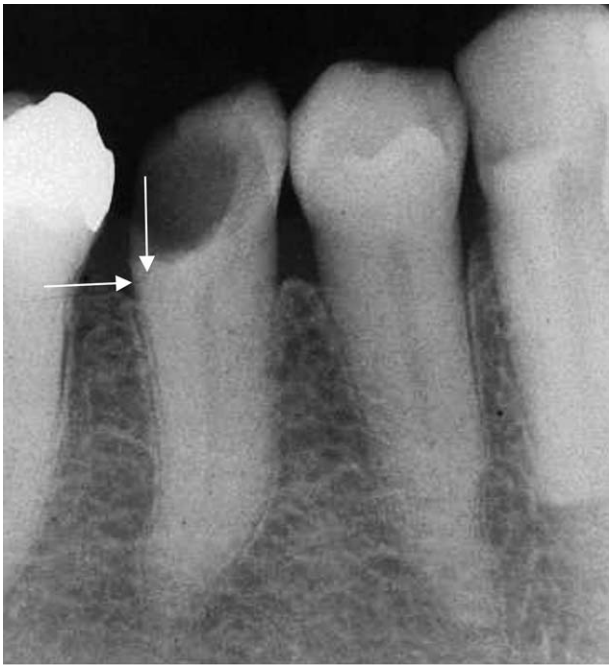

Figure 2. Preoperative x-ray of tooth #45. After excavation of caries, the proximal cavity margin is located close to the alveolar crest (arrow).

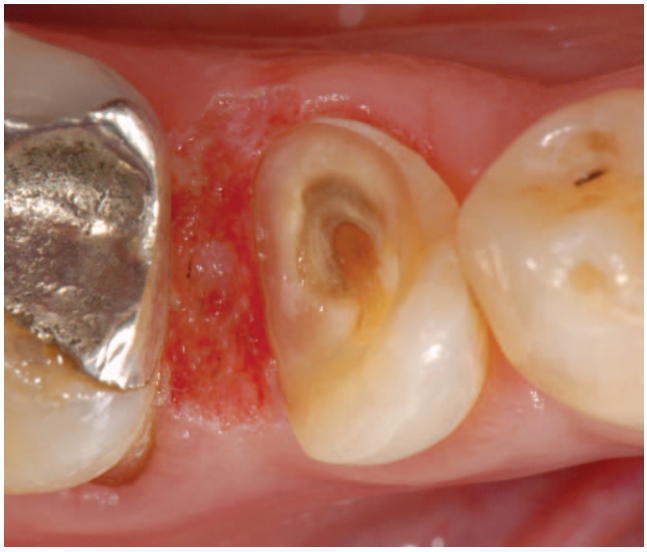

Figure 3. R2-technique: Placement of a direct resin composite restoration in the two-step technique. Step one (PBE): Clinical situation after gingivectomy (Elektrotom) and caries excavation. The proximal cavity margin is located below the CEJ next to the alveolar crest.

abandonment of a matrix, marginal overhangs could not be avoided. Subsequently, they were removed carefully with a rotary diamond instrument #128-130 (Flamme 128-130; Komet, Gebr. Brasseler GmbH & Co.KG) and a scalpel (Figure 7a).

Step Two (direct composite resin restoration)—A rubber dam (Hygienic Dental Dam, Coltene Whaledent, Langenau, Germany) was placed, and the previously placed PBE was cleaned carefully and

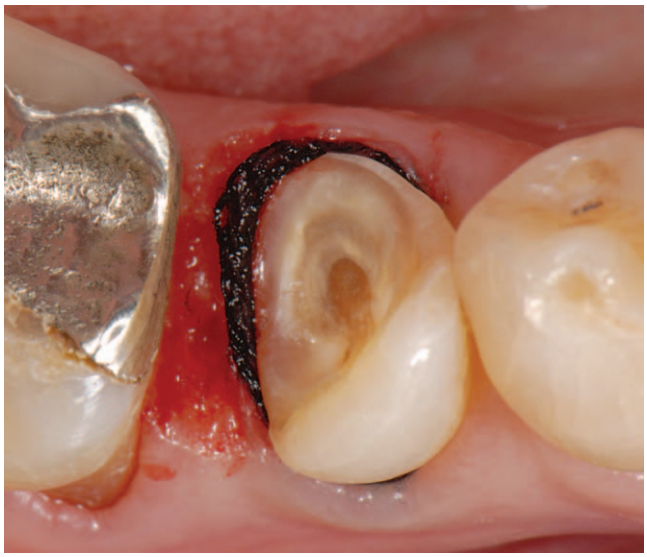

Figure 4. Application of a retraction cord. The cord could not be inserted fully into the sulcus because of the proximity of the alveolar crest. Subsequently, an astringent paste was applied for 2 min.

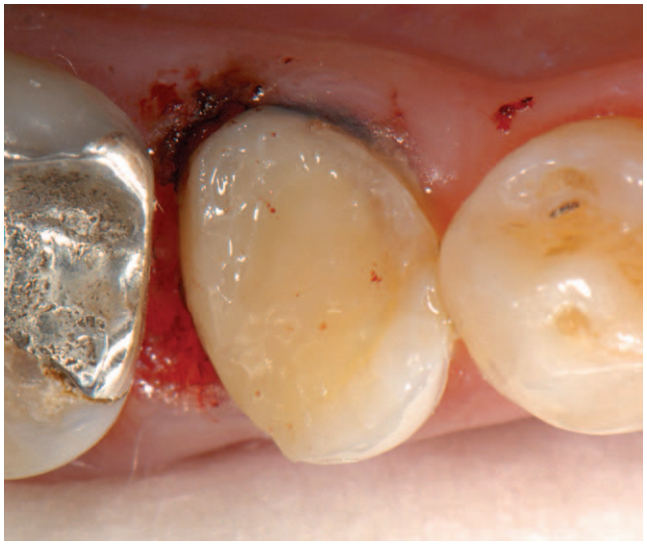

Figure 5. After etching, priming, and bonding, a layer of flowable composite was placed meticulously on the cavity margin, followed by a layer of viscous resin composite (both unpolymerized). After modeling and shaping both materials, the final light polymerization was carried out (Snowplough technique).

roughened by Al_2O_3 powder (50 μm**,** Kaltenbach & Voigt, Biberach, Germany). A sectional matrix (Palodent, Dentsply DeTrey, Konstanz, Germany) was inserted and fixed with a wedge and a separation ring. Between the PBE placed in step one and the sectional matrix, a narrow and sharp angled junction occurs. Etching and bonding steps were carried out using the same materials described previously.

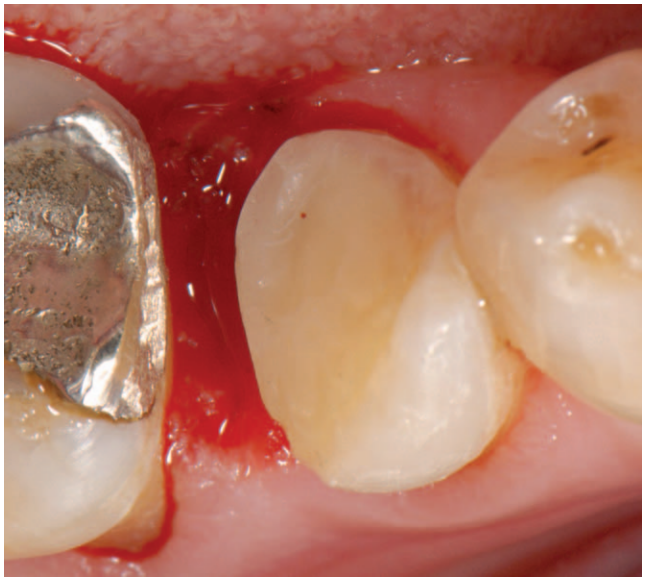

Figure 6. Schematic drawing of Snowplough technique: Note that in clinical practice there is a narrow and sharp angled junction between PBE placed in step one and the sectional matrix.

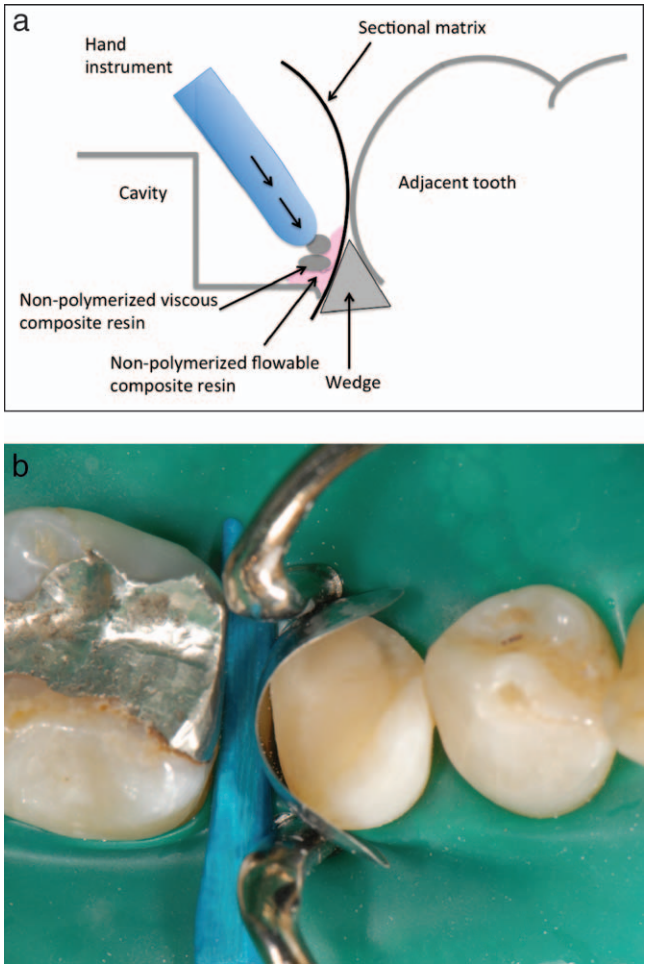

Figure 7. (a) Clinical situation after the PBE. The subgingival restorative margin was finished with rotary diamond instruments and a scalpel to remove overhangs and to create a smooth, planed, and nonirritating surface. (b) Step two: Occlusal view after application of the rubber dam, subsequent sandblasting with aluminium oxide, placement of a sectional matrix, wedging, and application of a separation ring.

The composite resin was applied using the Snowplough technique (Figure 6).

A small amount of flowable composite resin (Tetric Evo Flow, Ivoclar Vivadent) was applied on the bottom of the cavity and gently dispersed with a dental probe for nonporous adaptation. The nonpolymerized flowable resin should cover the sharp angled junction between the cavity margin and sectional matrix completely. On top of the nonpolymerized layer of flowable resin, small amounts of viscous composite resin were applied (Tetric Evo Ceram, Ivoclar Vivadent) and gently pressed into the flowable resin using a hand instrument. In this way, the composite resin was adapted tightly to the cavity surface, resulting in a nonporous restoration–tooth interface.

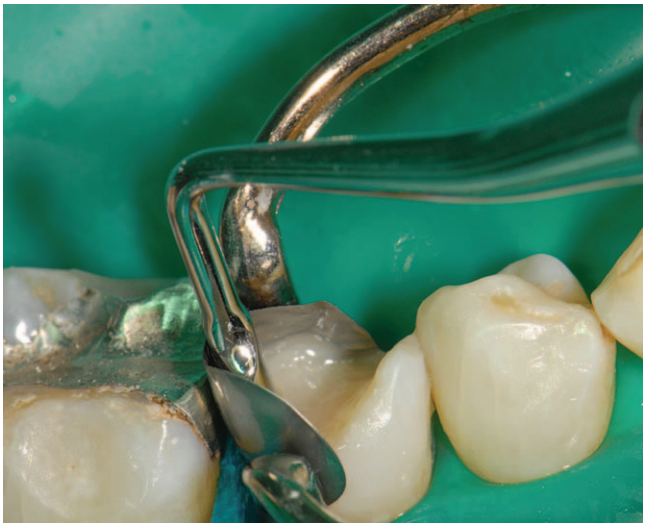

Figure 8. Composite resin is applied using the Snowplough technique. To obtain a tight proximal contact, a special hand instrument was used to separate the teeth during light polymerization.

To obtain a tight proximal contact, a special hand instrument (OptraContact, Ivoclar Vivadent) was used (Figures 8 and 9). Final polymerization of both the flowable and the viscous composite resin was then completed with light at 800 mW/cm^2 (40 seconds). Finally, the rubber dam was removed, the occlusion was checked, and the restoration was finished using the Astropol HP Finishing Kit (Astropol HP, Ivoclar Vivadent) (Figures 7b through 10). After the treatment session, the patient underwent oral hygiene training, and accurately fitting interdental brushes were chosen (Figure 11).

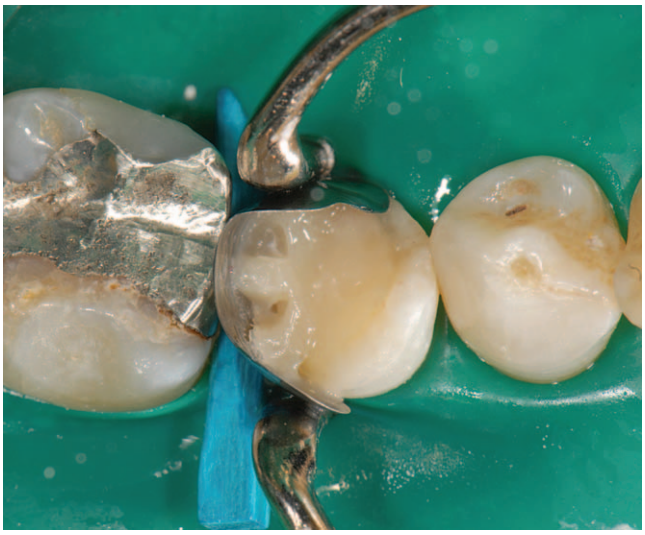

Figure 9. Occlusal view after removal of the proximal contact instrument. A tight proximal contact to the adjacent tooth is accomplished.

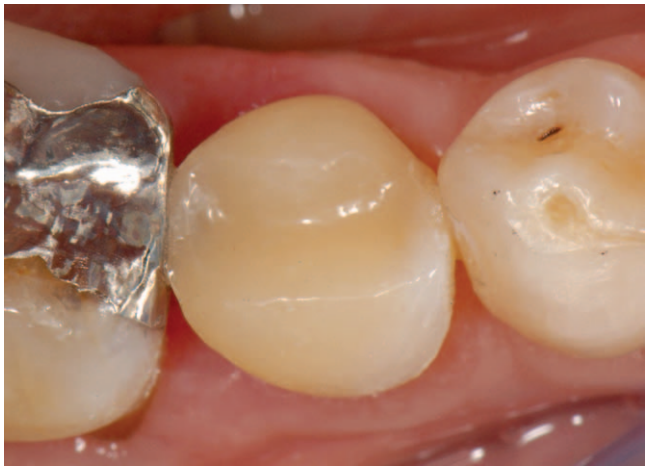

Figure 10. Clinical situation after removal of the rubber dam.

The postoperative radiographic examination of tooth #45 revealed that the proximal cavity margin was located adjacent to the alveolar bone crest and in close contact to connective tissue fibres of the dentogingival complex (distance 0.5–1.0 mm) (Figure 12).

12-Month Recall—The clinical observation after 12 months revealed a vital tooth #45 with no inflammatory signs in the surrounding soft and hard tissue (Figure 13). Despite the fact that the biological width was clearly violated, the probing depths were 2 mm, and no bleeding occurred on probing (Figure 14). Radiographic examination revealed a distance of 1 mm between the restorative margin and the alveolar crest. Over the 12-month period, only a minimal loss of alveolar bone was observed (Figure 15).

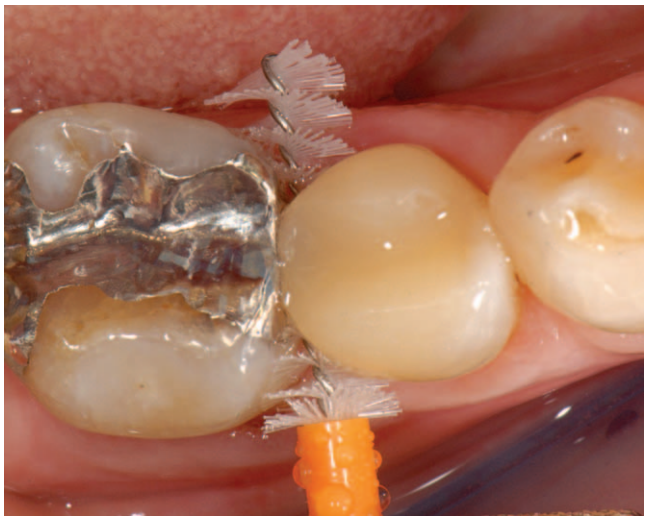

Figure 11. Postoperative view showing the selection of an accurately fitting interdental brush.

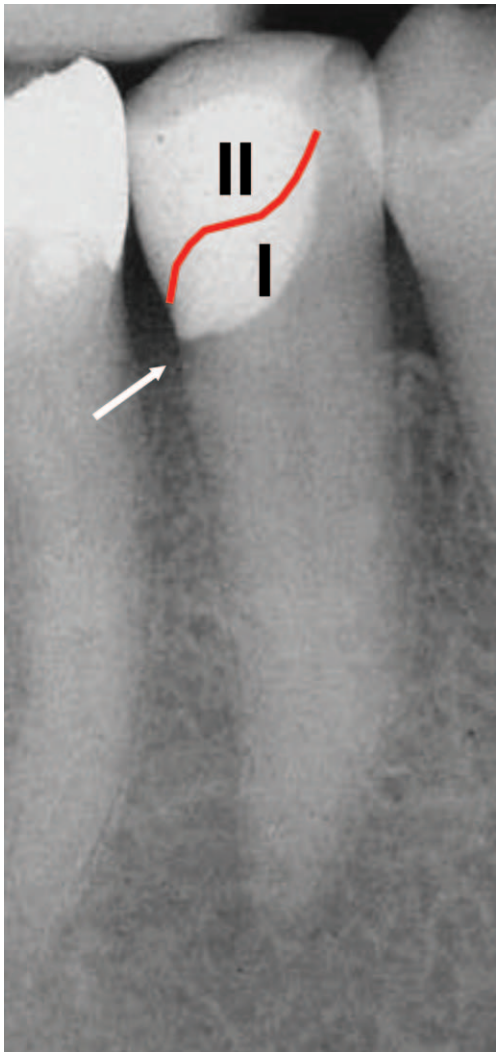

Figure 12. Postoperative x-ray of tooth #45. The subgingival restorative margin invades the biological width (the distance between restorative margin and alveolar crest was 0.5–1.0 mm). The emergence profile of the direct composite resin restoration is anatomically correct. The first part of the R2-restoration (PBE) merges continuously into the second part of the restoration

DISCUSSION

Successful and long-term composite resin restoration of cavities reaching below the CEJ is only possible if adequate moisture management is possible. During the first step of the presented two-step R2- technique, the complex problem of moisture management and restoration accomplishment is reduced to the circumscribed area of the proximal box. In this comparatively small area of the tooth, contamination is easier to handle and prevent, even if no rubber

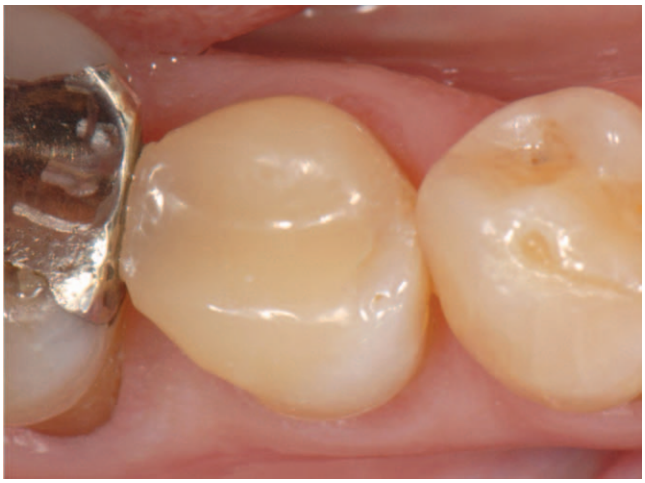

Figure 13. Clinical situation after 12 months: occlusal view.

dam is placed. After this critical part of the cavity is taken care of separately, a rubber dam can be placed much easier in step two of the restorative procedure, as described previously.[5]

The Snowplough technique contributes essentially to achieving a homogenous and nonporous restoration–tooth interface. It is described as the combined use of a flowable composite and a viscous composite resin molded together in an unpolymerized state, followed by final polymerization of both materials (Figure 6).[17]

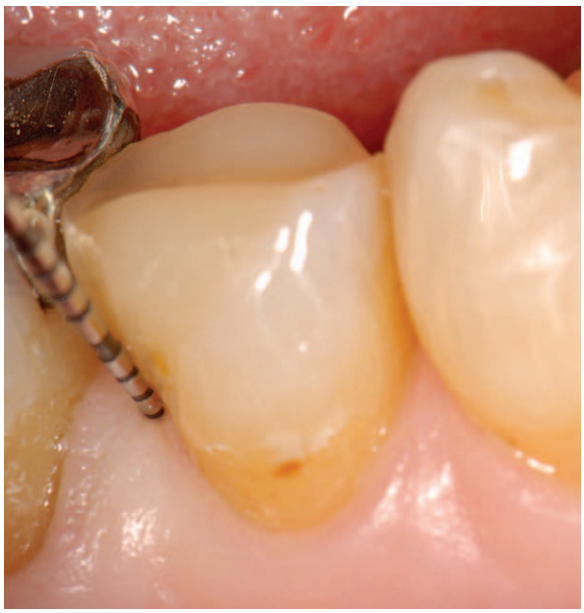

Figure 14. Buccal view after 12 months. The probing pocket depths in the proximal area were 2 mm, and no bleeding occurred on probing.

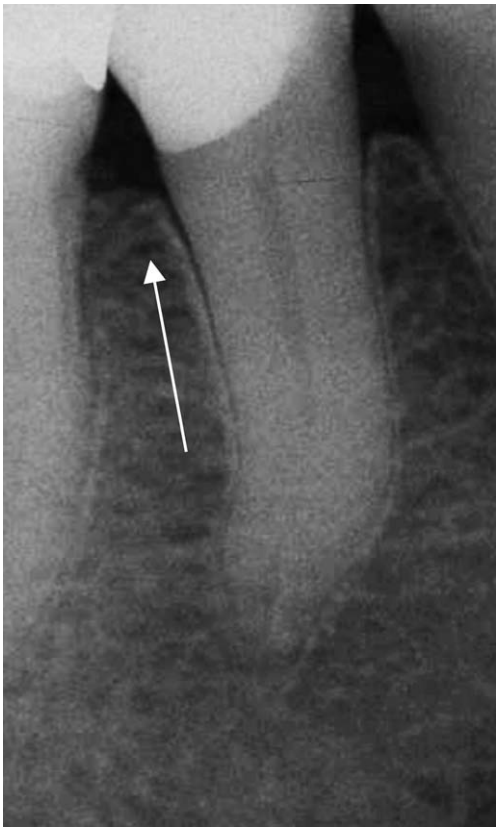

Figure 15. Radiograph of tooth #45 after 12 months. Radiographic examination revealed a distance of 1 mm between the restorative margin and the alveolar crest. Minimal loss of alveolar bone can be observed after 12 months (arrow).

In the clinical case presented, the occluso-proximal restoration margin was located below the CEJ and invaded the biological width. However, no adverse reactions, such as chronic inflammation of soft and hard tissues, attachment loss, or bone resorption, were observed at the 12-month follow-up.

The principle of biological width suggests that severely damaged teeth resulting from trauma or caries should be pretreated surgically or orthodontically to gain an adequate space of supracrestal, sound, hard tissue.[18,19] In contrast to the anatomically defined area of the dentogingival junction, the dimension of the biological width is defined based on several clinical studies and the opinion of experts.[20] Obligatory values do not exist because of individually differing characteristics of gingival morphology, the width of the keratinized gingiva, and periodontal condition.[15]

All radiographs of the presented case were taken using the long-cone parallel technique with Rinn's film holders to achieve utmost accuracy and minimal

distortion.[7] At the 12-month follow-up, the radiographic examination revealed a distance of 0.5–1.0 mm between the restorative margin and the alveolar crest with no signs of clinical inflammation.

How Can These Clinical Observations Be Explained With the Current Literature?

Restorative margins completely surrounded by sound enamel are an ideal situation for structural conservation of surrounding soft and hard tissues.[21] Extensive and undermining carious lesions or severe trauma often provide the possibility of placing restorative margins in sound enamel. Additionally, the degree of difficulty in placing deep subgingival restorations increases dramatically because of inferior insight into and access to the cavity, leading to problematic marginal control, management of undermining areas, and moisture control.

In a literature review, Brunsvold and Lane[22] could show that the prevalence of marginal overhangs was between 25% and 76% in all restored surfaces. Subgingival restorative margins, and especially marginal overhangs, contribute to plaque accumulation, chronic inflammation, attachment loss, and bone resorption.[20,22] Molars restored with indirect crowns or direct occluso-proximal restorations showed increased involvement of the furcation compared with sound molars.[23] Furthermore, Flores-de-Jacoby and others[16] reported increased amounts of spirochetes, fusiforms, rods, and filamentous bacteria in subgingival plaque. However, no association was found between restorative margins below the CEJ and the occurrence of secondary caries.[2]

A possible explanation for the sound periodontal and gingival condition in the presented case may be the polished, planed, and nonirritating subgingival margin, which was created during the first step (PBE) of the R2-technique. This, in combination with the distinct oral hygiene protocol, the individually adapted interdental brushes, and their adequate and regular use, may have contributed to the clinical success at the 12-month follow-up.

We assume that during wound healing an epithelial reattachment may have taken place on both the cementum and the apical parts of the composite resin surface. After iatrogenic detachment resulting from surgical or restorative procedures, wound healing takes place, involving hemidesmosomes and the restructuring of the basal lamina under the influence of fibrin.[24] It is known that epithelial attachment is not specific for one surface structure. It is capable of being formed on enamel, cementum, afibrillar cementum, and cuticle.[24]

Is Reattachment During Wound Healing on a Plain Resin Composite Surface Possible?

On the basis of our clinical observations, it is not possible to draw any conclusions about epithelial reattachment on a plain resin composite surface. However, a noninflammatory rehabilitation of soft and hard tissue next to deep proximal cavities after PBE can be achieved with the clinical R2-technique presented here.

In restorative dentistry, the search for an ideal material to restore the apical part of deep proximal cavities is not new. Glass ionomer cements,[25,26] polyacid-modified resin composite materials[1,27] and composite resin systems[2] are discussed intensely regarding their role in long-term durability. Yet with increased degree of difficulty, there are some substantial factors influencing the long-term outcome of a restoration substantially below the CEJ. The individual skills of the operator[28] or the degree of contamination with blood or saliva[29] are prone to the development of secondary caries and/or failure of a restoration.

However in recent years, several new techniques, for example the PBE,[5,6] the elastic cavity wall,[3,4] and the Snowplough technique[17] (Figure 6) were developed to increase clinical sucess in managing difficult situations. They provide promising approaches to manage complex direct resin restorations on severely decayed teeth. Remarkably, these techniques are mainly designated for building up only parts of teeth, here proximal areas. It is assumed that the violation of the biological width within a limited extent, under the precondition of superior oral hygiene, can be successful. Further experimental and clinical research should be encouraged to gain further information on relevant questions, such as the tolerable extent of violation of the biological width, favorable materials in the subgingival area and their long-term bond strength and surface characteristics, and the evaluation of patient characteristics.

CONCLUSION

Advantages

1. The two-step R2-technique (step one: PBE; step two: direct composite resin restoration) provides

an additional treatment option for the restoration of deep and undermining cavities reaching below the CEJ.
2. Distinct oral hygiene training (including the use of accurately fitting interdental brushes) in patients with occluso-proximal restorations invading the biological width is necessary to achieve a noninflammatory clinical situation.
3. It is assumed that the extent of biological width violation plays a role in the biological reaction of soft and hard tissues: limited proximal area versus complete circumferential margin.

Disadvantages

1. The type of restoration, materials used, and marginal quality are determining factors in the clinical performance of restorations invading the biological width (direct versus indirect restorations).
2. The reasons for individual variations in biological response to restorations below the CEJ that are invading biological width are yet unknown.
3. There is no evidence in the literature about the long-term bond strength and marginal quality of two-step composite resin restorations.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Clinical Research

Clinical Performance of Ormocer, Nanofilled, and Nanoceramic Resin Composites in Class I and Class II Restorations: A Three-year Evaluation

SH Mahmoud • AE El-Embaby • AM AbdAllah

Clinical Relevance

Ormocer, nanofilled, and nanoceramic composites exhibited clinical performance similar to that of conventional microhybrid composite in Class I and Class II restorations.

SUMMARY

Purpose: This prospective long-term clinical trial evaluated and compared the three-year clinical performance of an ormocer, a nanofilled, and a nanoceramic resin composite with that of a microhybrid composite placed in Class I and Class II cavities.

Methods: Forty patients, each with four Class I and II restorations under occlusion, were enrolled in this study. A total of 160 restorations were placed, 25% for each material, as follows: an ormocer-based composite, Admira; a nanofilled resin composite, Filtek Supreme XT; a nanoceramic resin composite, Ceram X; and a microhybrid resin composite, Tetric Ceram. A single operator placed all restorations according to the manufacturers' instructions. Immediately after placement the restorations were finished/polished. Clinical evaluation was performed at baseline and at yearly intervals after placement by two other independent examiners using modified US Public Health Service (USPHS) criteria. The changes in the USPHS parameters during the three-year period were analyzed with the Friedman test. Comparison of the baseline scores with those at the recall visits was made

*Salah Hasab Mahmoud, BDS, MSD, DDS, professor, Chairman of Conservative Dentistry Department, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

Abeer E El-Embaby, BDS, MSD, DDS, assistant professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

Asmaa Mohamed AbdAllah, BDS, MSD, DDS, assistant professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

*Corresponding author: El Gomhoreya St, PO Box 35516, Mansoura, Egypt; e-mail: salahmahmoud2010@yahoo.com

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using the Wilcoxon signed rank test. The level of significance was set at $p < 0.05$.

Results: All materials showed only minor changes, and no differences were detected between their performance at baseline and after three years. Only two ormocer, one nanofilled, and one microhybrid restorations in molars failed because of loss of retention. Regarding the clinical performance, there were no statistically significant differences among the materials used ($p>0.05$).

Conclusions: The ormocer, nanofilled, and nanoceramic composites provided acceptable clinical performance over a three-year period.

INTRODUCTION

In recent years, composite restorations have become a routine procedure for Class I and Class II lesions.[1] However, polymerization shrinkage and associated stresses remain a genuine problem.[2] These stresses may produce defects in the composite-tooth bond, leading to microleakage and bond failure and causing deformation of the surrounding tooth structure, predisposing the tooth to fracture.[3] The performance of a dental composite resin is influenced by many variables, such as resin matrix formulation, filler type and amount, and degree of polymerization.[4]

In an attempt to overcome some of the concerns associated with the traditional composite filling materials a new type of inorganic-organic hybrid restorative material called ormocer (organically modified ceramics) was developed in 1997.[5] Ormocers are characterized by the inorganic-organic copolymers in the formulation that modify the mechanical properties,[6] and ormocers are reported[7] to have increased fracture and wear resistance compared with resin-based composites. The alkoxysilyl groups of the silane form an inorganic Si-O-Si network by hydrolysis and polycondensation reactions, while the (meth)acrylate groups photochemically induce organic polymerization,[7] which may reduce polymerization stress following light irradiation. The ormocer materials are considered amalgam alternatives or even fully adequate substitutes.[1,8] Laboratory studies on ormocer demonstrated good performance of the material with respect to polymerization shrinkage,[9] wear,[10] biocompatibility,[11] and marginal integrity.[12]

Recently, nanofiller particles have been introduced in resin composite materials. Nanotechnology is based on the production of functional materials and structures in the range of 100 nm using various physical and chemical methods. Resin composites based on nanotechnology have certain advantages, such as reduced polymerization shrinkage, increased mechanical properties, better gloss retention, and diminished wear.[13] The organically modified, ceramic-based, nanoceramic composite was also developed through a combination of both the ormocer technology and nanotechnology. This composite contains methacrylate-modified, silicon dioxide–containing nanofiller, and resin matrix that is replaced by a matrix full of highly dispersed methacrylate-modified polysiloxane particles.[14]

Laboratory investigations are crucial for an early assessment of a dental restorative, but only a clinical study[15,16] can take into account all of the potential variables (which vary from patient to patient) influencing the overall performance of a restorative.[17] These variables include mastication forces, abrasive foods, chemically active foods and fluids, temperature fluctuations, humidity variations, bacterial byproducts, and salivary enzymes.[18,19] However, only a few clinical studies[20-23] concerning the performance of ormocer, nanofilled, and nanoceramic composites have been published, and more clinical data are still required. In addition, an increasingly confusing array of promising new materials has now become available. To evaluate the factual clinical worth of a highly branded restorative material without being carried away by its proposed qualities is a challenge that we as clinicians must accept. Therefore, the current study evaluated and compared the three-year clinical performance of an ormocer, a nanofilled, and a nanoceramic resin composite with that of a conventional microhybrid composite placed in Class I and II cavities.

MATERIALS AND METHODS

Restorative Materials

Brand names, specifications, manufacturers, and compositions of the four tested restorative materials are listed in Table 1. Because composite restoratives are generally marketed as a complete system, including the proprietary etchant, primer, and bonding products, in the present study the clinical evaluation of the investigated restorative materials was performed using each composite with its proprietary adhesive system. The composite restorative systems employed in the current study were an ormocer-based composite, Admira with Admira Bond (Voco GmbH, Cuxhaven, Germany); a nanofilled resin composite, Filtek Supreme with Single Bond (3M ESPE, St Paul, MN, USA); a nanoceramic

Table 1: *Materials Used in the Study*

Restorative System	Manufacturer	Matrix	Filler	Filler Degree
Admira (Ad)	Voco, Cuxhaven Germany	Ormocer, Bis-GMA, UDMA,TEG DMA	Glass ceramic SiO_2 (microfiller), 0.7 μm	56 vol%, 79 wt%
Admira Bond (two-step etch-and-rinse)	Voco	Etchant: 36% phosphoric acid Adhesive: acetone, ormocer matrix, DMA, polyfunctional methacrylate, CQ stabilizer		
Filtek Supreme XT (FS)	3M ESPE, St Paul, MN, USA	Bis-GMA, Bis-EMA, UDMA, and TEGDMA	Dispersed filler particles nonagglomerated/ nonaggregated (5-75 nm), partially calcined porous clusters (~1.3 μm) of agglomerated nanosized particles, with a primary particle size of 5-20 nm, infiltrated with silane	59 vol%, 78.5 wt%
Single Bond (two-step etch-and-rinse	3M ESPE	Etchant: 36% phosphoric acid with colloidal silica Adhesive: Bis-GMA, HEMA, DMA, polyalkenoic acid copolymer, initiator, water, ethanol		
Ceram-X Mono (CX)	Dentsply De Trey GmbH, Konstanz, Germany	Methacrylate modified polysiloxane, dimethacrylate	Barium-aluminum-borosilicate glass, methacrylate functionalized silicon dioxide (nano filler), 10 nm (57 vol%, 76 wt%)	57 vol%, 76 wt%
Prime & Bond NT (two-step etch-and-rinse)	Dentsply Detrey	PENTA, UDMA resin, Resin R5-62-1, T-resin, D-resin, nanofiller, initiators, stabilizer, cetylamine hydrofluoride, acetone		
Tetric Ceram (TC)	Ivoclar-Vivadent, Schaan, Liechtenstein	Bis-GMA, UDMA, and TEGDMA	Barium glass, Ba-Al-fluorosilicate glass, Al_2O_3, YbF3, pyrogenic SO_2. Mean particle size 0.7 μm	60 vol%, 79 wt%
Excite (two-step etch-and-rinse)	Ivoclar-Vivadent	Etchant: 37% phosphoric acid with colloidal silica Adhesive: HEMA, DMA, phosphoric acid acrylate, silicon dioxide, initiator, stabilizers in an alcohol solution		

Abbreviations: Bis-GMA, bisephenol-A glycidyl methacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, *bisephenol-ethyl methacrylate;* DMA*, dimethaacrylate;* HEMA*, hydroxyethyl methacrylate*

composite, Ceram X with Prime & Bond NT (Dentsply DeTrey, Konstanz, Germany); and a microhybrid resin composite, Tetric Ceram with Excite (Ivoclar Vivadent, Schaan, Liechtenstein). They were used in accordance with the manufacturers' instructions.

Patient Selection

Forty patients from the Outpatient Clinic at Mansoura University, Faculty of Dentistry, with a total of 160 posterior lesions were enrolled in this study. Prior to participating in the study, each patient signed a consent form. The form and protocol were approved by our institution's ethics committee. Criteria for their inclusion included the presence of primary caries. Each patient received four posterior restorations. They were required to have complete and normal occlusion as well as good oral hygiene. The patient population was selected to achieve a

Table 2: *Number of Evaluated Restorations by Location (Tooth) and Extension (Class) for Each Material*

Group	No. of Evaluated Restorations	Tooth Type		Type of Restoration	
		Premolars	Molars	Class I	Class II
Ad	40	14	26	28	12
FS	40	11	29	31	9
CX	40	14	26	30	10
TC	40	13	27	29	11
Total	160	52 (33%)	108 (67%)	118 (74%)	42 (26%)

Abbreviations: Ad, Admira; CX, Ceram X; FS, Filtek Supreme; TC, Tetric Ceram.

balance in age from 20 to 54 years, with a median age of 33 years.

Clinical Procedures

One experienced operator who was familiar with adhesive dentistry prepared, restored, and finished 160 posterior restorations, 40 with each restorative composite material used. The restorations were 118 Class I and 42 Class II restorations. The number of posterior teeth restored were as follows: 14 premolars and 26 molars (28 Class I and 12 Class II) with ormocer; 11 premolars and 29 molars (31 Class I and 9 Class II) with nanofilled composite; 14 premolars and 26 molars (30 Class I and 10 Class II) with nanoceramic composite; and 13 premolars and 27 molars (29 Class I and 11 Class II) with microhybrid composite (Table 2).

Before restorative procedures, periapical radiographs of the teeth to be treated were taken. Vitality test scores of the teeth were recorded with a vitality tester (Parkell Pulp Vitality Tester, Parkell Electronics DN, Farmingdale, NY, USA).

For cavity preparation, local anesthesia was applied to prevent patient discomfort during the restorative procedures. The cavities were prepared using round diamond and fissure burs (Komet, Brasseler GmbH & Co. KG, Lemgo, Germany) at high speed with water cooling. Hand instruments and slow-speed tungsten carbide burs were used to remove the caries. Control of the excavated preparation floor was mainly conducted by probing with a sharp explorer and by means of the color of the underlying dentin. Adhesive preparation design was used according to the principles of minimally invasive dentistry. The common characteristics of this preparation design were the following: 1) none of the cavity preparations involved one or more cusps; 2) all of the gingival margins included sound enamel and were placed above the gingival sulcus; and 3) no beveling was applied to the preparation walls and margins. The buccolingual width of the preparations did not exceed one-third of this distance.

After cavity preparation and shade selection, the operative field was isolated with cotton rolls together with suctioning. Calcium hydroxide–based material (Dycal, Dentsply/Caulk, Milford, DE, USA) was only used in deep preparations and was applied directly over the deep portion of the preparation and then sealed with a glass ionomer cement lining (Vivaglass Liner, Ivoclar Vivadent). All Class II preparations were restored using a sectional metal matrix fixed with a ring (Palodent, Dentsply DeTrey) in order to reestablish the anatomical shape and proximal contacts of the teeth. For all restorations, two-step etch-and-rinse adhesive systems were used (Admira Bond, Voco) for ormocer, Single Bond (3M ESPE) for nanofilled composite, Prime & Bond NT (Dentsply DeTrey) for nanoceramic, and Excite (Ivoclar Vivadent) for microhybrid composite.

The preparations in which ormocer was to be placed were etched with 36% phosphoric acid gel (Vococid, Voco). The acid gel was first placed on the enamel and then the dentin was conditioned during the last 15 seconds of the 30-second etching time. Each preparation was then thoroughly rinsed with water for 10 seconds. The adhesive was applied for 30 seconds, the solvent was removed using a gentle stream of air, and light-curing was then performed for 10 seconds with a halogen light-curing unit (Astralis 5, Ivoclar Vivadent). The wavelength of the unit measured between 400 and 500 nm. Light intensity was 530 mW/cm^2, as measured by a radiometer (Optilux Radiometer Model 100, SDS Kerr, Danbury, CT, USA).

For nanofilled composite restorations, the preparation was etched with 36% phosphoric acid gel (Scotchbond Etchant, 3M ESPE) for 15 seconds. The preparation was then thoroughly rinsed for 10 seconds and gently dried. The adhesive was applied two times followed by light-curing for 10 seconds.

The preparations in which nanoceramic (Ceram-X mono) composite was to be placed were etched with 34% phosphoric acid (Caulk 34% Tooth Conditioner Gel), as for the ormocer group. The preparation was then rinsed thoroughly with water for 10 seconds, and a generous amount of Prime & Bond NT adhesive was applied to thoroughly wet all of the preparation surfaces. The solvent was removed using a gentle stream of air, and light-curing was performed for 20 seconds.

Where microhybrid composite was used, the preparation was etched with 37% phosphoric acid gel (Total Etch, Ivoclar Vivadent), as for the ormocer group. The preparation was then thoroughly rinsed with water for 15 seconds. The adhesive was applied with a microbrush. After 10 seconds, the solvent was evaporated with a gentle air stream followed by polymerization for 20 seconds.

Restoration of preparations was incrementally made in oblique layers with ormocer, nanofilled, or nanoceramic composite materials or microhybrid resin composite. Each increment was light-cured for 40 seconds. Following removal of the matrix band, the proximal regions of the restorations were additionally polymerized buccally and lingually/palatally for 40 seconds. Contouring and finishing of the restorations was performed at the same appointment using a water-cooled, fine-grit diamond finishing instrument (Komet, Lemgo, Germany). Articulating paper (Bausch, Nashua, NH, USA) was used to establish appropriate occlusal morphology and contact. Flexible points impregnated with silicone dioxide were used to obtain smooth surfaces (Astropol, Ivoclar Vivadent). For finishing and polishing of the proximal surfaces, aluminum oxide finishing strips (Dentonics Inc, Monroe, NC, USA) were used. The quality of the interproximal contacts was checked with dental floss.

Evaluation Procedures

All restorations were clinically evaluated immediately following finishing and polishing (baseline) and after one year, two years, and three years by two independent examiners. The Cohen Kappa index was used as a measure of interexaminer agreement. Examiners were not involved in the filling procedures. When disagreement occurred during evaluations, the restorations were reevaluated by both examiners and a consensus was obtained. Restorations were evaluated using the US Public Health Service (USPHS) modified Ryge[24] criteria for retention, color match, cavosurface marginal discoloration, anatomic form, secondary caries, surface roughness, marginal adaptation, and postoperative sensitivity (Table 3). Restorations were given the score "Alpha" for the ideal clinical situation, "Bravo" for clinically acceptable, "Charlie" for clinically unacceptable and in need of replacement, or "Delta," representing fractured, mobile, or missing restorations in need of immediate replacement. In addition, each restoration was assessed for postoperative sensitivity by blowing a stream of compressed air for three seconds at a distance of 2-3 cm from the restoration and by moving the probe over the restored tooth surface. To detect secondary caries, the presence of softness, opacity, etching, or white spots are considered as evidence of undermining or demineralization in areas where the explorer catches or resists removal after insertion. Furthermore, bitewing radiographs (Kodak, Rochester, NY, USA) were taken at each follow-up appointment. A magnifying aid was used for examination of marginal adaptation. Retention loss, severe marginal defects, discoloration that needed repair or replacement, and the occurrence of caries along the restoration margins were considered to represent clinical failures.

Statistical Analysis

A statistical analysis was performed using an SPSS (version 17) software program (SPSS, Chicago, IL, USA). Since the assessment of the restorations yielded clearly ordinal structural data, only nonparametric procedures were used. The changes in the parameters during the three-year period were analyzed using the Friedman test, which is a nonparametric analysis of variance. The baseline scores were compared with those at the recall visits using the Wilcoxon signed rank test. The level of significance was set at $p < 0.05$.

RESULTS

The results of this study are summarized in Table 4. All patients attended the three-year recall visit, and no patient reported any negative appreciation for restorative procedures that were performed. The Cohen Kappa statistics (Kappa = 0.90) showed strong examiner agreement, and no statistical difference was observed in patients' answers ($p > 0.05$).

The scores for all of the performance criteria were either Alpha or Bravo. At baseline examination, postoperative sensitivity of two ormocer and three microhybrid restorations was scored as Bravo, but it disappeared by the one-year evaluation. No secondary caries were observed after three years of clinical

Table 3: *US Public Health Service (USPHS) Modified Ryge Direct Evaluation Criteria Rating System*

Category and Rating	Criteria
Retention	
Alpha	Restoration is present.
Delta	Restoration is partially or totally missing.
Color match	
Alpha	The restoration matches the adjacent tooth tissue in color, shade, or translucency.
Bravo	There is a slight mismatch in color, shade, or translucency, but within the normal range of adjacent tooth structure.
Charlie	There is a slight mismatch in color, shade, or translucency, but outside of the normal range of adjacent tooth structure.
Marginal discoloration	
Alpha	There is discoloration anywhere along the margin between the restoration and the adjacent tooth structure.
Bravo	Discoloration is present but has not penetrated along the margin in a pulpal direction.
Charlie	Discoloration has penetrated along the margin in a pulpal direction.
Anatomic form	
Alpha	The restoration is continuous with existing anatomic form.
Bravo	The restoration is discontinuous with existing anatomic form, but missing material is not sufficient to expose the dentin or base.
Charlie	Sufficient restorative material is missing to expose the dentin or base.
Secondary caries	
Alpha	No caries are present at the margin of the restoration, as evidenced by softness, opacity, or etching at the margin.
Bravo	There is evidence of caries at the margin of the restoration.
Surface roughness	
Alpha	The restoration surface is as smooth as surrounding enamel.
Bravo	The restoration surface is rougher than the surrounding enamel.
Charlie	There are a crevice and fracture on the restoration.
Marginal adaptation	
Alpha	There is no visible evidence of a crevice along the margin into which the explorer penetrates.
Bravo	There is visible evidence of a crevice along the margin into which the explorer penetrates or catches.
Charlie	The explorer penetrates the crevice, and dentin or base is exposed.
Delta	The restoration is mobile, or missing, either in part or total.
Postoperative sensitivity	
Alpha	Normal reaction to cold spray compared to that of nonrestored teeth
Bravo	Increased cold sensitivity
Charlie	Spontaneous pain
Delta	Nonvital

service. With regard to retention criterion, two restorations from ormocer, one restoration from nanofilled, and one restoration from microhybrid groups were lost at the three-year recall, resulting in a retention rate of 95% for ormocer, of 97.5% for nanofilled, of 100% for nanoceramic, and of 95% for microhybrid composite restorations, with no significant differences ($p>0.05$) noted.

For color match criterion, slight differences were observed in two ormocer, two microhybrid, one nanofilled, and one nanoceramic restorations after three years. These shade mismatches were clinically acceptable (Bravo), with no significant differences noted between the materials investigated ($p>0.05$).

According to the cavosurface marginal discoloration and surface roughness criteria, there were no significant differences among the restorative materials ($p>0.05$). Marginal adaptation rate was 100% for nanofilled and nanoceramic, 97.5% for the microhybrid, and 95% for ormocer restorations at both one and two years. However, after three years this criterion was 97.5% for nanofilled and nanoceramic

Table 4: *Results of the Clinical Evaluation as Number of Restorations for Which This Score Was Given*[a]

Evaluation Criteria Materials	Score	Baseline				1 y				2 y				3 y			
		AD	FS	CX	TC	AD	FS	CX	TC	AD	FS	CX	TC	AD	FS	CX	TC
Retention	A	40	40	40	40	40	40	40	40	40	40	40	40	38	39	40	38
	D	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2
Color match	A	40	40	40	40	40	40	40	40	40	40	40	40	37	39	38	38
	B	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	2
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marginal discoloration	A	40	40	40	40	39	40	40	39	39	40	40	39	38	39	39	38
	B	0	0	0	0	1	0	0	1	1	0	0	1	2	1	1	2
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marginal adaptation	A	40	40	40	40	38	40	40	39	38	40	40	39	38	39	39	38
	B	0	0	0	0	2	0	0	1	2	0	0	1	2	1	1	2
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface roughness	A	40	40	40	40	38	40	40	38	38	40	40	38	37	40	40	38
	B	0	0	0	0	2	0	0	2	2	0	0	2	3	0	0	2
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anatomic form	A	40	40	40	40	39	40	40	38	37	40	40	38	37	40	40	37
	B	0	0	0	0	1	0	0	2	3	0	0	2	3	0	0	3
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Postoperative sensitivity	A	39	40	40	38	40	40	40	40	40	40	40	40	40	40	40	40
	B	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary caries	A	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
	B	0	0	0	0	0	0	0	O	0	0	0	0	0	0	0	0

Abbreviations: Ad, Admira; CX, Ceram X; FS, Filtek Supreme; TC, Tetric Ceram.
[a] *The scores for each composite material include their proprietary adhesive systems.*

and 95% for ormocer and microhybrid composite restorations, with no significant differences noted among the restorative materials ($p>0.05$). The marginal defects recorded were small detectable V-shaped defects at the enamel margin of the restorations. In addition to hand instruments, a magnifying aid was used for investigation of the restoration margins. According to the anatomic form criterion, there were no significant differences among the restorative materials ($p>0.05$). All of the restorative materials were clinically successful.

DISCUSSION

The current study evaluated the first marketed resin composite based on ormocer matrix technology (Admira), resin composite containing only nanofillers (Filtek Supreme XT), and the composite based on both ormocer and nanofiller technology (Ceram X). Microhybrid resin composite (Tetric Ceram) was used as a control. Clinical trials require objective, reliable, and relevant criteria with which to assess the performance of restorations. Composite restoration quality is evaluated using a system of clinical parameters developed by Gunnar Ryge[24] and known as the USPHS Criteria or Ryge Criteria. These criteria were adapted by the California Dental Association for quality evaluation and referred to as Modified USPHS Criteria or USPHS/CAD Criteria.[25] However, this evaluation technique was designed to reflect differences in acceptability (yes/no) rather than degree of success. In the present study, the performance of the tested restorative systems was different at three years compared to at baseline.

The scores for color match, cavosurface marginal discoloration, marginal adaptation, surface roughness, and anatomic form for all restorative systems changed from Alpha to Bravo; both of the scores were considered acceptable. On the other hand, the retention rate of the ormocer and microhybrid composite restorations was 95%, and 97.5% for the nanofilled and 100% for the nanoceramic after three

years. According to the American Dental Association (ADA) acceptance criteria,[26] the clinical evaluation of restorations must show a failure rate of less than 5% at two years. Based on that, ormocer and microhybrid restorations were considered acceptable. This was in contrast with the findings of Oberländer and others,[1] who reported that ormocer (Definite) did not attain ADA acceptance criteria for restorative materials. A clinically satisfactory performance was reported for the nanofilled resin composite in two one-year and one three-year follow-ups.[21,27,28] In a recent two-year clinical evaluation,[29] Class II restorations of the nanofilled resin composite were compared in a similar intraindividual comparison with the well-known Tetric Ceram. Both restorative materials showed acceptable clinical performance, and the nanofilled resin composite showed no significant difference in overall clinical performance compared to Tetric Ceram. A failure rate of 1.9% was observed for both materials after two years, confirming the clinical performance in the present study, with a clinical failure rate of 2.5% for nanofilled composite and 5% for microhybrid composite after a three-year clinical evaluation period. Recently published controlled clinical longitudinal studies[30,31] of hybrid resin composites showed annual failure rates varying between 1.1% and 7.0% after two to four years. Tetric Ceram showed 5% failure rates, indicating a good clinical effectiveness of the nanofilled and nanoceramic resin composite studied.

A hybrid resin composite system was reported[32] to exhibit a statistically better marginal integrity along the occlusal and cervical margins of unloaded and loaded restorations than did ormocer. Consistent with this finding, the clinically ideal marginal adaptation (Alpha) rate in the present study was 100% for the nanoceramic composite and nanofilled composite and 97.5% for microhybrid composite, while the rate for the ormocer at both one and two years was 97.5%. However, this criterion was changed after three years for all materials without clinically significant differences. Long-term clinical studies[32,33] demonstrated good clinical performance of Tetric Ceram in posterior teeth, as well as for its predecessor, Tetric resin composite. Rosin and others[34] examined the clinical performance of ormocer restorations and reported excellent results regarding marginal integrity and marginal discoloration after six months. Bottenberg and others[35] stated that in occlusal stress-bearing cavities, the ormocer-based composite materials tested (Definite and Admira) performed comparably to the conventional microhybrid bisphenol A diglycidyl ether dimethacrylate–based composite, with the exception that ormocer had a poor color match.

The clinical performance of ormocer and nanofill composite material lined or not lined with flowable composites after two years was tested by Efes and others.[36] They reported that neither of the restorative materials exhibited postoperative sensitivity or secondary caries, and both showed ideal clinical performance. In this study, no secondary caries were detected in all of the tested restorative systems. Furthermore, postoperative sensitivity was observed at the baseline examination in two ormocer restoration and three microhybrid restorations. No secondary caries were reported in the earlier-discussed two-year study of Ernst and others either.[29]On the other hand, one has to realize that a three-year evaluation is far too short to observe the formation of secondary caries. This condition will develop mainly after four to six years of intraoral aging, as shown in earlier, longer follow-ups.[37] The operative field in the present study was isolated with cotton rolls and suction device, simulating operative dental procedures in most general clinics. No difference in annual failure rate was observed compared to the study of Ernst and others,[29] in which all restorations were placed under rubber dam isolation after application of the matrix system, 1.1% and 1.0%, respectively. This confirms the nonsignificant clinical differences observed in an earlier study[38] comparing the two isolation methods; in particular, in box-like preparations with high configuration factor, polymerization stresses may cause cohesive and/or adhesive failures.

At the three-year evaluation, all of the restorative materials demonstrated good color stability. Bravo scores were recorded for only two ormocer, two microhybrid, one nanoceramic, and one nanofilled composite restorations. These scores were insignificantly different. However, a slight color mismatch in tooth-colored restorations in posterior teeth might be desirable so that enamel adjacent to a composite restoration is not damaged during finishing.

Regarding the cavosurface marginal discoloration criterion, the majority of the scores were Alpha. Bravo scores were only recorded at the one-year examination in one ormocer and one microhybrid restoration. These scores had not changed during the two-year period. However, after three years, two microhybrid, two ormocer, one nanoceramic, and one nanofilled restorations recorded Bravo scores. All of the discoloration was located at the enamel margin; hence, it was clinically acceptable. This discoloration

might be due to the patients' food choices and smoking habits. Cavosurface marginal discoloration might indicate a breakdown of the bond between restorative material and tooth structure and, consequently, marginal leakage. In composite restorations, polymerization shrinkage is one of the main factors causing marginal discoloration,[39] especially in occlusal cavities with a high C-factor, the ratio between bonded walls to free walls.[40]

In the present study, the score of the surface roughness criterion of all the nanoceramic and nanofilled restorations was Alpha, while the score was Bravo for two ormocer and two microhybrid restorations at the one-year examination. These scores did not change during the three-year period, except for in the case of one ormocer restoration, which then received a Bravo rating. However, there were no significant differences among the materials. A laboratory study[41] evaluated the effect of several finishing and polishing procedures on the surface roughness of nanofilled composite (Filtek Supreme), nanohybrid (Grandio) composite, and ormocer-based (Admira) dental restorative materials. This study showed that nanofilled and nanohybrid composites achieved a smoother surface than did ormocer against Mylar strip finishing and polishing methods. Therefore, the slightly rough surface texture of the ormocer restoration observed in this study could be attributed to its particle size, yielding to the effects of masticatory forces and some abrasive foods. Ergucu and Turkun[42] analyzed the surface roughness of five novel nanocomposites (Ceram X, Filtek Supreme XT, Grandio, Premise, and Tetric EvoCeram) after polishing with three different one-step systems. They reported that differences between polishing systems were significant and that their effectiveness depends on material properties.

None of the tested restorative composites showed an unacceptable wear pattern, as evaluated by the USPHS criteria (anatomical form).These results could be attributed to filler size and content of the tested materials. The presence of nanoparticles and clusters in the nanofilled resin composite provide higher filler loading and distinct mechanical and physical properties compared with those of nanohybrid resin composites. Theoretical and experimental considerations of the wear and mechanical properties of nanofilled and nanohybrid composites, as compared with materials containing fillers in the micrometer range, have indicated the improved performance of the nanofilled and nanohybrid composites.[13] Recently, Palaniappan and others[43] tested the null hypothesis that there are no differences between the clinical-wear performances of nanofilled, microfilled, and conventional hybrids placed in Class I and Class II cavities. The findings of the five-year clinical trial revealed that operators and preparation type can affect restoration wear magnitude but do not contribute to increased functional risk of fracture or harmful effects on pulp and periodontal biocompatibility. However, one has to realize that this scoring system has no optimal wear evaluation method, and, therefore, no direct conclusions can be made concerning the suggested lower wear properties of the material. More sophisticated replicas involving evaluation methods and longer evaluation periods are necessary.[21]

In this study, ormocer, nanoceramic, and nanofilled composites performed as well as the microhybrid composite in posterior teeth. These results were in agreement with those of other clinical studies. For example, Rosin and others[34] evaluated the clinical performance of an ormocer (Definite, Degussa) in combination with a self-conditioning adhesive after one year and observed that ormocers are clinically effective in a private practice setting.

Schirrmeister and others[14] reported that after two years of clinical service, 96.8% of the Ceram·X/K-0127 and 100% of the Tetric Ceram/Syntac Classic restorations were in place and performed clinically well. Efes and others[36] compared the clinical performance of packable ormocer, nanofilled, and hybrid composites in occlusal cavities prepared with a minimally invasive technique. They reported that despite the high configuration factor of the cavity, both materials were clinically acceptable. In a recent two-year clinical evaluation, Class I ormocer, nanofilled, and nanohybrid resin composites were compared with microhybrid composite. All of the restorative materials showed acceptable clinical performance.[20] In addition, the evaluation of Stefanski and van Dijken[23] of 54 Class II nanofilled restorations with and without the intermediary of a nanofilled flowable resin composite showed a good clinical performance with a 2.2% failure rate after two years, and no differences were observed between the restorations with and without the nanofilled flowable resin intermediary layer.

CONCLUSIONS

On the basis of the results of this study, and despite the limitations of the small sample size, it seems reasonable to conclude that ormocer (Admira), nanofilled (Filtek Supreme XT), nanoceramic (Ceram X),

and the microhybrid composites (Tetric Ceram) exhibited excellent clinical performance over an evaluation period of three years. However, longer evaluations are necessary.

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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Frequency of Restoration Replacement in Posterior Teeth for U.S. Navy and Marine Corps Personnel

M Laccabue • RL Ahlf • JW Simecek

Clinical Relevance

Both composite resin and dental amalgam are being utilized as direct restorative materials in military dental clinics. When clinicians are choosing one material over another material, it is important to evaluate patient and tooth factors for optimum clinical success.

SUMMARY

Statement of Problem: There are no recent data that describe the replacement rates of resin composite and dental amalgam restorations placed by US Navy dentists. Information is needed to provide the best possible care for our military personnel which would minimize the probability of dental emergencies, especially for those who are deployed.

Purpose: The purpose of this study was to determine if the frequency of posterior restoration replacement in military personnel differed based on the type of restorative material utilized.

Methods and Materials: Data contained in dental records in an observational study (retrospective cohort) were evaluated to identify resin composite and dental amalgam restorations placed by navy dentists in posterior teeth. The status of all erupted, unerupted, missing, and replaced teeth was documented. The type and condition of all existing restorations were recorded for each posterior tooth. Investigators reviewed 2921 dental records, and of those, 247 patients met the criteria for inclusion in the study. A total of 1050 restorations (485 resin composite and 565 amalgam) were evaluated.

Results: A Cox proportional hazards model was adjusted for number of tooth surfaces restored, caries risk, and filled posterior surfaces at initial exam. The overall rate of replacement for all restorations in the sample was 5.7% during the average 2.8-year follow-up. No significant elevation of risk for resto-

*Marguerite Laccabue, MPH, DDS, Naval Medical Research Unit, San Antonio; and Dental and Biomedical Research, Fort Sam Houston, TX, USA

Reneé L Ahlf, RDH, MSEd, Naval Medical Research Unit, San Antonio; and Dental and Biomedical Research, Fort Sam Houston, TX, USA

John W Simecek, DDS, MPH, Naval Medical Research Unit, San Antonio, TX, USA

*Corresponding author: Dental and Biomedical Research, 3650 Chambers Pass, Building 3610, Fort Sam Houston, TX 78234; e-mail: marguerite.laccabue.ngo@mail.mil

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ration replacement existed when comparing resin composite and amalgam. Both the number of restored surfaces and caries risk status were independent risk factors for replacement. When restoring multisurface cavity preparations, providers placed amalgams by an approximate 2:1 ratio over resin composites for this study population.

Conclusion: The results for this study show that no difference existed in the rate of replacement for amalgam vs resin composite. When restorations increased from just a single occlusal surface to additional surfaces, the rate of replacement was elevated and statistically significant for both materials. A higher caries risk status was also significant in elevating replacement rates for both materials.

INTRODUCTION

According to an American Dental Association (ADA) survey conducted in 2005-2006, the number of resin composite restorations on posterior teeth, placed by private practitioners in the United States, surpassed the number of amalgam restorations placed on posterior teeth.[1] Over 76 million resin composite restorations were estimated to have been placed in one year on posterior teeth, accounting for approximately sixty percent of all direct posterior restorations.[1] Many private practices are currently choosing not to utilize amalgam in their offices. Another ADA survey among private practitioners who were currently using amalgam in 2007 showed that over half of the dentists indicated that the number of patients with whom they used amalgam restorations had decreased in the past 12 months.[2] Record reviews of baseline exams conducted on US Navy and Marine Corps recruits also demonstrated this important trend. Simecek and others[3] determined that a cohort of recruits in 1997 had only 10 percent of posterior fillings as composite; however, between five and eight years later, 25 percent of the posterior restorations were resin-based composite.

In an era where dental professionals are promoting minimally invasive management of dental caries, dental schools in both the United States and Canada are currently expanding the time devoted to teaching posterior resin techniques.[4] In fact, the schools surveyed by Lynch and others[4] indicated that 49% of posterior intracoronal restorations were resin-based composite, while amalgam placement was at 48%. Clearly, both amalgam and composite resin are considered suitable materials for restoring Class I and Class II cavities, although specific advantages as well as disadvantages exist for both types of materials. Composites have been documented to have better esthetics, more adhesive properties that result in reduced preparation size, and an ability to reinforce the remaining dental structure, unlike dental amalgam.[5] Although US dental schools have reported an increased amount of time teaching the placement of resin-based composites on posterior teeth, there are situations where students are advised to use other restorative materials.[4] The contraindications taught for resin-based composite restorations on posterior teeth include an inability to place rubber dam, parafunctional activity, pathological wear, poor oral hygiene, replacement of large amalgam restorations, and interproximal cavities that would lead to subgingival margins.[4]

Factors such as the patient, the material, the tooth, and even the operator all contribute to the long-term success of dental restorations.[6] When restorations are evaluated for longevity, mean annual failure rates (AFR) are compared during a period of follow-up. A randomized controlled clinical trial by Bernardo and others[7] demonstrated mean AFRs for amalgam to be 0.82%, whereas for composites it was higher, at a value of 2.21%. When reviewing multiple recent clinical studies, Demarco and others[5] determined that when "gold standard" hybrid composites are used to restore posterior teeth, an AFR between 1% and 3% can be expected. Unfortunately, with a greater number of surfaces involved in a restoration, AFRs tend to be higher for both amalgam and resin composites. Bernardo and others[7] demonstrated this trend with an AFR for a one-surface amalgam to be 0.17% and a two-surface to be 1.41%. Likewise, an increase was also seen for composites, with a one-surface restoration having an AFR of 0.95% and a two-surface restoration having an AFR of 3.03%. This upward trend continued with restorations involving three or more surfaces.

Two main causes of failure identified by Demarco and others[5] were fracture (restoration or tooth) and secondary caries. In a previous review of longevity by Downer and others,[8] the investigators pointed out that having a high caries activity has a negative influence on restoration survival. Demarco and others[5] pointed out that factors such as patient caries risk, the clinical setting of the study, and characteristics of the socioeconomic status of the population would be more of the determinant for the reasons for failure than the clinical age of the restoration. Secondary caries is related to the individual caries risk, and fracture can be related to the presence of a lining or the strength of the

material used as well as patient factors, such as bruxism.

Every year, the US Navy dental care system sees thousands of new recruits who might be in need of dental care to be classified as mission ready. Based on the 2008 Department of Defense Recruit Oral Health Survey, the mean number of restorations needed for US Navy and US Marine Corps active duty recruits is approximately three.[9] Restorations may be needed for primary caries or recurrent caries or for those restorations that are deemed non-serviceable. The dentists placing the restorations in these recruits are utilizing both resin composite and amalgam materials for posterior teeth. Being able to look back on the performance of both of these restorative materials that are being placed by many operators with varying degrees of experience can provide valuable information, including an ability to compare the longevity of the two different materials.

With a growing number of posterior resin composite restorations being placed in the mouths of Americans, it becomes necessary to understand the long-term prognoses for resin composites compared to the dental material (amalgam) that previously dominated in terms of direct restorations. Considering recent advancements in composite materials and current techniques, it was hypothesized that replacement rates for both amalgam and composite restorations placed in posterior teeth of sailors and marines during active duty are comparable and fairly low for the duration of their active-duty service.

METHODS AND MATERIALS

In 2011, a retrospective cohort study of resin composite and dental amalgam restorations placed in posterior teeth of US Navy and Marine Corps personnel was initiated. Dental records, maintained at a large Navy Dental Treatment Facility (DTF), were reviewed to obtain data pertaining to restorations placed by navy providers in DTFs. The initial review screened for those dental records that documented the placement of at least one posterior resin composite on a stress-bearing surface (either Class I or Class II restoration) during active duty. From those dental records with a posterior resin composite on either a premolar, a first molar, or a second molar (third molars were not included in the study), only those patients with a documented comprehensive baseline-type exam that included the documentation of existing restorations (forensic exam) were included in the study.

For each patient included in the study, data regarding all direct posterior Class I or Class II restorations placed during active duty were recorded in an Excel spreadsheet with all identifying markers masked. The number of missing and filled teeth, based on the forensic exam, was gathered for all patients. Each posterior tooth identified with either a resin composite or an amalgam restoration was analyzed for the following data: tooth number, number of surfaces, restoration material and type, isolation techniques, existence of previous restoration, placement date, replacement date if applicable, and exam information when need for restoration was diagnosed. Gender and year of birth were also documented for each patient. Caries risk was assessed for each tooth and patient based on information gathered from forensic and annual dental exams in conjunction with the guidelines in Table 1. The study protocol was approved by the Naval Medical Research Unit San Antonio Institutional Review Board in compliance with all applicable federal regulations governing the protection of human subjects.

Statistical Analysis

The numbers and percentages of amalgam and resin composite restorations placed by navy providers in posterior teeth (third molars excluded) of US Navy and Marine Corps personnel were calculated. For all restorations, the date of placement was used as the beginning of follow-up. The date of record review was used as date of censor for restorations that did not fail. For those restorations that did require replacement, the date of the actual replacement was used as the date of failure. The number of resin composite and amalgam restorations that required replacement was calculated on the basis of these parameters. Follow-up was limited to 12 years, and a *t*-test was performed to check for a difference in follow-up time based on material. Preventive resin restorations and any type of crown buildup were excluded from the analysis.

Estimated AFRs were calculated for each material utilizing the percentage of total failures divided by the average number of follow-up years. An estimated five-year failure rate was calculated for each material using Kaplan-Meier product-limit estimates. A log-rank test was used to determine a difference in two survival curves, while a chi-square test was utilized to determine differences in proportions. Fisher's exact test was used when the chi-square test was not appropriate. The relative risk for replacement of restorations was described by calcu-

Table 1: *U.S. Navy Dental Corps Caries Risk Assessment Criteria*[a]

Caries Risk Status	Criteria
Low	No new incipient or cavitated primary or secondary carious lesions during current exam
	No factors[b] that may increase caries risk
Moderate	One or two new incipient or cavitated primary or secondary carious lesions during current exam OR
	(Presence of at least one factor[b] that may increase caries risk
High	Three or more new incipient or cavitated primary or secondary carious lesions during current exam OR
	Presence of multiple factors[b] that may increase caries risk OR
	Xerostomia

[a] *Source: Chief, Bureau of Medicine and Surgery, BUMED Instruction 6600.16A 23 August 2010.*
[b] *Factors may include but are not limited to poor oral hygiene, cariogenic diet, presence of exposed root surfaces, enamel defects or genetic abnormality of teeth, many multisurface restorations, restoration overhangs or open margins, active orthodontic treatment, high titers of cariogenic bacteria, chemotherapy or radiation therapy, eating disorders, physical or mental disability with inability or unavailability of performing proper oral health care, and suboptimal fluoride exposure.*

lating the adjusted hazard ratio (HR), a comparison of the risk of replacement of resin composite to the risk of replacement of amalgam. This calculation takes into consideration the time to replacement to estimate differences in required retreatment while allowing for control of covariates. The sampling methodology ensured the clustering of restorations within patients. In order to arrive at a more accurate estimate of variance in light of the clusters, sandwich variance estimates were calculated in addition to model-based estimates. To identify potential confounders, we calculated HR using Cox's Proportional Hazard Regression to compare the risk of replacement for resin composite and amalgam restorations. A backward stepwise method was used with covariates entered into the model if the p-value < 0.25 and retained if the p-value < 0.15. Seven potential confounders were included for analysis: 1) number of surfaces in the restoration (one surface vs two or more), 2) caries risk status (low, moderate, high), 3) tooth type (molar, premolar), 4) isolation use (yes, no), 5) number of filled posterior surfaces at initial examination, 6) whether the restoration was the initial restoration, and 7) age of patient at restoration placement. The data were analyzed using statistical software (SAS®, Version 9.2, SAS Institute, Inc, Cary, NC, USA), setting all α levels of error at 0.05 and all confidence limits (CL) at the 95% level.

Table 2: *Number of Subjects and Restored Teeth by Caries Risk Status and Number of Filled Posterior Surfaces*

Caries Risk Status	Subjects (%) (n=247)	Teeth (%) (n=1050)
Low	13 (5.3)	17 (1.6)
Moderate	106 (42.9)	311 (29.6)
High	128 (51.8)	722 (68.8)
Number of filled posterior surfaces[a]		
0	71 (28.7)	284 (27.0)
1-9	140 (56.7)	598 (57.0)
>9	36 (14.6)	168 (16.0)

[a] *At initial examination.*

RESULTS

A total of 2921 dental records of US Navy and Marine Corps personnel were reviewed. Only 247 (8.5%) of the records reviewed had a resin composite posterior restoration placed by a navy provider. Data were available for 1050 restorations (485 resin composite and 565 amalgam). The mean age of the subjects when restorations were placed was 22 years (minimum 18 years, maximum 39 years), and all were male. The average time of follow-up was 2.8 years (SD = 2.2 years; range: 1 day-11.6 years). There was no significant difference (p=0.08) in the time of follow-up for amalgam (2.9 years; range: 1 day-11.4 years) and resin composite restorations (2.6 years; range: 24 days-11.6 years).

Table 2 describes the numbers of teeth and subjects in each of the three caries risk categories as well as the number of filled posterior surfaces for the patients and their teeth included in this sample. Table 3 summarizes the number of amalgam and resin composite restorations placed according to tooth type and surfaces as well as the need for replacement. Less than two percent (1.6%) of the teeth were in low-risk patients, 29.6% were in moderate-risk patients, and over two-thirds (68.8%) were in high-risk patients. The number of filled surfaces at initial examination had a range of 0-44 surfaces. Slightly over one-quarter (27.0%) of the teeth were in patients who had no restorations at initial examination. Over half (57.0%) of the teeth were in patients having one to nine filled surfaces, while the remaining 16.0% of the teeth were in patients with more than nine filled surfaces at initial examination. Slightly over half (52.9%) of the restorations involved only occlusal surfaces. Of the 495 multisurface restorations (two surfaces or more), 337 (68.1%) were amalgam, while only 31.9% were resin composite (see Table 3). For resin composite

Table 3: *Number of Restorations Placed and Replaced on Posterior Teeth*

Restoration Type (by Surface or by Tooth)	Resin Composite				Amalgam			
	Placed	Replaced		% Requiring Replacement	Placed	Replaced		% Requiring Replacement
		Yes	No			Yes	No	
One surface	327	11	316	3.4%	228	9	219	4.0%
Multisurface	158	10	148	6.3%	337	30	307	8.9%
Premolar	103	5	98	4.9%	130	11	119	8.5%
Molar	382	16	366	4.2%	435	28	407	6.4%
All restorations	485	21	464	4.3%	565	39	526	6.9%

restorations, 382 (78.8%) were in molars, and 103 (21.2%) were in premolars. Likewise, for amalgam restorations, 435 (77.0%) were in molars, and 130 (23.0%) were in premolars.

The overall rate of replacement for all restorations in the sample was 5.7% during the average 2.8-year follow-up (60 of 1050 restorations requiring replacement). Of the 565 amalgam restorations observed, 39 (6.9%) required replacement, while only 21 (4.3%) of the 485 resin composite restorations were cited for replacement. Greater percentages of multisurface restorations required replacement for both materials. Amalgam multisurface restorations had a higher need for replacement (8.9%) compared to 6.3% of resin composite restorations needing replacements. Both composite and amalgam restorations showed an apparent trend in the percentages of replacement as the number of surfaces increased (see Table 4). No significant differences in the proportions existed between resin composite and amalgam restorations when analyzing by the number of surfaces ($p>0.05$). Although resin composite restorations showed a lower rate of replacement (resin composite: 4.3%; amalgam: 6.9%), there was no statistically significant difference in the risk for resin composite restoration replacement when compared to amalgam replacement as demonstrated by an unadjusted HR of 0.69 (95% CL 0.37-1.27).

The estimated AFR for amalgam was 2.38% per year, and for composite it was 1.65% per year. Likewise, the five-year failure rate was 12.8% for amalgam restorations, while the five-year failure rate for resin composite restorations was 6.7%. The survival curves for resin composite and amalgam (see Figure 1) demonstrated no statistical difference ($p>0.05$).

After backward stepwise Cox proportional hazards regression, the final model contained number of surfaces ($p=0.0056$), caries risk ($p<0.0123$), filled posterior surfaces ($p=0.0942$), and material ($p=0.7337$). The adjusted HR showed no significant difference between the rate of replacement for resin composite and amalgam posterior restorations (HR = 0.89; 95% CL 0.46-1.74). As demonstrated in Table 5, the rate of replacement of multisurface restorations showed a significant elevation when compared to single-surface restorations (HR = 2.24; 95% CL 1.27-3.96). In addition, an increase in caries risk also demonstrated a significant increase in restoration replacement.

DISCUSSION

A multitude of studies have been conducted[5] demonstrating variability on the longevity of routine direct dental restorations in permanent posterior teeth. Factors influencing variability have been documented to be restoration type, materials, the patient, the operator, the practice environment, and the type of care system.[8] The contraindications taught at dental schools for resin-based composite

Table 4: *Number of Restorations Placed and Replaced Based on Number of Surfaces*

No. of Surfaces	Resin Composite (n=485)			Amalgam (n=565)		
	Placed	No. of Replacements	% Replacements	Placed	No. of Replacements	% Replacements
1	327	11	3.4	228	9	4.0
2	138	9	6.5	237	22	9.3
3	16	0	0.0	58	2	3.5
4	2	0	0.0	23	2	8.7
5	2	1	50.0	19	4	21.1

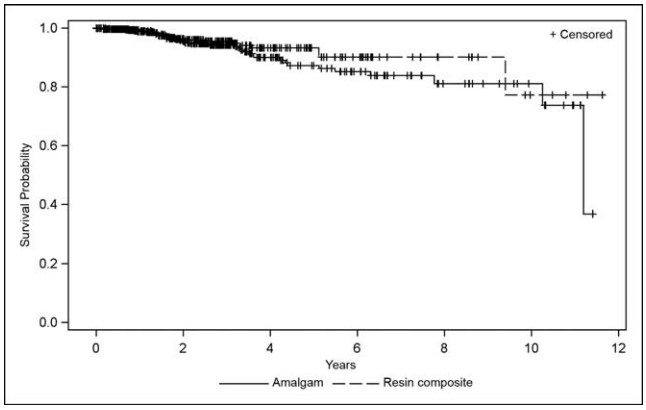

Figure 1. *Survival distribution of resin composite and amalgam restorations.*

Table 5: *Comparison of Adjusted Hazard Ratios for Replacement Rates of Resin Composite and Amalgam Restorations During Follow-Up*

Variables	Adjusted Hazard Ratio for Replacement[a] (95% Confidence Limits)
Material (resin composite vs amalgam)	0.89[b] (0.46-1.74)
Number of surfaces of restoration	2.24[c] (1.27-3.96)
Caries risk	2.20[d] (1.19-4.09)
Filled posterior surfaces	0.95[b] (0.90-1.01)

[a] *Full model: material, restoration surfaces, caries risk, and filled posterior surfaces.*
[b] *Not significant;* $p > 0.05$.
[c] $p < 0.01$.
[d] $p < 0.05$.

restorations on posterior teeth take these factors into consideration.[4] These contraindications are taught to increase the success and longevity of the restorative material used.

A retrospective clinical study on longevity of posterior composite and amalgam restorations by Opdam and others[10] demonstrated that resin composite and amalgam were comparable in their failure rates. The study focused on restorations placed by operators who were trained not only in the use of amalgam but also in the use of resin composite. With the growing confidence in the quality and advantages of posterior composites as well as an increase in the skills of trained dentists, Opdam and others[10] were optimistic toward the longevity of posterior composite restorations. The AFRs calculated in our study for both materials are low and demonstrate an acceptable survival rate in a clinical environment where multiple operators deliver treatment. Based on the HR in this study, amalgam and resin composite had no significant differences in the rate of replacement, thus demonstrating the same clinical success. Although the randomized controlled clinical trial conducted by Bernardo and others[7] demonstrated that AFRs were over three times greater for composites than amalgams, their study also showed that large restorations and those with three or more surfaces (with composite being lower than amalgam) had the lowest survival rates. This paralleled our study. Although multisurface restorations had less clinical success, the performance of both materials was similar, thus indicating that each material is being utilized in a manner that will optimize the success of the restoration.

The caries risk of patients was determined to have an effect on the replacement rate of restorations in this study. This is similar to several reviews and studies that determined that the caries risk of patients plays a significant role in the long-term survival of restorations.[5,8,11] Navy dentists assess a patient's caries risk and provide dental care that is appropriate for the determined risk status. In essence, providing certain types of restorations will be based on the caries risk status of the individual. As indicated in Table 1, many of the factors that are considered to determine a person's caries risk status are also those factors that are taught as contraindications to placing direct composite restorations. The criteria and protocols in place to assist navy dentists in selecting teeth appropriate for composite restorations assist in controlling for caries risk.

Study Limitations

Reasons for restoration failure were not documented in this study. The failure of some restorations may have been due to fracture of material or recurrent caries around the actual restoration. Other restorations may have been replaced because an adjacent surface had primary caries and there was a need to remove a sound restoration to include an additional surface. This would not necessarily constitute failure of the material or the restoration.

A limited number of women access the DTF where the records were reviewed to be included in the study. Out of the 2921 records reviewed, no women met the inclusion criteria for this study. Gender itself is not necessarily a risk factor for caries, but there are gender differences in treatment-seeking behaviors and adherence to treatment and preventive instructions that could potentially affect outcome.[12]

The length of follow-up time for all restorations was limited. Another study by Opdam and others[11]

found that amalgam and composite showed a comparable performance at five years, but differences were seen at 12 years. Thus, restorations with less than a three-year life span might not demonstrate differences in replacement rates due to the limitation of follow-up time.

CONCLUSIONS

The results for this study show that no difference existed in the rate of replacement for amalgam versus resin composite in navy DTFs. When restorations increased from just a single occlusal surface to additional surfaces, the rate of replacement was elevated and statistically significant for both materials. Additionally, a higher caries risk status also significantly elevated the risk for restoration replacement. There will always be a risk of fracture and failure of restorations that can occur among sailors and marines, but selectively choosing appropriate dental materials based on the patient appears to minimize this risk of failure and fracture.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Laboratory Research

Evaluation of Resin Bond Strength to Yttria-stabilized Tetragonal Zirconia and Framework Marginal Fit: Comparison of Different Surface Conditionings

A Vanderlei • MA Bottino • LF Valandro

Clinical Relevance

The low-fusing glass application followed by hydrofluoric acid etching and silanization seems to be a promising method for improving the resin bond strength to yttria-stabilized tetragonal zirconia, but the adhesion to this substrate is still a challenge.

Aleska D Vanderlei, PhD student, São José dos Campos Dental School, São Paulo State University (UNESP), Brazil

Marco Antonio Bottino, DDS, PhD, professor, Department of Dental Materials and Prosthodontics, São Paulo State University São José dos Campos, São Paulo, Brazil

*Luiz Felipe Valandro, DDS, MSciD, PhD, associate professor, Head of MsciD/PhD Graduate Programs in Oral Science, Prosthodontic Unit, Faculty of Odontology, Federal University of Santa Maria, Santa Maria, Brazil

*Corresponding author: Federal University of Santa Maria, MsciD/PhD Graduate Programs in Oral Science, Prosthodontic Unit, Faculty of Odontology, R. Floriano Peixoto 1184, 97015-372, Santa Maria, Brazil; e-mail: lfvalandro@hotmail.com

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SUMMARY

The purpose of this study was to evaluate the effect of different surface treatments of yttria-stabilized tetragonal zirconia (Y-TZP) on bond strength durability and marginal discrepancies. For adhesion testing, 144 specimens of VITA In-Ceram YZ ceramic for InLab were obtained (5.25×3.75×4.5 mm) and divided into six groups (n=24) according to the surface treatment: 1) Control (CRTL): untreated; 2) SIL: tribochemical silica coating (CoJet system, 3M/ESPE AG); 3) V1+HF: spray application of low-fusing porcelain glaze (V1, VITA Akzent Spray Glaze) followed by etching with hydrofluoric acid (HF) (one minute); 4) V1+SIL: V1 glazing (VITA Akzent Spray Glaze) followed

by tribochemical silica coating; 5) V2+HF: brush application of low-fusing porcelain glaze (VITA Akzent Glaze) plus etching with HF (one minute); and 6) V2+SIL: V2 glazing (VITA Akzent Glaze) plus tribochemical silica coating. After all treatments, the surfaces were silanized for five minutes (ESPE-SIL) and cementation was performed using Panavia F (Kuraray). Half of the specimens in each treatment were tested 24 hours after cementation (dry), with the other half subjected to storage (150 days) and thermocycling (12,000×) (aging), and then a shear test was carried out (1 mm/min). The micromorphological (digital optical profilometry and scanning electron microscopy) and elemental analyses of the treated surfaces were performed. The inner surfaces of 60 Y-TZP infrastructures were conditioned and marginal fit was evaluated. The statistical analysis revealed that the groups treated via surface glaze application followed by hydrofluoric acid etching and silanization showed the highest bond strength (in dry and aging conditions), but the bond strengths were affected by aging. The highest marginal discrepancies were observed in the groups receiving glaze (117.4 ± 29.6 to 105.8 ± 12.2 μm) when compared to other groups (55.3 ± 8.7 and 55 ± 8.5 μm). Low-fusing porcelain glaze + hydrofluoric acid etching changed the morphology of the Y-TZP ceramic and improved the adhesion to the resin cement, but obtaining high and stable bond values to Y-TZP remains challenging. Marginal discrepancies increased with glazing.

INTRODUCTION

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) has been increasingly used as an infrastructure for metal-free prostheses as a result of its microstructure, which provides excellent mechanical properties, such as high flexural strength, fracture toughness, and phase transformation toughening (through the stresses generated by cracks).[1] These frameworks are suitable for fixed partial dentures with up to two anterior and posterior pontics.[2]

In the case of adhesive cementation of Y-TZP–based restorations, the surface conditioning is a challenge because these materials are highly crystalline (free of the glassy phase),[3,4] unlike the feldspathic ceramics (rich in silicon oxides), which have more established bonding mechanisms.[4,5] A successful bond between the feldspathic ceramic and resin cement is obtained through the formation of chemical bonds and micromechanical retention between both materials.[6] This bonding is well established for ceramics with a high content of silica by selective conditioning of the glassy phase when the ceramics are exposed to hydrofluoric acid, which increases the surface area and surface roughness, improves the wettability and surface free energy, and exposes a greater amount of silicon oxides.[5] The application of coupling agents based on methacryloxypropyltrimethoxysilane produces increased wettability and forms siloxane bonds between the silica content of the ceramic and the organic matrix of the resin cement.[7,8] As a result of the absence of the glassy phase in the Y-TZP ceramics, etching with hydrofluoric acid does not generate sufficient surface changes and does not promote micromechanical retention, nor does it make the surface chemically reactive.[3,4]

To overcome this problem, surface pretreatment for Y-TZP ceramics has been suggested.[9-15] Airborne particle abrasion with aluminum oxide or tribochemical silica coating associated with the use of silanes and 10-methacryloyloxydecyl dihydrogen phosphate (MDP)-containing resin cements were evaluated and the results were found to be contradictory. Passos and others,[16] Nishigawa and others,[17] and May and others[18] found better bond strength results when the surface was silica-coated and silanized. Matinlinna and others[19] found low and unstable bond strength results with the use of silanization as the surface treatment. Currently, another questionable and conflicting aspect of bonding these substrates concerns the strong impact that air-particle abrasion may cause on the surface of Y-TZP. Some studies[20-22] observed detrimental effects of air abrasion on the strength of Y-TZP ceramics, depending on the development of microcracks and possible premature catastrophic fracture of the restorations. However, other studies[23-27] have reported increased mechanical strengths of these ceramics after airborne particle abrasion.

The use of adhesion promoters (primers) with experimental zirconia has been considered as an alternative protocol to promote this bonding, although these primers still have adhesive strength results[12,19] that are less than those obtained with the cementation of feldspathic ceramics.[4,28] Another treatment that has been tried is surface modification of ceramic Y-TZP via vitrification, which renders it rich in silicon oxides. This film could be selectively conditioned or totally removed to make the surface retentive and chemically reactive, similar to the bonding mecha-

nisms of feldspathic ceramics.[9-11,14,15,29-33] Promising results of Y-TZP/resin cement bond strengths have been observed after the ceramic surface has been glazed and subjected to air-particle abrasion with aluminum oxide and silanization[11,14,15] or etching with hydrofluoric acid.[10,15,31-33] However, a controversial issue still requires an answer: how durable is the bonding promoted by these innovative methods? In addition to this question, there is still no recent evidence regarding the influence of the application of a silicon oxide–based film on the intaglio surface on the marginal fit of Y-TZP crowns.

According to Denissem and others[34] and Kokubo and others,[35] the clinical success of restorations depends on many factors, including the internal and marginal fit of the ceramic crown. Sharp marginal discrepancies between the restoration and prepared tooth interfere with the longevity of the restorative treatment.

Cement that is exposed to the oral environment serves as a weak point between the restoration and the prepared tooth.[36] The marginal fit of Y-TZP crowns was evaluated by Att and others,[37] who found marginal gaps of between 64 and 78 μm. A cervical misfit of up to 119 μm is considered clinically acceptable,[38-42] which makes it important to observe the effect caused by the vitrification of crowns on the marginal fit of Y-TZP crowns.

Within this context, this present study proposed a "new" technique for the treatment of the cementation surface for Y-TZP ceramics (glass film application) and compared that new method to methods routinely used for ceramic conditioning. The marginal fit of an infrastructure made of Y-TZP ceramics under different conditionings was also evaluated to examine whether this technique could be clinically viable. The hypotheses were the following: glazing of the Y-TZP crown intaglio surface would improve adhesion of the ceramic to resin cement; storage/thermal cycling would degrade the bond strengths; and the glazing would not interfere with the marginal fit.

MATERIALS AND METHODS

Production of Specimens

Y-TZP ceramic blocks (14×15×20 mm; VITA In-Ceram 2000 YZ cubes for InLab) were prepared using a cutting machine (ISOMET 1000, Buehler Ltd, Lake Bluff, IL, USA), resulting in 144 blocks (7×6×5 mm). These blocks were sintered (ZYrcomat,-VITA Zahnfabrik Oven, Bad Sackingen, Germany) according to the manufacturer's guidelines, obtaining specimens with standardized final dimensions (5.25×3.75×4.5 mm).

The samples were polished with wet sandpaper of decreasing granulation (400 and 600 grit up to 1200 grit). All of the specimens were submitted to an ultrasonic bath (Vitasonic, VITA Zahnfabrik, Bad Sackingen, Germany) for five minutes in distilled water and were then randomly divided into six groups according to the surface treatments. The specimens were then embedded in chemically activated acrylic resin for the shear bond strength test, keeping the surface for adhesion exposed. All of the specimens were subjected to an ultrasonic bath again for five minutes in distilled water and then cleaned with alcohol.

Y-TZP Surface Treatments

The 144 Y-TZP samples were allocated into six groups, according to the method of conditioning of the bonding surface (n=24), as follows: 1) Control group (CRTL): no surface treatment (control group). 2) SIL: silica-coating by air-borne particle abrasion with silica-coated aluminum oxide particles (CoJet®-Sand, 3M ESPE AG, Seefeld, Germany), using a microetcher device (Cojet-Prep™, 3M ESPE AG). The distance between the ceramic surface and the device point was standardized at 10 mm and had an inclination of 45°, with the aid of a device (pressure 2.5 bar for 10 seconds). 3) V1+HF: low-fusing porcelain glaze (Glaze Spray VITA Akzent, VITA Zahnfabrik, Bad Sackingen, Germany): glaze spray was applied twice and sintered according to the manufacturer's guidelines. Subsequently, the glazed surface was etched with 9% hydrofluoric acid gel (HF) for one minute (Ultradent Porcelain Etch, South Jordan, Ultradent), rinsed with air-water spray, and dried. Finally, the samples were cleaned in a sonic bath (five minutes in distilled H_2O). 4) V1+SIL: The Y-TZP surface was glazed as described for the V1+HF group (Glaze Spray VITA Akzent, VITA Zahnfabrik). Then the surface was conditioned with a tribochemical silica coating method (as described for the SIL group). 5) V2+HF: low-fusing porcelain glaze (Glaze VITA Akzent, VITA Zahnfabrik). According to the manufacturer's instructions, the glaze was prepared and applied once on the surface using a brush, followed by sintering, as recommended. The glazed surface was etched with 9% HF for one minute, rinsed with air-water spray, and dried. Finally, the samples were cleaned in a sonic bath (five minutes in distilled H_2O). 6) V2+SIL: The surface was glazed as described for the V2+HF group (Glaze VITA Akzent, VITA

Table 1: *Testing Groups for Bond Strength Evaluation, Considering the Two Studied Factors (Y-TZP Surface Conditioning [in Six Levels] and Storage Condition [in Two Levels])*

Groups	Y-TZP Surface Conditionings (n=12)	Aging	Bond Results[a]	Student *t*-Test[b]	Surface Roughness[c]
Control (CTRL)	Without surface conditioning	Baseline (no aging)	2.3 ± 1.2 D		0.14
SIL	Tribochemical silica coating		7.9 ± 2.6 C	0.0001	0.35
V1+HF	Glazing 1 + etching with 9% hydrofluoric acid		13.3 ± 4.1 AB	0.019	3.37
V1+SIL	Glazing 1 + silica coating		9.2 ± 1.9 BC	0.0001	0.41
V2+HF	Glazing 2 + etching with 9% hydrofluoric acid		17.8 ± 5.5 A	0.030	3.79
V2+SIL	Glazing 2 + silica coating		12.5 ± 4.3 BC	0.123, ns	0.40
CTRL(TC)	Without surface conditioning	Aging	0.01 ± 0.0 c		
SIL(TC)	Tribochemical silica coating		2.2 ± 1.8 bc		
V1+HF(TC)	Glazing 1 + etching with 9% hydrofluoric acid		9.3 ± 2.7 a		
V1+SIL(TC)	Glazing 1 + silica coating		4.7 ± 1.2 b		
V2+HF(TC)	Glazing 2 + etching with 9% hydrofluoric acid		12.5 ± 4.2 a		
V2+SIL(TC)	Glazing 2 + silica coating		9.8 ± 2.8 a		

Abbreviations: CTRL, control group; SIL, tribochemical silica coating; TC, during aging; V1+HF, spray application of low-fusing porcelain glaze followed by etching with hydrofluoric acid (HF); V1+SIL, V1 glazing followed by tribochemical silica coating; V2+HF, brush application of low-fusing porcelain glaze plus etching with HF; V2+SIL, V2 glazing plus SIL; Y-TZP, Yttria-stabilized tetragonal ceramic.
[a] Means (±standard deviation[SD]) of the bond strength data (MPa) and Tukey test are presented. Uppercase letters indicate statistically similar Baseline groups. Lowercase letters indicate statistically similar Aging groups.
[b] p values for comparison (Student t-test) between the groups submitted to the same Y-TZP surface conditioning under different storage conditions (p-value<0.05 represents the means of bond strength have significant difference; ns, no difference).
[c] The surface roughness results (R_a, in μm).

Zahnfabrik) and conditioned with a tribochemical silica coating method (as described for the SIL group).

After conditioning, all of the specimens were submitted to silanization for five minutes (ESPE-SIL silane, 3M/ESPE).

Cement Application

After conditioning of the Y-TZP bonding surface, a cement was mixed (Panavia F 2.0, Kuraray Medical Inc, Okayama, Japan) and applied using a syringe (Centrix Syringe system, Dentsply Detrey, Konstanz, Germany) inside a metal matrix (diameter: 3.5 mm; height: 2 mm) that had been placed on the ceramic surface. The resin cement was light-activated for 40 seconds (XL 3000, 3M/ESPE; light intensity=600 mW/cm^2) and the matrix was removed.

Aging (Storage and Thermal Cycling)

Half of the specimens in each treatment were tested 24 hours after cementation (dry condition) and the other half were subjected to storage (150 days) and thermocycling (12,000 cycles; 5°C and 55°C water baths; 30 seconds each bath; two seconds of transition) (aging condition); then the shear bond strength testing was performed. Twelve groups were formed (six Y-TZP surface conditionings and two aging conditions) (Table 1).

Shear Bond Strength Test

The samples were subjected to a shear bond strength test in a universal testing machine (EMIC DL-1000, São José dos Pinhais, Brazil). A knife-shaped indenter applied the load at a cross-head speed of 1 mm/min. A metal frame was used for holding each specimen to guarantee that the adhesive interface was parallel to the path of the knife and as near as possible to the long axis of the knife. The bond strength was calculated according to the formula $\sigma = F/A$, in which σ represents the strength (MPa), F is the load for the specimen failure (N), and A is the specimen interfacial area (mm^2). The bonded area (A) was uniform at 9.42 mm^2 ($A=\pi\times r^2$, in which $\pi=3.14$ and r=radius of the bonded area [1.5 mm]).

Failure Analysis

All specimens that were submitted to the shear testing were observed under 50×-200× magnifications using a stereomicroscope (Discovery V20, Zeiss, Gottingen, Germany) to observe their failure pattern. Specimens with representative fractures were chosen for microscopic analysis. The chosen specimens were mounted on metallic stubs, sputter-

coated with gold (Denton Vacuum, DESK II), and observed under a scanning electron microscope (SEM; JEOL JSM-6360, Tokyo, Japan) at different magnifications.

The failures were classified as follows: 1) Adhesive failure: failure at the ceramic-cement interface; 2) Cohesive failure in the cement; 3) Cohesive failure in the ceramic; and 4) Mixed failure: adhesive failure combined with cohesive failure in the cement.

Surface Characterization

For the qualitative analysis of the surface after treatment, two samples (301.3×229.2 μm) from each surface treatment were evaluated under a SEM (JEOL JSM-6360, Tokyo, Japan) (1000× magnification) and a digital optical profilometer (Wyko, Model NT 1100, Veeco, Tucson, USA). The profilometer was connected to a PC containing imaging software (Vision 32, Veeco, USA) for data analysis of R_a roughness (arithmetic mean of all peaks and valleys found during reading of the sample). The measurements of the roughness parameters were performed at a magnification of 20× on five representative areas of each sample.

Chemical Analysis

Constituents and trace elements on the ceramic surfaces of each group were determined using energy dispersive x-ray spectroscopy (EDS; JEOL JSM-6360), which was performed on two areas per sample in each group. The concentration of elements was calculated based on the mass concentration of the elements present in each reading.

Marginal Fit Analysis

A metal die prepared for a full crown was used. Impressions were taken using addition silicone (Elite HD Putty Soft Normal Setting and Light Body Normal Setting, Zhermack SpA, Badia Polesine, Italy) through the double impression technique, following the recommendations of the manufacturer. The models were poured with type IV die stone for the Cerec system (No. 10300206, CAM-base®, Denton AG, Deutschland, Germany). Using the Cerec 3D program, 60 ceramic infrastructures were fabricated from 60 prefabricated ceramic blocks (VITA In-Ceram YZ for InLab, VITA Zanhfabrik).

The analysis of marginal discrepancy (vertical distance from one point of the crown margin to a point on the preparation margin) was evaluated using an optical microscope (Mitutoyo IM, 176-581A) with a magnification of 250× at 50 points along the margins of the infrastructure.

Statistical Analysis

Statistical software was used (Statistix 8.0 for Windows, Analytical Software Inc, Tallahassee, FL, USA) for data analysis.

Bond strength data from dry and aging conditions separately were submitted to one-way analysis of variance (ANOVA) and Tukey test (α=0.05). In addition, the groups were compared 2-2 to elucidate the isolated effect of storage for each surface treatment, using the Student *t*-test ($p<0.05$).

To compare the six experimental conditions on the outcome "marginal discrepancy," the data were submitted to Kruskal-Wallis and Dunn multiple comparison tests (5%).

RESULTS

Descriptive statistics (means and standard deviations) of the bond strength data and the Tukey test ($p<0.05$) are shown in Table 1 and Figure 1.

With regard to the pretest failures, Table 2 indicates that all of the specimens from the control group failed during the aging procedures.

In both the dry and aging conditions separately, the one-way ANOVA of bond strength data showed the surface conditionings (p=0.00001) had a significant influence.

Tukey analysis showed that the surface treatment Glazing 2 + HF (V2+HF) presented the highest bond strengths and the control group the lowest bond strengths in both the dry and aging conditions.

The pairwise comparison (Student *t*-test; Table 1) shows that the bond strengths from all of the surface conditionings decreased after aging, except in the case of V2+SIL.

The measurements of roughness parameters (arithmetic mean of all peaks and valleys) encountered during the reading of the samples are described in Table 1. There was a greater roughness in the groups with silica deposition (vitrification), followed by those with etching. The micrographs confirm the micromorphological changes (Figure 2E,F). When glass application and acid etching were observed, significant pits were formed by selective etching of the glass film, which seemed to promote better micromechanical retention of the resin cement. In the groups with silanization (Figure 2C,D,G,H), a slight increase in roughness occurred compared to the control (Figure 2A,B).

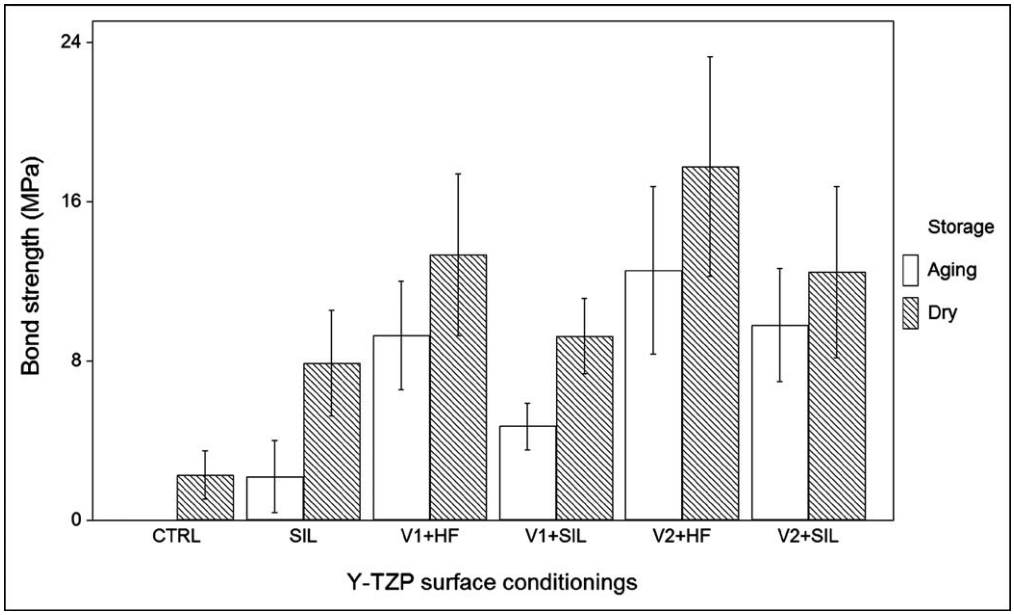

Figure 1. *Mean shear bond strength (MPa) and standard deviation (bars) of bond strength data for the different Y-TZP surface conditionings and storage conditions.*

The EDS elemental chemical analysis (Table 3) indicated a stronger presence of silica in the groups with glass application.

The failure analyses (Table 4) indicated that mixed failure was the predominant failure type. However, the CTRL and CTRL(aging) groups presented 75% and 100% adhesive failures, respectively. Representative failures are presented in Figure 3.

Table 2: *Number (N) and Percentages (%) of the Specimens (sp), Which Spontaneously Prematurely Failed (FPT) During Aging (TC), and Total N of the Specimens Submitted to Bond Strength Test (SBS)*

Groups	N of sp	N (%) of Pretest Failure During Aging	Total N (%) of sp Tested
CTRL	12	0 (0)	12 (100)
SIL	12	0 (0)	12 (100)
V1+HF	12	0 (0)	12 (100)
V1+SIL	12	0 (0)	12 (100)
V2+HF	12	0 (0)	12 (100)
V2+SIL	12	0 (0)	12 (100)
CTRL(TC)	12	12 (100)	0 (0)
SIL(TC)	12	3 (25)	9 (75)
V1+HF(TC)	12	0 (0)	12 (100)
V1+SIL(TC)	12	0 (0)	12 (100)
V2+HF(TC)	12	0 (0)	12 (100)
V2+SIL(TC)	12	0 (0)	12 (100)

Abbreviations: CTRL, control group; SIL, tribochemical silica coating; V1+HF, spray application of low-fusing porcelain glaze followed by etching with hydrofluoric acid (HF); V1+SIL, V1 glazing followed by tribochemical silica coating; V2+HF, brush application of low-fusing porcelain glaze plus etching with HF; V2+SIL, V2 glazing plus SIL.

The medians of the marginal misfit data are presented in Table 5. The Kruskal-Wallis test showed the surface conditionings ($p=0.001$) had significant influence on the results. The Dunn test multiple comparisons showed that glazing groups had the highest values of marginal misfit when compared to other groups.

A preliminary analysis of the different thicknesses and surface glazes was performed (VITA Aktent spray glaze and VITA Akzent glaze) after the application on the Y-TZP ceramic surface, as shown in Figures 4 and 5. The thickness of the glaze was approximately 10 μm.

DISCUSSION

In studies of bond strength, a relevant aspect concerns the influence of premature failure of specimens on the primary outcome (bond strength). It has been reported[43] that the analysis of variance of bond strength data becomes more consistent when the specimens lost prematurely are considered for statistical analysis and that their omission can provide a significant overestimation of the results. Many studies in the literature do not consider premature failures; consequently, those findings might not accurately reflect the bonding performance,[44,45] leading to false interpretations. Thus, there is a need to report the percentage of premature

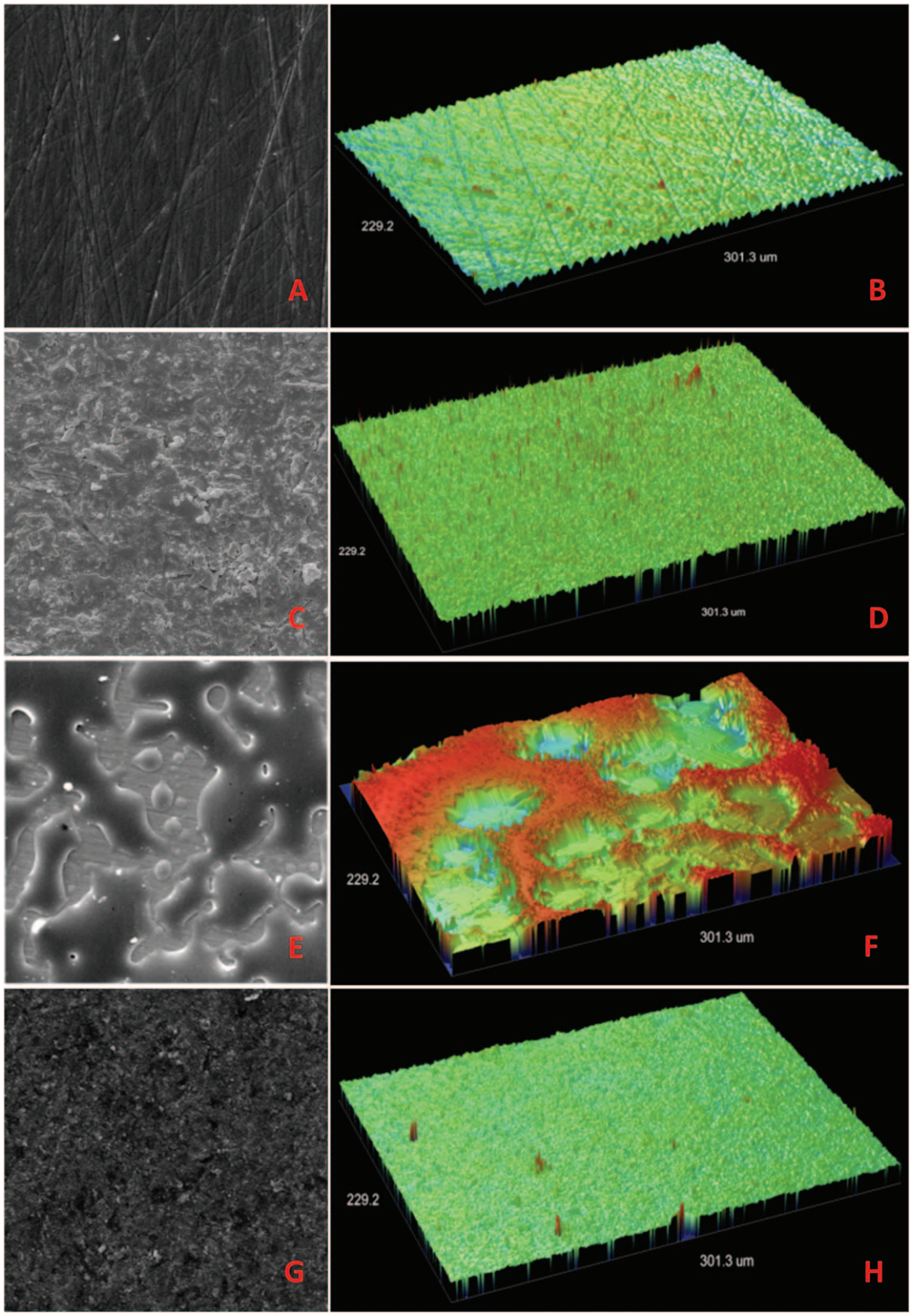

Figure 2. *Representative images of Y-TZP surface. Surface without conditioning (control group) under SEM (1000×) (A) and digital optical profilometer (B). Surface after silica coating (SIL group) under SEM (1000×) (C) and digital optical profilometer (D). Surface after glazing followed by etching with 9% hydrofluoric acid under SEM (1000×) (E) and digital optical profilometer (F) (representative of two glaze approaches). Surface after glazing followed by silica coating under SEM (1000×) (G) and digital optical profilometer (H) (representative of two glaze approaches).*

Table 3: *Elemental Chemical Analysis (%) of the Y-TZP Surface Submitted to the Different Conditionings (Energy Dispersive X-ray Spectroscopy [EDS] Analysis)*

	CTRL	SIL	V1+HF	V1+SIL	V2+HF	V2+SIL
Zr	71.54	55.28	52.35	51.04	49.62	21.50
O	27.07	32.76	33.22	32.73	33.03	40.86
Si	—	8.74	11.15	11.57	12.09	25.04
K	—	—	1.13	2.36	2.56	5.34
Ca	—	—	—	1.79	2.18	5.61
Al	—	2.15	2.15	0.51	0.51	1.63
Y	1.39	1.07	—	—	—	—

Abbreviations: Al, aluminum; Ca, calcium; CTRL, control group; K, potassium; O, oxygen; Si, silicon; SIL, tribochemical silica coating; V1+HF, spray application of low-fusing porcelain glaze followed by etching with hydrofluoric acid (HF); V1+SIL, V1 glazing followed by tribochemical silica coating; V2+HF, brush application of low-fusing porcelain glaze plus etching with HF; V2+SIL, V2 glazing plus SIL; Y, yttrium; Zr, zirconium.

specimen failures due to their weak bonding, even before testing.[46] According to Table 2, the percentage of specimens lost during the aging procedures reached 100% for the control group. This dramatic percentage of pretest failures is related to the low values of bond strength in this group, detected during testing of the "dry" specimens (2.3 MPa). The group that received silanization [V2+SIL(aging)] had 25% spontaneous failures during aging, which explains the low values observed after aging.

In order to consider the deleterious effects of specimens with pretest failures, the value of 0.01 MPa was arbitrarily assigned to each specimen "lost," and these specimens were considered in the statistical analysis. This value was considered only to allow for statistical calculations. These "losses" indicate greater susceptibility to degradation of the interface, and assigning an arbitrary value allows a more precise interpretation of the adhesive performance between the substrate and adhesive, preventing misinterpretations.[45]

The study of bond strength of Y-TZP restorations has been the subject of several works,[9,12,17-19,33,47-49] as the difficulty of bonding to the adhesive cement is reported as one of the main limitations.[3,9,33] For this reason, several studies have been developed to improve the bond strength of Y-TZP ceramics to the adhesive cement using different surface conditionings, such as modifying the surface through air-abrasion with particles of alumina or silica (tribosilanization)[16-18] zirconia primers,[12,19] glazing,[10,15] or deposition of silica films.[9,11,14,29,30-33,50] Even though the manufacturers allow the use of conventional cements (zinc phosphate and glass ionomer) for the cementation of Y-TZP crowns,[51] it is known that adhesive cementation provides greater retention from microretentions provided by the surface conditioning of dental hard tissues and restorative

Table 4: *Number and Percentage (%) of Specimens (sp) Submitted to the Shear Test and of Type of Failure*

Groups	sp Tested	Type of Failure			
		Adhesive	Mixed	Cohesive (Cement)	Cohesive (Ceramic)
CTRL	12 (100)	9 (75)	3 (25)	0 (0)	0 (0)
SIL	12 (100)	2 (16.6)	10 (83.4)	0 (0)	0 (0)
V1+HF	12 (100)	0 (0)	11 (91.6)	1 (8.4)	0 (0)
V1+SIL	12 (100)	0 (0)	12 (100)	0 (0)	0 (0)
V2+HF	12 (100)	0 (0)	11 (91.6)	1 (8.4)	0 (0)
V2+SIL	12 (100)	0 (0)	12 (100)	0 (0)	0 (0)
CTRL(TC)	0 (0)	12 (100)	0 (0)	0 (0)	0 (0)
SIL(TC)	9 (75)	11 (91.6)	1 (8.4)	0 (0)	0 (0)
V1+HF(TC)	12 (100)	0 (0)	12 (100)	0 (0)	0 (0)
V1+SIL(TC)	12 (100)	3 (25)	9 (75)	0 (0)	0 (0)
V2+HF(TC)	12 (100)	0 (0)	12 (100)	0 (0)	0 (0)
V2+SIL(TC)	12 (100)	1 (8.4)	11 (91.6)	0 (0)	0 (0)

Abbreviations: CTRL, control group; SIL, tribochemical silica coating; TC, during aging; V1+HF, spray application of low-fusing porcelain glaze followed by etching with hydrofluoric acid (HF); V1+SIL, V1 glazing followed by tribochemical silica coating; V2+HF, brush application of low-fusing porcelain glaze plus etching with HF; V2+SIL, V2 glazing plus SIL.

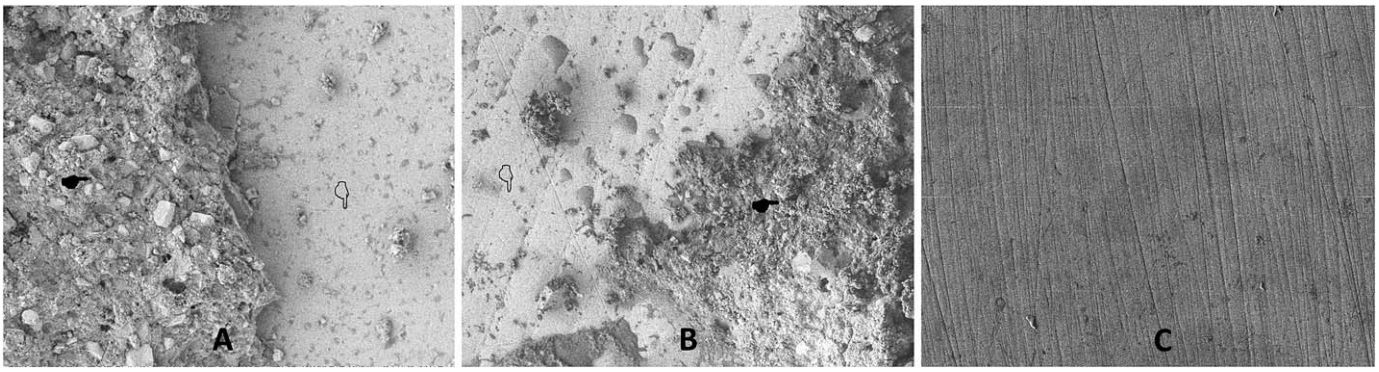

Figure 3. *Representative micrographs of fractured surface from tested specimens (400× magnification): (A, B) mixed failure: ☛ indicates the resin cement and ♌ means Y-TZP surface. (C) Adhesive failure: Y-TZP surface cement free.*

materials,[52,53] while also providing lower solubility of cement and lower marginal leakage,[54] which is the main culprit in the replacement of restorations.[55] Given these characteristics, this current study modified the surface of Y-TZP in order to improve the bond strength to resin cements.

When considering the approaches presented in the literature, the application of low-fusing glass followed by hydrofluoric acid etching appears to be a promising method when conditioning Y-TZP.[9-11,14,15,29-33,50] After this treatment, the Y-TZP behaves as a silicon oxide–based ceramic from the standpoint of the adhesive, in that the treated surface presents of the possibility of micromechanical bonding by acid etching while providing a chemically reactive surface via the chemical bonds of silane, which serves as a link between the deposited/applied silica and the organic matrix of resin cements (siloxane bond).[4-6,19,29,56,57] Aboushelib and others[29] coated the surface of Y-TZP with low-fusion glass (30% silicon, 13% titanium, 8% aluminum, 3% potassium, 1% rubidium, 1% magnesium, and the remnants of O_2) and found increased bond strengths when compared to the control group (without glass application). Valentino and others[15] found higher bond strength values when the Y-TZP surface was glass-coated and acid-conditioned. Kitayama and others[11] modified the surface of zirconia, covering it with a thin layer of glass ceramics (100 μm), and achieved better bond strength results to resin cement by acquiring the characteristics of a feldspathic ceramic.[4-6]

In this current study, two strategies for surface glazing from the same manufacturer were used (two types of commercially available glazing agents) with similar chemical compositions, but with different modes of application: spray (Spray Glaze, VITA Akzent: Glazing 1) and powder + liquid (liquid-powder Glaze: VITA Akzent: Glazing 2).

The glazing surface treatment followed by hydrofluoric acid etching and silanization improved the bond strength when compared to the control group (Table 1). Even though the application method of glass application suffered a significant reduction in bond strength after aging, the values obtained in the aged condition were higher when compared to those of other groups (Table 1).

These results can be explained by two mechanisms: 1) bonding via micromechanical retention: the strong micromorphological changes (increased roughness) optimized the interaction between the adhesive and substrate[4,28,58-61] (Figure 2E,F), or 2) chemical bond: the increased percentage of silica on the surface (Table 3) may have contributed to an enhanced physical and chemical interaction between the glassy film–silane-resin cement.[2,4,19,29,57]

However, according to Student t test, the bond strengths from all surface treatments were reduced significantly after long-term aging, except for the treatment of V2 + silanization (Table 1). These present findings demonstrate the strong difficulty

Table 5: *Medians of Marginal Fit Data of the Y-TZP Frameworks After Different Conditionings of the Intaglio Surface and Dunn Test[a] (α=5%)*

Y-TZP Surface Conditionings	Medians[a]
Glazing 1 + silica coating (V1+SIL)	106.15 A
Glazing 1 + acid etching (V1+HF)	103.90 A
Glazing 2 + silica coating (V2+SIL)	105.20 A
Glazing 2 + acid etching (V2+HF)	103.20 A
Control group	56.0 B
Silica coating (SIL)	54.5 B

[a] Dunn test. Same letters = no significant difference. Different letters = significant difference.

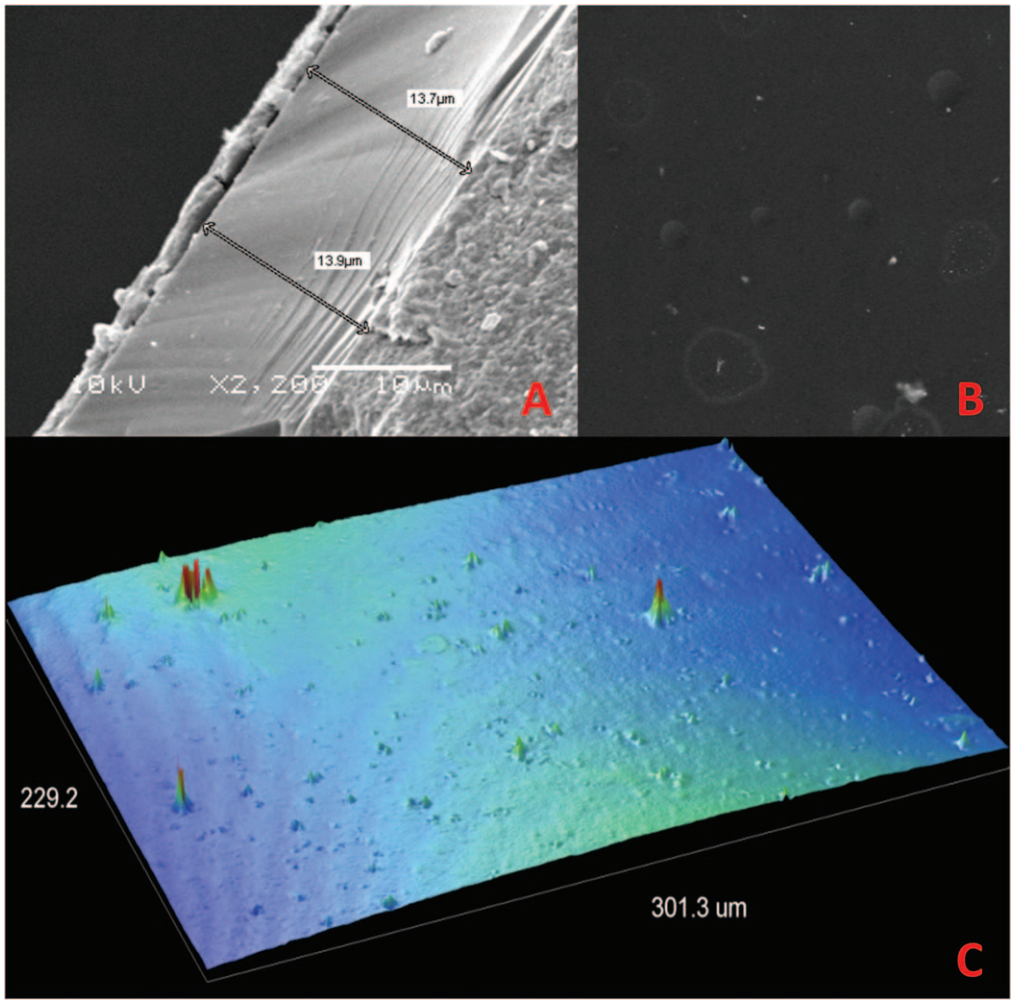

Figure 4. *Representative images of Y-TZP surface after glazing obtained from SEM (1000×) at transversal view (A) and surface view (B) and from digital optical profilometer (C).*

associated with stabilizing resin adhesion to the Y-TZP–based ceramic. Aboushelib and others[29,30] found no influence of storage on the values of bond strength after one, two, three, and four weeks of storage when performing vitrification of the Y-TZP ceramics and cementing with an MDP-containing resin cement (Panavia F), which may have occurred because of the short period for degradation of the

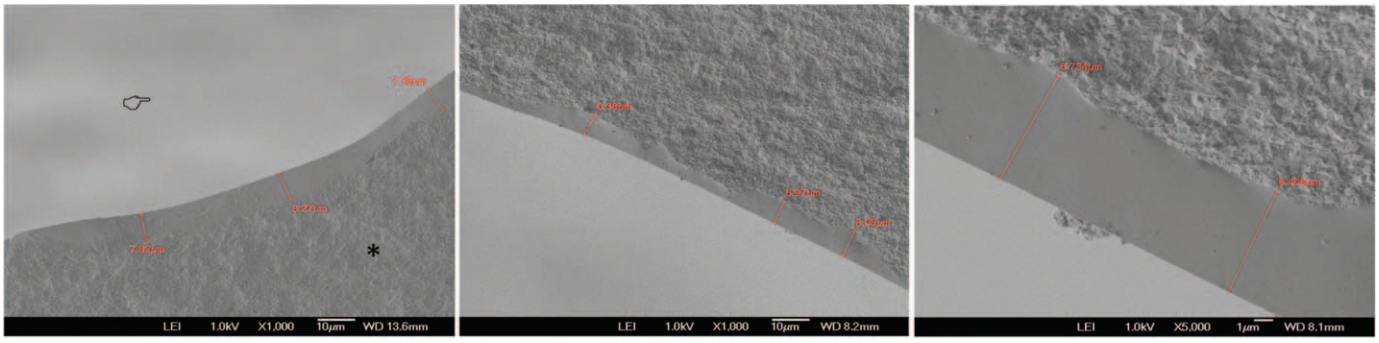

Figure 5. *Representative micrographs of the transversal surface of Y-TZP frameworks submitted to glazing ("spray" approach). The frameworks were fractured in order for it to be possible to produce these images: Whiter zone (☞) represents the Y-TZP material and blacker zone (*) indicates the glaze material.*

interface cement/Y-TZP. Another study[31] with a storage time of 90 days found a decrease in bond strength. Despite the reduction in bond strength values after storage/thermocycling, the bond strengths for the groups that received surface treatments were higher than the bond strengths of the control group, which showed 100% spontaneous failures and a high percentage of adhesive failures (dry and aging conditions), demonstrating the weak adhesive interaction of the resin cement to the Y-TZP surface (Table 4; Figure 5).

In the groups with glass coating associated with the air-abrasion of silica particles (SIL group), the deposition of silica particles can be observed, associated with a uniform surface roughness (R_a, 0.41-0.40) (Figure 2C,D). The current authors hypothesized that the "soft" glass surface may optimize the incrustation of silica particles onto the glass-coated Y-TZP surface; however, the results were lower than those for the groups submitted to etching with hydrofluoric acid. Thus, the possibility of introducing cracks in the ceramic through the impact pressure of the air-borne particle abrasion seems to be an unnecessary risk because the bond strength was higher when conditioning with hydrofluoric acid.[20-22]

Taking into account that the marginal discrepancy evaluation is influenced, among other factors, by the thickness of the cement[62] and that the technique of cementation affects the marginal fit,[63] cementation was performed in the current study to assess marginal fit. Moreover, it has been shown that the cement layer usually covers the points of measurement, making it difficult to perform accurate measurements.[64-66]

The control and tribosilicatization (SIL) groups showed statistically lower marginal discrepancies when compared to the groups that received glass application. A plausible explanation for this may be that the glass applied on the intaglio surface of the Y-TZP infrastructure formed a layer thick enough to interfere with seating of the infrastructure. This reflects the difficulty in standardizing the glaze application inside the Y-TZP infrastructure. This fact is a major limitation of this present study. However, despite this limitation, the mean values of marginal fit obtained in the current study appear to be within the range of clinically acceptable marginal discrepancies.[38-41,67] Besides, taking into account the marginal misfit results of control and tribosilicatization (SIL) groups, it can be hypothesized that the nano-film deposition approach of Y-TZP silicon oxide surface conditioning likely has no impact on marginal misfit.

Finally, given the present results, it appears that the glass application on the surface of Y-TZP, followed by hydrofluoric acid etching, is promising with regard to bond improvement. However, some issues should be further studied to better establish a plausible technique: the bond durability, the effect on the marginal discrepancies, the influence of conditioning on the mechanical behavior of the material, the duration of etching with hydrofluoric acid, and the technique of glass application on the intaglio surface of the restorations. Clinical studies may be needed to confirm the clinical feasibility of these procedures.

CONCLUSION

- The application of low-fusing glass on the surface of Y-TZP, followed by hydrofluoric acid etching and silanization, significantly improved the bond between Y-TZP and resin cement, but the resin adhesion was unstable.
- Storage/thermocycling affected the bond strength results, demonstrating bond instability to Y-TZP.
- The glass application increased the marginal discrepancies when compared to the results associated with other treatments.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Influence of Chlorhexidine and/or Ethanol Treatment on Bond Strength of an Etch-and-rinse Adhesive to Dentin: An *In Vitro* and *In Situ* Study

DMS Simões • RT Basting • FLB Amaral
CP Turssi • FMG França

Clinical Relevance

Bond strength suffered degradation over time and was not influenced by dentin treatments with chlorhexidine and/or ethanol. Adhesive bond degradation was less affected under *in situ* conditions than *in vitro*.

SUMMARY

The aim of this study was to evaluate the effect of a chlorhexidine and/or ethanol application on the bond strength of an etch-and-rinse, hydrophobic adhesive system either under *in vitro* aging or *in situ* cariogenic challenge. The dentin surface of 36 human third molars were flattened and allocated into four groups to be treated with chlorhexidine, ethanol, or chlorhexidine + ethanol or left unexposed to any solution (control) (n=9). Then, a resin composite restoration was made on the dentin surface and longitudinal sticks were obtained. Sticks from each tooth were assigned to three test conditions: stored in water *in vitro* for 24 hours, stored in water *in vitro* for 6 months, or worn *in situ* for 14 days. During *in situ* wear time, a high-cariogenic challenge condition was simulated. Specimens were tested for microtensile bond strength (μTBS). Multivariate analysis of variance and Tukey's test showed that chlorhexidine, ethanol, or chlorhexidine + ethanol did not affect the μTBS. The *in vitro* μTBS values were significantly lower for the specimens stored for 6 months than for those stored for 24 hours. Intermediate μTBS values were shown by the specimens worn *in situ*. Thus, use of chlorhexidine and/or ethanol was incapable of containing the degradation

Dulce Maria Santos Simões, MS, São Leopoldo Mandic Institute and Research Center, Operative Dentistry, Campinas/São Paulo, Brazil

Roberta Tarkany Basting, PhD, São Leopoldo Mandic Institute and Research Center, Operative Dentistry, Campinas/São Paulo, Brazil

Flávia Lucisano Botelho do Amaral, PhD, São Leopoldo Mandic Institute and Research Center, Operative Dentistry, Campinas/São Paulo, Brazil

Cecilia Pedroso Turssi, PhD, São Leopoldo Mandic Institute and Research Center, Campinas/São Paulo, Brazil

*Fabiana Mantovani Gomes França, PhD, São Leopoldo Mandic Institute and Research Center, Operative Dentistry, Campinas/São Paulo, Brazil

*Corresponding author: Rua José Rocha Junqueira, 13, Campinas, São Paulo 13045-755, Brazil; e-mail: biagomes@yahoo.com

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at the bond interface in the *in vitro* model. The *in situ* model was capable of reducing bond strength similarly to the *in vitro*/6 months model. Despite this, the *in situ* bond strength was still similar to that of the *in vitro*/24-hour model.

INTRODUCTION

Enamel and dentin are tissues that differ in composition, structure, and water concentration.[1] Although a lasting seal occurs between adhesive systems and enamel, the same has not been observed in dentin, in which bond strength decreases over time.[2-4]

Extrinsic and intrinsic factors are related to the integrity of the bond interface, such as the chemical and physical stability of the composite and dentin, the adhesive system itself, and the collagen fibers involved in the hybridization process.[5] The intrinsic water content of dentin and water coming from the oral cavity negatively affect the bond stability over time.[6]

Additionally, in an attempt to simplify the protocols of adhesive application, many adhesive systems have become increasingly hydrophilic, which can result in a trend toward hydrolytic degradation. In view of this knowledge, the use of hydrophobic dimethacrylates is expected to reduce water sorption.[7] However, during a conventional wet-bonding technique, the remaining water can potentially promote phase separation of the hydrophobic monomer, which has less solubility.[8] Studies[8,9] have demonstrated that use of anhydrous solvents, such as ethanol (ETH), on demineralized dentin keeps the demineralized collagen matrix expanded and ready for receiving the adhesive system. Also, the tissue would be less hydrophilic, which would prevent the phase separation of the hydrophobic monomer and result in a more stable bond over time.

Nevertheless, it has been observed that there is degradation of the hybrid layer even in well-sealed restorations. It has been demonstrated that the decrease in bond strength is not solely related to the resin material.[10] Another factor seems to play an important role in this process: collagen proteolysis.[11]

Dentin contains enzymes from the metalloproteinase (MMP) family, which exhibit a collagenolytic and gelatinolytic action capable of degrading collagen fibrils not encapsulated by the adhesive system.[3,11] It has been observed that chlorhexidine gluconate is an MMP inhibitor capable of maintaining hybrid layer integrity by preventing collagen from degrading.[10,12-15]

Studies have evaluated the application of ethanol with the aim of favoring the use of either hydrophobic monomers[9,16-19] or chlorhexidine as an MMP inhibitor.[11,15,20,21] However, it is still unclear whether the association of these two substances would act additively or synergistically.

One of the most commonly used methods to simulate bond degradation is the storage of restorations in water.[22] Such models, however, do not properly simulate the processes taking place in an intraoral situation. One of these processes involves the pH fluctuations caused by cariogenic challenges, which can reduce bond strength.[23]

In addition, *in situ* models are appropriate for evaluating bond degradation because host-derived MMPs can originate from saliva and from dentin.[24] Recently, Reinke and others[23] reported that the *in situ* model seems to be a suitable short-term methodology to investigate the degradation of resin-dentin bonds under a more realistic condition.

Therefore, the aim of this study was to compare the bond strength of a three-step adhesive system at time intervals of 24 hours and 6 months, and in an *in situ* cariogenic challenge. The following null hypotheses were tested: 1) Neither chlorhexidine nor ethanol, used alone or in combination, influences bond strength values; 2) time has no influence on bond degradation; and 3) *in situ* cariogenic challenge does not influence bond strength.

METHODS AND MATERIALS

Experimental Design

The experimental design of this study followed a randomized complete block design with repeated measures, in a 4x3 factorial scheme. The following factors were under study:

- Treatment at four levels: control, chlorhexidine, ethanol, and chlorhexidine + ethanol;
- Test condition at three levels: after *in vitro* storage for 24 hours or 6 months and *in situ*.

The response variable was microtensile bond strength, measured in MPa. In this study each tooth was considered an experimental unit. Therefore, beams taken from each tooth (*in vitro*/24 hours, *in vitro*/6 months, and *in situ*) were not independent. Due to this dependent relationship, multivariate analysis of variance (MANOVA) was applied.

Selection and Preparation of Teeth

Thirty-six sound, recently extracted human third molars were randomly selected from a pool of extracted teeth (stored in a 0.1% thymol solution)

Table 1: *Materials, Manufacturers, Composition, Description, and Mode of Application of Materials*

Material	Manufacturer	Lot	Description
All Bond 3	(Bisco Inc)	Lot 1000004752	Conventional three-step application adhesive system: acid, part A (primer), and part B (light-activated adhesive).
Filtek Z100	(3M ESPE)	Lot N142512BR	Microhybrid resin composite
Chlorhexidine (FGM)		Lot 301110	Solution
100% Ethanol	(Chemco Ltda, Brazil)	Lot: 24631	Solution

Abbreviations: MgNTG-GMA, tolylglycine glycidyl methacrylate, definition; Bis-GMA, *bisphenol A glycidylmethacrylate; BPDN, biphenyl dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate.*

from the São Leopoldo Mandic School of Dentistry, with appropriate ethical approval from the local ethics committee (protocol 2010/0294).

Teeth were sectioned perpendicular to the long axis at the amelodentinal junction. Two-thirds of the most apical root portion was also removed, exposing the pulp chamber, so dentin thickness could be standardized to 2 mm. Pulp chambers were filled with an adhesive and resin composite (Single Bond and Z100 shade A2, 3M/ESPE, St Paul, MN, USA). The exposed occlusal dentin was flattened and polished using a metallographic grinder (Politriz Aropol 2V, Arotec, Cotia, São Paulo, Brazil) with 600-grit silicon carbide abrasive paper. Samples were randomly divided into four experimental groups (n=9) to be treated with chlorhexidine, ethanol, or chlorhexidine + ethanol, or left untreated. At this time, all specimens were submitted to ethylene oxide sterilization.[25,26]

Restorative Procedures

Table 1 describes the materials used, manufacturers, lots, manufacturers' instructions, and dentinal treatments. Specimens were prepared (Table 2) according to the experimental group to which they were assigned. After the adhesive procedures, the resin composite (Z100, 3M/ESPE) was inserted in three increments of 2 mm and individually light polymerized for 40 seconds between each increment, using a halogen light unit at 450 mW/cm^2 (Demetron LC, Kerr, Danbury, CT, USA). Irradiance was monitored with a radiometer (RD-7, Ecel Ind. e Com. Ltda, Ribeirão Preto/São Paulo, Brazil).

Specimen Preparation for Microtensile Test and Storage

Samples were individually fixed on acrylic plates. This appliance was duly fixed to a precision cutter (Isomet 1000, Buehler, Lake Bluff, IL, USA) used to serially section the samples from the resin composite, parallel to their long axis in the mesiodistal and vestibular-lingual directions, with a distance of 1 mm between the cuts, thereby obtaining around 12 sticks per tooth. One-third of the sticks were randomly assigned to be stored in distilled water at 37°C for 24 hours. Another third was kept in distilled water at 37°C for 6 months, and the remaining sticks were assigned to be worn *in situ*.

In Situ Test

After signing an informed consent form, nine volunteers of both genders, aged 20 to 50 years,

Table 2: *Description of the Experimental Groups and Treatments*

Groups	Treatments
1	Acid etching for 15 seconds, washing with water, removing excess water, and adhesive system application
2	Acid etching for 15 seconds, washing with water, removing excess water, chlorhexidine application for 30 seconds, removing excess chlorhexidine, and adhesive system application.
3	Acid etching for 15 seconds, washing with water, removing excess water, 100% ethanol application for 1 minute, drying, and adhesive system application
4	Acid etching for 15 seconds, washing with water, removing excess water, 100% ethanol application for 1 minute, drying, chlorhexidine application for 30 seconds, removing excess chlorhexidine, and adhesive system application

Table 1: *Materials, Manufacturers, Composition, Description, and Mode of Application of Materials (ext.)*

Composition (Main Components)	Application Mode
Acid: 32% phosphoric acid with benzalkonium chloride	Acid etching of dentin for 15 seconds, washing, removing excess humidity, application of 2 coats of primer, drying for 5 seconds, primer polymerization for 10 seconds, adhesive application, and light polymerization for 20 seconds
Part A: Ethanol, MgNTG-GMA	
Part B: Bis-GMA, BPDN, HEMA, photoinitiator, and stabilizer	
Bis-GMA and TEGDMA	2-mm layers
2% Chlorhexidine digluconate	Acid etching for 15 seconds, washing with water, removing excess water, chlorhexidine application for 30 seconds, removing excess chlorhexidine, and adhesive system application.
100% Ethanol	Acid etching for 15 seconds, washing with water, removing excess water, 100% ethanol application for 1 minute, drying, and adhesive system application.

were enrolled. The inclusion criteria were as follows: stimulated salivary flow >0.7 mL/min, available to follow the schedule established for the experiment, and no active caries lesions. The exclusion criteria were as follows: taking medication; pregnant or lactating, having a periodontal disease; wearing removable dentures, orthodontic appliances (fixed or removable), or occlusal plates; or presenting systemic diseases.

The sticks assigned to the *in situ* test were mounted in an intraoral appliance, which was fabricated of self-polymerizing acrylic resin made from the volunteers' casts. The appliances contained four niches, and one stick from each of the four experimental groups was mounted. The sticks were fixed into their respective niches using a gauze and wax. Palatal appliances were then inserted into each participants' mouth.

The *in situ* phase volunteers were instructed in how to use the dentifrice (Sorriso Colgate Palmolive Company, São Bernardo do Campo, São Paulo, Brazil) and toothbrush (Colgate Palmolive Company, São Bernardo do Campo, São Paulo, Brazil) provided by the researcher. Seven days later, the appliance was inserted and worn for 14 days.[27] Cariogenic challenges were started on the second day, as the first day served to allow saliva pellicle formation. The volunteers were instructed to remove the palatal appliance and drip a 20% sucrose solution into each niche four times a day (8:00 AM, 11:00 AM, 3:30 PM, and 7:00 PM). After 5 minutes of dripping the solution, the appliance was reinserted into the oral cavity.[27] During the experimental period, the volunteers were instructed to brush their teeth after the main meals (7:30 AM, 12:30 PM, and 8:00 PM) and to use the device continually, removing it only for oral hygiene and during meals.

Microtensile Test

Sticks were attached to an acrylic testing device using a cyanoacrylate adhesive (Super Bonder Gel, Henkel Ltda, São Paulo, Brazil) and subjected to tensile stress in a universal testing machine (MEM-2.000 model, EMIC, São José dos Pinhais, Paraná, Brazil) at a crosshead speed of 0.5 mm/min and a 20N load cell until fracture. After testing, fractured surfaces were observed under a stereomicroscope to determine the mode of failure according to one of the four criteria: 1) adhesive fracture, 2) part adhesive fracture and part cohesive in resin, 3) cohesive fracture in resin, and 4) cohesive fracture in dentin.

Statistical Analysis

Data were submitted to MANOVA and Tukey's test. The significance level was set at 5%.

RESULTS

Table 3 summarizes the mean values and standard deviations found for each group.

Table 3: *Means (MPa) (Standard Deviation) of Bond Strength Values Per Treatment and Test Condition*

Treatment	Test Condition		
	In Vitro 24 h	*In Situ*	*In Vitro* 6 mo
Control	28.77	21.38	19.37
	(11.02)	(7.27)	(5.74)
Chlorhexidine	24.43	19.12	17.47
	(8.01)	(8.87)	(6.62)
Ethanol	20.86	19.69	19.28
	(7.09)	(12.05)	(9.68)
Chlorhexidine + ethanol	27.01	26.86	21.22
	(17.86)	(18.78)	(9.97)

Table 4: *Mean Values (Standard Deviation), According to Test Condition, Regardless of the Dentin Treatment*

Test Condition	Bond Strength (MPa)
In vitro 24 h	25.27 (11.66) a
In situ	21.76 (12.39) ab
In vitro 6 mo	19.33 (7.97) b

Distinct letters indicate statistical differences between groups ($p<0.05$)

MANOVA revealed no significant interaction between treatment and test condition ($p=0.7657$). No differences in microtensile bond strength were caused by the treatments applied on the dentin ($p=0.5410$). Test Condition had a significant effect on microtensile bond strength ($p=0.0174$). Tukey's test showed that, regardless of the treatment applied to the dentin, under *in vitro* conditions significantly lower bond strength values were observed when the sticks were stored for 6 months (Table 4). Bond strength values of the sticks submitted to the *in situ* condition did not differ from those observed in the *in vitro* conditions (24 hours and 6 months).

With regard to the failure mode, for all test conditions, cohesive failures were the most common, followed by mixed failures and adhesive failures, regardless of the treatment received by the dentin (Table 5).

DISCUSSION

The results of this study demonstrated that water storage had a significant influence on the adhesive interface degradation, regardless of the dentin treatment. Thus, null hypothesis 1 was rejected and null hypothesis 2 was accepted. The loss of bond strength along the hybrid layer may occur by degradation of the resin material, collagen fibrils, or both.[2,28]

Ideally, adhesive systems should have formulations based on hydrophobic monomers, as they are more stable both chemically and mechanically.[16] However, hydrophobicity is incompatible with dentinal humidity. Therefore, in order to use hydrophobic adhesive systems it is necessary to alter the dentinal substrate. Because of this aspect, the use of ethanol (ethanol wet-bonding) has supported the rationale that a less hydrophilic substrate would favor the encapsulation of unprotected collagen by hydrophobic monomers.[16-18] In fact, many studies have shown promising results for this technique,[16-18,29,30] even though most of them used increasing concentrations of ethanol. However, clinically, this appears to be unfeasible, seeing that it excessively increases the clinical working time. Therefore, the technique used in this study was dehydration with 100% ethanol for 1 minute.[31] Considering that null hypothesis 1 was rejected because all dentin treatments (including application of ethanol) yielded no differences in bond strength, it may be suggested that this simplified technique may not have been sufficient to dehydrate the dentin in order to improve the penetration of the adhesive system used and thereby prevent degradation of the hybrid layer.[32]

Moreover, it is to be expected that a hydrophobic material, such as the adhesive system used in the present study, would maintain bond integrity for a longer time. Nevertheless, it was observed that this did not occur, as there was a decrease in bond strength over the 6-month period of water storage. Perhaps acid etching for 15 seconds demineralized the dentin to a depth that was not completely achieved by the adhesive monomer,[33] thus leaving the unprotected collagen more vulnerable to proteolytic degradation. Ethanol in small concentrations is known to favor the mechanism of polymerization and a degree of conversion of adhesive systems. Nevertheless, these properties may be jeopardized when the ethanol concentration appears to be above 30%.[6] The All Bond 3 system contains approximately 49% ethanol after the mixture of primers A and B (per the manufacturer). This concentration of ethanol in an

Table 5: *Failure Mode According to Treatment and Test Conditions*

Failure Mode	*In Vitro* 24 h				*In Situ*			
	Control	Chlorhexidine	Ethanol	Chlorhexidine + Ethanol	Control	Chlorhexidine	Ethanol	Chlorhexidine + Ethanol
Adhesive	10%	20%	35%	23%	19%	29%	6%	24%
Cohesive in resin	27%	29%	22%	27%	33%	33%	18%	24%
Cohesive in dentin	27%	31%	26%	27%	29%	24%	47%	24%
Mixed	36%	20%	17%	23%	19%	14%	29%	28%

adhesive added to the high-concentrated ethanol applied on the dentin lead us to think that the dentin was supersaturated with ethanol. This may explain the results seen in the groups in which the ethanol was applied. This hypothesis may be confirmed by the fracture patterns. After 6 months there was a large quantity of fractures of the cohesive type in the resin and adhesive, showing adverse effects of ethanol on the resin material polymerization and on bond stability.

However, it is known that control of dentinal humidity alone does not prevent the degradation of collagen fibers that are incompletely infiltrated by the monomer. This degradation may also occur through the action of MMPs.[11,14,31] When the dentin is etched during adhesive procedures, the MMPs are activated and may slowly degrade the collagen fibrils. It is known that MMPs may be inhibited by protease inhibitors, such as chlorhexidine. Consequently, it has been demonstrated that the use of chlorhexidine can possibly decrease the hybrid layer degradation, even at low concentrations.[12]

Although a reduction in immediate bond strength has been demonstrated when chlorhexidine is used,[34] this was not observed in the present study (null hypothesis 1 was rejected), and it has not been corroborated by other authors.[10,15,21,35,36] Nevertheless, the results of the present study showed no significant effect of chlorhexidine on bond strength stability, results that were also found in the literature.[37] These differences may be attributed to the diverse forms of dentin surface preparation, different ages of dentin, diverse measurement techniques used (such as the mode of force application), and material properties (such as modulus of elasticity and size of samples tested).[38] Moreover, the chlorhexidine may have lost its capacity of substantivity. Considering that the small extensions of the sticks represent a form of accelerated aging, so that water could easily diffuse from the surface toward the center, thus, the water diffusion could lead to dilution or displacement of the chlorhexidine and loss of substantivity.[15]

Table 5: *Failure Mode According to Treatment and Test Conditions (ext.)*

In Vitro 6 mo			
Control	**Chlorhexidine**	**Ethanol**	**Chlorhexidine + Ethanol**
4%	12%	33%	15%
28%	27%	33%	11%
28%	37%	10%	41%
40%	24%	24%	33%

In vitro methods provide important information about the fundamental factors involved in the degradation at the resin/dentin interface. However, *in vitro* methods fail to consider the complexity of the intraoral medium (eg, bacterial plaque, enzymes, acidity of foods, chemical agents).[28] Therefore, in this study an *in situ* model was used, which is usually adopted to exacerbate the cariogenic challenge,[27] as no other methodology appropriate for evaluating degradation at the bond interface in an *in situ* model has been found in the literature. The results showed that the *in situ* condition was statistically similar at 24 hours and at 6 months, demonstrating degradation at the bond interface to a limited extent, so null hypothesis 3 was partially accepted. Nevertheless, the interference of the model was not as exacerbated as that which occurred during *in vitro* storage for 180 days. This fact shows that perhaps the deleterious effect of time is more important in bond degradation than the immediate oral conditions. In view of these results, further research needs to be conducted to develop an *in situ* methodology that simulates adhesive interface degradation.

Thus, knowledge of the importance of bonding with reference to the clinical longevity of restorations combined with the knowledge of the limitations of contemporary adhesive systems, explain why the use of chlorhexidine and ethanol associated with a hydrophobic adhesive system was not capable of containing the degradation of the bond interface in the *in vitro* model after 180 days of storage.

CONCLUSION

The use of chlorhexidine and/or ethanol could not contain the degradation at the bond interface in the *in vitro* model. The *in situ* model was capable of reducing bond strength similarly to the *in vitro*/6-month model. Despite this, *in situ* bond strength was still similar to the *in vitro*/24-hour model.

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Influence of Immediate Dentin Sealing Techniques on Cuspal Deflection and Fracture Resistance of Teeth Restored with Composite Resin Inlays

L Oliveira • EG Mota • GA Borges
LH Burnett Jr • AM Spohr

Clinical Relevance

Immediate dentin sealing with Clearfil SE Bond can contribute to less cuspal deflection of teeth restored with composite resin inlays luted with Panavia F.

SUMMARY

This research evaluated the influence of immediate dentin sealing (IDS) techniques on cuspal deflection and fracture resistance of teeth restored with composite resin inlays. Forty-eight maxillary premolars were divided into four groups: G1, sound teeth (control); G2, without IDS; G3, IDS with Clearfil SE Bond (CSE); and G4, IDS with CSE and Protect Liner F. The teeth from groups 2, 3, and 4 received mesio-distal-occlusal preparations. The impressions were made with vinyl polysiloxane, followed by provisional restoration and storage in water for seven days. The impressions were poured using type IV die stone, and inlays with Filtek Z250 composite resin were built over each cast. The inlays were luted with Panavia F. After storage in water for 72 hours, a 200-N load was applied on the occlusal surface using a metal sphere connected to a universal testing machine, and the cuspal deflection was measured with a micrometer. The specimens were then submitted to an axial load until failure. The following mean cuspal deflection (μm) and mean fracture resistance (N) followed by the same lowercase letter represent no statistical difference by analysis

Luiz Henrique Burnett Jr, DDS, MS, PhD, Department of Restorative Dentistry, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

Leandro G de Oliveira, DDS, MS, Department of Restorative Dentistry, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

Eduardo Gonçalves Mota, DDS, MS, PhD, Department of Restorative Dentistry, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

Gilberto Antonio Borges, DDS, MS, PhD, Department of Dental Materials, University of Uberaba, Uberaba, Brazil

*Ana Maria Spohr, DDS, MS, PhD, Department of Dental Materials, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

*Corresponding author: Dental Materials, Avenida Ipiranga, 6681, Porto Alegre, Rio Grande do Sul 90619-900, Brazil; e-mail: ana.spohr@pucrs.br

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of variance and Tukey ($p<0.05$): cuspal deflection: G1, 3.1 ± 1.5[a]; G2, 10.3 ± 4.6[b]; G3, 5.5 ± 1.8[ac]; and G4, 7.7 ± 5.1[bc]; fracture resistance: G1, 1974 ± 708[a]; G2, 1162 ± 474[b]; G3, 700 ± 280[b]; and G4, 810 ± 343[b]. IDS with CSE allowed cuspal deflection comparable with that associated with sound teeth. The application of Protect Liner F did not contribute to a decrease in cuspal deflection. The IDS techniques did not influence the fracture resistance of teeth.

INTRODUCTION

Indirect composite restorations have been used to fabricate inlays, onlays, veneers, and crowns as a result of improved mechanical properties and controlled polymerization shrinkage stresses.[1] The traditional technique consists of making an impression of the tooth immediately after preparation and luting an acrylic resin restoration with provisional cements; the traditional approach may involve the use of provisional resin materials applied directly on the prepared tooth. Once the permanent restoration is ready, the provisional material is removed and an adhesive system is applied to the tooth, followed by a resin cement for the adhesive luting procedure.[2]

Studies[3,4] have shown that adhesive systems bond better to freshly cut dentin in comparison with dentin contaminated with temporary materials. This contamination may cause microleakage,[5] failure in hybridization, and sensitivity.[6] To avoid these problems, the immediate dentin sealing (IDS) technique was developed in the early 1990s[7]; this technique consists of the application of an adhesive system immediately after concluding the tooth preparation and prior to impression. Another technique consists of the application of an adhesive system and a low-viscosity composite resin to dentin immediately after concluding the preparation.[8,9] It is believed[10] that a layer of low-viscosity composite resin helps to protect the hybrid layer and, consequently, preserves the dentin seal.

With both techniques, further adhesion of the luting agent to the preexisting resin layer must be promoted by surface cleaning prior to luting,[11] with the purpose of removing remnants of provisional cements that may cause a significant decrease in the bond strength of the luting agent.[6,12]

These techniques have the clinical advantages of covering the prepared dentin with a resin agent immediately after cavity preparation, sealing and protecting the dentin-pulp complex, and preventing and decreasing sensitivity and bacterial infiltration during the provisional stage.[11]

With the IDS technique, studies have shown that there is good bonding of the resin material with an adhesive system[13] and an increase in bond strength with an adhesive system and low-viscosity composite resin.[8,9,14,15] Jayasooriya and others[16] observed fewer gaps at the internal dentin–restoration interface in the specimens coated with an adhesive system and a low-viscosity microfilled resin compared with noncoated specimens. With regard to the marginal sealing capacity, the higher bond strength does not necessarily provide less microleakage when the IDS is used.[17] However, there is no information about the influence of IDS on cuspal deflection and fracture resistance of restored teeth.

The aim of this study was to evaluate the influence of the two IDS techniques on cuspal deflection and fracture resistance of teeth restored with composite resin inlays. This study was conducted under the null hypothesis that these techniques do not influence cuspal deflection and fracture resistance.

MATERIALS AND METHODS

Forty-eight sound maxillary first premolars were obtained from the Tooth Bank of Pontifical Catholic University of Rio Grande do Sul after ethics committee approval was obtained. The teeth were cleaned and disinfected in 0.5% chloramine for 24 hours and then stored in distilled water at 4°C. The buccal-palatal and mesio-distal dimensions of each tooth were measured with a digital caliper (Mitutoyo, Suzano, SP, Brazil). A variation of 0.5 mm was allowed for each measurement to standardize the dimensions of the teeth.

The teeth were randomly divided into four groups (n=12), as follows: group 1, sound teeth (control); group 2, inlay cavity; group 3, inlay cavity and IDS with adhesive system; and group 4, inlay cavity and IDS with adhesive system and low-viscosity composite resin. The materials used are listed in Table 1.

Preparation of the Mesial, Distal, and Occlusal Surfaces

Each tooth was mounted vertically in a plastic ring with self-cured acrylic resin (Jet Classico, São Paulo, SP, Brazil) up to 2 mm below the cemento-enamel junction (CEJ) to mimic the alveolar bone support in a sound tooth. In groups 2, 3, and 4, a single operator performed cavity preparation on the mesial, distal, and occlusal surfaces with a 4159 diamond bur (KG Sorensen, Barueri, SP, Brazil) at high speed under

Table 1: *Materials Used in the Study*

Materials	Composition	Manufacturer
Clearfil SE Bond	Self-etch primer: 10-MDP, HEMA, hydrophilic dimethacrylate, photoinitiator, water	Kuraray Medical Inc, Tokyo, Japan
	Adhesive: 10-MDP, bis-GMA, HEMA, hydrophilic dimethacrylate, microfiller	
Protect Liner F	TEG-DMA, Bis-GMA, methacryloyl fluoride-methyl, methacrylate copolymer	Kuraray Medical Inc, Tokyo, Japan
Panavia F	ED primer A: HEMA, 10-MDP, 5-NMSA, water, accelerator	Kuraray Medical Inc, Tokyo, Japan
	ED primer B: accelerator, water, sodium benzene sulfinate	
	A-Paste: methacrylate, 10-MDP, quartz-glass, microfiller, photoinitiator	
	B-Paste: methacrylate, barium glass, sodium fluoride, chemical initiator	
Filtek Z250	Bis-EMA, UDMA, Bis-GMA, TEGDMA, silane-treated ceramic	3M ESPE, St Paul, MN, USA

Abbreviations: Bis-EMA, ethoxylated bisphenol A dimethacrylate; Bis-GMA, bisphenol-glycidyl methacrylate; 5-NMSA, N-methacryloxyl-5-aminosalicylic acid; HEMA, hydroxyethylmethacrylate; TEGDMA, triethylene glycol dimethacrylate; 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; UDMA, urethane dimethacrylate.

constant water and air cooling. The width between the buccal and lingual cavosurface angle was two-thirds of the distance between the buccal and lingual cusp tips, and the occlusal isthmus was 3 mm deep. The widths of the proximal boxes corresponded to one-third of the distance between the buccal and lingual surfaces of the teeth at the level of the gingival wall and measured 1.5 mm deep. The proximal boxes were located 1 mm coronal to the CEJ. The internal line angles were rounded, the cavosurface angles were approximately 90°, and the angle of divergence of the walls of the preparations was approximately 6°. The dimensions of the cavity were standardized using a digital paquimeter with precision of 0.01 mm.

IDS Techniques

Immediately after cavity preparation, one of the IDS techniques was applied to the teeth in groups 3 and 4. In group 3, the Clearfil SE Bond adhesive system was applied as follows: the self-etching primer was applied to dentin using a brush tip and was left in place for 30 seconds. Excess solvent was removed by air-drying for five seconds. The bond was applied to the surface cavity with a brush tip, and gentle air-drying was applied for three seconds, followed by light-curing for 20 seconds with a light-curing unit (Optilux Plus, Gnatus, Ribeirão Preto, SP, Brazil). The irradiance was monitored by a radiometer (Model 100 Demetron, Kerr, Danbury, CT, USA) set between 450 and 500 mW/cm^2. Polymerization of the adhesive was followed by the application of an air-blocking barrier (glycerin jelly) and 10 seconds of additional light-curing to polymerize the oxygen inhibition layer.[13] In group 4, Clearfil SE Bond was applied as described in group 3 without the air-blocking barrier. After application of the adhesive, Protect Liner F was placed on the adhesive surface using a brush-on technique and light-cured for 20 seconds. The surface of the cured flowable composite resin was wiped with a cotton pellet soaked in alcohol for 10 seconds to remove the unpolymerized layer on the surface.[18]

Restorative Procedures

Impressions of the preparations were taken with polyvinyl siloxane (3M ESPE, St Paul, MN, USA), with individual trays made from self-cured acrylic resin using the putty/wash one-step technique. The impression material was allowed to set for 10 minutes before it was removed from the preparation. Temporary self-cured acrylic resin crowns were then luted onto the preparations with non-eugenol cement (Temp Bond NE, Kerr). Tooth specimens were stored in water at 37°C water for seven days. The impressions were poured after one hour using Durone Type IV stone (Dentsply, York, PA, USA).

The casts were lined with die spacer, except in the marginal areas. Four horizontal layers of composite resin (Filtek Z250, 3M ESPE) were inserted in the casts with a Thompson spatula (nos. 2 and 12), which resulted in a 90° inclination between the internal slopes and cusps. Each resin layer was light-cured for 40 seconds, followed by finishing with polishing discs and silicone tips (Soft-Lex, 3M ESPE).

Luting Procedures

Following storage, the provisional restorations were removed, and the remaining temporary cement on the inlay preparation was scraped off with a dental instrument. Subsequently, the dentin (group 2) and the sealed dentin (groups 3 and 4) were cleaned with a mixture of water and pumice using a rotary brush for 10 seconds. The fitting surface of the restoration was cleaned with alcohol and sandblasted with 50 μm aluminum oxide for five seconds, rinsed, and dried. A layer of silane (Ceramic Primer, 3M ESPE) was applied, followed by gentle air-drying for five

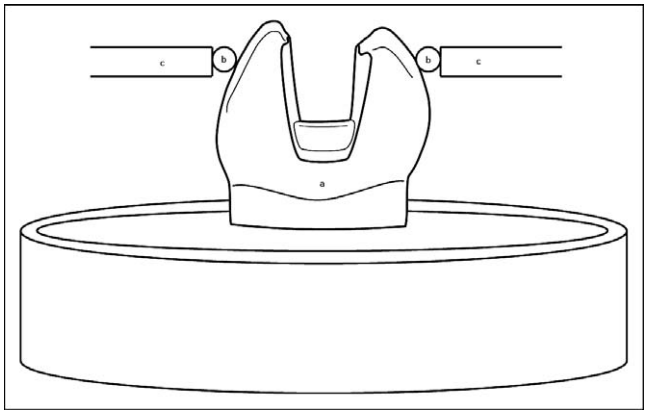

Figure 1. *Schematic figure of the cuspal deflection test: (a) tooth; (b) resin spheres; (c) micrometer.*

seconds. The coated surfaces of the preparation (except in group 2) were then acid-etched with 37% phosphoric acid for 10 seconds and rinsed and dried to remove debris. A mixture of ED Primer A and B was applied for 30 seconds and gently air-dried for five seconds. The base and catalyst of Panavia F resin cement were mixed according to the manufacturer's instructions. The crowns were seated using a 1-kg standard load for two minutes. Excess cement was removed with a microbrush and each surface (buccal, lingual, mesial, distal, and occlusal) was light-cured for 40 seconds. The margins were finished with polishing discs (Sof-Lex). The specimens were stored in distilled water at 37°C for 72 hours and were then submitted to the cuspal deflection and fracture resistance tests.

Cuspal Deflection Testing

Resin spheres (approximately 1.5 mm in diameter) were fixed with adhesive to both cusps. Following the methodology of González-López and others,[19] the spheres were positioned on the cuspal vertices and served as reference points for measuring the intercuspal distance, using a precision micrometer (Mitutoyo), with a measurement sensitivity of 1 μm (Figure 1). A fixation device was used to fix the micrometer in the same position. Each specimen was attached to the lower platen of a universal testing machine (Emic DL-2000, EMIC, São José dos Campos, PR, Brazil), and a steel sphere with an 8-mm diameter was used to apply a 200-N occlusal load at a cross-head speed of 0.5 mm/min. The load was applied perpendicular to the long axis of the tooth, simultaneously contacting the buccal and palatal cuspal inclines. When the 200-N load was achieved, the machine was locked and three consecutive measurements of the cuspal deflection were made. The mean distance of the composite resin spheres prior to loading was subtracted from the mean distance of the spheres after application of the load. Thus, the cuspal deflection was obtained. The specimens were then submitted to a compression test until fracture occurred.

Fracture Resistance Testing

The specimens were submitted to compression in a universal testing machine (EMIC-DL2000). A steel sphere with an 8-mm diameter was used to apply an occlusal load perpendicular to the long axis of the tooth at a cross-head speed of 0.5 mm/min, simultaneously contacting the buccal and palatal cuspal inclines. The load was applied until fracture occurred. The maximum load was recorded in Newtons.

Fracture Mode Analysis

After visual examination, the fractures were classified as follows: type I, cusp fracture at the CEJ; type II, cusp fracture below the CEJ; type III, restoration fracture and cusp fracture at the CEJ; type IV, restoration fracture and cusp fracture below the CEJ; and type V, longitudinal fracture dividing the tooth along the axis.

Statistical Analysis

After data collection, the Kolmogorov-Smirnov normality test was applied to the cuspal deflection and fracture resistance data. The analysis of variance (ANOVA) and Tukey ($p<0.05$) parametric statistical tests were applied to compare the study groups. All statistical analyses were performed using SPSS version 10.0 (SPSS Inc, Chicago, IL, USA).

RESULTS

According to the ANOVA and Tukey tests, the lowest mean cuspal deflection was obtained in group 1 (3.1 μm), differing statistically from group 4 (7.7 μm) and from group 2 (10.3 μm) ($p<0.05$) but not differing statistically from group 3 (5.5 μm) ($p>0.05$). Group 3 did not differ statistically from group 4. The highest mean cuspal deflection was obtained for group 2, which did not differ statistically from group 4 (Table 2).

The highest mean fracture resistance was obtained for group 1 (1974 N), differing statistically from the other groups ($p<0.05$). The fracture resistances of group 2 (1162 N), group 3 (700 N), and group 4 (810 N) were not statistically different from each other ($p>0.05$) (Table 3).

Table 2: *Mean Cuspal Deflection (μm) of the Groups*

Groups	n	Mean, μm	±SD
Group 1 (sound teeth)	12	3.1 A	1.5
Group 2 (without IDS)	12	10.3 B	4.6
Group 3 (IDS with CSE)	12	5.5 AC	1.8
Group 4 (IDS with CSE + Protect Liner F)	12	7.7 BC	5.1

Abbreviations: CSE, Clearfil SE Bond; IDS, immediate dentin sealing; SD, standard deviation.
[a] *Means followed by the same letter did not differ statistically according to Tukey test at a significance level of 5%.*

All sound teeth (group 1) presented type I fractures (100%). There was a predominance of type I and type II fractures in the experimental groups. Type III fractures occurred in groups 3 and 4, and type IV fractures occurred in groups 2, 3, and 4. Type V fractures were less common and occurred in one specimen in groups 3 and 4 (Table 4).

DISCUSSION

The null hypothesis of the present study was partially rejected. IDS caused a decrease in cuspal deflection, but neither sealing technique had an influence on fracture resistance.

Cuspal deflection is a nondestructive methodology that verifies the deformation of the cuspids when a load is applied in the occlusal region. In this study, an occlusal load of 200 N was applied to perform this nondestructive test; a load of up to 300 N can be applied without the risk of tooth fracture.[20]

The lowest mean cuspal deflection was obtained for the sound teeth (3.1 μm), corroborating the results of the study of Jantarat and others.[20] This small cuspal deflection is due to the biomechanical behavior of the dentin-enamel junction, which allows a strong bond between these two substrates.[21] Intact teeth with a complete enamel covering are very stiff, and an occlusal load causes only a small deformation. The deformation depends on the intensity of the force applied.[19,20] Sound teeth distribute load-generated stress more homogeneously because enamel is not appreciably deformed, and the deformation is transferred to the more resilient dentin.[22] When the continuity of the enamel is lost as a result of preparation, the properties of the dentin play a major role in cusp behavior.[23] The loss of dental structure, such as enamel and dentin, causes a decrease in tooth stiffness, and consequently there is an increase in cuspal deflection under occlusal loads.[19,20,24] Therefore, it is necessary to try to recover this stiffness when restoring the tooth.

In the case of inlay restoration, the stiffness of the tooth tends to be restored when the material used for luting bonds strongly with the tooth tissues and restorative material, with the formation of a monobloc restoration. Therefore, two bond interfaces are formed, corresponding to the tooth/luting material and restoration/luting material. Among the three experimental groups in the present study, variation occurred only at the tooth interface; the same treatment was used at the restoration interface.

Group 3, in which IDS with the adhesive system only was performed, presented cuspal deflection (5.5 μm) that did not differ statistically from that of the sound teeth and that was statistically lower than that of group 2 (10.3 μm), in which no IDS technique was performed. A possible explanation for this finding could be that the Clearfil SE Bond adhesive system was applied directly on the cut dentin. Studies[3,4] have shown that adhesive systems bond better to freshly cut dentin immediately after preparation, in comparison with dentin contaminated with temporary materials, thereby providing greater bond strength to the dentin substrate and, consequently, less cuspal deflection. Another factor to consider is that in group 2, ED Primer was applied on dentin, whereas in group 3, Clearfil SE Bond was

Table 3: *Mean Fracture Resistance (N) of the Experimental Groups*

Groups	n	Mean	±SD
Group 1 (sound teeth)	12	1974 A	708
Group 2 (without IDS)	12	1162 B	474
Group 3 (IDS with CSE)	12	700 B	280
Group 4 (IDS with CSE + Protect Liner F)	12	810 B	342

Abbreviations: CSE, Clearfil SE Bond; IDS, immediate dentin sealing; SD, standard deviation.
[a] *Means followed by the same letter did not differ statistically according to Tukey test at a significance level of 5%.*

Table 4: *Fracture Mode in the Experimental Groups*

Groups	Type I	Type II	Type III	Type IV	Type V
Group 1 (sound teeth)	12	—	—	—	—
Group 2 (without IDS)	5	3	—	4	—
Group 3 (IDS with CSE)	4	3	2	2	1
Group 4 (IDS with CSE + Protect Liner F)	4	4	2	1	1

Abbreviations: CSE, Clearfil SE Bond; IDS, immediate dentin sealing.

applied. Both resin materials have some similarities and some differences in their composition, which may influence the results.

ED Primer is a one-step self-etching primer that has a moderate capacity for dentin demineralization. As a result of the presence of the hydrophilic monomer 2-hydroxyethyl methacrylate (HEMA), ED Primer presents some permeability, allowing changes at the dentin-adhesive interface and, consequently, hydrolytic degradation of this interface.[25] Clearfil SE Bond is a two-step adhesive system that has a self-etching primer and an adhesive, with a pH close to 2, and it also has moderate capacity to demineralize dentin.[26] As the primer in this adhesive system also has the hydrophilic monomer HEMA, it has some permeability. However, the application of the adhesive on the primer, which contains a larger quantity of hydrophobic monomers, tends to reduce the permeability of this adhesive system.[27] Although the specimens were stored in water for the period of only 72 hours in this study, researchers[28,29] have shown that hydrolytic degradation begins in the first moments after the application of adhesive. It is likely that a lower permeability of Clearfil SE Bond may have favored the maintenance of the bond to the substrate and less cuspal deflection. In addition, the better bond between Clearfil SE Bond and the substrate may have favored greater absorption of polymerization stresses generated by shrinkage of the resin cement, contributing to the greater polymerization stress relief at the bond interface.[30,31] Studies[31,32] have shown that polymerization shrinkage, which is generated as a result of the lack of nonadhered surfaces, may rupture the bond between the resin material and cavity walls, resulting in gaps or failures at the interfaces.

In group 4 (IDS with the adhesive system and low-viscosity composite resin), the mean cuspal deflection was intermediate, at 7.7 μm, which differed statistically only from the control group. Although some studies[8,9,14,15] have shown higher bond strength to dentin with this technique, this bond capacity was not reflected in the cuspal deflection methodology. Nevertheless, the difference of only 2.2 μm between group 3 and group 4 may have occurred by chance, considering that no statistically significant difference was found. In the literature, there is no study evaluating the cuspal deflection of teeth restored with the IDS technique. Therefore, the present study provides new information and demonstrates that the application of a low-viscosity composite resin does not significantly contribute to a decrease in cuspal deflection.

The clinical importance of cuspal deflection is that the greater the magnitude of this deflection, the greater the deformation and, consequently, the greater the possibility of fatigue failure. This type of failure, characterized by fracture in the presence of stress far below the maximum strength of the restored tooth, occurs in most dental fractures.[33] Therefore, the results obtained for cuspal deflection indicate that the teeth restored with composite resin inlays using the IDS technique would take a longer time to suffer failure due to mechanical fatigue.

In both IDS techniques, the bond of the luting agent to the preexisting resin layer must be promoted by cleaning the surface prior to luting[11] to remove remnants of temporary cements, which may cause a significant decrease in the bond strength of the luting agent.[6,12] Therefore, after removing the provisional restoration, the preparations in all of the groups received prophylaxis with pumice stone and water. ED Primer was then applied on the Clearfil SE Bond adhesive (group 3) and on the low-viscosity composite resin (group 4). ED Primer contains water, as well as the hydrophilic monomer HEMA; it would be more appropriate to apply a hydrophobic adhesive that did not contain water. Nevertheless, according to the study of Okuda and others,[34] ED Primer did not negatively influence the bond strength when it was applied on Protect Liner F for luting with Panavia F, and higher bond strength was obtained in the study of Udo and others.[18] The reason for this finding is not clear, but it may be related to the polymerization of Panavia F in the presence of ED Primer.[18] ED Primer contains aromatic sulfinate salts, and it is believed that this

accelerates interfacial polymerization between the dentin sealing surface and resin cement.[34]

The fracture resistance and mode of fracture were also evaluated in this study. Many variables may be found in the literature with respect to the fracture resistance test, such as location of the forces applied, speed of the tests, and shape of the compression devices.[35] In the present study, an 8-mm sphere coupled to a universal testing machine was used as a result of the extensive cavity preparation performed in the teeth. In destructive tests, it is fundamental for the compression sphere to be in contact with the internal slopes of the buccal and lingual cuspids. Under these conditions, a compressive force is applied to the tooth, and the buccal and lingual cuspids are externally displaced, with a resultant stress on the tooth-restoration interface. If the compression sphere is located exclusively on the restoration, stress absorption by the restorative material will occur, with a vertical force crushing the restoration.[35] In the present study, the contacts were verified and the sphere was in contact with the buccal and palatal cuspal inclines.

The sound teeth group presented the highest mean fracture resistance (1902 N), differing statistically from the other groups, and these data concur with those of previously published studies.[36-38] The enamel is supported by the total dentin volume, making it less prone to fracture, which explains the higher mean obtained for the fracture resistance.[39] The fracture resistances in groups 2, 3, and 4 did not differ statistically. Group 2 recovered 58% of the resistance of a sound tooth, group 3 35%, and group 4 41%. These findings are in agreement with those of other studies[36,37,40] that verified that the different restorative techniques did not restore the resistance of a sound tooth. Nevertheless, the use of adhesive restorations has been recommended for reinforcing remaining dental structures,[38,41] even if full strength is not recovered.[36,42]

The results of the present study show that the IDS techniques did not contribute to an increase in fracture resistance of teeth. However, the mean fracture resistances in groups 3 and 4 were very close to or even higher than the values for habitual occlusal forces. Occlusal forces may clinically attain 800 N in bruxers, a value similar to the mean obtained for the test specimens in group 4. There is no consensus in the literature, but the physiological values are even lower, considering that clinically, the forces are distributed over more than one dental element, decreasing the load on an individual tooth even further.[35]

It is also important to analyze the mode of fracture. Not only does the result of the fracture resistance test guarantee that a material is ideal for restoring a weakened tooth but it also shows the mode of failure when a fracture does occur, that is, whether or not the prognosis will be favorable.[21,43] The classification of fractures used in the present study was created in accordance with the fractures observed in the specimens. In the sound teeth group, all fractures were at the CEJ (type I). The predominance of this fracture type might be due to the maximum strength inherent in sound teeth. When a sound tooth is submitted to a compressive load, it presents a higher stress concentration in enamel and dentin around the cervical area, which explains the fractures in this region.[39] Fractures also occurred below the CEJ (types II and IV) in the experimental groups. This may be explained by the loss of tooth volume, both in terms of depth and thickness, leading to an increase in stress in the region below the CEJ.[39,44] In general, there was a predominance of type I and type II fractures for the experimental groups. These fractures occurred between the tooth substance and the inlay, indicating that this interface represents the weakest part of the restored tooth. However, type III and type IV fractures were also observed in the experimental groups. These fractures occurred in the composite resin inlay first, preserving the tooth/inlay interface and leaving part of the restoration attached to the cusp, showing the bond capacity of the resin materials to the tooth structure. Nevertheless, most of the fractures that occurred in the experimental groups still allowed the salvage of the tooth. Dalpino and others[45] and Silva and others[46] also verified a prevalence of recoverable fractures when the teeth were restored with resin materials.

Transfer of the results of laboratory studies to the clinic must be done with caution because *in vitro* studies cannot reproduce the real situation in the oral cavity. According to the results obtained, IDS techniques with Clearfil SE Bond produced less cuspal deflection in composite resin inlay restorations when the adhesive luting technique with Panavia F was used. It would be interesting to analyze, *in vitro,* the cuspal deflection behavior after aging by means of mechanical fatigue and/or thermal cycling.

CONCLUSIONS

Despite the limitations of this *in vitro* study, the following conclusions can be drawn:

- The IDS technique with the Clearfil SE Bond

adhesive system allowed cuspal deflection comparable to that of a sound tooth.
- Application of the low-viscosity composite resin Protect Liner F on the Clearfil SE Bond adhesive system did not contribute to a decrease in cuspal deflection.
- The IDS techniques did not influence the fracture resistance of teeth.
- Most of the fractures that occurred in the experimental groups allowed recovery of the dental structure.

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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In Vitro Effect of Air-abrasion Operating Parameters on Dynamic Cutting Characteristics of Alumina and Bio-active Glass Powders

H Milly • RS Austin • I Thompson
A Banerjee

Clinical Relevance

Bio-active glass (BAG) powder exhibits more air-abrasion conservative cutting characteristics compared to alumina powder, particularly within specific operating parameters. Clinical air-abrasion use should be preceded by studying the powder flow rate to identify the factors affecting the abrasive powder propulsion.

SUMMARY

Minimally invasive dentistry advocates the maintenance of all repairable tooth structures during operative caries management in combination with remineralization strategies. This study evaluated the effect of air-abrasion operating parameters on its cutting efficiency/pattern using bio-active glass (BAG) powder and alumina powder as a control in order to develop its use as a minimally invasive operative technique. The cutting efficiency/pattern assessment on an enamel analogue, Macor, was preceded by studying the powder flow rate (PFR) of two different commercial intraoral air-abrasion units with differing powder-air admix systems. The parameters tested included air pressure, powder flow rate, nozzle-substrate distance, nozzle angle, shrouding the air stream with a curtain of water, and the chemistry of abrasive powder. The abraded troughs were scanned and analyzed using confocal white light profilometry and MountainsMap surface analysis software. Data were analyzed statistically using one-way and repeated-measures analysis of variance tests (p=0.05). The air-abrasion unit using a vibration mechanism to admix the abrasive powder

*Hussam Milly, BDS, DipOS, MSc, Biomaterials, Biomimetics & Biophotonics Research Group, King's College London Dental Institute at Guy's Hospital, King's Health Partners, London, United Kingdom

Rupert S Austin, BDS, PhD, Unit of Prosthodontics, King's College London Dental Institute at Guy's Hospital, King's Health Partners, London, United Kingdom

Ian Thompson, B.Eng, PhD, Biomaterials, Biomimetics & Biophotonics Research Group, King's College London Dental Institute at Guy's Hospital, King's Health Partners, London, United Kingdom

Avijit Banerjee, BDS, MSc, PhD, FDS (Rest Dent) FDS RCS (Eng) FHEA, Unit of Conservative Dentistry , Biomaterials, Biomimetics & Biophotonics Research Group, King's College London Dental Institute at Guy's Hospital, King's Health Partners, London, United Kingdom

*Corresponding author: SE1 9RT, United Kingdom; e-mail: milly.hussam@kcl.ac.uk

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with the air stream exhibited a constant PFR regardless of the set air pressure. Significant differences in cutting efficiency were observed according to the tested parameters ($p<0.05$). Alumina powder removed significantly more material than did BAG powder. Using low air pressure and suitable consideration of the effect of air-abrasion parameters on cutting efficiency/patterns can improve the ultraconservative cutting characteristics of BAG air-abrasion, thereby allowing an introduction of this technology for the controlled cleaning/removal of enamel, where it is indicated clinically.

INTRODUCTION

Minimally invasive dentistry (MID) encourages the preparation of the smallest cavity possible, maintaining the presence of as much repairable tissue as possible, and relying on adhesion techniques to achieve the retention and seal of the overlying restorative materials.[1-4] Air-abrasion cuts tooth tissue through the use of kinetics to blast away surface hard tissues.[5] The variables controlling air-abrasion cutting efficiency (and, therefore, its potential intrinsic ability to remove tissues selectively) can be divided into three main categories: 1) the built-in physics and mechanics of the equipment, which includes the powder-air admix mechanism, powder flow rate (PFR), powder volume reservoir, nozzle output pressure, and water shrouding the powder stream; 2) the parameters controlled by the operator, including the nozzle angle, nozzle-substrate distance, nozzle movement speed, and the targeted substrate itself; and 3) the variations found in the abrasive powder used, including the size, shape, hardness, and chemistry of the particles and their interaction with the substrate.[6-14]

There are a large number of available commercial air-abrasion units, and each can be used at various settings with different powder admix mechanisms. Therefore, in order to improve the comparability of air-abrasion studies and their clinical use, it is important to study the PFR. In addition, water shrouding the powder stream has been introduced in some units to reduce atmospheric powder scattering. The consequence of this modification on air-abrasion cutting efficiency has not been studied previously.

Using alumina powder as an abrasive can lead to undesirable clinical over-preparation of dental hard tissues.[6,13,15,16] Therefore, with the purpose of promoting air-abrasion cutting tissues selectively to meet the MID paradigm, bio-active glass (BAG) powder has been introduced with the hope that practitioners can benefit from its properties, including its antibacterial effects, remineralization potential, and its potential to remove selectively more softened diseased or damaged tooth structures.[17-21]

In order to use air-abrasion appropriately, this study assessed the effect of certain parameters on BAG air-abrasion cutting efficiency/pattern using an enamel analogue, Macor, in simulated clinical conditions, compared to conventional 27-μm alumina air-abrasion (the positive control). The abrasion assessment was preceded by a PFR study of two different intraoral air-abrasion units using different powder-air admix mechanisms.

The three null hypotheses investigated in this study were

1. There is no effect of air pressure on powder flow rate in either Aquacut or Air-Flow Master air-abrasion units.
2. Operating parameters have no effect on the cutting efficiency/pattern on an artificial enamel analogue.
3. There are no differences in the cutting efficiency between alumina and BAG powders when used under standardized clinical conditions.

MATERIALS AND METHODS

Characterization of the abrasive powders' surface topography and elemental composition were determined using scanning electron microscopy-energy dispersive x-ray spectroscopy (SEM-EDX, accelerating voltage of 25 kV, working distance of 13 mm). Particle size analysis was carried out using a laser diffraction particle analyzer (Cilas, Orleans, France), and the results were analyzed with the Particle Size Expert software package (Cilas).

The nozzle output air pressure of the air-abrasion unit was measured using a digital pressure indicator (DPI 705, Druck, UK) attached to the output nozzle. The nozzle diameter was validated using a digital measurement device (Quadra-Check 300). Periodic calibration of output pressure and the nozzle diameter was conducted throughout the experiments to ensure consistency and standardization under all experimental conditions.

PFR Evaluation

Comparing the weight of a collecting container, including a layer of sponge and a paper filter, before and after one minute of active air-abrasion permitted the study of PFR.[22] The powder reservoir was

consistently refilled with the abrasive powder to a predetermined line, and the powder was manually stirred prior to use throughout.

In order to investigate the effect of air pressure on PFR on both Aquacut (Velopex, Harlesden, UK) and Air-Flow Master (EMS, Nyon, Switzerland) air-abrasion units, the powder feed dial was fixed at the middle setting and the air pressure was adjusted into 40, 60, and 80 psi. Ten measurements were conducted within each experimental group using BAG powder.

The same method was used to calculate the PFR (g/min) for each of the powder feed dial settings—1, 3, and 5—used as a variable during cutting efficiency/pattern assessment using the Aquacut unit (nozzle output internal diameter 600 μm). This experiment was conducted by fixing the air pressure at a constant 60 psi.

Cutting Efficiency/Pattern Assessment

The dynamic abrasion procedure was performed within a plastic chamber attached to high vacuum suction using a micropositioning device to fix the nozzle and a stage to move the substrate. A Macor sheet (50×50×5 mm) was located on the stage attached to a moving coil actuator (SMAC, Crowley, UK), programmed to obtain 10-mm linear movement at a velocity of 0.5 mm/s.

The variables assessed in this study were air pressure (20, 40, and 60 psi), powder feed dial value (1, 3, and 5), nozzle angle (45° and 90°), nozzle distance (1, 2, and 5 mm), and the cutting mode (dry and wet) for both alumina and BAG powders. When each variable was investigated, the remaining parameters were fixed as follows: air pressure, 60 psi; powder feed dial, 3; nozzle angle, 90°; nozzle distance, 2 mm. Ten troughs were made in each experimental group.

Evaluation of the effect of different parameters was conducted using dry air-abrasion mode. However, to evaluate the influence of shrouding the air-powder stream with a water curtain on the cutting efficiency, a disposable plastic tip, used to mix the air stream with water, was attached to the tip of the nozzle.

Using proprietary measurement control software (STAGES, TaiCaan Technologies Ltd, Southampton, UK), a standard scan area of 5 × 2 mm was chosen over the central region of each trough. Optical white light confocal profilometry (Xyris 4000 WL, TaiCaan Technologies) was used to image the surface topography of the resulting 200 troughs. The white light sensor had a 0.01-μm resolution, a spot size of 7 μm, and a gauge range of 350 μm. The scan was performed with a 10-μm step-over distance in medium precision measurement mode.

The resulting three-dimensional (3D) topographic data sets were analyzed using MountainsMap surface analysis software (Version 6.2.6332, SARL Digital Surf, Besançon, France) to obtain the volume of the troughs (mm^3). A macro was written to read and analyze the 3D data automatically using the "measure volume of a hole" function. Air-abrasion cutting efficiency was established by comparing the volume removed with the assumption that the settings were more efficient when air-abrasion removed a greater volume of Macor. Representative 3D selected images from BAG powder groups were examined to characterize the cutting pattern.

The statistical analysis was conducted using the SPSS Statistical Package (version 19.0, SPSS Inc/IBM, Chicago, IL, USA). One-way analysis of variance (ANOVA) and Bonferroni *post hoc* testing was performed to analyze the PFR data, and repeated-measures ANOVA followed by Bonferroni *post hoc* test was used for the analysis of the cutting efficiency assessment data. The level of statistical significance was established at $p=0.05$ for both tests.

RESULTS

The alumina powder had an angular shape, while BAG powder had an aspect ratio of 1:1, with some angular edges seen on the particle surface (Figure 1). The compositions of alumina and BAG powder are shown in Figure 2. The particle size distribution percentiles (10%, 50%, and 90%) of the alumina powder were 23, 37, and 51 μm, respectively, while those of BAG powder were 23, 56, and 82 μm, respectively.

PFR Evaluation

PFR mean values (±standard deviations) regarding the effect of air pressure on PFR are shown in Figure 3. Air pressure had no effect on the PFR in the Aquacut unit, which showed constant PFR for all air pressure values. In contrast, increasing the air pressure in the Air-Flow Master® unit from 40 and 60 psi to 80 psi increased the PFR in a statistically significant manner ($p<0.001$, $p=0.01$, respectively).

PFR ranges for the Aquacut unit settings involved in this study for both powders are shown in Figure 4. The PFR increased significantly when the powder feed dial was adjusted from the minimum to the

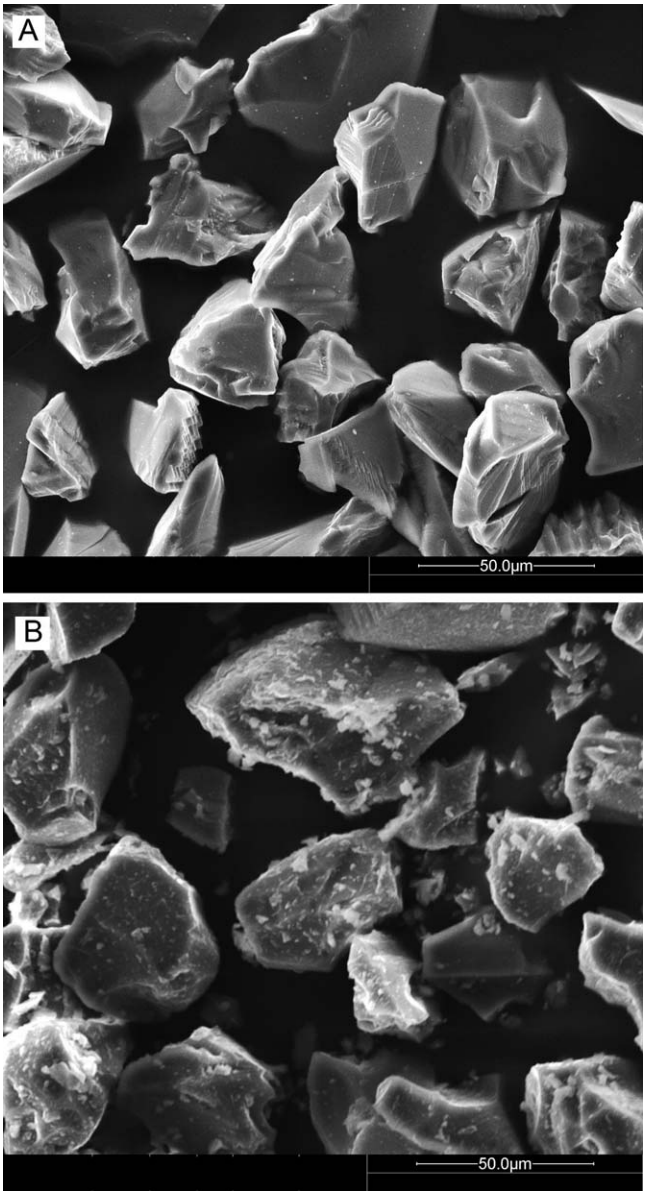

Figure 1. *(A) SEM of alumina particles; (B) SEM of BAG particles (accelerating voltage: 25 kV; working distance: 13 mm; magnification: 1500). Alumina powder exhibits an angular shape, while BAG powder has an aspect ratio of 1:1, with some angular edges seen on the particles.*

maximum value within the BAG powder groups ($p<0.001$).

Cutting Efficiency/Pattern Assessment

An increase in air pressure resulted in an increase in Macor volume removal in both powder groups. With alumina, the increase was not different statistically between the 40 and 60 psi values, while it was significant within BAG groups, which showed statistical differences among all the air pressures tested

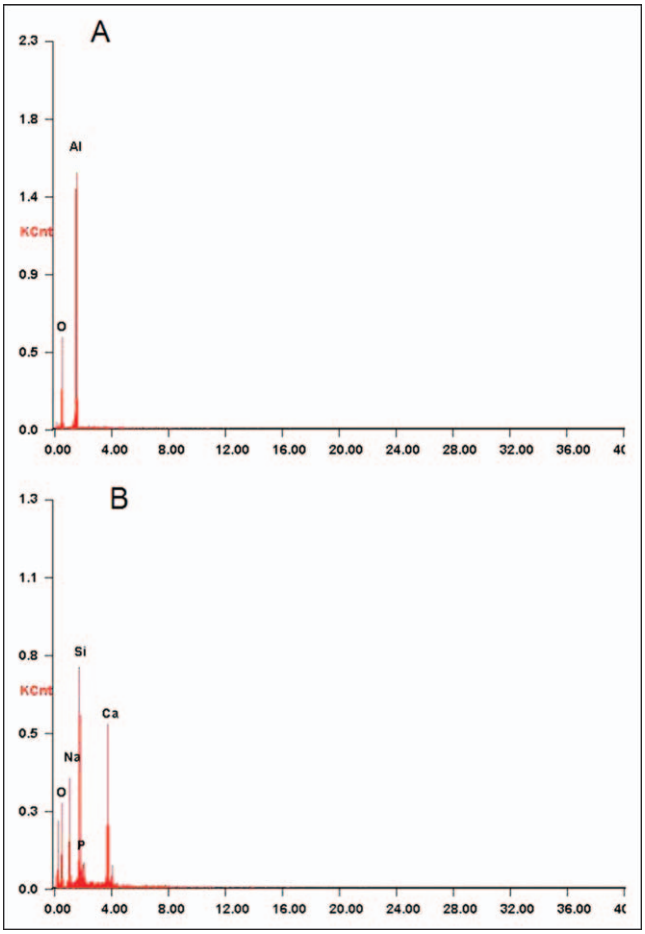

Figure 2. *(A) EDX revealed aluminium and oxygen peaks in alumina powder; (B) EDX revealed silicon, calcium, phosphorus, sodium, and oxygen peaks in BAG powder (accelerating voltage: 25 kV; working distance: 13 mm).*

($p<0.001$). The volume of material removed when the air pressure was fixed at 20 psi was 0.75 ± 0.16 mm^3 (mean ± standard deviation) in the alumina group, whereas 60%, statistically less, was removed in the BAG group (0.3 ± 0.02 mm^3; $p=0.01$). However, the difference in the Macor volume removed between the two powders was not statistically significant and declined to 30% (1.39 ± 0.33 mm^3) in the alumina group and 0.97 ± 0.04 mm^3 in the BAG group when the overall air pressure was increased to 60 psi.

Adjusting the powder feed dial to the highest value increased the volume of Macor removed ($p<0.001$, $p=0.005$ in alumina and BAG groups, respectively) (Figure 5). In addition, increasing the nozzle-substrate distance from 1 to 5 mm improved air-abrasion cutting efficiency ($p<0.001$) (Figure 6). Setting the PFR to the lowest value caused more pronounced fluctuation in the base of the trough

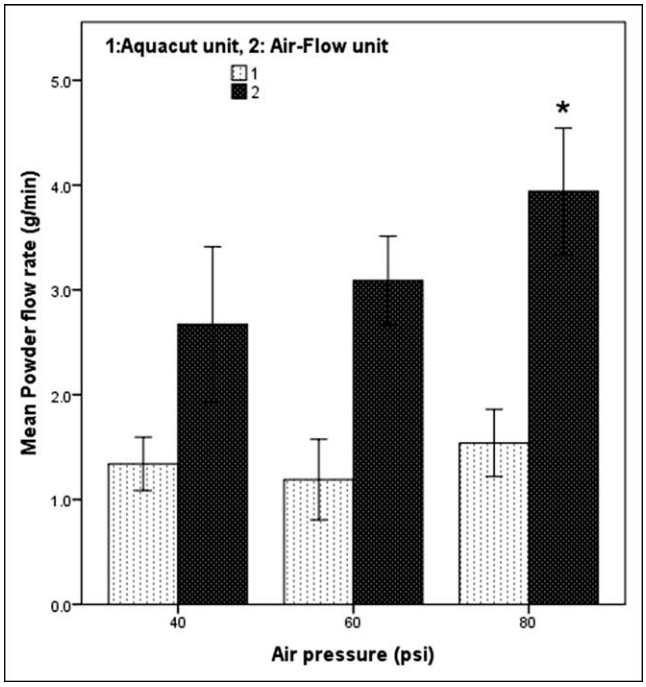

Figure 3. *PFR mean value ± standard deviation (SD) (g/min) correlated with variable air pressures (powder feed rate dial setting fixed at middle values). *Indicates statistically significant differences between air pressure at 40/60 psi and 80 psi in Air-Flow Master unit (p<0.05).*

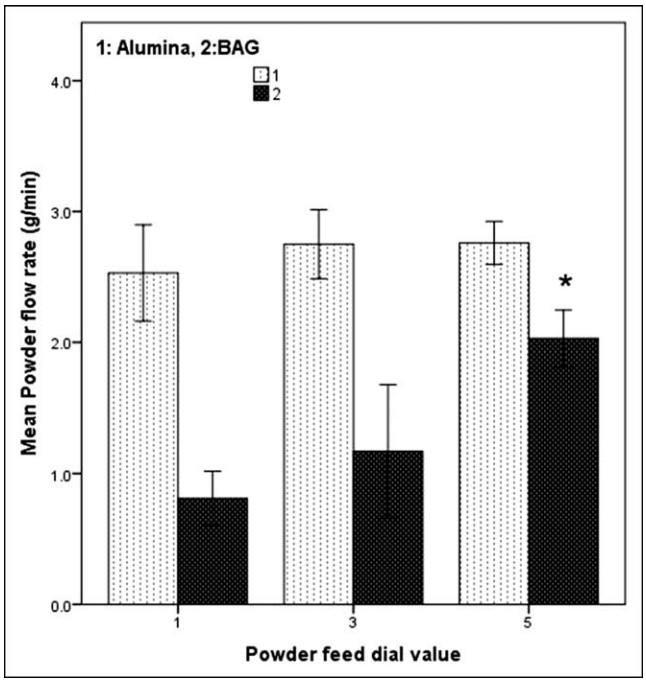

Figure 4. *PFR mean value ± standard deviation (SD) (g/min) for alumina and BAG powders correlated with variable powder feed rate settings (air pressure fixed at 60 psi). *Indicates statistically significant differences between powder feed rate dials 1 and 5 within BAG powder group (p<0.05).*

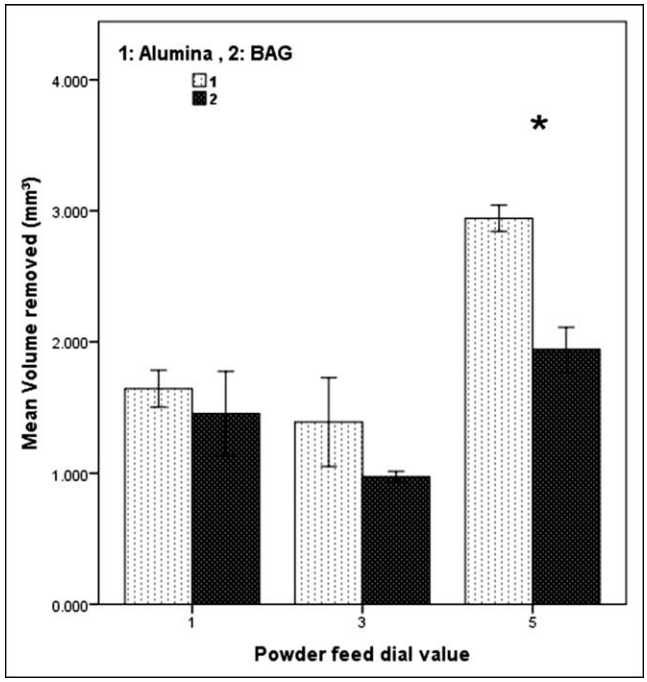

Figure 5. *Macor volume removed mean ± standard deviation (SD) for alumina and BAG groups correlated with variable powder feed rate dial settings. *Indicates statistically significant differences between powder feed rate dials 1/3 and 5 in both powder groups (p<0.05).*

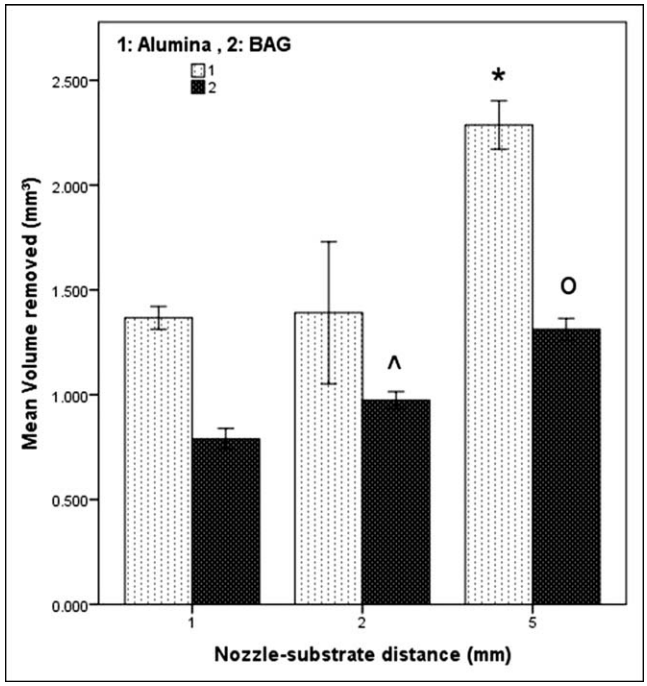

Figure 6. *Macor volume removed mean ± standard deviation (SD) for alumina and BAG groups correlated with variable nozzle-substrate distance. *Statistically significant differences between distances of 1/2 and 5 mm in alumina groups; ^Statistically significant differences between distances of 1 and 2 mm in BAG groups; °Statistically significant differences between distances of 1/2 and 5 mm in BAG groups (p<0.05).*

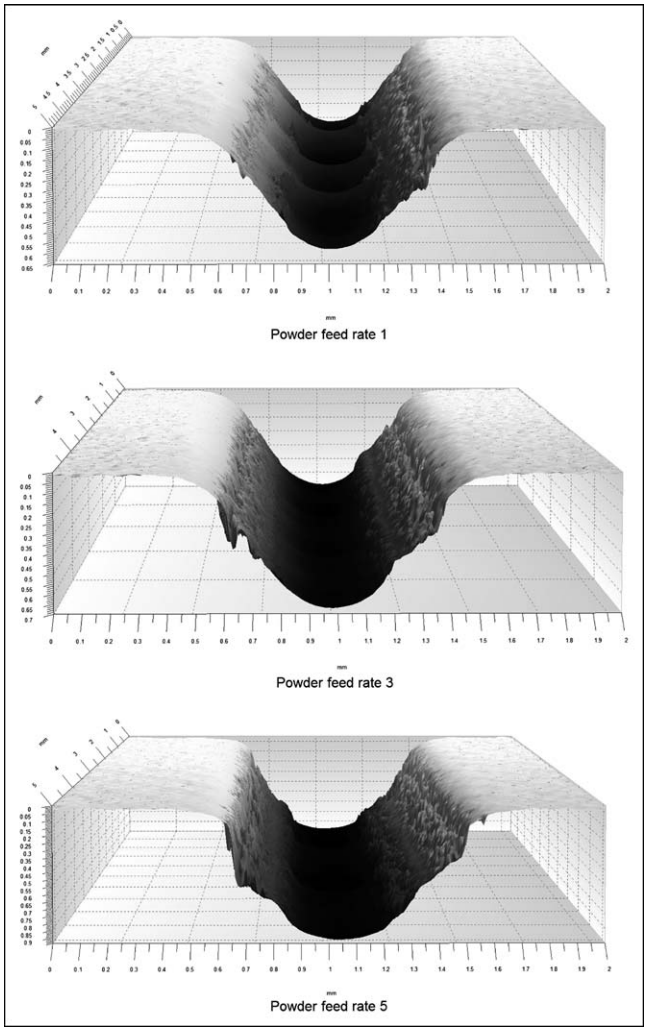

Figure 7. *3D scans of selected, representative BAG air-abrasion troughs. (A) The fluctuation in the base of the trough when powder feed dial was set at 1. (B and C) Troughs prepared using powder feed dial 3 and 5, respectively.*

along its length (Figure 7). The nozzle distance of 5 mm produced more rounded trough margins compared to those produced with shorter distances (Figure 8).

Statistically significantly more Macor was removed when the air-abrasion nozzle was fixed at 45° (2.52 ± 0.14 mm^3 and 1.76 ± 0.08 mm^3 within alumina and BAG, respectively) rather than 90° (1.39 ± 0.33 mm^3 and 0.97 ± 0.04 mm^3 within alumina and BAG, respectively) ($p<0.001$). The shape of the troughs varied according to the nozzle angle: 45° produced a trough with a "V" cross-section, while 90° presented troughs with a "U"-shaped cross section (Figure 9).

There was no significant difference in the cutting efficiency between dry and wet air-abrasion systems

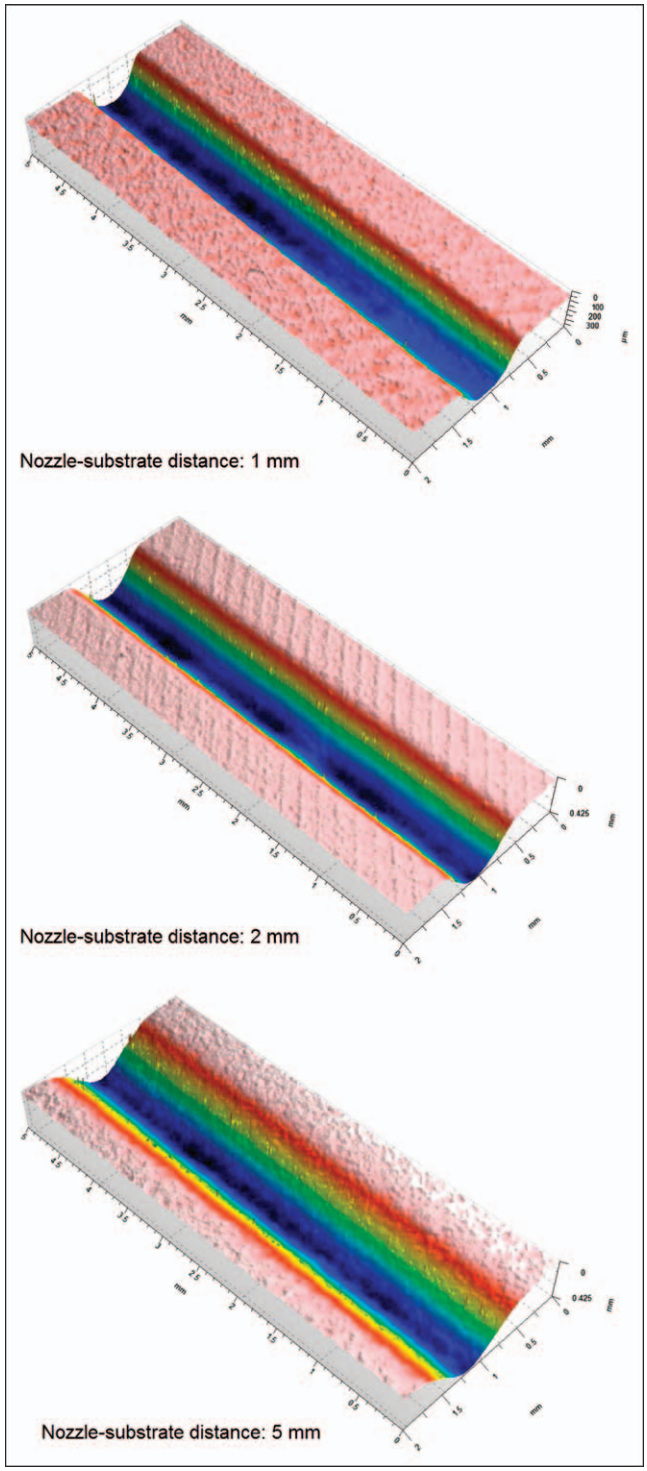

Figure 8. *Trough margin variation according to the nozzle-substrate distance within BAG powder group. Nozzle-substrate distance of 5 mm (C) results in a rounded, less well-defined trough margin compared to nozzle-substrate distances of 1 mm (A) and 2 mm (B).*

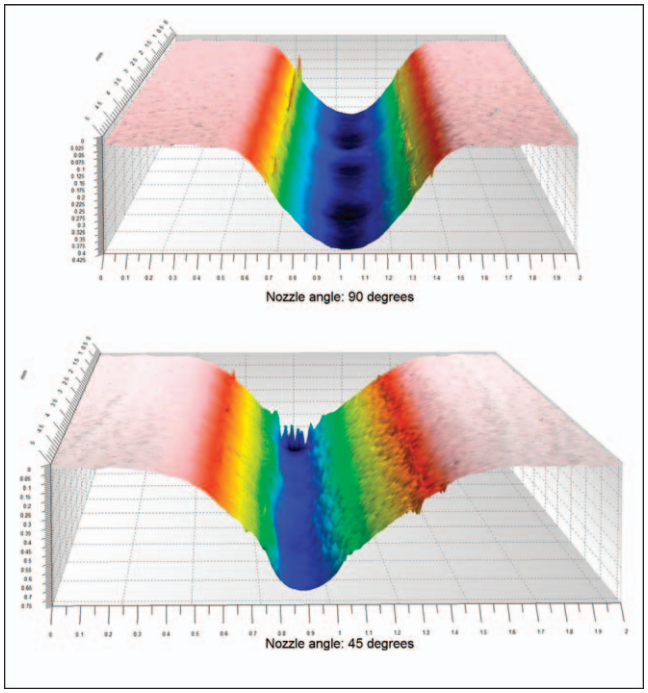

Figure 9. *Representative scans revealed the cross-sectional trough shape difference between the 90° nozzle angle (trough with "U" cross section) (A) and 45° nozzle angle (trough with "V" cross section) (B) within BAG powder groups.*

for both powders. In alumina groups, dry air-abrasion removed 3.36 ± 0.17 mm^3 and wet air-abrasion removed 3.49 ± 0.48 mm^3. The Macor volume removed in the BAG groups was 1.84 ± 0.34 mm^3 and 1.93 ± 0.61 mm^3 using dry and wet abrasion, respectively.

DISCUSSION

The two air-abrasion units employed in this study use different mechanisms to admix the abrasive powder with the air propellant stream. The Aquacut unit uses a vibration mechanism to admix the abrasive particles with the air stream, and this explains why a constant PFR was recorded regardless of the air pressure values. However, in the Airflow unit, in which an air vortex is created inside the powder chamber, air pressure not only modifies the particles velocity but it also alters the amount of expelled powder from the nozzle. PFR measurement (g/min) for the powder feed dial values during air-abrasion studies makes the results obtained using a specific air-abrasion unit comparable and reproducible using different air-abrasion units when the PFR is equilibrated to the same ranges. BAG powder exhibits different bulk density, atmospheric moisture uptake, and particle size/shape when compared to alumina, which in turn explains the variation in their flowability. Therefore, it is advised that BAG powder should be manually stirred in the reservoir prior to the abrasion procedure to help prevent the separation of the different particle sizes, which will affect the flow rate and, therefore, cutting efficiency.

Macor was used as the control substrate, as it has been used for assessing the cutting rate and efficiency of operative technologies in dentistry as a result of its consistent, uniform hardness, which is not found in human enamel, as the enamel hardness varies from person to person according to the individual's food consumption and is depth-dependent within the same tooth as a result of histological heterogeneity.[23,24] Using Macor sheets also provided a reliable, flat surface as a target for air-abrasion cutting and subsequent objective analysis using optical surface profilometry, which was used in the present study to determine the volume of material removed, as it is considered an accurate method by which to measure hard tissue loss.[25,26]

Assessing the dynamic cutting efficiency has the advantage over static cutting, as it mimics more realistically the clinical situation, in which the procedure is accomplished by moving the nozzle over the target substrate.

The findings of this study indicate that there is an increase in the air-abrasion cutting rate for both powders when air pressure increases. Since the increase in air pressure does not increase the PFR in the Aquacut unit, as proved in the PFR evaluation study, this finding may be explained based on the dependency upon the increased kinetic energy of the particles, a finding consistent with those of previous studies.[7,27] It is important to be aware that when low air pressure was applied, the difference in air-abrasion cutting efficiency between the two powders more than doubled, implying that at low air pressure settings, the cutting efficiency of air-abrasion depends mainly on the nature of the abrasive powder rather than on the physics of air-abrasion unit itself.

The finding concerning the effect of PFR on the cutting efficiency is inconsistent with the findings of a previous study,[14] which claimed that an increase in PFR without a concomitant increase in the air pressure is pointless. In the present study, employing both a dynamic cutting protocol and high vacuum suction reduced the surface choking of particles when excessive quantities of abrasive were applied. The undulating troughs resulting from using less powder may be caused by the irregular distribution of particles within the air stream. Most

of the particles are concentrated into a small portion of the stream's cross-sectional area.[28]

Previous studies[9,29] indicated an inverse relationship between the distance and the cutting efficiency. In those studies, the researchers used the cross-sectional views of the cut surfaces to assess the cutting efficiency, whereas in this experiment the whole volume removed was calculated using the 3D measurement methodology.

When the nozzle was fixed at 45°, the percentage of the air stream's peripheral portion, which presents a reduced concentration of particles with reduced velocity,[10] increased, and that in turn produced cross-sectional "V"-shaped troughs.

The air-abrasion operating parameters controlling the nozzle position affected significantly the cutting efficiency observed in both powder groups. This can be explained by the fact that increasing the distance and fixing the nozzle at 45° reduced the surface choking of particles, which is assumed to disturb negatively the propellant stream.

One of the objectives in this study was to determine the difference in cutting efficiency between alumina and BAG powders. It was noticeable that alumina powder removed considerably more material than did BAG powder. In addition, the cutting efficiency was more controllable within BAG powder groups since only slight differences in operating parameters altered the cutting efficiency, while alumina powder groups demanded considerable alterations in the parameters to exhibit statistical differences in the cutting rate. The abrasive powders consisted of different shapes, particle size distributions, and hardnesses,[13,30] which may explain the variations observed in this study of cutting efficiency and sensitivity to the operating parameters.

CONCLUSIONS

The three null hypotheses investigated were rejected. Using air-abrasion should be preceded by system calibration to identify the factors affecting the abrasive powder propulsion, as they differ according to the unit's design. Vibration admix units exhibited a constant powder flow rate regardless of air pressure. However, it is advocated that practitioners check the BAG powder condition within the powder chamber before the abrasion procedures to obtain a sufficient powder flow rate. Manufacturers need to take note and provide this information clearly to clinicians. Air-abrasion cutting efficiency is more conservative and controllable when BAG powder is used as an abrasive powder, encouraging its role in minimally invasive operative dentistry.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Influence of Radiopacity of Dental Composites on the Diagnosis of Secondary Caries: The Correlation Between Objective and Subjective Analyses

AD Cruz • RG Esteves • IAVP Poiate
PP Portero • SM Almeida

Clinical Relevance

Distinguishing among images of restorative materials, carious lesions, and sound dental tissue is challenging when making a radiographic diagnosis. Therefore, assessing the adaptation and integrity of restorations depends on the radiopacity of the restorative material. If the material is too radiopaque, it may be difficult to distinguish from dental tissues. If poorly radiopaque, it can camouflage possible failures.

*Adriana Dibo Cruz, DDS, PhD, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Radiology, Nova Friburgo, Rio de Janeiro, Brazil

Renata Gama Esteves, DDS student, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Nova Friburgo, Brazil

Isis Andréa Venturini Pola Poiate, DDS, PhD, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Clinic, Nova Friburgo, Rio de Janeiro, Brazil.

Priscila Paiva Portero, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Clinic, Nova Friburgo, Rio de Janeiro, Brazil.

Solange Maria Almeida, DDS, MS, PhD, Dentistry School of Piracicaba, State University of Campinas, Department of Oral Diagnostic, Piracicaba, Brazil

*Corresponding author: 22, Dr Silvio Henrique Braune Street, Nova Friburgo, Rio de Janeiro 28625-650, Brazil; e-mail: adrianadibo@id.uff.br

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SUMMARY

This study aimed to objectively evaluate the radiopacity of different dental composites and their subjective influence on diagnosing secondary caries–like lesions and how these results correlate. For objective analysis, three resin specimens (1 mm thick, with a 4-mm internal diameter) were made with four composites: 1) Charisma; 2) Filtek Z250; 3) Prisma AP.H; and 4) Glacier. Three human teeth were selected and then mesio-distally sectioned (1 mm thick) to make the dental specimens. An aluminum (Al) wedge (12 steps, 1 mm thick, 99.8% purity) was used as an internal standard to calculate the radiopacity. For subjective analysis, 20 human teeth were selected and then prepared with a mesio-occluso-distal (MOD) inlay cavity, with half the teeth receiving a round cavity to simulate the carious lesion. The MOD was restored using the com-

posites at four different times. Standardized radiographs were acquired and then digitized (300 dpi and eight-bit TIFF) for both analyses. A histogram objectively measured the pixel intensity values of the images, which were converted into millimeters of Al using linear regressions. Eight observers subjectively evaluated the images using a five-point rating scale to diagnose the caries. The data were statistically analyzed using the Student *t*-test, the Kappa test, diagnostic testing, and the Pearson correlation coefficient (α=0.05). All materials showed radiopacity values compatible with dental tissues ($p>0.05$); Glacier was similar to dentin and Prisma AP.H was similar to enamel, while the remaining materials showed a middle radiopacity. Prisma AP.H and Glacier differed ($p<0.05$) in relation to their accuracy to caries diagnosis, with Glacier having greater accuracy. There was a correlation between objective and subjective analyses with negative linear dependence. An increase in the material's radiopacity could have a subjectively negative influence on the diagnosis of secondary caries; thus, an ideal radiopacity for a dental composite is closer to the dentin image and produces similar attenuation to X-rays than does dentin.

INTRODUCTION

Dental composites have been routinely used as the dental restorative material of choice to fulfill the growing concern over esthetics. However, despite improvements in these composites, some disadvantages still need to be overcome, including secondary caries, detecting marginal overhangs, or contouring and adaptation failures.[1-3] Secondary caries is a common cause of restoration loss. An accurate diagnosis of this condition is key to determining the use of these restorations.

The radiographic exam remains the primary method of diagnosing secondary caries in posterior teeth. However, optical factors may influence this diagnosis, such as factors derived from different radiopacities, including those from restorative material, carious lesions, and dental tissues.[4] For better diagnosis, a restoration needs to have a radiopacity similar to that of dental tissues.[3] Therefore, it has been recommended[3,5,6] that the restorative material be more radiopaque than dentin and, preferably, have a radiopacity closer to that of enamel. However, an increase in the restorative material's radiopacity can reduce secondary caries detection and increase the incidence of false-positive results.[7]

There are technical groups that have developed guidelines[8,9] on how to define a level of radiopacity of the material for clinical use, generally in relation to a reference image, such as enamel, dentin, or aluminum (Al). Thus, it is recommended that the radiopacity of composite materials needs to be equal to or greater than that of the same thickness of Al, with 98% purity (less than 0.1% copper and less than 1% iron) and no less than 0.5 mm below any value. However, the primary challenge is establishing the quantity of radiopacity that the material should have for the ideal diagnosis.

For that reason, considering radiopacity as a property of great importance for making a radiographic diagnosis, the aim of this study was to objectively evaluate the radiopacity of different dental composites and their subjective influence on the diagnosis of secondary caries–like lesions and to make a correlation between both results.

MATERIALS AND METHODS

After receiving approval to conduct this research from the Research Ethics Committee, 23 human, noncarious permanent teeth, 12 premolars and 11 molars, were selected as test teeth. Three teeth (two premolars and one molar) were randomly selected for use in the objective analysis of radiopacity, whereas the 20 remaining teeth were used in the analysis of the subjective influence of radiopacity. To confirm the absence of caries, the teeth were clinically examined, and their proximal faces could not have any apparent lesions. Another five nontest teeth were included in the sample to serve as the contact point to simulate the anatomical condition during the analysis of the subjective influence of radiopacity. All of the teeth were cleaned by removing debris and were stored in distilled water at 4°C for no more than six months postextraction.

Objective Analysis of Radiopacity

The materials evaluated in this study (listed in Table 1) consisted of four different resin composites, as follows: 1) Charisma; 2) Filtek Z250; 3) Prisma AP.H; and 4) Glacier. Three resin specimens of each material were produced according to the manufacturers' instructions. These dental composites were inserted into 1-mm-thick stainless-steel ring molds with an internal 4-mm-diameter hole. In order to achieve uniformly smooth surfaces, the molds were placed between two glass slides covered with Mylar strips and were then

Table 1: *List of Materials Tested in this Study*

Composite Resins	Manufacturer	Shade	Filler by Volume, %	Lot No.
Charisma®	Heraeus Kulzer GmbH, Hanau, Germany	A3	61	010325 2013-02
Filtek™ Z250	3M ESPE, Saint Paul, MN, USA	A3	60	9YH 2012-03
Prisma AP.H™	Dentsply International Inc, Petrópolis, RJ, Brazil	A3	57	L257026C V02/13
Glacier®	SDI Limited Bayswater, Melbourne, Vic., Australia	A3	62	080790 2013-07

submitted to one minute of 1 kg/cm^2 pressure to remove the excess material. The resin specimens were light-cured using the Elipar S10 LED Curing Light (3M/ESPE, St Paul, MN, USA), according to the manufacturer's instructions. They were then stored at 37°C (±1°C) and 95% (±5%) relative humidity until radiographic examination.

Dental crowns of three test teeth were mesio-distally sectioned 1 mm thick using a diamond saw at low speed (KG Sorensen 7020 flexible diamond disc, KG Sorensen, Barueri, SP, Brazil) in an IsoMet Low Speed Saw machine (Buehler Ltd, Lake Bluff, IL, USA) and water-cooling. The dental specimens with dentin and enamel were stored at 37°C (±1°C) and 95% (±5%) relative humidity.

An Al wedge (99.8% purity) with 12 steps, each 1 mm thick, was used as an internal standard to calculate the radiopacity of the resin and dental specimens in terms of their Al equivalent thicknesses (mmAl).

Standardized sets of radiographs (radiographic film, Al wedge, resin and dental specimens) were acquired in an X-ray machine (Heliodent 60B, Siemens, Erlangen, Germany) operating at 60 kVp (10 mA, 0.20 seconds, 40-cm target-to-receptor distance), with total filtration at 2 mm of Al. As the image receptor, E-speed radiography films (Ektaspeed Plus; Carestream Health Inc, Kodak Dental System, Rochester, NY, USA), which were processed automatically (GXP; Dentsply International/Gendex; Dentsply International Inc, York, PA, USA), were used. Each set was radiographed three times, producing nine radiographs.

Conventional radiographs were digitized by means of a laser scanner (HP Scanjet G4050; Hewlett Packard Corporation, Palo Alto, CA, USA) at 300 dpi and stored as eight-bit TIFF images. Each digital image was measured using the histogram function of the ImageJ 1.43u software (Wayne Rasband, National Institutes of Health, Bethesda, MD, USA). A trained evaluator collected three areas with the same size in regions of interest (ROIs) on the center of each resin and dental specimen and on each step of the wedge. The image was enlarged in order to accurately delimit ROIs. Data relating to pixel intensity values were tabulated and converted to mmAl using a function of linear regressions.

Analysis of the Subjective Influence of Radiopacity

In all 20 test teeth, a mesio-occluso-distal (MOD) inlay cavity was prepared[2] with a No. 1094 cylindrical diamond bur in a water-cooled, high-speed air turbine handpiece coupled in standardized equipment (Figure 1). For premolars, the MOD inlay preparations had a depth of 1.5 mm in the occlusal box and 3 mm in the proximal boxes, and in molars, the depth was 2 mm in the occlusal box and 4 mm in the proximal boxes. The MOD width was the same as the bur width (3 mm). The teeth were randomly divided into two groups: the experimental group (n=10, with five molars and five premolars), which received a round cavity in the floor of the proximal box (medial or distal) to simulate the carious lesion, and the control group (n=10, with five molars and five premolars), which did not receive a simulated lesion. The round cavities that simulated secondary carious lesions were made with a No. 1 round bur at a depth approximately equal to one-half of the bur. These cavities were filled with No. 7 wax to provide a nonradiographic image.

The MOD cavities were sequentially filled with four resin composites at four different times. The same protocol was followed for all teeth: restoration with one of the four resin composites, radiographic examination, removal of the restoration with a No. 1094 diamond bur at high speed, and restoration with another resin until all four materials were used in each tooth. To standardize the process, the cavity preparation or removal of the restoration needed to be done in a day, while the restoration and radiographic examination needed to be done on the following day. The teeth were stored at 37°C (±1°C) and 95% (±5%) relative humidity during all experimental procedures.

Using an imaging phantom and bitewing projection geometry, six teeth were mounted for each radiographic exposition—five nontest teeth and one test

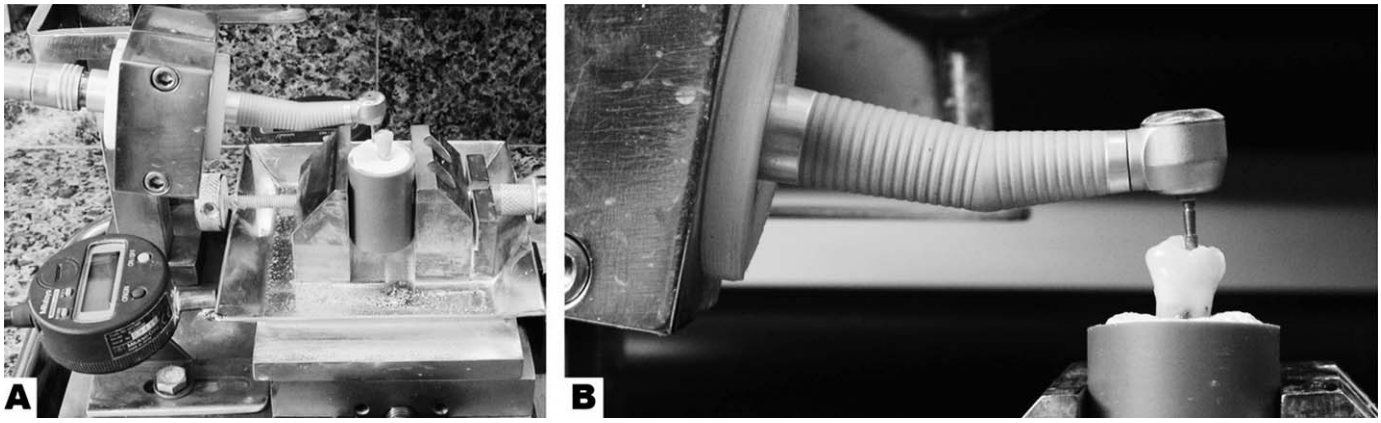

Figure 1. *Equipment for standardization of the mesio-occluso-distal (MOD) inlay cavity. (A) Wide view; (B) Detail.*

tooth. A restored test tooth was mounted in contact with two nontest teeth in a phantom, simulating the upper dental arch; the remaining three nontest teeth were mounted to simulate the lower dental arch. All radiographic images of this phantom were obtained, changing only the restored test tooth.

Standardized bitewing radiographs from the phantom were acquired using the same X-ray machine, Heliodent 60B (Siemens), following the same procedure as previously mentioned. A 12-mm-thick soft tissue–equivalent material was placed between the tube extension and the phantom to simulate radiation scatter. The conditions for processing and digitizing the conventional radiographs followed all previously mentioned procedures.

Digital images from digitized radiographs were randomly ordered in four PowerPoint presentations, each containing 20 images. Eight observers (all undergraduate dental students one semester prior to receiving their academic degree) independently recorded the images using a five-point rating scale, as follows: 1) secondary caries–like lesion definitely absent; 2) secondary caries–like lesion probably absent; 3) unsure if a secondary caries–like lesion is present or absent; 4) secondary caries–like lesion probably present; and 5) secondary caries–like lesion definitely present. Prior to the appraisals, a rehearsal session was held, allowing the observers to become familiar with the scoring program and with how to evaluate the images for secondary caries–like lesion diagnosis. The reading order of the presentations varied for each observer, and a period of at least one day separated the sessions. When viewing the images, the room light was turned off. Upon conclusion of the four presentations, 50% of the samples were reevaluated to obtain intraobserver reliability.

Statistical Analysis

Data in mmAl from the objective analysis of the radiopacity were tabulated and then statistically analyzed using the two-tailed, unpaired Student *t*-test. An independent comparison was made between images from each resin and dental reference (dentin or enamel). The data in the five-point rating scale from the analysis of the subjective influence of radiopacity were binarized, considering 1, 2, and 3 scores as "0" (absence of caries-like lesions) and 4 and 5 scores as "1" (presence of a caries-like lesion). The Kappa test (κ) was used to evaluate the intra- and interobserver reliability response pattern. Diagnostic testing (accuracy, specificity, sensitivity, negative predictive value [NPV], and positive predictive value [PPV]) was used to assess the observers' performance in detecting secondary caries–like lesions. The significance between each measure of the performance was obtained by the two-tailed, unpaired Student *t*-test. The Pearson correlation coefficient was used to determine the degree of linear dependence between the objective and subjective analyses. All statistical analyses were conducted with a significance level setting of 5% (α=0.05).

RESULTS

Regression analyses provided linear equations with a good fit (mean R^2=0.969 [0.961-0.973]) for converting pixel intensity values to mmAl. Table 2 shows the results in mmAl from the objective analysis of the radiopacity. All materials showed radiopacity values compatible with dental tissues. The radiopacity material Glacier did not differ statistically from dentin ($p>0.05$), and Prisma AP.H did not differ from enamel ($p>0.05$). Filtek Z250 showed a middle radiopacity between Prisma AP.H and both Charis-

Table 2: *The Mean and Standard Deviation (SD) Values in Al Equivalent Thickness (mmAl) of each Material Tested Against Dental References*[a]

Specimens	Mean ± SD
Enamel	3.45 ± 0.46
Dentin	1.09 ± 0.36
Charisma®	1.47 ± 0.33[bc] C
Filtek™ Z250	2.46 ± 0.39[bc] B
Prisma AP.H™	3.55 ± 0.46[c] A
Glacier®	1.39 ± 0.43[b] C

[a] *Different capital letters designate materials that differed by* t-*test* ($p<0.05$).
[b] *Values that differed from enamel by* t-*test* ($p<0.05$).
[c] *Values that differed from dentin by* t-*test* ($p<0.05$);

ma and Glacier, which were similar to each other ($p<0.05$).

The reliability response pattern to the presence of caries-like lesions ranged from good to very good ($0.65\leq\kappa\leq0.83$) in the intraobserver analyses and ranged from fair to moderate ($0.31\leq\kappa\leq0.45$) in the interobserver analyses. Table 3 shows the results of diagnostic testing from the subjective influence of radiopacity. The materials Prisma AP.H and Glacier differed statistically ($p<0.05$) in relation to their accurate determination of the presence of caries-like lesions, with Glacier showing greater accuracy, whereas Charisma and Filtek Z250 showed middle-level accuracy. Non–statistically significant differences in all other measures of the performance were observed ($p>0.05$).

Figure 2 shows the results of the correlation between the objective and subjective analyses. In terms of results, a greater strength ($-0.701\leq\rho\leq-0.922$) of negative linear dependence between the analyses, excluding specificity that showed a medium strength ($\rho=-0.410$) of negative linear dependence, was observed.

DISCUSSION

Generally, two distinct types of study evaluations of the radiopacity of dental composites have been found in the literature. There are those studies[1,4-6,10-12] that conducted this evaluation using objective analysis, comparing the image of materials to a reference image, and other studies[2,3,7,13-15] that made this evaluation by means of subjective analysis, comparing the observers' performance to a specific diagnosis. In this *in vitro* study, both analyses, objective and subjective, were used. Radiopacity values were objectively measured, and then their subjective influence was assessed through the diagnosis of secondary caries–like lesions, finishing with a correlation between the results based on both analyses.

In the current study, in terms of the objective analysis of radiopacity, all materials show a radiopacity similar to that of dental tissues, ranging from dentin to enamel, as represented by Glacier and Prisma AP.H materials, respectively. According to the guidelines,[8,9] radiopacity should be similar to or higher than that of an equal thickness of Al, and dentin has a radiopacity similar to an equal thickness of Al. In the current study, all materials conformed to these guidelines. Other studies[1,5,10] related that currently the composite materials have presented an appropriate radiopacity to the guidelines, despite a wide range of radiopacity, as observed in the current study as well. These wide ranges of radiopacity occur principally as a result of different kinds and proportions by volume of radiopacifying agents, considering the diversity of the manufacturers. Variations in radiopacity values of the same restorative materials among different studies can already occur because there are many methodological factors, such as those relating to film, X-ray machines, radiographic processing, and image analysis, that could induce such ranges.[10] Another important factor to be considered is the pureness of the Al wedge used in the conversion unit, considering the different alloys used as potent filtering objects for radiation; any alloy changes, related to a contaminating agent with a higher or lower atomic number, can significantly modify the radiation

Table 3: *The Mean and Standard Deviation (SD) Values of the Diagnostic Testing for Observers' Performance in Detecting Secondary Caries-like Lesion*[a]

Summary	Charisma®	Filtek™ Z250	Prisma AP.H™	Glacier®
Accuracy	0.558 ± 0.072 AB	0.525 ± 0.050 AB	0.533 ± 0.014 B	0.625 ± 0.025 A
Specificity	0.500 ± 0.058 A	0.489 ± 0.069 A	0.511 ± 0.051 A	0.567 ± 0.067 A
Sensitivity	0.733 ± 0.115 A	0.633 ± 0.058 A	0.600 ± 0.200 A	0.800 ± 0.265 A
NPV	0.847 ± 0.072 A	0.799 ± 0.031 A	0.801 ± 0.069 A	0.912 ± 0.108 A
PPV	0.429 ± 0.124 A	0.336 ± 0.044 A	0.324 ± 0.117 A	0.541 ± 0.198 A

Abbreviations: NPV, negative predictive value; PPV, positive predictive value.
[a] *Different on-line letters designating the observers' performance that differed by* t-*test* ($p<0.05$).

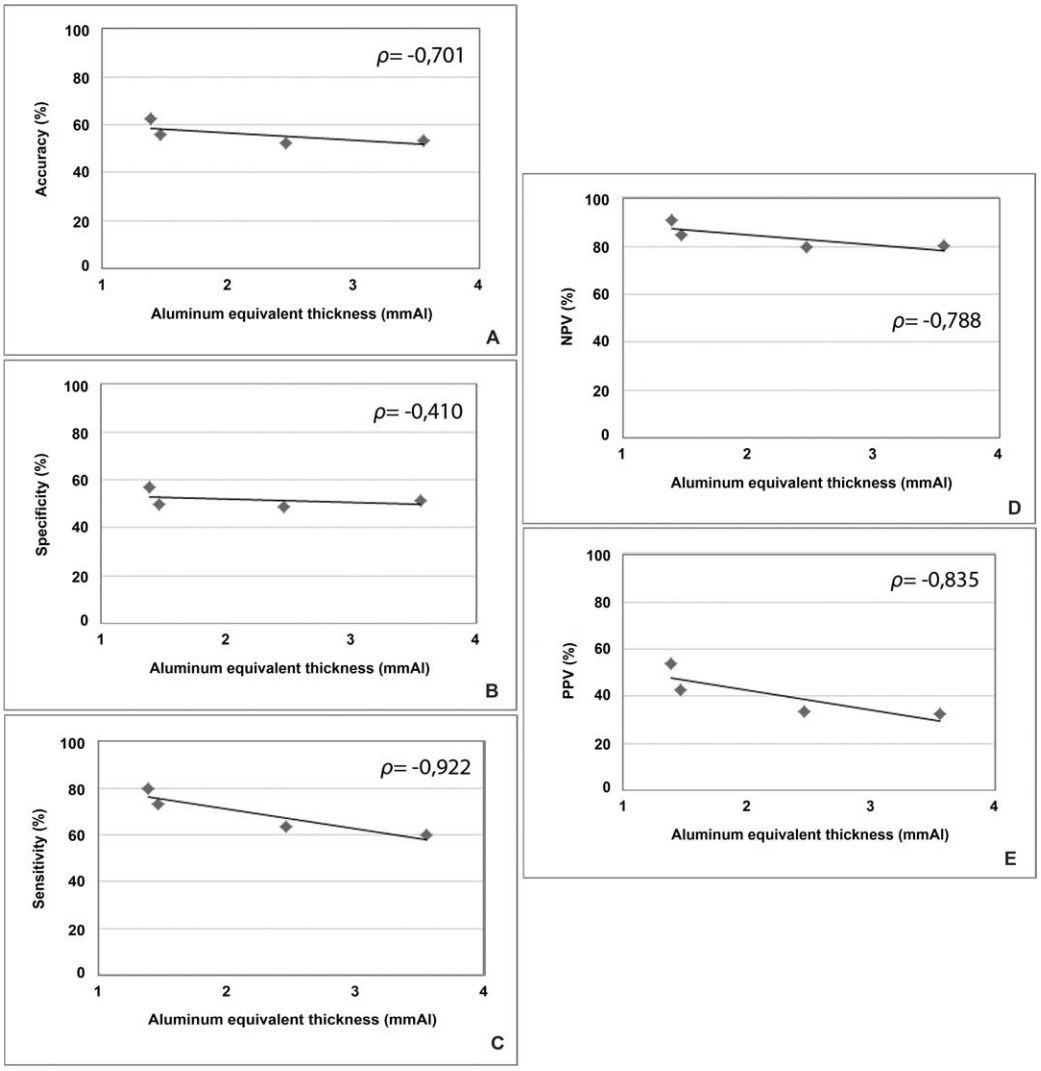

Figure 2. *Results of the degree of linear dependence between the objective and subjective analyses. (A) Accuracy; (B) Specificity; (C) Sensitivity; (D) Negative predictive value; (E) Positive predictive value.*

spectrum and result in a different image.[16] In the current study, the Al wedge had 99.8% purity, similar to the alloy used in the tube of the X-ray machine, such as Al X-ray filters.[16] However, another important factor is that the 12 steps of the Al wedge used in the current study are 1 mm thick. This could result in a model of regression with a good fit, which could perhaps not be obtained if each step was thicker.

In relation to the subjective influence of radiopacity, the Glacier material provided greater accuracy in detecting secondary caries, while there was no difference with Charisma and Filtek Z250, which differed only from Prisma AP.H, because it had a higher radiopacity. These results corroborate those of a previous study[2] that found that the accuracy was statistically similar and in which the worst accuracy of secondary caries detection was observed with materials of higher radiopacity. On the other hand, these results failed to support the findings of another previous study[7] that showed no difference in the accuracy of secondary caries detection as a result of very similar clinical radiopacities of the tested materials, which were similar to the radiopacity of dental tissues. As a consequence of the wide range of radiopacity of resin composites, care must be taken when choosing an appropriate material to facilitate secondary caries detection under posterior composite restorations;[1] diagnosis of carious lesions under esthetic restorations is more challenging as a result of optical interference from the radiopacity of the restoration added to the carious lesion image.[15,17]

Clinically, there are more challenges, because in addition to the characteristics of the carious lesion,

there are also the inherent troubles associated with the radiographic image[2,3] because caries detection is possible when demineralization has occurred in more than 40% of tooth tissue.[18] The use of secondary caries–like lesions for analysis of observers' performance has been previously applied,[2,12,13,16] and the size of the cavity bears an influence in this performance.[12] In this study, a same-sized bur[12] was used in repeated specimens because the perceptive reliability was an important factor under consideration. An oversize cavity of regular borders could make the perception process of the image easier, distancing further from the clinical condition.[19]

Another important factor to be considered is the experience of the observers who are diagnosing the secondary caries.[20] The results of a previous study[20] showed that there is a lack of instruction in how to accurately diagnose secondary carious lesions in everyday clinical practice. Only an accurate diagnosis can provide a good basis for dental treatment planning. According to another study,[21] resin composites maintain a low level of performance as the restorative material in posterior teeth, and they should be periodically checked to prevent secondary caries. In spite of the low precision of bitewing radiographs for secondary caries, they have been recommended as a means by which to periodically check for the presence of secondary carious lesions (in conjunction with a clinical examination), which can help to improve the diagnosis.[22] Nevertheless, in the case of the current study, which used an experimental model of simulated secondary carious lesions, the perception of the image is more important than the experience of the observers. However, even with minimal experience in caries diagnosis, because the observer sample consisted of dental students during their last phase prior to receiving their academic degree, intra- and inter-observer reliability values found in the current study were similar to those observed in previous studies.[3,20]

Diagnostic challenges can occur in a clinical situation as the result of a low perception of differences in radiopacity values that are very similar between materials, making it difficult for observers to distinguish these minor variations on a radiographic image.[23] Others studies[3-7] showed that restorative materials with a radiopacity closer to that of enamel supported greater accuracy in diagnosing secondary caries. To the contrary, the current study observed a correlation between both objective and subjective analyses, wherein an increase in radiopacity decreased the observers' ability to diagnose secondary caries. This can be generally verified with a material that has a greater radiopacity than dental tissue, such as amalgam. The increase in radiopacity of restorative materials reduces caries detection and increases the incidence of false-positive results.[3,14] Thus, when radiographically diagnosing secondary caries under amalgam, sometimes several different X-rays are needed to detect those lesions.[2,14,17] Furthermore, it must be emphasized that the results of any *in vitro* study are not directly applicable to a secondary caries diagnosis in the oral environment because challenges are more complex. In the oral cavity, the perception of caries formed under these materials depends on several other factors, among them radiographic and cognitive factors, and these should be taken into account.

CONCLUSION

Within the limitations of this *in vitro* study, the authors found that a material's radiopacity can have a subjective influence on diagnosing secondary caries–like lesions, and an increase in radiopacity can interfere negatively with rendering this type of diagnosis. Thus, the authors have indicated that an ideal radiopacity for dental composite is the radiographic image that is closer to the dentin image, which ultimately produces a similar attenuation to that of sound dentin tissue.

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 Sodium Ascorbate on Resin Bonding to Sodium Perborate–bleached Dentin

M Yoon • MF Burrow • R Wong
P Parashos

Clinical Relevance

Resin dentin bonding can be performed immediately after sodium perborate bleaching without the need for sodium ascorbate pretreatment; however, the two-step self-etching adhesive performed better than the all-in-one system. The all-in-one adhesive, Xeno IV, exhibited significantly lower microshear bond strength when bonded to positions associated with larger-diameter dentinal tubules.

SUMMARY

This was an *in vitro* study to evaluate the effect of sodium ascorbate on the microshear bond strength (MSBS) of resin composite to sodium perborate–bleached dentin. Molar dentin sections were divided into six groups: 1) control, 2) sodium perborate (SP) bleach and immediate bonding, 3) SP and 30 second sodium ascorbate (SA); 4) SP and 1 minute SA; 5) SP and 2 minute SA; and 6) SP and 7 day delay before bonding. They were further divided into two-step self-etching (Clearfil SE Bond) or all-in-one self-etching (Xeno IV) adhesive systems. Resin composite microtubes were bonded according to dentin location—center, pulp horn, and peripheral positions—and an MSBS test was carried out. Failure mode was determined using light microscopy and scanning electron microscopy. There were no significant differences between the treatment types/groups. MSBSs were significantly higher for two-step self-etching adhesive compared with all-in-one self-etching adhesive ($p=0.028$). For the all-in-one adhesive, MSBSs at the center and pulp horn positions were significantly lower than the peripheral positions ($p<0.001$). All-in-one groups had significantly more adhesive failures than two-step adhesive groups ($p=0.015$). The odds of adhesive failure were higher at the pulp horn position than the peripheral position ($p=0.004$). Sodium perborate bleaching of dentin had no effect on MSBS or mode of failure for either two-step or all-in-one self-etching adhesives; therefore, the effect of sodium ascorbate was negligible. The two-step

Michael Yoon, BDSc, DCD, FRACDS, Melbourne Dental School, University of Melbourne, Melbourne, Australia

Michael F Burrow, BDS, MDS, PhD, MEd, MRACDS(Pros), FRACDS, Faculty of Dentistry University of Hong Kong, Hong Kong

Rebecca Wong, BDSc, MDSc, PhD, FRACDS, Melbourne Dental School, University of Melbourne, Melbourne, Australia

*Peter Parashos, BDSc, MDSc, PhD, FRACDS, MRACDS (Endo), Melbourne Dental School, University of Melbourne, Melbourne, Australia

*Corresponding author: 720 Swanston St., Melbourne, Victoria 3010, Australia; e-mail: parashos@unimelb.edu.au

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adhesive groups demonstrated the highest MSBS, and the all-in-one groups, when bonded to center and pulp horn dentin, exhibited the lowest MSBS.

INTRODUCTION

In the current era of minimally invasive dentistry, bleaching is readily considered when treatment planning for discolored teeth. Tooth discoloration can occur intrinsically and extrinsically, and the origin and nature of the stain will determine whether external and/or internal bleaching will be most effective.

Bleaching agents composed of hydrogen peroxide, in particular sodium perborate (SP), have been reported to be very effective when bleaching internally in endodontically treated teeth. The success rate ranges from 93% to 100% with 1- to 6-year follow-ups,[1-4] although other studies have reported lower rates of 50% to 79% over 3 to 8 years.[5,6]

Despite the obvious benefits of the ability of hydrogen peroxide–containing agents to eliminate stains by cleaving double bonds of pigmented molecules, negative effects on dentin at the morphological,[7] chemical,[8] and biomechanical[9] levels have been reported. The pH of the bleach formulation may play a critical role in these effects.[10] Reductions in the resin bond strength to dentin have been reported when dentin was exposed to SP[11,12] as well as to a variety of concentrations of hydrogen peroxide[13,14] and carbamide peroxide.[14,15]

Recent developments of resin bonding agents have led to a move toward self-etch adhesion and away from the classic etch-and-rinse approach. Self-etch adhesives have several advantages: the rinsing phase is eliminated and clinical time and risk of errors during application are reduced. Despite the apparent advancement in resin adhesives, self-etch resin bond strengths have been reported to be compromised by prebleaching of the dentin substrate.[11]

The probable mechanism for the reduction in bond quality in bleach-treated dentin is the residual bleach within the collagen matrices and dentinal tubules after bleaching that eventually break down to oxygen and water.[16] The liberation of oxygen could either interfere with resin infiltration into enamel and dentin[17] or directly inhibit the free-radical polymerization of resins,[18] which would lead to a defective resin-dentin interface that cannot sufficiently withstand debonding forces, thus reducing the strength.

The most common method of reversing the compromised resin bond to bleached dentin has been to delay bonding long enough to allow the residual peroxide to leach away. The time required to achieve a return to baseline bond strengths has been reported to be approximately 1week when exposed to SP with or without hydrogen peroxide[11,12] however, others have reported that a delay of 1week was not long enough when the dentin was exposed to hydrogen peroxide and carbamide peroxide as the bleaching agent[14,19] before bonding.

Of promise is pretreating bleached dentin with sodium ascorbate (SA), a neutral biocompatible antioxidant, based on its ability to neutralize and reverse the oxidizing effects of hydrogen peroxide[20,21] by altering the redox potential of the bleached tooth, thereby preventing the premature termination of the free-radical polymerization of the adhesive.[16] The ability of SA to reverse the effects of 5% sodium hypochlorite and 10% hydrogen peroxide on resin-dentin bonding was initially found to have positive results because it restored the microtensile bond strengths when SA was applied for the equivalent duration of peroxide exposure (1-minute or 10-minute applications).[16] Further evidence of its action has been reported with 10%-22% carbamide peroxide–bleached enamel[22,23] and 35% hydrogen peroxide–bleached human dentin.[24] Both solution and hydrogel forms of SA significantly increased the shear bond strength when dentin was exposed to 10% carbamide peroxide; no differences were associated with two forms.[25,26]

However, the limitation of the action of SA noted in the literature has been the time required for complete recovery to nonbleached bond strength levels, as the durations of application required have been reported to range from 10 minutes[23] to 3 hours.[22,27] Previous studies of the action of SA have tested the microtensile bond strength of resin composite bond to bleached dentin or enamel. As yet, no studies have evaluated the effect of SA on microshear bond strength (MSBS) of resin composite to SP-bleached dentin.

This study aimed to investigate the effect of SA on MSBS and mode of failure of a resin composite bonded to SP-bleached dentin, while considering the resin adhesive type and dentin location as possible variables. The null hypothesis tested was that SA has no effect on MSBS or mode of failure of the resin composite bond to SP-bleached dentin with no difference between the types of resin adhesive or dentin location.

MATERIALS AND METHODS

Overview

Ethics approval was obtained for the collection of teeth from The University of Melbourne Human Research Ethics Committee (ID 1033324). Forty-eight extracted non-carious human molars were collected. Immediately after extraction, the teeth were stored in 1% chloramine-T solution (pH 9.1) (Dentalife, Melbourne, Australia) for at least 2 weeks, transferred to phosphate buffered saline solution (Dentalife) and stored at 4°C for no longer than 1 month after extraction.

Tooth Sample Preparations

Horizontal mid-coronal sections were obtained at the level coronal to the pulp chamber using a diamond saw at slow speed under water cooling to produce dentin disc sections approximately 2 mm thick. Each tooth section was mounted in dental stone in a 30-mm diameter polyvinylchloride cylinder and polished using 600-grit silicon carbide paper at 150 rpm under running water (Tegrapol-25, Struers, Ballerup, Denmark) to ensure that a standardized, flat smear-covered surface of dentin was produced. The teeth preparations were subsequently stored in an incubator (Thermoline Scientific, New South Wales, Australia) at 37°C and 95% relative humidity throughout the experiment.

Resin Composite Bonding

The specimens were divided into six groups of eight teeth as follows:

Group 1: No prebonding treatment (control) was applied.

Group 2: SP bleaching agent (2 g SP and 1 mL of water) was applied on the specimen. It was stored for 7 days and rinsed off with air-water spray for 10 seconds.

Group 3: SP bleaching agent was applied on the dentin surface of the specimen. It was stored for 7 days and rinsed off with air-water spray for 10 seconds. The specimen was exposed to 10% SA (Dentalife) solution for 30 seconds and rinsed off with air-water spray for 10 seconds.

Group 4: SP bleaching agent was applied on the specimen. It was stored for 7 days and rinsed off with air-water spray for 10 seconds. The specimen was exposed to 10% SA solution for 1 minute and rinsed with air-water spray for 10 seconds.

Group 5: SP bleaching agent was applied on the specimen. It was stored for 7 days and rinsed off with air-water spray for 10 seconds. The specimen was exposed to 10% SA solution for 2 minutes and rinsed with air-water spray for 10 seconds.

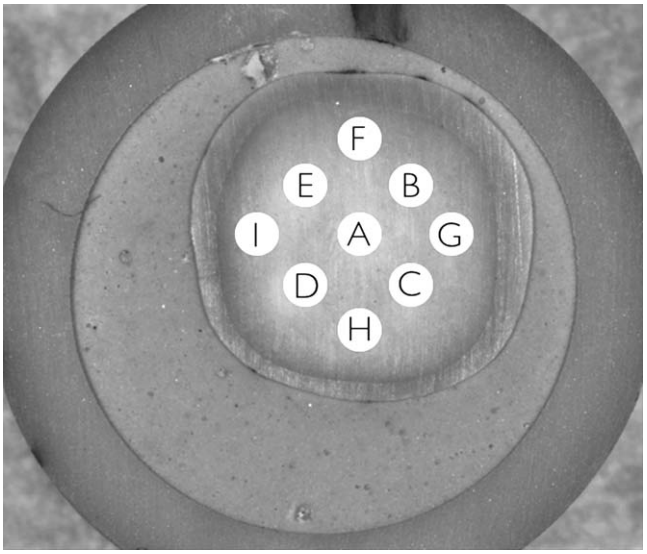

Figure 1. *Predetermined microtube positions: Center position (A); pulp horn positions (B, C, D, and E); peripheral positions (F, G, H, and I).*

Group 6: SP bleaching agent was applied on the specimen. It was stored for 7 days and rinsed off with air-water spray for 10 seconds. The specimen was stored in the incubator at 37°C for 7 days without further treatment.

Following the procedures described earlier, the specimens from each group were divided equally into two subgroups: the two-step self-etching adhesive, Clearfil SE Bond (Kuraray-Noritake, Tokyo, Japan), which was designated SE, and the all-in-one adhesive, Xeno IV (Dentsply Caulk, Milford, CT, USA), which was designated X. All specimens were subjected to bonding procedures on the final day of the surface treatments.

The specimens in the SE group were dried but not desiccated, and SE was applied according to the manufacturer's instructions to the dentin surface in a predetermined configuration (Figure 1). Seven to ten translucent polyvinylchloride microtubes (Microtube extensions, New South Wales, Australia), 0.75 mm internal diameter by 1.5 mm high, were placed perpendicular to the adhesive-covered specimens, and the adhesive was cured using a light-emitting diode light unit of 800 mW/cm^2 irradiance (BluePhase C8, Ivoclar Vivadent AG, Schaan, Liechtenstein) for 10 seconds. The microtubes were filled with a nano-filled hybrid resin composite,

Table 1: *Compositions of the Adhesives Used in the Study*

Adhesive	Code	Contents	Manufacturer	Batch No.
Clearfil SE bond	SE	Primer: 10-MDP; HEMA; hydrophilic DMA; dl-camphorquinone; N,N-diethanol-p-toluidine; water	Kuraray Medical, Tokyo, Japan	51800
		Bond: 10-MDP; Bis-GMA; HEMA; hydrophobic DMA; dl-camphorquinone; N,N-diethanol-p-toluidine; silanated colloidal silica		
Xeno IV	X	UDMA, PENTA, acetone, polymerizable trimethacrylate resin, 2 polymerizable DMA resins, photoinitiator	Dentsply Caulk, Milford, CT	100608

Abbreviations: Bis-GMA: bisphenol A glycidylmethacrylate; HEMA: 2-hydroxyethyl methacrylate; 10-MDP: 10-methacryloyloxydecyl dihydrogen phosphate; UDMA: urethane dimethacrylate; PENTA: dipentaerythritol pentaacrylate phosphate; DMA: dimethacrylate.

Esthet.X HF (Dentsply Caulk), and light cured for 30 seconds.

The specimens in the X group were dried in the same way as the SE specimens, and X was applied according to manufacturer's instructions to the dentin surfaces in the predetermined orientation. Microtubes were placed, filled with the nano-filled hybrid resin composite, and cured in the same manner as the SE specimens.

The composition and batch numbers of the adhesives are listed in Table 1.

After the bonding procedures, specimens were checked under a light microscope to detect any defects in the resin packing of the microtubes and discarded if voids or defects were evident. All specimens were stored for a further 24 hours before testing.

MSBS Testing

Each specimen was placed in the jig of the universal testing machine (Imperial 1000, Mecmesin, Slinfold, UK) so that the shear force could be applied parallel to the specimen surface. MSBS tests were carried out on each of the resin composite cylinders via a 0.35 mm diameter stainless steel wire loop placed around the base of each resin cylinder at the dentin/resin composite interface. The load was applied to the resin cylinders at a crosshead speed of 1.0 mm/min until bond failure occurred. The maximum load applied (N) was recorded using computer software (Emperor version 01, Mecmesin, Slinfold, UK) and converted to MSBS (MPa) by dividing the load by the bonded surface area (mm^2). Statistical analyses of MSBSs were performed with GenStat for Windows, 14th edition SP1 (VSN International Ltd, Hemel Hempstead, UK), using both three-way and two-way analysis of variance with the three factors being treatment type (groups 1-6), bonding agent (SE Bond or Xeno IV), and bond position (center, pulp horn, or periphery). This was followed by multiple comparisons using Tukey's test, with statistical significance set at $\alpha = 0.05$.

Fracture Analysis

Fractured surfaces were examined under a light microscope at ×10 magnification (Leica S8 APO, Leica Microsystems, Wetzlar, Germany) by a single observer (MY), who was blinded to the experimental groups of the specimens. The specimen fractures were classified as A = adhesive failure when it occurred at the resin-dentin interface over more than approximately 75% of the bonding surface, C = cohesive failure when it occurred within the resin more than approximately 75% of the bonding surface, or M = mixed failure when either modes of failure occurred on approximately 25%-75% of the bonding surface. Data were analyzed using a generalized linear mixed model (GenStat 14, a = 0.05).

Scanning electron microscopy (SEM) (FEI Quanta Scanning Electron Microscope, FEI, Hillsboro, OR, USA) was carried out on randomly selected resin-dentin interfaces to further examine the previously resin-bonded substrate and to identify any effects of the various treatments. Images for analysis were acquired at ×2000 and ×8000 magnification by Image Pro Plus 6.0 (MediaCybernetics, Rockville, MD, USA).

RESULTS

MSBS

The effects of the various treatments involving SP and SA on the MSBS of two-step and all-in-one adhesives are shown in Table 2. There were no significant differences between the treatment groups; however, the MSBS values for two-step adhesive groups were significantly higher than those of the all-in-one groups (p=0.028). No interaction was found between the treatment and bond type factors.

Table 2: *Microshear Bond Strength of Resin Adhesives to Dentine After Various Treatments*

Group	Treatment	Clearfil SE Bond, Bond Strength* (MPa)	Xeno IV, Bond Strength* (MPa)
1	Distilled water (control)	8.98 ± 4.72 (36)[a]	7.39 ± 3.82 (34)[b]
2	7 d SP	10.49 ± 2.45 (36)[a]	6.63 ± 3.90 (33)[b]
3	7 d SP + 30 s 10% SA	9.49 ± 4.08 (36)[a]	8.06 ± 4.92 (33)[b]
4	7 d SP + 1 min 10% SA	9.27 ± 4.09 (33)[a]	9.84 ± 4.78 (34)[b]
5	7 d SP + 2 min 10% SA	9.94 ± 4.50 (35)[a]	8.27 ± 4.48 (32)[b]
6	7 d SP	9.86 ± 3.43 (34)[a]	7.60 ± 3.27 (33)[b]

Abbreviations: SA: sodium ascorbate; SP: sodium perborate.
**Values are mean ± SD. The number of specimens tested is included in parentheses. Bond strength results were analyzed by two-way analysis of variance and Tukey's multiple-comparison tests. Groups identified by the same superscript letter are not significantly different ($p>0.05$).*

Table 3: *Microshear Bond Strength of Resin Adhesives to Dentine Based on Microtube Position*

Microtube Position	Clearfil SE Bond, Bond Strength* (MPa)	Xeno IV, Bond Strength* (MPa)
Center (A)	9.40 ± 3.65 (23)[a]	6.64 ± 3.95 (21)[b]
Pulp horn (B, C, D, E)	9.97 ± 4.49 (92)[a]	6.73 ± 4.11 (89)[b]
Peripheral (F, G, H, I)	9.45 ± 3.42 (95)[a]	9.55 ± 4.08 (89)[a]

**Values are mean ± SD. The number of specimens tested is included in parentheses. Bond strength results were analyzed by two-way analysis of variance and Tukey's multiple-comparison tests. Groups identified by the same superscript letter are not significantly different ($p>0.05$).*

The effect of bond site on the MSBS of two-step and all-in-one adhesives is shown in Table 3. The microtube position had no significant effect on the MSBS of the two-step adhesive groups; however, the all-in-one adhesive bond strengths at the center (A) and pulp horn positions (B-E) were significantly lower than those at the peripheral position (F-I) ($p<0.001$).

Failure Mode

Under light microscopy analysis, no cohesive failures were detected on any of the bond interfaces; most of the failures were adhesive in nature (n=323), and the remainder were mixed failures (n=86). There were no significant differences between the treatment types on the proportion of adhesive failures. In contrast, bond type had a significant effect; the all-in-one adhesive groups showed significantly more adhesive failures than the two-step adhesive groups ($p=0.015$). Microtube position had a significant effect on the bond failure mode; the odds of adhesive failure were 0.47 at the peripheral position compared with the pulp horn position ($p=0.004$).

SEM analysis demonstrated areas of dentin with variable smear layer and resin bond coverage (Figures 2 through 4); however, no differences could be determined between treatment groups and bond types. Generally, larger diameter dentinal tubules were evident in pulp horn and center dentin positions compared with the peripheral dentin position.

DISCUSSION

The fundamental mechanism of resin bonding to dentin is essentially a two-stage exchange process between the synthetic resin and the dental substrate resulting in a micromechanical interlocking between the resin monomers and the components of the prepared dental hard tissues.

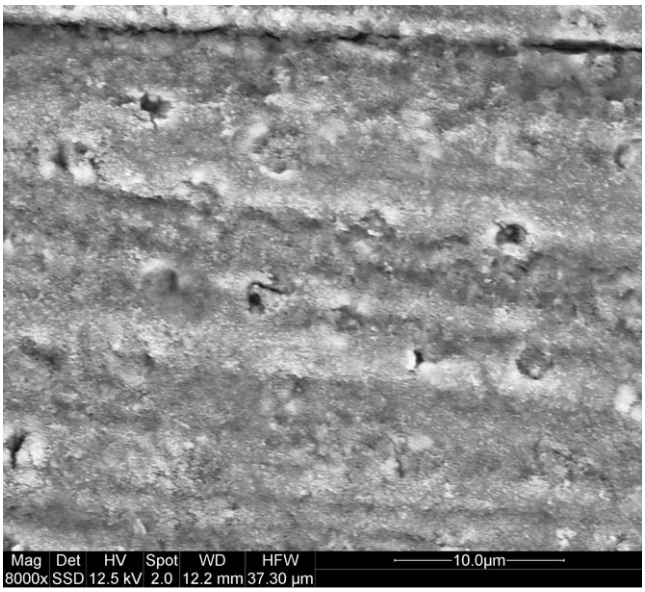

Figure 2. *SEM micrograph (×8000) of microshear failure interface of the all-in-one bonded peripheral dentin (2 min SA treatment after 7 d SP bleach) showing presence of smear layer.*

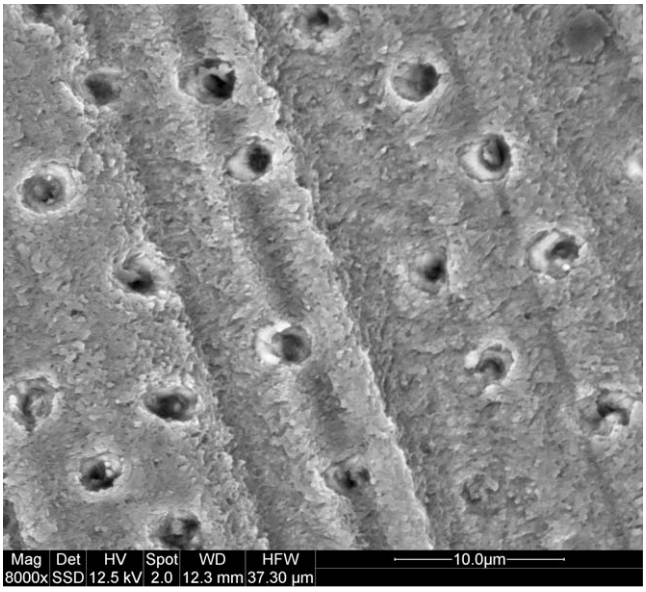

Figure 3. *SEM photograph (×8000) of microshear failure interface of the two-step adhesive bonded pulp horn dentin (1 min SA treatment after 7 d SP bleach) showing a predominantly absent smear layer and patent dentinal tubules.*

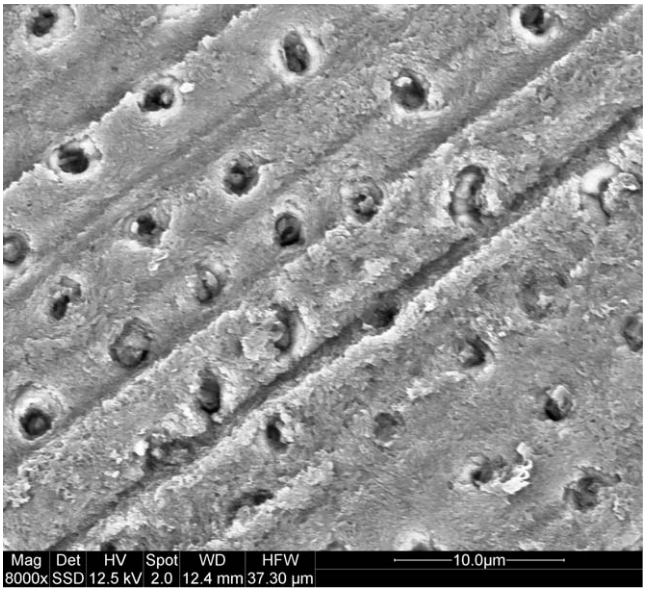

Figure 4. *SEM photograph (×8000) of microshear failure interface of the two-step adhesive bonded peripheral dentin (7 d delay after 7 d SP bleach) showing a predominantly absent smear layer and some filled dentinal tubules.*

Both bonding agents tested in this study are self-etch adhesives with the difference being the number of procedural bonding steps required: SE bond is a two-step self-etch resin-bonding agent with a separate mild acidic primer (pH 2.0) and adhesive resin monomer containing 10-MDP; Xeno IV is acetone-based all-in-one self-etch resin bonding agent that combines all the components into a single solution. It is also classified as a mild etching adhesive (pH=2.1).[28] The other significant difference between the two adhesives is the use of 10-MDP as the functional monomer in SE bond, which enables chemical bonding to tooth structure. Using x-ray photo-electron spectroscopy, phosphate groups of 10-MDP have been shown to form an ionic bond with calcium of hydroxyapatite and also seem to form a regularly ordered nano-layered structure at the hydroxyapatite surface.[29]

In this study, SP bleaching of dentin before resin bonding had no significant effect on the MSBS of either the two-step or the all-in-one adhesives. This is in contrast to reports in the literature,[11,12] although this may be attributed to differences in study designs. Elkhatib and others[11] used a sodium perborate-hydrogen peroxide mixture and reported microtensile bond strengths, whereas Shinohara and others[12] investigated shear bond strengths to SP-bleached bovine dentin. The use of human dentin in this study may also explain the variation in the resin bonding outcome compared with studies utilizing bovine dentin. Furthermore, the minimal effect of SA on subsequent resin bonding is likely to be related to the low concentration of the oxidizing breakdown products compared with those produced from hydrogen peroxide and carbamide peroxide bleaching agents, which, in general, have been reported to negatively affect resin-dentin bond strengths.[13-15,19,30]

The post-bleach application of the antioxidant SA on the bleached dentin surface had no significant effect on the MSBS of the two-step adhesive and all-in-one adhesives. This is not surprising, as there was no reduction in bond strength as a result of bleaching. It also demonstrated that SA did not interfere with the resin-dentin bonding. The potential beneficial effect of SA on restoring resin bond strengths of enamel and dentin has been reported widely in the literature when bond strengths have been compromised by carbamide peroxide[22,23] and hydrogen peroxide[16,24] bleaching agents.

In general, the two-step adhesive groups were found to have significantly higher MSBS values than the all-in-one adhesive groups, a finding that has been supported by other studies comparing the same two-step adhesive with other all-in-one bonding agents.[31,32] It can be postulated that the combined micromechanical and chemical bonding mechanism of mild self-etch adhesives containing 10-MDP, as is

the case with the two-step adhesive in this study, may contribute to the higher MSBS values, although there is a lack of evidence proving that chemical interaction improves immediate bond strength. However, improved bond stability has been proven by clinical data, as they demonstrated that two-step self-etch adhesives, in general, show reliable long-term performance.[33,34]

The reliable bonding ability of the two-step adhesive was further evident in this study after assessing the effect of bond position on the MSBS. The microtubes were positioned in a particular orientation (Figure 1) to determine whether the dentin location, as established by the depth and position of dentin relative to the pulp chamber, affected resin bonding. Dentinal tubules, which are wider and have a greater surface area as they approach the pulp chamber, were simulated by the center (A) and pulp horn (B-E) positions in this study. Superficial dentin, which is characterized by smaller tubule diameters, was simulated by the peripheral positions close to the dentinoenamel junction (F-I). This difference in tubule diameter was evident from the SEM analysis of selected specimens performed (Figures 3 and 4). The microtube position had no significant effect on the MSBS of the two-step adhesive; however, in the all-in-one adhesive groups both center and pulp horn positions had significantly lower MSBS than the values found in the peripheral position. Any conclusions from these statistical findings, especially those involving the center position, must be carefully made because of the difference between specimen numbers according to position: center (n=21 for two-step adhesive $_{SE}$; n=23 for all-in-one adhesive $_{X}$), pulp horn (n_{SE}=92, n_X=89), and peripheral (n_{SE}=95, n_X=89) positions.

The increased distance from the periphery means that the center and pulp horn positions represent areas of deeper dentin. Dentin that is closer to the pulp chamber is characterized by wider dentinal tubules, increased permeability, and greater dentin wetness.[35] The reduced dentin surface area and increased moisture content most likely explain the inconsistent behavior of the all-in-one adhesive, Xeno IV, which is believed to rely on primarily micromechanical bonding for adhesion to the tooth surface. All-in-one self-etching resin adhesives, with their greater degree of hydrophilicity, are prone to attract more water from the intrinsically moist dentin substrate, and this property has raised concerns about these bonding agents possibly acting as semipermeable membranes.[36] Besides resulting in a decrease in resin bond strength,[37] such permeability of the adhesive layer appeared to contribute to the hydrolysis of resin polymers and the resultant degradation of resin bond over time.[38] Furthermore, adhesives containing acetone as the solvent, as present in the all-in-one system used, have been found to be more susceptible to the formation of defects along the bond interface, such as primer globules and blisterlike spaces when used on wet dentin, that is, the overwet phenomenon.[39,40] Although the two-step adhesive may also be affected by wetter dentin through the dilution of the monomer, its intrinsic ability to form a chemical bond may overcome the potentially moisture-compromised micromechanical bond at the center and pulp horn regions.

Although treatment type (SP bleach and SA application of various exposure times) had no effect on the proportion of adhesive failures, the Xeno IV groups had significantly more adhesive failures than the SE bond groups. The overwet phenomenon affecting Xeno IV is a possible explanation for its susceptibility of failure at the dentin-bonding agent interface. This explanation is further supported by the observed higher frequency of adhesive failures at the wetter pulp horn position compared with bonding to peripheral dentin, which is drier and composed of smaller diameter dentinal tubules.

CONCLUSION

The results of this study support resin bonding with either the two-step adhesive, SE Bond, or the all-in-one adhesive, Xeno IV, immediately after bleaching with SP with no need for the antioxidant SA. Generally, SE Bond performed more consistently than Xeno IV, as higher MSBS values were evident with SE bond groups and lower MSBS values were evident in the Xeno IV groups when bonded to wetter center and pulp horn dentin.

The null hypothesis cannot be rejected completely as SA had no effect on the MSBS or mode of failure of the resin bond to bleached dentin; however, there were differences between the types of resin adhesive and dentin.

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Conflict of Interest

The authors 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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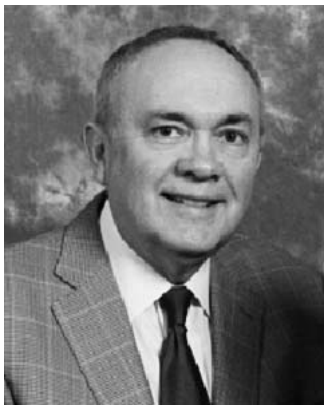
American Academy of Gold Foil Operators' 2013 Clinician of the Year Award



Dr Bruce W. Small

When Mr Vic Williams, then president of Williams Gold Company, started this award many years ago; he wanted to recognize a younger clinician who is a member of the American Academy of Gold Foil Operators, was using direct gold in the office, and publishing articles on direct gold as well as its advocation in teaching of dental students. I have known and worked with this year's recipient for Clinician of the Year Award for over twenty years. I have seen his epiphany from the dark side of dentistry to seeing the light of gold. He has seen and learned the value that direct and cast gold teaches and how it affects all of the other materials used in restorative dentistry today. He not only started a Tucker Cast Gold Study Club on the East Coast some twenty years ago but was very instrumental in the formation of four other gold study clubs, one of which emphasized direct gold restorations; two of which he mentors.

He was born and raised in New York City, got his BS degree from Muhlenberg College in Pennsylvania before going to the University of Medicine and Dentistry of New Jersey where he graduated with a DMD in 1973. He was also president of his dental school class.

He started an elective course for cast and direct gold in the New Jersey Dental School about twelve years ago. He is still actively involved in teaching the course. It has become one of the most sought after courses in the dental school curriculum by the students. There is always a waiting list of students desiring to take the course and have a direct gold restoration placed in their mouths.

He has not only been a prolific writer and lecturer on both direct and cast gold techniques but has given numerous hands-on courses to stimulate the benefits of gold and hands-on study club learning.

This year's recipient has a lovely supportive wife Pat and three wonderful grown children; one of which is in practice with him. He has become a refined operator and has learned to appreciate the effort needed to become one. He himself has belonged to a direct and cast gold study club for over twenty years.

He has been an officer of this Academy, R V Tucker Academy, and will be going through the chairs of the Operative Academy. He has also been very active in the Academy of General Dentistry and the L D Pankey Institute in Florida.

He is a member in good standing of this academy as well as of the Restorative, Operative, Tucker and General Dentistry academies. He has contributed and been deeply involved in all of the organizations to which he belongs.

I could go on and on about the exploits of this individual in the dental field but I think it is time to announce the recipient of this years Clinician of the Year Award which goes to Dr Bruce W. Small.

Dr Warren K Johnson

Departments

Faculty Positions

GROUP PRACTICE FACULTY COLLEGE OF DENTAL MEDICINE – ILLINOIS

The College of Dental Medicine-Illinois (CDMI) at Midwestern University is a new predoctoral dental education program located in suburban Chicago, IL. CDMI is developing an innovative, integrated and patient-centered curriculum focusing on clinical excellence, critical thinking and ethical practice with an emphasis on oral health and the prevention and management of oral diseases in an evidence-based environment.

CDMI is seeking full-time clinical faculty to serve in the Group Practice student clinics at the rank of Instructor, Assistant, or Associate Professor to begin February, 2014. Primary responsibility is for the overall well-being of the patients being treated. The Group Practice faculty member has responsibility for instruction and demonstration in one-on-one, small group and plenary settings. The Group Practice faculty will supervise student dentists and provide direct patient care as required by the degree of difficulty of certain cases or for demonstration purposes. There is an opportunity to engage in scholarly activity, as deemed appropriate and as mutually agreed upon by the Group Practice Faculty and CDMI administration.

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Appointment at the Instructor, Assistant, or Associate Professor level will be based on individual experience and credentials. Midwestern University offers competitive salaries and opportunities exist for advancement.

Interested individuals should submit a letter of application, curriculum vitae, and 3 professional references to:

Midwestern University
Dental Institute
Attn: Dr. Darryn Weinstein
3450 Lacey Rd., Suite 120
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TEMPLE UNIVERSITY KORNBERG SCHOOL OF DENTISTRY Director of the Division of Operative Dentistry, Department of Restorative Dentistry

Temple University Kornberg School of Dentistry is seeking applicants for a full-time Assistant/Associate Professor position to serve as the Director of the Division of Operative Dentistry, Department of Restorative Dentistry. The candidate should have experience and demonstrated leadership skills in teaching and providing patient care using current evidence-based methods in caries management. The responsibilities forthis position will include designing and implementing a new curriculum in cariology and restorative dentistry, teaching, development of contemporary didactic curriculum materials, lecturing, preclinical instruction, and research in the field of cariology. Applicants should be familiar with current pedagogical teaching methods including evidence-basedoral health care. Qualified candidates must have a DDS, DMD or equivalent and must have an MSc or PhD degree (preferable) and funded research track records. Email CV to Dr. Lisa Deem, Chair Search Committee, ldeem@dental.temple.edu. Temple University is an equal opportunity/affirmative action employer, female and minority applicants areencouraged to apply.

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Triethylene Glycol Dimethacrylate Induction of Apoptotic Proteins in Pulp Fibroblasts

G Batarseh • LJ Windsor • NY Labban
Y Liu • K Gregson

Clinical Relevance

Pulp exposed to triethylene glycol dimethacrylate (TEGDMA) containing resin composite may be at higher risk of endodontic treatment.

SUMMARY

Objective: Monomers such as triethylene glycol dimethacrylate (TEGDMA) can leach from dental composites. TEGDMA-induced apoptosis in human pulp has been reported. However, the apoptotic (pro or anti) proteins involved in this process remain unclear. Therefore, the purpose of this study was to determine which apoptotic proteins are enhanced or suppressed during TEGDMA-induced apoptosis.

Materials and Methods: Human pulp fibroblasts (HPFs) were incubated with different TEGDMA concentrations (0.125-1.0 mM) and cytotoxicity was determined. TEGDMA was shown to be cell cytotoxic at concentrations of 0.50 mM and higher. The highest concentration with no significant cytotoxicity was then incubated (0.25 mM TEGDMA) with the HPFs. Cell lysates were then prepared and the protein concentrations determined. Human Apoptosis Array kits were utilized to detect the relative levels of 43 apoptotic proteins.

Results: HPFs exposed to TEGDMA showed significant increases in multiple pro-apoptotic proteins such as Bid, Bim, Caspase 3, Caspase 8, and Cytochrome c at 24 hours. Some anti-apoptotic proteins were also altered.

Conclusions: The results indicated that TEGDMA activates both the extrinsic and intrinsic apoptotic pathways.

Ghada Batarseh, DDS, MSD, Department of Oral Biology, Indiana University-Purdue University–Indianapolis, Indianapolis, IN, USA

*L Jack Windsor, PhD, Department of Oral Biology, Indiana University-Purdue University–Indianapolis, Indianapolis, IN, USA

Nawaf Y Labban, BDS, MSD, Department of Oral Biology, Indiana University School of Dentistry, Indianapolis, IN, USA and Department of Prosthetic Dental Science, King Saud University College of Dentistry, Riyadh, KSA

Yang Liu, Sichuan University, State Key Laboratory of Oral Diseases, Chengdu, China

Karen Gregson, Indiana University, Indianapolis, IN, USA

*Corresponding author: 1121 West Michigan Street, Indianapolis, IN 46202; e-mail: ljwindso@iu.edu

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INTRODUCTION

Resin composites (RC) are widely used as a result of increases in esthetic demands and increased concerns related to mercury toxicity. Dentists choose RC because of the conservative approach of this preparation when compared to amalgam restorations. The

mechanical properties of these restorations are improving continuously as a result of the ongoing research in this area. More research is still needed to test the biocompatibility of these materials. Cytotoxicity tests done *in vitro* and *in vivo* have shown that there are monomers that leach from the RC that can cause cell death and damage to the surrounding tissues, specifically pulp tissue. A study by Qvist and others in 1989[1] showed that teeth restored with RC using different leakage-reducing methods experienced increases in pulp inflammation as well as necrosis. Studies that compared amalgam to resin-based composite restorations showed that composites do have higher failure rates than does amalgam.[2] In a primary care setting, pulp breakdown and endodontic complications were four times more likely with composite restorations than with amalgam restorations.[2] One of the components of RC that was found to leach was triethylene glycol dimethacrylate (TEGDMA). TEGDMA comprises small hydrophilic monomers. They form approximately 30-50% of almost all of the resin-based composites. TEGDMA is added to improve viscosity and to make the RC more manageable clinically. These monomers were found to leach as a result of either incomplete polymerization of the resin or mechanical/chemical degradation of the restoration.[3]

Unpolymerized TEGDMA is responsible for some of the cytotoxic effects of RC and dental adhesives on pulp and gingival fibroblasts.[4] According to a study conducted by Janke and others[5] on gingival fibroblasts, TEGDMA caused apoptotic cell death rather than necrotic cell death. A study conducted by Spagnuolo and others[6] showed that TEGDMA induced apoptosis rather than necrosis in pulp fibroblasts. Apoptosis is a programmed, energy-dependent cell death that causes cells to shrink with no loss of the membrane integrity. In contrast, necrosis is an uncontrolled, pathological process that does not require energy, and the cells swell and lose their membrane integrity. The main difference between necrosis and apoptosis is that there are minimal inflammatory responses initiated in apoptosis.

TEGDMA-induced apoptosis was time and concentration dependent.[6] Noda and others[7] were able to calculate the amount of TEGDMA leaching from RC to the pulp. They noted that the concentration of TEGDMA in many composites is approximately 30-50%. Pure TEGDMA has a concentration of 3.8 mol/L (3.8 M). Therefore, the molar concentration in composites is slightly less than 2 mol/L (2 M).[8] The dilution factor of TEGDMA across 0.5 mm of dentin was determined to be 500.[8] Based on that, the amount of TEGDMA that reaches pulp fibroblasts is around 4 mM.[7] Small concentrations of unpolymerized TEGDMA in the lower millimolar range are clinically significant[7] and may cause pulp tissue injury.[9]

Although TEGDMA-induced apoptosis in primary human pulp has been reported,[6] the exact molecular mechanisms and the signal transduction pathways through which apoptosis occurs are not clear. The purpose of this study was to determine which anti-apoptotic and pro-apoptotic proteins are involved in TEGDMA-induced apoptosis in human pulp fibroblasts (HPFs). The hypothesis of this study was that TEGDMA will increase the concentrations of pro-apoptotic proteins in the apoptosis extrinsic pathway in HPFs.

MATERIALS AND METHODS

Primary Cell Culture

Human pulp tissues were obtained from extracted healthy impacted wisdom teeth. The use of the teeth was approved by the Indiana University-Purdue University Indianapolis Institutional Review Board. The pulp tissues were removed from the pulp cavities using tweezers after cutting the teeth in half using a high-speed hand piece with a 330 fissure bur and water spray. The fissure bur was changed regularly to avoid heat damage to the pulp tissues. The pulp tissues were then minced with a blade into several fragments measuring approximately 1 mm × 1 mm × 2 mm in size. These fragments were then placed in 100-mm^2 culture dishes and air-dried, and then Dulbecco Modified Essential Media (DMEM) supplemented with 10% fetal bovine serum, 4 mM L-glutamine, 2.5 g/mL fungizone, 100 unit/mL penicillin, and 50 g/mL gentamicin was added.[10] The tissues were maintained at 37°C in a humidified atmosphere of 5% CO_2. The pulp cells that grew out from the tissue fragments were then allowed to reach confluence. Confluent cells were detached with 0.25% trypsin and 0.05% ethylenediaminetetraacetic acid and subcultured as needed. Cells were used at passages 3-8.

Cytotoxicity by Lactate Dehydrogenase (LDH) Assays

Cellular membrane integrity was monitored using the permeability assay based on the determination of the release of LDH from cells into the media. The Cytotoxicity Detection Kit^{PLUS} (Roche Applied Science, Mannheim, Germany), which measures the

conversion of tetrazolium salt into a red formazan product, was used, as described previously.[11] Cells were treated with 0.125, 0.25, 0.50, 0.75, and 1.00 mM of TEGDMA in 100-mm^2 culture dishes with serum-free DMEM for 24 hours. The positive control (total cell death) was generated by adding 1.9 mL of serum-free DMEM and 100 μL of lysis solution to the control cells, as described by the manufacturer, after 24 hours, which resulted in the maximum release of LDH. The negative control consisted of serum-free DMEM from the untreated control cells after 24 hours and gave the minimal release of LDH. Serum-free DMEM without cells was utilized as the background level of the assay. After 24 hours, media from each of the wells was transferred to a 96-well plate and 100 μL of reconstituted mix (per the manufacturer, Roche) was added to each well and the plates were incubated for 15 minutes at room temperature. Absorbance was recorded at 490 nm in a microplate reader (Titertek, Multiskan MCC, Flow Laboratories, McLean, VA, USA). The experiments were repeated five times and the mean value was calculated. The percentage release of LDH from the treated cells was calculated by comparing it to the maximum release of LDH. To determine the cytotoxicity, the absorbance values of the background were subtracted from those of the experimented samples, and the cytotoxicity was calculated by the following equation:

$$\text{Cytotoxicity}(\%) = (\text{experiment value} - \text{low control})/(\text{high control} - \text{low control}) \times 100\%.$$

Cell Treatment with TEGDMA and Preparation of Cell Lysates

HPFs at passages 3-8 were utilized for the Ray Bio Antibody Apoptosis kit (Norcross, GA, USA). HPFs (2×10^5 cells/100-mm dish) were incubated with or without 0.25 mM TEGDMA for six and 24 hours. Cell lysates were prepared per the manufacturer. Briefly, the cells were rinsed twice with cold phosphate-buffered saline. The cells were then solubilized in lysis buffer containing a protease inhibitor cocktail, as per the manufacturer. The cells were then pipetted up and down, and the lysate was rocked gently at 4°C for 30 minutes. The extracts were transferred to tubes and centrifuged at 14,000*g* for 10 minutes and then the supernatant was collected (cell lysate). The protein concentrations of the cell lysates were determined using a Bio-Rad Protein Assay kit (Hercules, CA, USA). All of the lysates were diluted at least fivefold with blocking buffer to the same protein concentration of 200 μg/mL, per the manufacturer.

RayBio Apoptosis Array

A Human Apoptosis Antibody Array kit (Ray Biotech) was used to detect the relative levels of 43 apoptosis-related proteins in the cell lysates according to the manufacturer's instructions. The experiment was repeated four times. The arrays were analyzed with a Gel-Doc XR imaging system (Bio-Rad). Quantity one analysis software (Bio-Rad) was used to analyze the images obtained. Measurements were repeated three times.

Briefly, for the arrays, the treated or untreated cell lysates were added to the antibody array membranes and incubated overnight with rocking at 4°C. After extensive washing, the membranes were incubated with a cocktail of biotin-conjugated anti-antibodies to apoptotic proteins at room temperature for two hours, as per the manufacturer's recommendations. After incubation with horseradish peroxidase–streptavidin at room temperature for an hour and a half, the signals were visualized by chemiluminescence.

Statistical Analyses

Data were reported as mean ± standard deviation (SD). The data were analyzed by one-way analysis of variance followed by Tukey test. Level of significance was $p < 0.05$.

RESULTS

Cytotoxicity Results (LDH)

The LDH assays were performed and the averages with SD determined. TEGDMA at 0.50 mM (p=0.004), 0.75 mM (p=0.000), and 1.00 mM (p=0.000) was significantly higher than the control (Table 1). The highest nontoxic concentration of TEGDMA was 0.25 mM TEGDMA (p=0.806), which then was used for the human apoptosis antibody arrays.

RayBio Apoptosis Array Results

The relative expression of apoptotic proteins (Table 2) that were significantly higher at six hours were B-cell lymphoma-w (Bcl-w, p=0.010), BH3-interacting domain death agonist (BID, p=0.001), Bim (p=0.009), heat shock protein 27 (HSP 27, p=0.022), HSP 60 (p=0.007), HSP 70 (p=0.010), heat shock-inducible protein (HTRA, p=0.001), in-

Table 1: *Lactate Dehydrogenase (LDH) Assays*

Concentration of TEGDMA, mM NC (negative control, 0 mM)	Cytotoxicity ± SD 0 ± 0.00	*p*-Value
0.13	−0.74 ± 0.02	1.00
0.25	1.46 ± 0.01	0.806
0.50	4.96 ± 0.02	0.004*
0.75	10.7 ± 0.02	0.000*
1.00	20.6 ± 0.01	0.000*

Abbreviations: SD, standard deviation; TEGDMA, triethylene glycol dimethacrylate.
** Denotes statistically significant (p<0.05) differences compared to the negative control.*

sulin-like growth factor-1 (IGF-1, p=0.021), insulin-like growth factor binding protein-1 (IGFBP-1, p=0.004), IGFBP-2 (p=0.011), P21 (p=0.016), P27 (p=0.015), and second mitochondria-derived activator of Caspases (SMAC, p=0.018) (Figure 1). All of these were pro-apoptotic proteins. The only anti-apoptotic proteins that were significantly increased compared to the control at six hours were Survivin (p=0.015), IGFBP-5 (p=0.012), and Livin (p=0.006). The pro-apoptotic proteins that significantly decreased compared to the control at six hours were tumor necrosis factor (TNF) ligand superfamily member 6 (FasL, p=0.010), TNF-"β (p=0.046), and TNF-related apoptosis-inducing ligand receptor 2 (TRAILR 2, p=0.003).

At 24 hours, more pro-apoptotic proteins were significantly increased compared to the control than at six hours. These were Bad (p=0.021), Bax (p=0.027), Bcl-w (p=0.017), Bid (p=0.005), Bim (p=0.031), Caspase 3 (p=0.028), Caspase 8 (p=0.028), CD40L (p=0.006), Cytochrome c (Cyto c, p=0.001), IGFBP-5 (p=0.020), IGFBP-6 (p=0.005), cyclin-dependent kinase inhibitor 1 (p21, kip1, p=0.009), P27 (p=0.006), serum TNF receptor 1 (sTNF-R1, p=0.001), sTNF-r2 (p=0.004), tumor necrotizing factor–α (TNF-α, p=0.001), TNF-"β (p=0.003), TRAILR 1 (p=0.016), and TRAILR 2 (p=0.028). The anti-apoptotic proteins that increased significantly compared to the control at 24 hours were Bcl-2 (p=0.005), Livin (p=0.001), Survivin (p=0.001), TRAILR 3 (p=0.039), TRAILR 4 (p=0.010), and IGF-2 (p=0.001). The only anti-apoptotic protein that significantly decreased was HSP 70 (p=0.034). There were no pro-apoptotic proteins that were significantly decreased in their relative expression at 24 hours compared to the controls.

DISCUSSION

The effects of TEGDMA on apoptosis of pulp fibroblasts were examined. First, LDH assays were used to measure cell cytotoxicity. The rationale for using the LDH assays was to verify the concentration at which necrosis starts and to hopefully insure the presence of apoptotic cells rather than necrotic cells. The results showed that TEGDMA had statistically significant cytotoxic effects at 0.5 mM and above. Therefore, 0.25 mM of TEGDMA was used in this study.[7] It was verified by a ss DNA Elisa apoptosis kit (EMD Millipore Corporation, Billerica, MA, USA) that these cells were going through apoptosis at 0.25 mM of TEGDMA (data not shown). The results of this study demonstrated that TEGDMA increases the expression of the multiple pro-apoptotic proteins. There were statistically significant increases in the expression of some pro-apoptotic proteins after six and 24 hrs when compared to the control.

The extrinsic apoptotic pathway is activated through the activation of the transmembrane receptors of the TNF family. Members of the TNF family

Table 2: *RayBio Human Apoptosis Antibody Array*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Pos	Pos	Neg	Neg	Blank	Blank	BAD	BAX	Bcl-2	Bcl-w	BID	BIM	Caspase 3	Caspase 8
2	Pos	Pos	Neg	Neg	Blank	Blank	BAD	BAX	Bcl-2	Bcl-w	BID	BIM	Caspase 3	Caspase 8
3	CD40	CD40L	cIAP-2	Cyto C	DR6	Fas	FasL	Blank	HSP 27	HSP 60	HSP 70	HTRA	IGF-I	IGF-II
4	CD40	CD40L	cIAP-2	Cyto C	DR6	Fas	FasL	Blank	HSP 27	HSP 60	HSP 70	HTRA	IGF-I	IGF-II
5	IGFBP-1	IGFBP-2	IGFBP-3	IGFBP-4	IGFBP-5	IGFBP-6	IGF-1sR	Blank	Livin	p21	p27	p53	SMAC	Survivin
6	IGFBP-1	IGFBP-2	IGFBP-3	IGFBP-4	IGFBP-5	IGFBP-6	IGF-1sR	Blank	Livin	p21	p27	p53	SMAC	Survivin
7	sTNF-R1	sTNF-R2	TNF-α	TNF-"β	TRAIL-R1	TRAIL-R2	TRAIL-R3	TRAIL-R4	XIAP	Blank	Neg	Neg	Neg	Pos
8	sTNF-R1	sTNF-R2	TNF-α	TNF-"β	TRAIL-R1	TRAIL-R2	TRAIL-R3	TRAIL-R4	XIAP	Blank	Neg	Neg	Neg	Pos

Abbreviations: BAD, Bcl-2 antagonist of cell death; BAX, Bcl-2–associated X protein; Bcl-2, B-cell lymphoma 2; Bcl-w, apoptosis regulator Bcl-W; BID, BH3-interacting domain death agonist; BIM, Bcl2 interacting protein BIM; Caspase 8, cysteinyl aspartic acid-protease 8; Cyto c, Cytochrome c; DR, death receptor; Fas, fatty acid synthetase; FasL, fatty acid synthetase ligand; HSP, heat shock protein; HTRA2, High-temperature requirement protein A2; IAP, inhibitor of apoptotic protein; IGF, insulin-like growth factor; IGFBP, insulinlike growth factor binding protein; neg, negative; pos, positive; SMAC, second mitochondria-derived activator of Caspases; TNF, tissue necrotizing factor; TRAIL-R, TNF-related apoptosis-inducing ligand receptor; XIAP, X-linked inhibitor of apoptosis protein.

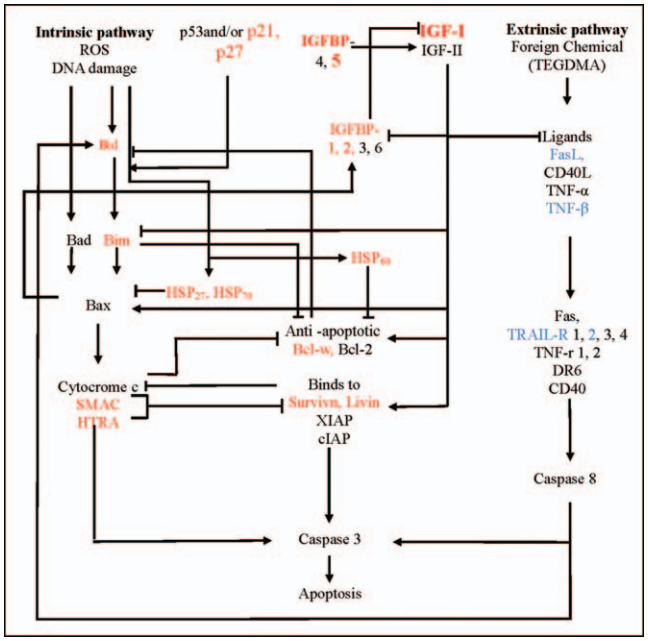

Figure 1. *Induced apoptotic proteins at six hours. Red indicates increases in relative expression, blue indicates decreases in relative expression, and black indicates no change in the relative expression.*

include TNFR 1 and 2, Fas, death receptor (DR) 6, CD40, and TRAIL-R 1-4, which bind to their corresponding ligands (TNF-α, TNF-"β, FasL, CD40L, and TRAIL, respectively). There were statistically significant increases in TNF-α and TNF-"β after 24 hours (Figure 2). TRAIL-R 1 and 2 contain death domains, which mean they are able to induce apoptosis by activating Caspase 8. However, TRAIL-R 3 and 4 are considered to be antagonistic decoys and do not induce death signals.[12] There were statistically significant increases in all of the TRAIL receptors after 24 hours (Table 3). Fas increased slightly when compared to the control at 24 hours, but this increase was not statistically significant. FasL showed a slight increase at 24 hours, but this increase was not statistically significant. However, it showed a statistically significant decrease at six hours (Table 3). This decrease in the expression of FasL could be explained by the presence of anti-apoptotic proteins, which could downregulate FasL.[13]

Iwama and others[14] reported that excessive reactive oxygen species (ROS) production due to arsenic trioxide toxicity resulted in changes in membrane permeability. Arsenic trioxide rapidly induced TRAIL and then activated Caspase 8, which resulted in the phosphorylation of Bid.[14] TEGDMA treatment leading to the production of ROS has been documented in the literature.[15] The current study

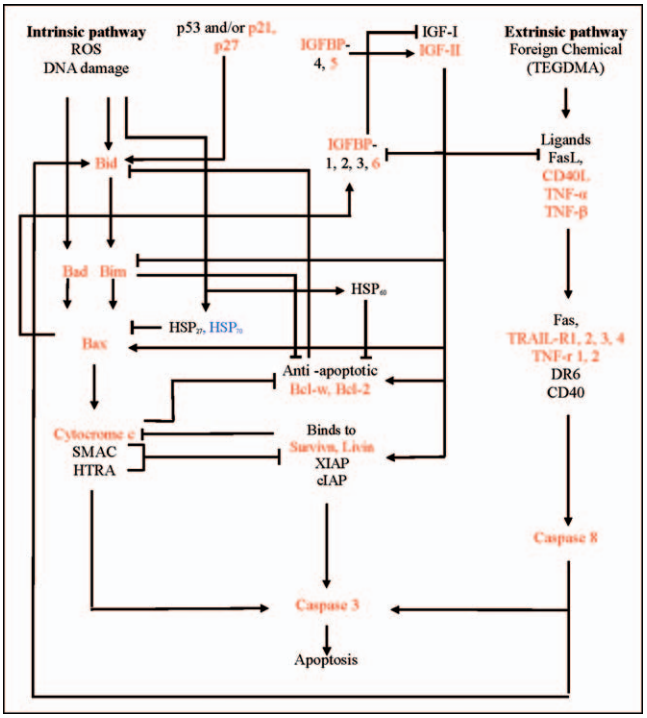

Figure 2. *Induced apoptotic proteins at 24 hours. Red indicates increases in relative expression, blue indicates decreases in relative expression, and black indicates no change in the relative expression.*

showed significant increases in all of the TRAIL receptors at 24 hours (Table 3), which is in agreement with the findings of a previous study.[14] Activation of the extrinsic pathway results in Caspase activation, specifically Caspase 8. The process is induced by two parallel pathways. The first pathway is through the cleavage and activation of Caspase 3, and the second one gets activated when the TRAIL receptors activate the extrinsic pathway. The intrinsic pathway (mitochondrial pathway) gets activated through the activation of the pro-apoptotic protein Bid by Caspase 8.[16,17] In the current study, the Caspase pathway was activated, as is evident by the statistically significant increases in both Caspase 8 and 3 after 24 hours, thus indicating that the extrinsic pathway had been activated (Figure 2). Bid increased significantly after 24 hours and demonstrated that the intrinsic pathway had been activated. Upon Bid activation, Bcl-2 family proteins get activated. The Bcl-2 family includes both pro- and anti-apoptotic proteins. Some of the pro-apoptotic proteins that were increased were Bim, Bax, and Bad. When Bad and Bim are phosphorylated, they become sequestered and enter into the mitochondria, causing the release of Cyto c, SMAC, and HtrA. Bad also binds to anti-apoptotic proteins (Bcl-2 and Bcl-w) and prevents their inhibition of apoptosis.[16,18]

Table 3: *Relative Expression of Apoptotic Proteins and* p-*Values*

Apoptotic Protein[1]	Mean (at 6 h) ± SD	*p*-Value	Mean (at 24 h) ± SD	*p*-Value
BAD	1.65 ± 0.71	0.116	1.57 ± 0.37	0.021*
BAX	1.29 ± 0.38	0.184	1.20 ± 0.17	0.027*
Bcl-2	2.24 ± 0.75	0.046	1.59 ± 0.34	0.005*
Bcl-w	2.11 ± 0.41	0.010*	1.20 ± 0.12	0.017*
BID	2.08 ± 0.53	0.001*	1.17 ± 0.12	0.005*
BIM	1.63 ± 0.54	0.009*	1.21 ± 0.18	0.031*
Caspase 3	1.41 ± 0.48	0.344	1.54 ± 0.28	0.028*
Caspase 8	1.52 ± 0.54	0.557	1.59 ± 0.30	0.028*
CD40	1.19 ± 0.46	0.510	0.83 ± 0.45	0.545
CD40L	0.74 ± 0.38	0.124	1.15 ± 0.07	0.006*
cIAP-2	1.23 ± 0.17	0.905	1.15 ± 0.29	0.335
Cyto c	0.88 ± 0.20	0.174	1.21 ± 0.05	0.001*
DR6	0.89 ± 0.24	0.303	1.02 ± 0.10	0.724
Fas	1.02 ± 0.21	0.792	1.12 ± 0.13	0.108
FasL	0.71 ± 0.22	0.010*	1.12 ± 0.11	0.072
HSP 27	1.91 ± 0.35	0.022*	1.00 ±0.08	0.966
HSP 60	1.20 ± 0.10	0.007*	0.95 ± 0.13	0.355
HSP 70	1.06 ± 0.05	0.010*	0.87 ± 0.13	0.034*
HTRA	1.24 ± 0.23	0.020*	1.16 ± 0.13	0.101
IGF-1	13.22 ± 5.74	0.021*	0.92 ± 0.06	0.147
IGF-2	0.82 ± 0.72	0.681	2.91 ± 0.41	0.001*
IGFBP-1	1.61 ± 0.47	0.004*	1.47 ± 0.49	0.104
IGFBP-2	1.53 ± 0.29	0.011*	1.13 ± 0.20	0.100
IGFBP-3	1.63 ± 0.54	0.113	1.11 ± 0.19	0.288
IGFBP-4	1.89 ± 1.14	0.247	1.01 ± 0.25	0.963
IGFBP-5	1.33 ± 0.19	0.012*	1.23 ± 0.14	0.020*
IGFBP-6	1.60 ± 0.68	0.200	1.41 ± 0.02	0.005*
IGF-1sr	0.97 ± 0.03	0.214	1.55± 0.41	0.036
Livin	2.74± 0.83	0.006*	1.61 ± 0.20	0.001*
p21	1.14± 0.12	0.016*	1.15 ± 0.08	0.009*
p27	2.01± 0.43	0.015*	1.27 ± 0.17	0.006*
p53	0.97 ± 0.18	0.671	1.31 ± 0.15	0.070
SMAC	1.32 ± 0.20	0.018*	1.06 ± 0.12	0.258
Survivin	1.29 ± 0.12	0.015*	1.21 ± 0.10	0.001*
sTNF-r1	0.55 ± 0.48	0.183	1.62 ± 0.02	0.001*
sTNF-r2	1.57 ± 0.39	0.063	2.24 ± 0.37	0.004*
TNF-α	1.01 ± 0.08	0.242	2.25 ± 0.01	0.001*
TNF-"β	0.57 ± 0.20	0.046*	1.53 ± 0.18	0.003*
TRAIL-R1	1.28 ± 0.37	0.257	1.42 ± 0.06	0.016*
TRAIL- R2	0.78 ± 0.14	0.003*	1.20 ± 0.07	0.028*
TRAIL-R3	1.00 ± 0.20	0.944	1.64 ± 0.36	0.039*
TRAIL-R4	1.39 ± 0.35	0.068	1.31 ± 0.13	0.010*
XIAP	1.15 ± 0.24	0.259	1.15 ±0.14	0.074

Abbreviation: SD, standard deviation.
[1] Reference abbreviation footnote for Table 2 for definition of terms.
** Denotes statistically significant (p<0.05) differences compared to the control.*

The interactions between the pro- and anti-apoptotic proteins result in no inhibition of apoptosis and thus cause depolarization of the mitochondria. Depolarization of the mitochondria results in increases in the permeability of their membranes, thus releasing more pro-apoptotic factors, such as SMAC, HtrA, and Cyto c. This study showed significant increases in some of the Bcl-2 family members that are involved in the intrinsic pathway. Bid and Bim (pro-apoptotic proteins of the Bcl-2 family) were both significantly increased at six (Table 3) and 24 hours (Table 3). Bcl-w (anti-apoptotic protein) was also significantly increased at six and 24 hours. SMAC and HtrA are two pro-apoptotic proteins that are released upon activation of the intrinsic pathway. These two pro-apoptotic proteins promote apoptosis through binding to the cIAP anti-apoptotic protein and prevent its attribution to apoptosis.[19] SMAC and HtrA were increased significantly at six hours (Table 3) and increased slightly at 24 hours, but the increases were not significant.

Another important pro-apoptotic protein that is released from the mitochondria upon the activation of the intrinsic pathway is Cyto c. Cyto c activates Caspase 9 and then Caspase 9 activates Caspase 3. Cyto c was statistically significantly (p=0.001) increased compared to the control at 24 hours (Table 3).

Members of the HSP family are overexpressed under biological stress such as heat or when treated with toxic materials. Their general function is to prevent cellular protein aggregation and to increase levels of reduced glutathione to protect the cell from ROS.[20] HSP 27 and 70 are anti-apoptotic proteins, while HSP 60 is a pro-apoptotic protein. The current study agrees with that of Noda and others,[7] which showed that TEGDMA inhibits the phosphorylation of HSPs, thereby decreasing their levels. The current study showed that there was activation of HSP 70 and that its increase was statistically significant at six hours (Table 3), but its level at 24 hours was decreased significantly (Table 3), which indicated that the anti-apoptotic effects of HSP 70 were counteracted. As for HSP 60, there was a slight decrease at 24 hours, yet it was not significant statistically. HSP 27 was unaltered.

IGF-1 plays an important role in the cell survival pathway and inhibits apoptosis. IGF-1 activation causes induction of two major signaling pathways: the phosphatidylinositol-triphosphate kinase/AK-Transforming (PI3K/AKT) pathway and the mitogen-activated protein kinase (MAPK) pathway.[21] This leads to lower concentrations of pro-apoptotic

proteins like Bax and Bad but increases the expression of anti-apoptotic proteins like Bcl-w. These pathways tend to inhibit Caspases, especially Caspase-3.[21] Spagnuolo and others[6] showed that AKT is a main target in TEGDMA-induced apoptosis. The current study showed significantly higher levels of IGF-1, especially after six hours. These results are in an agreement with those of Spagnuolo and others,[6] since IGF-1 activates the PI3K/AKT pathway. However, IGF-1 expression at 24 hours slightly decreased. One of the signs of apoptosis is a decrease in IGF levels.

IGFBPs have been described to have both pro- and anti-apoptotic effects. The effects of IGFBP-5 are variable depending on the tissue and cell type.[22,23] IGFBP-5 was shown to be anti-apoptotic in gingival fibroblasts.[22] However, in the current study, the increase of IGFBP-5 at 24 hours may have led to activation of Caspase 3. The increase of Caspase 3 is an important sign of apoptosis activation.[24] This study also showed increased levels of IGFBP-6. IGFBP-6 is associated with the apoptotic pathway c-jun N-terminal kinase (JNK) activation and the inhibition of nuclear factor kappa B (NFkappaB). Both of these pathways were shown by Samuelsen and others[15] to be involved in TEGDMA-induced apoptosis. The current study showed a significant increase ($p=0.005$) in the expression of IGFBP-6 in comparison to the control at 24 hours.

There are several reports about TEGDMA causing genotoxicity and cell-cycle delay.[25] The p21 and p27 proteins are cell cycle regulators. The tumor suppressor protein p53 is the main regulator of p21. Krifka and others[26] showed that there was a slight increase in p53 expression, while there was a noticeable increase in the expression of p21. This study agrees with their findings in that significant increases in p21 occurred at six hours and 24 hours. However, p53 showed a slight increase at 24 hours only and was not significant.

IAP proteins are Caspase inhibitor proteins. Survivn, Livin, XIAP, and cIAP are members of this family. It has been shown[13] that XIAP has a high affinity for Caspase 3 and tries to inhibit apoptosis once it is started. SMAC and HtrA (mitochondrial pro-apoptotic proteins) are known to bind to these IAP inhibitory apoptotic proteins and inhibit their functions.[13] Survivin and Livin significantly increased at six ($p=0.015$ and $p=0.006$, respectively) and 24 hours ($p=0.001$ and $p=0.001$, respectively). However, these increases were not enough to inhibit apoptosis. Caspase 8 and Caspase 3 were both activated at 24 hours, indicating that the apoptotic process was still continuing.[13]

This current study showed that TEGDMA activated apoptosis within 24 hours. The extrinsic pathway at 24 hours was clearly activated and appears to be activated through the activation of members of the TNFR family. The activation of the intrinsic pathway started at six hours, but it seems to be further amplified at 24 hours. Bax and Cyto c are essential pro-apoptotic proteins for the intrinsic pathway. However, Bax and Cyto c were not activated until the extrinsic pathway was also activated. Both the extrinsic and intrinsic pathways play a role in inducing apoptosis in TEGDMA-treated HPFs.

CONCLUSIONS

The results of this study showed significant increases in multiple examined pro-apoptotic proteins, and several anti-apoptotic proteins were also altered. Pro-apoptotic proteins involved in the intrinsic (mitochondrial) pathway were significantly increased after six and 24 hours. Numerous pro-apoptotic proteins of the extrinsic pathway were activated at 24 hours. The activation of these pro-apoptotic proteins in the extrinsic pathway seemed to amplify some of the intrinsic pro-apoptotic proteins at 24 hours. More pro-apoptotic proteins in the intrinsic pathway were activated at 24 hours than at six hours. TEGDMA had effects on both the extrinsic and intrinsic apoptotic pathways. Additional research is needed to elucidate the net effects of this apoptotic process on the pulp tissue and to find ways to prevent or even reverse this process, if possible.

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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Influence of Fiber Inserts, Type of Composite, and Gingival Margin Location on the Microleakage in Class II Resin Composite Restorations

V Dhingra • S Taneja • M Kumar
M Kumari

Clinical Relevance

Using low-shrink composites and placing the gingival margin in enamel resulted in a significant reduction in microleakage in Class II resin composite restorations, thus probably improving clinical outcomes. Conversely, the use of fiber inserts had no influence on microleakage in Class II resin composite restorations.

SUMMARY

This study evaluated the influence of fiber inserts, type of composites, and location of the gingival seat on microleakage in Class II resin composite restorations. Fifty noncarious human third molars were selected for the study. Standardized Class II box type cavities were prepared on the mesial and distal side of 45 teeth. The gingival margin was placed above the cementoenamel junction (CEJ) on the mesial side and below the CEJ on the distal side. The remaining five teeth received no cavity preparations. The prepared samples were divided randomly on the basis of type of composite and presence or absence of fiber inserts, into four experimental groups of 10 teeth each and two control groups of five teeth each. The groups were defined as follows: group I (n=10) – Z350 XT; group II (n=10) – Z350 XT with fibers; group III (n=10) – P90; group IV (n=10) – P90 with fibers; and group V (n=5) – positive controls, cavities were not restored; group VI (n=5) – negative controls, no cavities were prepared. The samples were stored in distilled water in incubator at 37°C for 24 hours and then subjected to 500 cycles of

Varun Dhingra, MDS, Department of Conservative Dentistry & Endodontics, ITS-CDSR, Murad Nagar, Ghaziabad, Uttar Pradesh, India

*Sonali Taneja, MDS, Department of Conservative Dentistry & Endodontics, ITS-CDSR, Murad Nagar, Ghaziabad, Uttar Pradesh, India

Mohit Kumar, MDS, Department of Conservative Dentistry & Endodontics, ITS-CDSR, Murad Nagar, Ghaziabad, Uttar Pradesh, India

Manju Kumari, MDS, Department of Conservative Dentistry & Endodontics, ITS-CDSR, Murad Nagar, Ghaziabad, Uttar Pradesh, India

*Corresponding author: Uttar Pradesh 201206, India; e-mail: drsonali_taneja@yahoo.com

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thermocycling (5°C and 55°C) with a dwell time of 15 seconds. They were then placed in a 2% methylene blue dye solution for 24 hours at 37°C. Samples were sectioned longitudinally and evaluated for microleakage at the occlusal and gingival margin under a stereomicroscope at 20× magnification. Kruskal-Wallis and Mann-Whitney U-tests were used to compare the mean leakage scores. Restorations with gingival margins in enamel showed significantly less microleakage. Significant reduction in microleakage was observed in groups restored with P90 composite than those restored with Z350 XT. No improvement in microleakage was observed with the use of fiber inserts ($p>0.05$).

INTRODUCTION

Adhesion in dentistry has greatly expanded the horizon of esthetic dentistry. The resin composite materials have evolved in their properties. Superior esthetics, excellent workability, increased flexural modulus, and depth of cure have licensed their use in posterior teeth with greater reliability today, but they may still be unsuccessful clinically due to wear, poor strength, technique sensitivity, bond deterioration with time, polymerization shrinkage, and inadequate polymerization, especially in the gingival areas of Class II restorations.[1]

One of the major disadvantages of resin composites is polymerization shrinkage. This shrinkage results in the production of internal and interfacial stresses leading to gap formation at the tooth restoration interface leading to microleakage. A powerful tool to prevent this problem is adequate bonding of the resin composite to the cavity walls. If such bonding can be achieved, gap formation can be prevented.[2]

This problem is more pronounced when the margins of the resin restoration are in dentin/cementum. Due to their higher organic content, dentin and cementum are less favorable substrates for bonding. Microleakage due to gap formation can lead to a range of problems, like marginal staining, postoperative sensitivity, recurrent caries, and possible loss of the restoration.[3,4]

Efforts have been made to develop methods to prevent microleakage in Class II composite restorations by decreasing the polymerization shrinkage. These include: altering the curing technique[5]; reducing C-factor by following strategic incremental placement techniques[6]; using flowable composites under conventional composites; changing the resin composition, eg, increasing the filler loading of the resin; altering the filler particle size and shape; adding prepolymerized fillers; incorporating matrix expanding monomers[7]; and reinforcing composite with fiber inserts.

According to Xu and others,[8] when fiber inserts are placed in Class II composite restorations, they increase the quality of the marginal zone in two ways. First, the fibers replace the part of the composite increment at this location, which results in a decrease in the overall volumetric polymerization contraction of the composite. Second, the fibers assist the initial increment of the composite to resist pull-away from the margins towards the light source. The fibers may also have a strengthening effect on the composite margin, which may increase resistance to dimensional change or deformation that occurs during thermal and mechanical loading, thus, improving marginal adaptation.

Research in increasing the filler loading of the resin has led to the development of nanocomposites. The properties of nanocomposites seem to be equivalent or sometimes even better than hybrid composites and significantly better than microfilled composites.[9] According to the manufacturer, Z350 XT is a recently introduced resin composite based on nanotechnology, which provides excellent wear resistance, high tensile strength, and compressive strength to fracture.

Recently, Weinmann and others[7] described the synthesis of a promising new monomer system, ie, silorane, which is obtained from the reaction of oxirane and siloxane molecules. P90 is a recently introduced silorane-based low-shrink resin composite. According to the manufacturer, it is the first composite that shrinks less than 1%. It has excellent compressive strength, high flexural strength, and good wear resistance.

Over the past few years, new dental products containing glass, polyethylene, quartz carbon, or other fibers have been made available. These products are meant to improve the mechanical properties of the materials and provide extended applications for resin composites.

Glass fibers have demonstrated their ability to withstand tensile stress and stop crack propagation in composite material.[10] everStick NET fibers are silanated E-glass fibers impregnated with bisphenol A-glycidyl methacrylate and polymethyl methacrylate. everStick NET has a unique interpenetrating polymer network that provides it superior bonding

Table 1: *Manufacturers and Composition of the Materials Utilized in the Study*

Products	Type	Composition	Manufacturer
Filtek Z350 XT	Nanocomposite	Organic matrix: Bis-GMA, UDMA, Bis-EMA 6, and small quantities of TEGDMA	3M ESPE, St Paul, MN, USA
		Inorganic particle: nonagglomerated nanoparticles of silica with a size of 20 nm and nanoagglomerates formed of zirconium/silica particles ranging from 0.6 to 1.4 mm in size, 78.5% by weight (59.5% by volume)	
Filtek P90 (silorane)	Matrix expanding composite	Silane treated quartz 60%-70%; yttrium trifluoride 5%-15%; Bis-3,4-epoxycyclohexylethyl-phenyl-methylsilane 5%-15%; 3,4-epoxycyclohexylcyclo-polymethylsiloxane 5%-15%	3M ESPE, St Paul, MN, USA
everStick NET	Glass fiber	E-glass (electric glass, silanated), bis-GMA, and PMMA	Stick Tech, Turku, Finland

Abbreviations: Bis-EMA, ethoxylated bisphenol -A dimethacrylate; Bis-GMA, bisphenol -A glycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate; PMMA, polymethyl methacrylate.

properties. No study has evaluated the effect of embedding glass fibers in silorane-based low-shrink composites on microleakage in Class II restorations.

The aim of this study was to evaluate the influence of fiber inserts, type of composites, and location of gingival margin on microleakage in Class II resin composite restorations.

MATERIALS AND METHODS

Ethical committee clearance was obtained for performing this study. Fifty non carious human third molars that were freshly extracted were used in this study. Residual soft tissue was carefully removed with the help of ultrasonic scaler, and teeth were carefully examined to rule out any preexisting cracks. The teeth were then stored in distilled water with thymol crystals until use. The manufacturers and components of the materials utilized in this *in vitro* study are presented in Table 1.

Forty-five teeth were randomly selected and standardized Class II box-type cavities were prepared on mesial and distal sides of teeth using a straight fissure bur in a high-speed handpiece. No cavities were prepared on the remaining five teeth.

The dimensions of the cavities were buccolingual width of 2 mm and axial depth of 1.5 mm. The dimensions of the cavities were gauged using the periodontal probe and a customized straight probe with a 1.5-mm marking. The gingival seat was placed 1 mm above the cementoenamel junction (CEJ) on the mesial side and 1 mm below the CEJ on the distal side of each tooth.

Of 45 teeth that received cavity preparation, 40 teeth were randomly assigned for the experimental group and five for the positive control group. The teeth that did not receive any cavity preparation were assigned as negative controls.

The teeth in the experimental group were then randomly divided into four groups as follows:

- Group I (n=10): Samples were restored with packable composite Filtek Z350 XT.
- Group II (n=10): Samples were restored with packable composite Filtek Z350 XT reinforced with everStick NET fibers.
- Group III (n=10): Samples were restored with low-shrink composite Filtek P90.
- Group IV (n=10): Samples were restored with low-shrink composite Filtek P90 reinforced with ever-Stick NET fibers.
- Group V: Positive control (n=5), the cavities were not restored.
- Group VI: Negative control (n=5), no cavities were made.

The cavity on the mesial and distal side of all samples was acid etched for 15 seconds and then rinsed with water from the three-way syringe and gently dried using a moist cotton pellet. The intensity of the quartz-tungsten-halogen (QTH) light was set at 600 mW/cm^2 and was verified with the built-in radiometer. Dentin bonding agent (Adper Single Bond 2) was applied with the help of a microbrush and light cured for 10 seconds from the occlusal aspect. Before restoration, universal Tofflemire band and retainer was positioned. Approximately a 1-mm

increment of the resin composite was first placed on the gingival floor with the help of a Teflon-coated composite instrument and light cured for 40 seconds from the occlusal aspect. The second increment was added along the buccal wall in an oblique direction and light cured for 40 seconds. The third increment was placed along the lingual wall obliquely and light cured for 40 seconds. The final increment was added to fill the remainder of the cavity and light cured for 40 seconds. The intensity of the QTH light was verified after restoration of each cavity.

In the samples of groups II and IV, after acid etching and application of the bonding agent, a 1-mm increment of the resin composite was placed on the gingival floor. Then, a 1.5 × 2.0 mm piece of everStick NET fiber was placed onto the composite increment and condensed through it to adapt it against the gingival floor, displacing the composite to fill into the corners of the box. It was then light cured for 40 seconds from the occlusal aspect. The rest of the cavity was restored as described above.

All of the specimens were then stored in distilled water in an incubator at 37°C for 24 hours. The teeth were then subjected to thermocycling (5° to 55°, 500 cycles) with a dwell time of 15 seconds in electronically maintained water baths.

Light-cured glass ionomer cement (Fuji 2 LC, GC Corporation, Tokyo, Japan) was then applied on apices of all the teeth and light cured for 40 seconds to seal the apices.

In the samples of groups I to V, two coats of nail varnish were applied on the teeth leaving a 1-mm window all around the gingival margin. The teeth in group VI (negative controls) were coated with two coats of nail varnish around the entire surfaces. The teeth were then immersed in 2% methylene blue dye solution for 24 hours at 37°C.

After removal from the dye, the specimens were rinsed thoroughly in tap water. The teeth were then sectioned longitudinally along the mesiodistal plane, cutting through the center of the mesial and distal cavities using a low-speed diamond disc.

The extent of dye penetration at the gingival margin on both sides was evaluated by examination under a stereomicroscope at a magnification of 20× (Olympus, Spectro Analytical Laboratory, New Delhi India), according to a six-point scale: 0 = no leakage, 1 = leakage extending to the outer half of the gingival floor, 2 = leakage extending to the inner half of the gingival floor, 3 = leakage extending through the gingival floor up to one third of the axial wall, 4 = leakage extending through the gingival wall up to two thirds of the axial wall, and 5 = leakage extending through the gingival wall up to the DEJ level.

The results were statistically analyzed using SPSS version 10.0. The scoring was done using an ordinal scale; hence, a nonparametric evaluation plan was adopted. Kruskal-Wallis test (nonparametric analysis of variance [ANOVA]) was carried out to compare leakage scores of different groups (type of composites and with and without fiber reinforcement). To verify whether the location of the gingival margin would influence the marginal leakage scores, regardless of the type of composites and fiber reinforcement, the Mann-Whitney U-test was used to compare enamel and dentin margins. Multiple linear regression analyses was applied to quantify the effect of independent variable factors on leakage score. A p-value of < 0.05 has been considered statistically significant.

RESULTS

The mean dye penetration and its standard deviation along with its number of observation in each experimental group were compared, and the results are tabulated in Table 2. All of the negative controls invariably had a score of 0 (minimum score) at both locations, while all positive controls invariably had a score of 5 (maximum score) at both locations; hence, intergroup comparison was restricted to the test groups only.

P90 (low-shrink composite) provides a significantly better marginal seal than Z350 XT (nanocomposite) in Class II resin restorations. Composites (Z350 XT and P90) with fiber inserts performed slightly better than composites without fibers; however, the difference was statistically insignificant. Restorations having gingival margins in enamel showed significantly less microleakage than those having gingival margins in cementum.

In the present study, of the three variables, the type of composite had the greatest influence on the microleakage, followed by the location of the gingival margin. Reinforcing the composite with glass fibers had the least effect.

DISCUSSION

The greatest limitation in the use of composite restoration as a posterior restorative material seems to be shrinkage during polymerization, which leads to poor marginal seal and microleakage.[11] This problem is more conspicuous when the gingival margins of the tooth preparation lie below the

Table 2: *Mean ± SD and Statistical Comparison Between Groups*[a]

Groups	Dye Penetration Leakage			Statistically Significant Difference Between the Groups							
	N	Mean	SD	Z350/EM	Z350/CM	Z350+FI/EM	Z350+FI/CM	P90/EM	P90/CM	P90+FI/EM	P90+FI/CM
Z350/EM	10	3.1	0.568	1	.014	0.57	—	<0.001	—	<0.001	—
Z350/CM	10	4.0	0.667		1	—	0.57	—	0.001	—	<0.002
Z350+FI/EM	10	2.9	0.738			1	0.012	<0.001	—	<0.001	—
Z350+FI/CM	10	3.9	0.738				1	—	<0.002	—	<0.001
P90/EM	10	1.4	0.516					1	<0.001	0.075	—
P90/CM	10	2.7	0.675						1	—	0.070
P90+FI/EM	10	0.8	0.632							1	0.036
P90+FI/CM	10	1.8	1.033								1

Abbreviations: CM, cementum margin; EM, enamel margin; FI, fiber inserts.
[a] $p < 0.05$ *considered statistically significant.*

cementoenamel junction. Microbial microleakage, an important sequel of polymerization shrinkage has been identified as a major factor in the pulpal reaction to composite resin restorations.[12]

For evaluation of microleakage, the 2% methylene blue dye penetration method was used in this study because it is a simple and inexpensive technique and has shown better penetration results than eosin or the radioisotope tracers Ca and labelled calcium chloride, c-labeled urea, and I-labeled albumin.[13,14] Methylene blue has a low molecular weight, and its molecular size is smaller compared to the diameter of dentinal tubules (1-4 μ) as well as bacteria (2-4 μ), allowing it to penetrate easily into the dentinal tubules, mimicking the passage of bacterial toxins into the dentinal tubules.[15]

In this study, greater microleakage was observed for the restorations with margins in cementum than for the restorations with margins in enamel. This finding is in accordance with the results of Araujo and others[1] and Tredwin and others[16] who reported that restorations with margins in cementum/dentin leaked significantly more than those with margins in enamel**.** The variation in the microleakage of enamel and cementum margin can be explained by the structural differences in the substrate. Dentin and cementum present a higher percentage of water and organic material than enamel, which makes it difficult to obtain a consistent adhesion capable of resisting the negative effects of polymerization shrinkage and the subsequent mechanical and thermal stresses.[1] Moreover, in clinical scenarios, the hydration level and the movement of dentinal tubular fluids may also interfere with the bonding of the resin composite with dentin.[17]

In the current study, the use of fibers did not significantly improve the microleakage scores, which is in accordance with the results of Tani and others,[18] Donly and others,[19] and Applequist and Meiers.[20] They found no significant improvement in microleakage with the use of glass inserts in Class II composite restorations.

However, the present finding is contrary to the results of Ozel and Soyman[21] who demonstrated significantly less dye penetration in restorations reinforced with fibers than restorations without fibers. The difference in the results of their study and the present study could be because glass fibers in their study were adapted through a flowable composite increment placed on the gingival seat, which could have improved the adaptation of the fibers to the cavity walls.

Results contradictory to the present study have also been reported by El-Mowafy and others[10] and Basavanna and others.[22] In their studies, they demonstrated significant reduction in dye penetration when glass fibers were used to reinforce a packable composite, P60. This difference could be because of the different type of composite used in their study.

Low-shrink composite P90 demonstrated significantly less microleakage than Z350 XT in the present study. This is in agreement with a study of Bagis and others[23] who compared silorane with nanohybrid composite (Gradio) and found silorane-based microhybrid composite to have no microleakage. Papadogiannis and others[24] and Bogra and others[25] also reported that silorane material showed better behavior than dimethacrylate materials in setting shrinkage and marginal adaptation. The probable reason for this may be attributed to difference in filler loading,[24,26,27] filler size,[24,27] or volumetric polymerization shrinkage.[25]

P90 composite is a silorane-based composite. It polymerizes by a cationic ring opening mechanism. Such a polymerization is attributed as "living" or "dark" polymerization. The reactive species in such a reaction do not extinguish as quickly as the free radicals contained within methacrylate-based resins. This results in slower rates of polymerization allowing stress relaxations during composite polymerization, thereby reducing polymerization shrinkage and associated stress.[28] P90 has a net volumetric shrinkage of less than 1%. On the other hand, Z350 XT is a nanocomposite, which has a net volumetric shrinkage of about 1.7%. The silorane-based composites are believed to withstand the fatigue at the tooth restoration interface better than the nanofilled and microfilled composites.

Moreover, Z350 XT has higher filler loading of 78.6% than P90, which has filler loading of 76%.[29,30] The filler load has a positive influence on polymerization shrinkage, but on the other hand, affects polymerization shrinkage strain negatively,[31] which might explain greater microleakage observed with Z350 XT.

CONCLUSIONS

According to the results, it is possible to conclude that:

1) P90 provides a significantly better marginal seal than Z350 XT in Class II resin restorations.
2) Composites with fiber inserts performed slightly better than composites without fibers. However, the difference was not statistically significant.
3) Restorations having gingival margins in enamel showed significantly less microleakage than those in cementum.

Further clinical trials are required to assess the success of low-shrink composites and reinforcement with glass fiber inserts in Class II composite restorations.

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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Etching a Fiber Post Surface with High-concentration Bleaching Agents

MS Menezes • AL Faria-e-Silva • FP Silva
GR Reis • CJ Soares • THS Stape
LR Martins

Clinical Relevance

High-concentration bleaching can etch the post surface and improve bonding of the resin core and resin cement.

Summary

Introduction: **Commonly, resin composites/cements fail to achieve proper bonding to fiber posts when their surfaces have not been previously etched. This study evaluated the effect of the concentration and application mode of hydrogen peroxide on the surface topography and bond strength of resin composite to glass-fiber posts.**

Methods and Materials: **Fiber posts were immersed in 24% or 35% solutions (a high-concentration bleaching agent) of hydrogen peroxide (H_2O_2), or these solutions were applied over the post surface using a microbrush (n=10). Posts without any treatment were used as a control. After etching, the posts were silanated and an adhesive was applied. The posts were positioned in a mold, and a resin composite was incrementally inserted and light-cured. The post/resin assembly was serially sectioned into several beams that were subjected to a tensile bond strength test. The data were subjected to the two-way analysis of variance and Tukey test (α=0.05). The Dunnet's test was used to compare the experimental conditions to the control. The surface topography was analyzed using scanning electronic microscopy.**

*Murilo S Menezes, PhD, DMD, DDS, Federal University of Uberlândia, Department of Operative Dentistry and Dental Materials, Uberlândia, Brazil

André L Faria-e-Silva, DDS, MD, PhD, Federal University of Sergipe, Department of Dentistry, Aracaju, Brazil

Fernanda P Silva, Federal University of Uberlândia, Department of Operative Dentistry and Dental Materials, Uberlândia, Brazil

Giselle R Reis, Federal University of Uberlândia, Department of Operative Dentistry and Dental Materials, Uberlândia, Brazil

Carlos J Soares, DDS, MS, PhD, School of Dentistry, Federal University of Uberlândia, Operative Dentistry and Dental Materials, Brazil

Thiago HS Stape, DDS, MS, State University of Campinas, Department of Restorative Dentistry, Piracicaba, Brazil

Luis R Martins, DDS, MD, PhD, State University of Campinas, Department of Restorative Dentistry, Piracicaba, Brazil

*Corresponding author: Av. Para 1720, Bloco 2B, Campus Umuarama, Uberlândia, MG 38400-902 Brazil; e-mail: murilomenezes@foufu.ufu.br

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Results: **The non-etched post presented a relatively smooth surface without fiber exposure. Except for the application of 24% H_2O_2, the other experimental conditions increased the number of exposed fibers and bond strength in relation to the control. Although immersion resulted in higher values for the 24% H_2O_2 application, the mode of application did not alter bond strength when 35% H_2O_2 was used.**

Conclusions: **The effect of the mode of application of H_2O_2 depended on its level of concentration. A high-concentration bleaching agent improved the bond strength of the resin composite to the post surface, regardless of which mode was used.**

INTRODUCTION

Despite biomechanical advantages, a relatively high rate of failure has been demonstrated in fiber post-retained restorations.[1,2] However, fewer irreparable failures have been associated with fiber posts than with traditional metallic cast posts.[3] Post debonding is one possible failure caused by the complexity of bonding to root canals.[4,5] Another commonly reported failure is fracture of the post and/or core.[6] In addition, debonding increases the risk of fracture.[7] Thus, proper bonding of resin cement to the post and the dentin of the root canal is essential for improving the success of fiber post-retained restorations.

Most failures of post-retained restorations result from debonding, and the cement/dentin interface is the weakest link.[8-10] However, bonding between the fiber post and core buildup composites is also essential to the success of the restoration. The organic component of fiber posts is generally composed of epoxy resin, which has a high degree of conversion and is highly crosslinked.[11,12] Thus, this polymer matrix is virtually unable to react with the monomers of resin cements. Among the various treatments proposed to improve adhesion to the fiber-post surface, silanization has been assessed in several laboratory studies.[13,14] However, silane coupling agents, commonly used in dentistry, react with glass fibers and may not bond well to the organic component.[15] Therefore, treating the post in order to roughen the surface and expose the glass fibers has been suggested; it allows for micromechanical interlocking of the adhesive/cement with the post.[12] In addition, chemical bonding may be established by using silane.[12,15-17]

Among chairside procedures, post-surface treatment with hydrogen peroxide (H_2O_2) is a simple and effective method to improve the bonding of adhesive/cement to the fiber post. Selectively, H_2O_2 removes the surface layer of epoxy resin and exposes the glass fibers,[15,18] resulting in chemical bonding between the adhesive/cement and the exposed fibers due to the ability of silane to couple with hydroxide-covered surfaces (such as glass fibers).[19,20] A previous study demonstrated that immersing a fiber post in a solution of 24% H_2O_2 improves bond strength to the post in one minute, which is a feasible clinical time.[18] Clinically, however, the application of H_2O_2 over the post is more favorable than immersion. Furthermore, limited information is available regarding the use of high-concentration bleaching agents on the post etching commonly available in dental offices.

Thus, the aim of this study was to evaluate the effect of concentrations of H_2O_2, including a high-concentration bleaching agent, and mode of use on the bond strength between resin composite and glass fiber posts. In addition, the surface of fiber posts was evaluated using scanning electronic microscopy (SEM). The null hypothesis tested was that neither the H_2O_2 concentration nor the mode used would affect bond strength.

METHODS AND MATERIALS

Microtensile Bond Strength Test

A glass fiber-reinforced epoxy post system (White Post DC3, FGM, Joinvile, SC, Brazil) was used. Polyvinylsiloxane impression material (Aquasil, Dentsply DeTrey, Konstanz, Germany) molds were obtained to standardize core buildup on the posts. Two plastic plates (10 mm long × 4 mm wide × 1 mm thick) were attached along the post surface; each plate was placed opposite the other, and both were located in the same plane using cyanoacrylate adhesive. The post attached to the plates was centrally positioned into a polyvinyl chloride (PVC) tube (20 mm inner diameter × 15 mm high) (Figure 1A), and the impression material was placed into the tube. The post attached to the plates was removed after polymerization of the polyvinylsiloxane (Figure 1B), leaving a space to insert the post and resin composite (Figure 1C).

A commercially available 35% H_2O_2 bleaching agent (Whiteness HP Max, FGM) or a 24% H_2O_2 solution (Dinâmica, São Paulo, SP, Brazil) was used to etch the posts. The fiber posts (n=10) immersed in the solution/bleaching agent were placed in Eppendorf tubes, or the solution/bleaching agent was applied over the post surface using a microbrush.

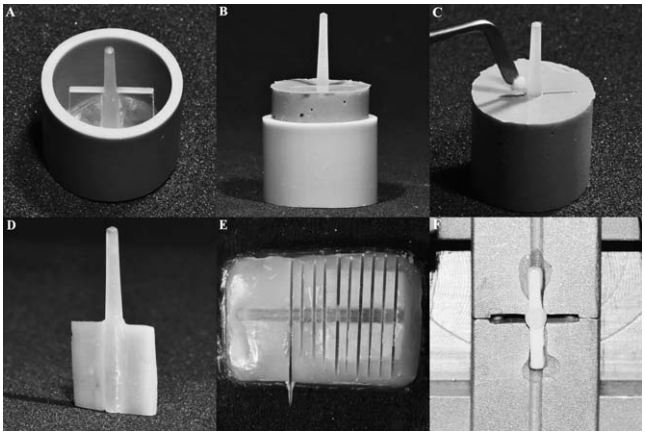

Figure 1. *Illustration of mold and sample preparation. (A): Fiber post with plastic plates attached and positioned into PVC tube. (B): Mold removal from PVC tube. (C): Post positioned into the mold created and insertion of composite resin. (D): Specimen with resin composite bonded to fiber post. (E): Sectioned specimen. (F) Specimen attached to tensile device.*

All etching protocols were performed for one minute. After etching with H_2O_2, the posts were rinsed with distilled water and air-dried. Ten posts were rinsed only with water and used as a control. A silane-coupling agent was applied in a single layer on the post surfaces and gently air-dried after 60 seconds. The adhesive resin Scotchbond Multi-Purpose Plus (3M ESPE, St Paul, MN, USA) was applied over the post surface and light-cured for 20 seconds using a light-emitting diode light-curing device (Radii-Cal, SDI, Bayswater, Victoria, Australia). The post was positioned into the corresponding space of the mold, and a microhybrid resin composite (Opallis, FGM) was incrementally inserted to fill the mold, with each increment being light-cured for 40 seconds. The samples were stored for 24 hours under 100% humidity conditions.

The specimens were serially sectioned using a low-speed saw (Extec, Enfield, CT, USA) to obtain 1-mm thick sections. The beams were attached to the flat grips of a microtensile testing device and tested in a mechanical testing machine (EMIC DL 2000, São José dos Pinhais, PR, Brazil) at a crosshead speed of 0.5 mm/minute until failure. The average value of the beams in the same specimen was recorded as the microtensile bond strength (MPa) for that specimen. Data for the experimental conditions were analyzed using two-way analysis of variance, followed by the Tukey's post-hoc test (α=0.05). The factors evaluated were concentration of H_2O_2 and mode of use. The Dunnet's test was used to compare experimental conditions to control conditions (α=0.05).

Table 1: *Means (SD) for Tensile Bond Strength (MPa)*[a]

	Concentration of H_2O_2	
Mode of Use	**24%**	**35%**
Immersion	18.7 (3.7) Aa*	21.1 (4.1) Aa*
Application	13.4 (3.0) Bb	21.0 (2.8) Aa*

[a] *Distinct uppercase letters in the same line indicate differences between concentrations; distinct lowercase letters in the same column indicate differences between application mode (α = 0.05).*
* *Differs from the control group (11.0 ± 4.1) using Dunnet's test (α = 0.05).*

Surface Topography

Two additional fiber posts per group were used to analyze the surface topography using SEM. After treatment with H_2O_2 (the control did not receive any treatment), the specimens were ultrasonically cleansed for 10 minutes using deionized water, followed by immersion in 96% ethanol for two minutes and air-dried. The posts were coated with gold (MED 010, Bal-Tec AG, Balzers, Liechtenstein) and evaluated by SEM (LEO 435 VP, Nano Technology Systems Division of Carl Zeiss SMT, Cambridge, UK) with magnifications ranging from 80 to 4000×. The microscope operated at 20KV, WD = 10 mm, and spot size ranged from 25 pA to 100 pA. Fiber integrity and homogeneity along the treated surface and at the resin-matrix fiber interface was thoroughly analyzed along the entire post surface extension.

RESULTS

Microtensile Bond Strength Test

The statistical analysis showed a significant effect for concentration of H_2O_2 ($p<0.001$), application mode ($p=0.02$), or the interaction between the factors ($p=0.02$). The results are shown in Table 1. For immersion of the post into H_2O_2 solutions, there was no difference between concentrations, although using 35% H_2O_2 resulted in higher bond strength when the solutions were applied over the post surface. The mode of use did not affect bond strength for 35% H_2O_2. Immersion into the solution resulted in higher values when 24% H_2O_2 was used. Except for the application of 24% H_2O_2, the other experimental conditions resulted in higher bond strength than the control (11.0 ± 4.1 MPa).

Surface Topography

Representative SEM images of each experimental condition and the control are shown in Figure 2. Figure 2A shows epoxy resin covering the glass fibers of the post without treatment and some areas with exposed fibers and flaws. The application of

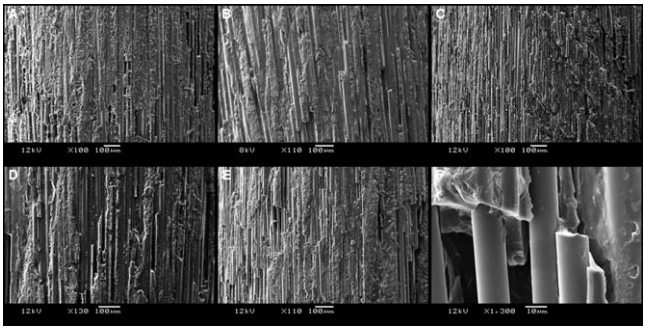

Figure 2. *Analysis of the surface topography by SEM. (A): Without treatment. (B) Application of 24% H_2O_2. (C): Immersion of fiber post into solution of 24% H_2O_2. (D): Application of 34% H_2O_2. (E and F): Immersion of fiber post into solution of 35% H_2O_2.*

24% H_2O_2 on the post surface did not effectively expose the glass fibers (Figure 2B). More exposed fibers were observed when the post was etched by immersion in H_2O_2 (both concentrations) or when 35% H_2O_2 was applied (Figures 2C through 2F).

DISCUSSION

Several studies have evaluated chairside protocols to allow a chemo-mechanical bonding of resin-based material to fiber post surfaces.[12,13,15-18,21-23] Sandblasting procedures with alumina particles[21,22] or aluminum oxide particles modified by silica[23] (Rocatec System, 3M ESPE) increase the roughness of the post surface and permit the mechanical bonding of resin-based materials to the fiber post. The use of Rocatec also allows chemical bonding by silanization due to the presence of the silica-coated surface.[23] However, these devices are not available in some dental offices. Using H_2O_2 over the post surface has also demonstrated mechanical-chemical bonding of resin-based material to the fiber post.[15,18] Frequently, H_2O_2 is available in dental offices as a result of bleaching procedures.

In the current study, fiber-post etching was performed for one minute, which is a feasible clinical time. Furthermore, a previous study demonstrated that immersing a post into 24% peroxide for one minute effectively improves the bond strength of resin composite to the post.[18] However, for this period, the effect of the mode of use of H_2O_2 on the bond strength of resin composite to fiber post was concentration dependent. Thus, the null hypothesis tested was rejected. Only in the case of 24% H_2O_2 did the mode of use affect bond strength, whereas immersing the post into the solution resulted in higher values. The application of 24% H_2O_2 failed to effectively improve bond strength, which showed similar values to the control (without treatment). On the other hand, the mode of use for 35% H_2O_2 did not affect bond strength nor did it improve values compared with the control.

The SEM analysis of the surface topography showed that the 24% H_2O_2 application did not increase the amount of exposed glass fibers. However, all experimental conditions increased the exposure of glass fibers without damaging them. It has been demonstrated that H_2O_2 solutions can partially dissolve epoxy resin, thus exposing the fibers. This dissolution is related to an electrophilic attack of H_2O_2 on the cured secondary amine.[24] The spaces created between the fibers provide conditions for the micromechanical interlocking of the resin adhesive with the post.[15,18] Furthermore, the exposed fibers bond chemically to the adhesive through the silane agent.

Based on the results of the current study, it is reasonable to assume that the ability of H_2O_2 to affect fiber post etching is related to the concentration and the application mode. The etching effect of H_2O_2 is based on oxidation of the post surface, thus breaking epoxy resin bonds.[24,25] Although the oxidizing effect of H_2O_2 depends on the concentration of the radicals that are released, it dissociates and releases oxygen-free radicals, hydrogen-free radicals, water, and peridroxyl.[26,27] A higher H_2O_2 concentration results in a higher oxidizing effect. This explains why 35% H_2O_2 is effective in improving bond strength independent of the application mode.

To the contrary, 24% H_2O_2 increased the bond strength of resin composite to fiber post compared with the control only when the post was immersed in the solution. The application of 24% H_2O_2 resulted in similar values to those observed by the control. A possible explanation is that a single layer of peroxide applied on the post only reacted superficially with the epoxy resin once there was no replacement of radicals by oxidation. This replacement probably occurred when the post was immersed in 24% H_2O_2 solution, thus increasing the potential for etching. Based on the results of this study, the application of high-concentration bleaching agents using a microbrush, which is frequently used in the dental practice for dental bleaching, is a feasible clinical procedure to improve the bond strength of resin composite to glass fiber posts.

It is important to emphasize that the current study only evaluated the bonding of a resin composite to a fiber post, simulating a core buildup. In this instance, an adhesive is applied over the post before the composite is inserted. Further studies are necessary to confirm that this protocol is also

effective for resin cements applied directly over etched posts without using an intermediate adhesive layer. Differences in the composition and viscosity of materials can alter the results.[23] Additionally, high stress generated by shrinkage of the resin cement during fiber-post cementation due the high C-factor of the root canal hinders bonding of the cement to the post.[28] Stability of the bonding obtained with post etching, using a commercial high-concentration bleaching agent, must also be evaluated in future studies. It has been demonstrated that thermal cycling can alter the bond strength of resin-based material to fiber posts.[29]

CONCLUSIONS

Within the limitations of the current study, the following conclusions can be made:

- The mode of use of peroxide affected bond strength of the resin composite only when 24% H_2O_2 was used, where immersion resulted in the highest mean.
- The use of a high-concentration bleaching agent over the fiber post improved bond strength of the resin composite to the post surface.

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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Microleakage of Nanofilled Resin-modified Glass-ionomer/Silorane- or Methacrylate-based Composite Sandwich Class II Restoration: Effect of Simultaneous Bonding

F Shafiei • S Akbarian

Clinical Relevance

One bonding step with SE Bond or Silorane Adhesive with either nano-ionomer or the respective composite could provide adequately sealed restorations in the deep interproximal box with a simplified and time-saving open sandwich technique.

SUMMARY

Objectives: Microleakage of composite restorations at the cervical margin placed apically to the cementoenamel junction (CEJ) is still a concern. This study evaluated the effect of simultaneous bonding application on cervical sealing of nano-ionomer/silorane- or methacrylate-based composite open sandwich Class II restorations in the modified technique compared with that of conventional bonding.

Methods and Materials: In 60 sound maxillary premolars, two standardized Class II cavities were prepared with cervical margins 1 mm below the CEJ. The teeth were randomly divided into six groups of 10 teeth each. In the first three groups (groups 1-3), Clearfil SE Bond and Clearfil APX (Kuraray) were used for restoration in the total bonding technique (group 1), conventional open sandwich technique associated with a nano-ionomer (Ketac N100, 3M ESPE) (group 2), and modified open sandwich technique with simultaneous bonding application for both nano-ionomer and composite (group 3). In the second three groups (groups 4-6), Silorane Adhesive and Filtek Silorane composite (3M ESPE) were used in the same manner as in the first three groups, respectively.

Results: The simultaneous bonding application in the modified sandwich restorations (with SE Bond or Silorane Adhesive) resulted in a significant reduction of the cervical microleakage compared with that of the conventional bonding ($p<0.05$). However, microleakage of the modified technique was similar to that of

*Fereshteh Shafiei, DMD, MS, associate professor, Department of Operative Dentistry, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

Sahar Akbarian, DMD, MS, assistant professor, Department of Operative Dentistry, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

*Corresponding author: Qasre Dasht St., Shiraz, Fars, Iran 7186783694
e-mail: shafief@sums.ac.ir

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the total bonding (with SE Bond or Silorane Adhesive) ($p>0.05$), both showing good marginal seal.

INTRODUCTION

Resin composites have been widely used as a direct restorative material. Despite significant advances in adhesive systems, they are not capable of totally eliminating marginal microleakage, in particular at the gingival margin of deep Class II restorations.[1-3] The stresses induced by polymerization shrinkage, temperature fluctuations, and mechanical load cycling may disrupt the bond between dentin and resin composite, resulting in postoperative sensitivity, bacterial leakage, and secondary caries initiation.[3-5] Moreover, in a deep Class II cavity, effective curing of the first composite increment due to the distance between the light-curing tip and this layer may be a problem if a metal matrix is used.[1,2]

Resin-modified glass-ionomer (RMGI) is a good dentin replacement in such deep cavities; this is referred to as an open sandwich restoration.[6] This technique allows the dentist to benefit from the clinical advantages of RMGI materials, including tri- or dual-cure setting, fluoride release, low coefficient of thermal expansion, greater tolerance to moisture than resin composite, and reduced volume of resin used.[7-9] Furthermore, the high elastic deformation or flow capacity of RMGI during the early stage of setting can act as a stress absorber. This property leads to reduced stress transfer toward the bonding interface.[10] Consequently, improved marginal seal has been reported in several studies.[1,6,9,11,12] In the open sandwich technique, that is highly recommended for patients with a medium or high risk of caries, RMGI is applied on the gingival floor of the proximal box, extending out to the cavosurface margins. This exposure of RMGI to the oral environment may lead to surface deterioration because of the high solubility of RMGI in the oral fluid.[13,14]

In the closed sandwich technique, RMGI is fully veneered by composite.[13-15] However, in the latter technique, correct placement of RMGI short of the gingival cavosurface margin or removal of its excess from this inaccessible area of the cavity is difficult.[15]

Alternatively, a novel, highly packed, nanofilled RMGI, Nano-Ionomer (NI), can be used in an open sandwich technique because of its improved mechanical strength,[16] resistance to biomechanical degradation,[17] and fluoride release comparable to RMGI.[18] Lower polymerization shrinkage and better cervical sealing were reported in Class V NI restorations.[19] When comparing abrasion resistance, NI behaved as an intermediate material between RMGI and nanocomposite.[17] The two-part paste of NI might facilitate its handling properties.[16]

On the other hand, new silorane-containing resin monomers using a combination of siloxane and oxirane have been developed based on cationic ring opening polymerization, resulting in reduced polymerization shrinkage of the hydrophobic composite.[20,21] The combination of NI and silorane composite in an open sandwich restoration may be a viable method to decrease the overall stresses within the whole restoration. The use of nano primer before NI and use of a silorane adhesive system before silorane composite are essential steps to bond these materials to tooth structure.[16,21,22] These separate and double-bonding applications lead to a time-consuming and complicated procedure. In addition, in the case of applying and light curing nano primer, this would possibly interfere with silorane adhesive conditioning before silorane composite placement. Silorane composite should be used solely with its dedicated adhesive.

The results of a recent study revealed that different self-etch adhesives can adequately bond the NI to the dentin, possibly providing simple NI/methacrylate composite sandwich restorations with one bonding step.[23]Again, the use of the same adhesive system (self-etch silorane adhesive) for NI and silorane composite would reduce the clinical application steps and time. Therefore, the present study aimed to investigate the marginal sealing of NI/silorane-based or methacrylate-based composite open sandwich technique with simultaneous bonding application compared with that of the conventional technique in deep Class II restorations.

METHODS AND MATERIALS

Sixty sound human maxillary premolars recently extracted for orthodontic treatments were collected, cleaned, and disinfected in 0.5% chloramine solution for 2 weeks. The teeth were then stored in distilled water at 4°C until use.

Two standardized Class II box-only cavities were prepared on the mesial and distal surfaces of each tooth (3 mm wide, 5-6 mm high, and 1.5 mm deep) with gingival margins placed approximately 1 mm below the cementoenamel junction (CEJ) using new straight fissure diamond burs (ISO 806 314, Hager & Meisinger GmbH, Neuss, Germany) for every five preparations. All dimensions of the preparations were verified with a periodontal probe. The buccal

Table 1: *Materials Used and Their Composition*

Material	Batch No.	Manufacturer	Composition
Silorane adhesive	N213019 N213052	3M ESPE, St Paul, MN, USA	Primer: phosphorylated methacrylates, vitrebond copolymer, bis-GMA, HEMA, water, ethanol, silane-treated silica filler, initiators, stabilizers Bond: hydrophobic dimethacrylate, phosphorylated methacrylates, TEGDMA, silane-treated silica filler, initiators, stabilizers
Clearfil SE Bond	1039AA 1550AA	Kuraray Medical Inc, Okayama, Japan	Primer: MDP, HEMA, hydrophilic dimethacrylate, photoinitiator, water Bond: 10-MDP, bis-GMA, HEMA, hydrophilic dimethacrylate, microfiller, photoinitiator
Ketac N100 Primer	N251185	3M ESPE	HEMA, water, Vitrebond copolymer, photoinitiator
Ketac N100	N271282	3M ESPE	HEMA,vitrebond copolymer, water,TEGDMA, PEGDMA, bis-GMA, fluoroaluminosilicate glass, silane-treated zirconia/ silica, photoinitiators
Silorane composite	N384451	3M ESPE	3,4-epoxycyclohexylethylcyclo polymethylsiloxane;bis-3,4-epoxycyclohexylethyl – phenylmethylsilane; silanized quartz; yttiumfluoride; camphorquinone
Clearfil AP-X	1080AB	Kuraray Medical Inc	BisGMA, TEGDMA silanated glass filler, silanated silica filler, silanated colloidal silica, comphorquinone

*Abbreviations: bis-GMA, bisphenol A diglycidyl ether dimethacryalate; HEMA, 2-*hydroxy*-ethyl-methacrylate; TEGDMA, triethylene glycol diemthacrylate; MDP, 10-methacryloxydecyl dihydrogen phosphate; PEGDMA, polyethylene glycol dimethacrylate.*

and lingual walls of the preparations were approximately parallel to each other and connected to the gingival wall with rounded line angles. All cavity preparations and restorations were performed by one operator. The materials used in this study are shown in Table 1.

The teeth were randomly divided into six groups of 10 teeth each (20 boxes in each group). The same materials and techniques were applied in the mesial and distal boxes of each tooth.

The restoration of the prepared teeth was performed as follows:

- Group 1 (total bonding SE): Primer of Clearfil SE Bond (Kuraray Inc) was applied to the cavity for 20 seconds and gently air dried for 5 seconds. The bond was then applied, thinned with a gentle air steam, and light cured for 10 seconds.
- Group 2 (conventional sandwich, NI primer+NI/ Clearfil SE Bond+methacrylate composite): Nanoionomer primer was applied for 15 seconds, air dried, and light cured for 10 seconds; then, the two pastes were mixed and applied to the gingival floor with approximately 2-mm thickness extending to the periphery of the proximal box. After light curing of NI, Ketac N100 (KN100, 3M ESPE), the remaining cavity walls were treated in the same way as in group 1.
- Group 3 (modified sandwich, simultaneous Clearfil SE Bond application+NI/methacrylate composite): The bonding procedures were the same as in group 1. Then, KN100 was applied as described in group 2.
- Group 4 (total bonding silorane): Primer of silorane adhesive (3M ESPE) was applied to the cavity for 20 seconds and gently air dried for 10 seconds, and the primer was light cured for 10 seconds. The bond was applied and light cured for 10 seconds.
- Group 5 (conventional sandwich, NI primer+NI/ silorane adhesive+silorane composite): The application of NI primer and KN100 was the same as in group 2. After light curing KN100, the remaining cavity walls were treated in the same manner as in group 4.
- Group 6 (simultaneous silorane adhesive application+NI/silorane composite): The bonding steps were done in the same manner as described in group 4. Then, KN100 was applied as performed in group 2.

After this step, a universal Tofflemire matrix retainer (Miltex Inc, York, PA, USA) with matrix band was placed around the tooth. The matrix was tightened and fixed by applying low-fusing compound so that formation of gingival overhang would not be allowed in the restorations. In the first three groups (groups 1-3), Clearfil APX composite-shade A2 (Kuraray Inc) was used; Filtek silorane composite-shade A2 (3M ESPE) was applied in the remaining three groups (groups 4-6), using an oblique incremental technique. Each layer was cured for 20 seconds for Clearfil APX and 40 seconds for silorane composite, according to manufacturers' instructions. All curing steps were done using a light-curing unit (VIP Junior, Bisco, Schaumburg, IL, USA) at 650 mW/cm^2 light intensity. The intensity was checked after every two restorations.

After matrix removal, the completed restorations were finished and polished with Opti-Disk (Kerr Corporation, Orange, CA, USA).The restored teeth were stored in distilled water at 37°C for 1 week to allow for complete acid-base reaction in NI and then

Table 2: *Microleakage Score Frequency in the Six Study Groups*

Group	Microleakage Scores					Mean* (SD)	Median
	0	1	2	3	4		
1. Total bonding SE	13	4	0	3	0	0.65[a] (1.08)	0.0
2. Conventional sandwich SE	3	10	4	2	1	1.40[b] (1.04)	1.0
3. Modified sandwich SE	15	4	0	1	0	0.35[a] (0.74)	0.0
4. Total bonding silorane	18	1	1	0	0	0.30[a] (0.65)	0.0
5. Conventional sandwich silorane	4	6	9	1	0	1.35[b] (0.87)	1.50
6. Modified sandwich silorane	13	7	0	0	0	0.35[a] (0.49)	0.0

** Different superscript letters indicate statistically significant differences among groups.*

thermocycled for 1000 cycles at 5°C to 55°C with a 30-second dwell time.

The root apices were sealed with utility wax, and all the surfaces, except for the restorations and an area 1 mm from the margins, were coated with two layers of nail varnish. The teeth were immersed in a 0.5% methylene blue dye solution for 24 hours. Upon removal from the dye, the teeth were rinsed, blotted dry, and sectioned vertically through the center of the restorations from the mesial to distal surface with a water-cooled diamond saw (Leitz 1600, Wetzlar, Germany)

The sections were blindly examined for dye penetration by two independent evaluators using a stereomicroscope (Carl Ziess Inc, Oberkochen, Germany) at 20× magnification. The extent of the dye penetration was analyzed according to a 0 to 4 scale (0=no dye penetration, 1=dye penetration less than ½ of the gingival wall, 2=dye penetration along the gingival wall, 3=dye penetration along the gingival wall and less than ½ of the axial wall, 4=dye penetration along the gingival wall and axial wall). The worst score from the two sections of each specimen was recorded.

The Kruskal-Wallis test was used to analyze the differences within the groups. Pairwise comparison among different groups was done with Mann-Whitney U-test (α=0.05).

RESULTS

Dye penentration scores in the six groups are presented in Table 2. None of the groups showed complete elimination of microleakage. According to the Kruskal-Wallis test, there was a significant difference in microleakage score among the six groups ($p<0.001$).

Among the first three groups (with methacrylate composite), group 2 (conventional sandwich) revealed significantly higher cervical microleakage than group 1 (SE total bonding) and group 3 (modified sandwich) ($p=0.009$ and $p<0.001$, respectively). There was no significant difference between group 1 and group 3 ($p>0.05$), revealing similar low cervical microleakage in the two groups.

The results of comparing the second three groups (with silorane composite) were similar to those of methacrylate composite groups; group 5 showed a significantly higher microleakage at the cervical margin than groups 4 and 6 ($p=0.001$ and $p=0.009$, respectively). However, no significant difference was found between groups 4 and 6 ($p>0.05$).

Similar groups with methacrylate composite versus silorane composite (group 1 vs group 4, group 2 vs group 5, and group 3 vs group 6) showed no significant difference ($p>0.05$) (Table 2). Examples of the specimens exhibiting different dye penetration scores are presented in Figure 1.

DISCUSSION

Microleakage is one of the major problems affecting the longevity of resin composite restorations. The dye penetration method is the most common and simplest technique for assessing microleakage along adhesive interface.[24] Although correlation between clinical evaluation and *in vitro* dye penetration testing may not be documented, the latter is still a popular and valuable test as a preclinical screening to compare the sealing ability of different adhesive materials and techniques.[25,26]

According to the results of the present study, the best cervical marginal seal was obtained by total bonding with silorane composite, which revealed no significant difference with the total bonding associated to SE Bond. Both conventional sandwich techniques had significantly higher microleakage than that of the respective total bonding. This result contradicts previous studies that reported that the open sandwich technique resulted in similar or better marginal sealing than total bonding.[1,6,9,11,12] This difference can be attributed to the different

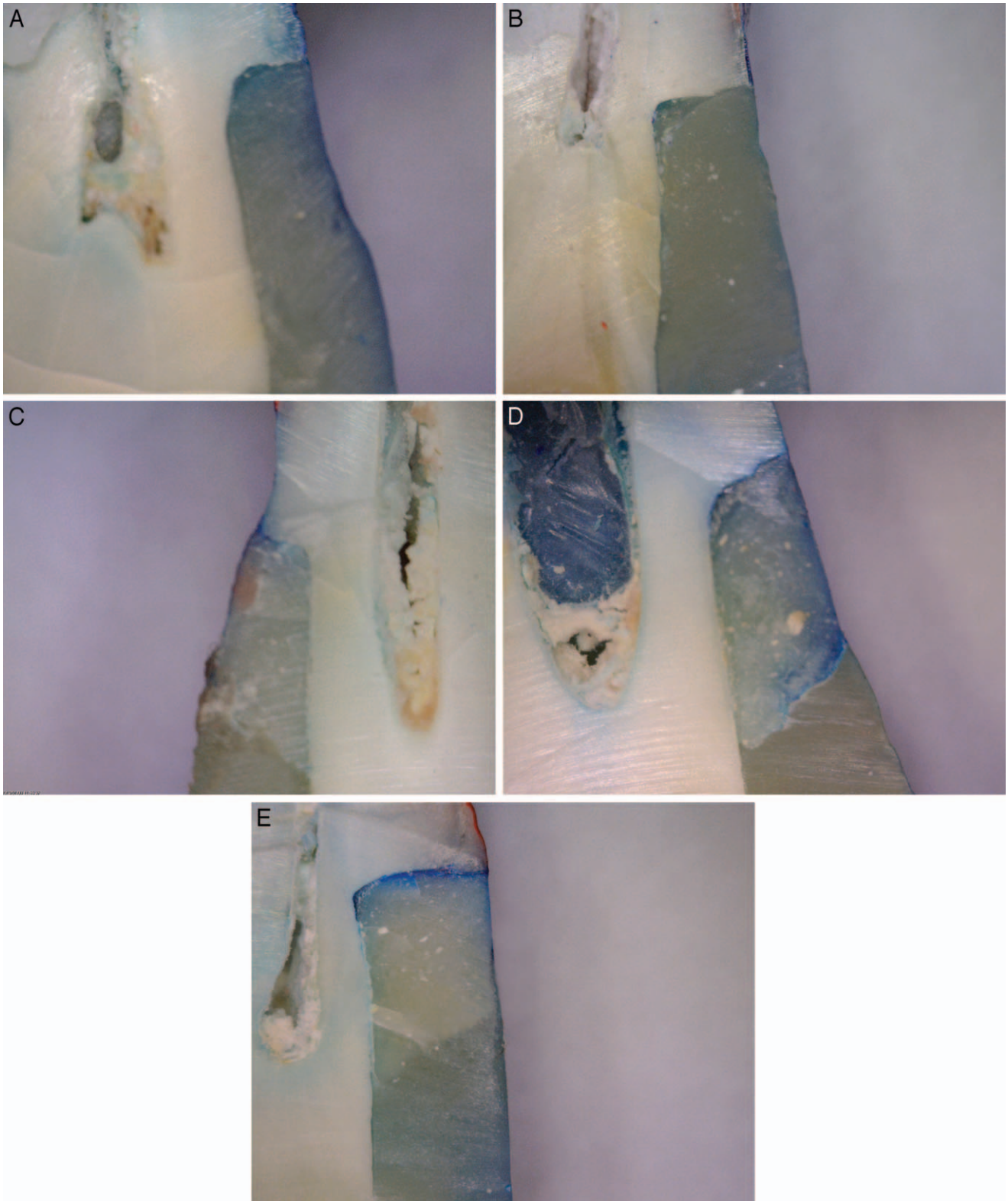

Figure 1. *Examples of the restorations exhibiting different dye penetration scores.(A): Total bonding restoration showing score 0; (B): Modified sandwich restoration showing score 0; (C): Modified sandwich restoration showing score 1; (D): Conventional sandwich restoration showing score 2 with dye penetration at the interface; and (E): Conventional sandwich restoration showing score 3.*

adhesive/composites and RMGI used in these studies. In particular, no study has compared the marginal quality of bonded silorane composite with sandwich restoration or the use of NI in sandwich technique versus total bonding.

So far, only Fahmy and Farrag[27] have recently evaluated microleakage in Class II primary molar cavities restored with NI/silorane or methacrylate nanofilled composite (open and closed sandwich) and total bonding. They found superior marginal sealing with total bonding compared with two sandwich techniques. This result is in agreement with our findings. Also, Beznos[2] concluded that RMGI could not prevent extensive leakage at the cervical margin of open sandwich restorations.

Previously, some authors speculated that the excellent sealing ability of silorane composite might be related to comparatively low volumetric shrinkage and shrinkage stress in this novel resin.[22,28-30] Slower polymerization reaction with the higher potential for stress relief by viscous flow of the molecules was reported to be responsible for this lower shrinkage stress rate and the resultant reduced stress.[20,31,32] Moreover, the bonding efficiency of the associated silorane adhesive system is an important factor.[22,30] The self-etching primer of this two-step adhesive has been recently claimed to create chemical bonding to the remaining hydroxyapatite crystals around collagens.[21] The tight interface at enamel and dentin was obtained via nanointeraction of this ultra-mild self-etch primer (pH=2.7). The separately applied and cured bond layer may contribute to maintaining the sealed interface.[21] On the other hand, somewhat higher but insignificant microleakage was obtained by total bonding with SE Bond/methacrylate compared with silorane adhesive/silorane composite. Again, it is well demonstrated that functional monomer (10-methacryloxydecyl dihydrogen phosphate [MDP]) in self-etch primer might be capable of bonding to the hydroxyapatite crystals.[33] This chemical bonding might lead to better resistance to hydrolytic degradation and improved sealing reported by some authors.[15,34,35]

Methacrylate composite used with SE Bond was applied in an incremental oblique layering technique. This method has been advocated to reduce overall contraction residual stress at the adhesive interface,[28,36] resulting in reduced microleakage by modifying C-factor and decreasing the composite bulk cured in each increment.[22,37] A recent clinical trial found no significant difference between marginal adaptation of silorane adhesive/silorane composite and one-step self-etch adhesive/methacrylate composite.[38]

The findings of the present study indicate that the two modified sandwich techniques using the same adhesive (SE Bond or silorane adhesive) associated with NI substantially improved the marginal sealing of the restorations compared with the respective conventional sandwich approach so that the modified methods exhibited no significant difference from the total bonding ones.

A number of studies have recently demonstrated that the use of different self-etch adhesives could improve the bond strength or marginal sealing of RMGI.[39-43] The acidic conditioners commonly used with RMGI partially demineralize the smear layer and superficial dentin, facilitating the penetration of the 2-hydroxy-ethyl-methacrylate (HEMA) incorporated in the RMGI into the exposed collagen network.[39] The self-etching primer may act in a similar manner, and copolymerization poly-HEMA and hydrophilic monomers of the self-etching adhesive may occur.[40] On the other hand, RMGI can bond very well to the resin layer formed on the surface of self-etch adhesives via unsaturated carbon-carbon covalent bonds upon copolymerization, providing similar results to bonding of resin composites.[41]

KN100 in association with a light-cured primer was used in the conventional sandwich groups. This self-etch primer (pH=3) may create a resin covering on the primed dentin resembling those of mild self-etch adhesives.[42] Nevertheless, the low acidity of the primer may not allow the primer to totally dissolve the smear layer.[16,42]

According to scanning electron microscopy (SEM) evaluations of two recent studies,[16,23] NI interacted very superficially with the dentin without demineralization or hybrid layer formation. The primary bonding mechanism of NI was found to be micromechanical infiltration only into the surface roughness. The secondary one may be a typical polyalkenoic acid copolymer chemical bonding to dentin.

Therefore, it was expected that two self-etch adhesives used with NI in the modified technique could improve the cervical sealing of the restorations. It was recently reported that carboxylic groups of acidic monomers and Vitrebond copolymer in some self-etch adhesives increased the bond strength of NI to the dentin.[23] SE Bond has acidic monomer (MDP) in its primer composition. The ultra-mild self-etch primer of silorane adhesive contained Vitrebond copolymer.[21] This copolymer is also a key component

of NI. These functional monomers contribute to establishing chemical bonding to the dentin and improving the marginal sealing of the modified sandwich restoration examined in this study. The SEM evaluation of these adhesive interfaces is required to detect the real interaction with the dentin.

Although KN100 is a methacrylate-based RMGI, it seems to be compatible with silorane adhesive. The bond of this adhesive creates a hydrophobic methacrylate-based (with phosphate group) layer placed on the cured primer surface, providing bonding to methacrylate resins.[44,45] In the same manner, this resin layer could act between KN100 and silorane composite, and its phosphate group may react with the overlying silorane composite.[45] The compatibility between methacrylate-based composite and silorane adhesive was recently indicated.[44,46]

One possible drawback of the open sandwich technique is the creation of additional interfaces exposed to oral environment in a restoration. In the current study, most of the sandwich restorations showed no dye penetration at the interface of NI/composites; few specimens had slight dye penetration. This observation may be due to the use of the respective adhesive as a bonding layer with high wettability, the low shrinkage composite, and the small increments of the composites applied on NI, achieving a good union between these two materials.[47] The chemical bonding of KN100 and resin layer is accomplished in the presence of unpolymerized HEMA and unreacted methacrylate groups on the poly acid chain.[48]

Although the use of an adhesive layer may somewhat decrease fluoride release from RMGI, fluoride ions could still diffuse through the resin layer.[39] Moreover, this open sandwich technique would take advantage of the cariostatic potential of NI in the proximal surfaces of the adjacent teeth. Further long-term *in vitro* and *in vivo* studies are needed to confirm the obtained results.

CONCLUSIONS

Within the limitations of this *in vitro* study, and based on obtained results, the introduced modified sandwich technique revealed no beneficial effect in terms of cervical sealing compared with the effects of total bonding. However, this technique exhibited significantly lower microleakage than the conventional technique. From a clinical consideration, the modified sandwich technique would facilitate the bonding procedures with simultaneous self-etching adhesive application for both the NI and methacrylate- or silorane-based composite. This simplified combination would provide the benefits of two materials in a single restoration performed in a reduced application time.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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The Role of Resin Cement on Bond Strength of Glass-fiber Posts Luted Into Root Canals: A Systematic Review and Meta-analysis of *In Vitro* Studies

R Sarkis-Onofre • JA Skupien • MS Cenci
RR Moraes • T Pereira-Cenci

Clinical Relevance

There is little clinical evidence on the performance of glass-fiber posts to guide clinical decisions when selecting the cementation strategy. This meta-analysis of *in vitro* studies suggests that the use of self-adhesive resin cement could improve the retention of glass-fiber posts.

SUMMARY

Because there are several ways to cement glass-fiber posts (GFPs) into root canals, there is no consensus on the best strategy to achieve high bond strengths. A systematic review was conducted to determine if there is difference in bond strength to dentin between regular and self-adhesive resin cements and to verify the influence of several variables on the retention of GFPs. This report followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement. *In vitro* studies that investigated the bond strength of GFPs luted with self-adhesive and regular resin cements were selected. Searches were carried out in the PubMed and Scopus databases. No publication year or language limit was used, and the last search was done in October 2012. A global comparison was performed between self-adhesive and regular resin cements. Two subgroup analyses were performed: 1) Self-adhesive × Regular resin cement + Etch-and-rinse adhesive and 2) Self-adhesive × Regular resin cement + Self-etch adhesive. The analyses were carried out using fixed-effect and random-effects models. The results showed heterogeneity in all comparisons, and higher bond

Rafael Sarkis-Onofre, DDS, MSc student, Graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil

Jovito Adiel Skupien, MSc, PhD student, Graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil

Maximiliano Sérgio Cenci, PhD, professor, Graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil

Rafael Ratto de Moraes, PhD, professor, Graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil

*Tatiana Pereira-Cenci, PhD, professor, Graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil

*Corresponding author: R. Gonçalves Chaves 457, Pelotas, RS, 96015-560 Brazil; e-mail: tatiana.cenci@ufpel.tche.br

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strength to dentin was identified for self-adhesive cements. Although the articles included in this meta-analysis showed high heterogeneity and high risk of bias, the *in vitro* literature seems to suggest that use of self-adhesive resin cement could improve the retention of GFPs into root canals.

INTRODUCTION

The use of glass-fiber posts (GFPs) has increased in recent years compared with other types of posts.[1] In addition to their esthetics,[2] GFPs have similar elastic modulus to that of dentin, providing a more homogeneous dissipation of loading stresses to the tooth/cement/post structure compared with more rigid posts.[3] However, the main reason for failure of GFPs is still debonding,[4] which occurs mainly because of the difficulties in achieving proper adhesion to intraradicular dentin. Cementing GFPs into root canals is a clinical challenge because of the complex cementation techniques and high level of technique sensitivity.[1]

Resin-based cements are commonly used for luting GFPs into intraradicular dentin. A combination of the etch-and-rinse adhesive system and regular resin cement is the approach most often used in dental practice.[1,5,6] In the past decade, self-adhesive resin cements were introduced to provide easier clinical application compared with regular resin cements.[7] Despite some clinical studies testing different types of posts reported in the literature,[5,6,8,9] most information about the retention of GFPs cemented with resin cements is available from *in vitro* studies, which have tested several cementation strategies and performed different bond strength tests.[10,11]

Irrespective of recent advances in materials and techniques to make cementation procedures easier, it is important to understand all factors involved in cementing posts, not only the type of resin cement used but also the different approaches attempted to improve bond strength. It is still difficult for clinicians to choose the best and most efficient strategy for luting GFPs. Clinical studies provide little evidence on the performance of GFPs on which to base clinical decisions, leading clinicians to rely on their clinical experience or on data from *in vitro* studies for choosing a cementation strategy. Therefore, pooled *in vitro* data could provide more solid conclusions on which strategy to use.

The aim of this study was to systematically review the literature for *in vitro* studies comparing the bond strength of GFPs cemented with regular and self-adhesive resin cements and to conduct a descriptive analysis to verify the influence of cementation strategies among studies on the retention of GFPs to intraradicular dentin. The hypothesis tested was that no significant difference in bond strength would be detected between GFPs cemented into root canals with regular resin cements or self-adhesive resin cements.

MATERIAL AND METHODS

Search Strategy

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[12] Two electronic databases (Medline and Scopus) were searched to identify articles that met the following inclusion criteria: *in vitro* studies that evaluated and compared the retention (bond strength values in MPa) of GFPs cemented into root canals of human or bovine teeth using both regular resin cement and self-adhesive resin cement.

The following strategy was used for the searches: (glass fiber post) AND (resin cement) AND (bond strength); (glass fiber post) AND (push out); (self* resin cement) AND (glass fiber post) AND (bond strength); (glass-fiber OR glass fiber), and (post) AND (bond* OR adhes*). The same strategy was then performed changing the term post for dowel.

Screening and Selection

No publication year or language limit was used, and the last search was done in October 2012. Reference lists of included studies were hand searched for additional articles. Excluded from the investigation were studies including *in vivo* or *in situ* analyses, studies testing posts other than GFPs (ie, carbon-fiber or metal posts), studies with cementation of posts performed in substrates other than teeth (artificial devices), and studies that did not compare bond strength between the two types of resin cements.

Two independent reviewers first screened the titles identified in the searches. If the title indicated possible inclusion, the abstract was then evaluated. After the abstracts were carefully appraised, articles considered eligible for the review were identified; if there was any doubt, the full text of the article was read. In case of disagreement, a third reviewer decided if the article should be included or not (Figure 1).

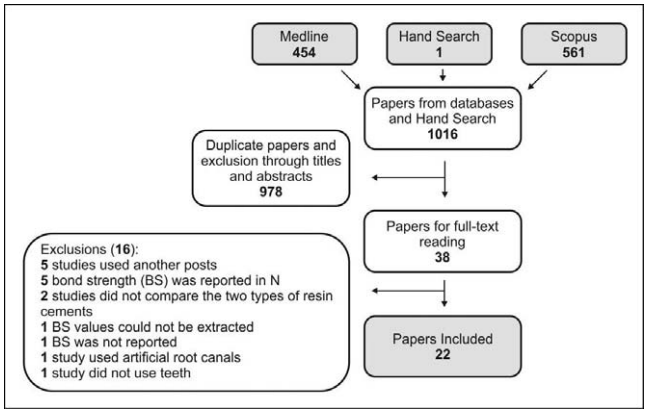

Figure 1. *Selection procedures according to the PRISMA statement.*

Data Collection

Two reviewers extracted all data simultaneously using a standardized outline. To more easily identify variables found in the articles, the authors categorized similar information into two or three groups (eg, cement application mode). In case of measurement of bond strength values for different root thirds (push-out test, for instance), the arithmetic average of the values of the thirds was used. In studies where bond strength test was performed, including other types of cement or post, only the data of interest were extracted.

Assessment of Risk of Bias

Risk of bias was evaluated according to the articles' description of the following parameters for study quality assessment: randomization of teeth, use of teeth free of caries or restoration, use of materials according to the manufacturer's instructions, use of teeth with similar dimensions, endodontic treatment performed by the same operator, description of sample-size calculation, and blinding of the operator of the testing machine. If the authors reported the parameter, the article had a "Y" (yes) on that specific parameter; if it was not possible to find the information, the article received an "N" (no). Articles that reported one to three items were classified as having high risk of bias, four or five items as medium risk of bias, and six or seven items as low risk of bias.

Statistical Analysis

Initially, each possible comparison of the bond strength of regular resin cement and self-adhesive resin cement in each study was carried out; for example, a study using two regular resin cements and four self-adhesive cements resulted in eight possible comparisons. Pooled-effect estimates were obtained by comparing the means of each resin cement and were expressed as the weighted mean difference between groups. A P value $\leq .05$ was considered statistically significant.

Statistical heterogeneity of the treatment effect among studies was assessed using the Cochran's Q test, in which a threshold P value of .1 was considered statistically significant, and the inconsistency I^2 test, in which values greater than 50% were considered indicative of high heterogeneity.[13]

The first global analysis was carried out using a fixed-effect model, and two subgroup analyses were carried out to explore heterogeneity between studies: 1) regular resin cement (etch-and-rinse adhesive) vs self-adhesive resin cement and 2) regular resin cement (self-etch adhesive) vs self-adhesive resin cement. The same analyses were carried out using random-effects models. All analyses were conducted using Review Manager Software version 5.1 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). The influence of cementation strategies among studies on the bond strength of luted GFPs was analyzed using descriptive statistics.

RESULTS

Risk of Bias

Of the 22 studies included, 3 studies presented medium risk of bias and 9 studies showed high risk of bias. The results are described in Table 1, according to the parameters considered in the analysis.

Meta-analysis

Meta-analysis was performed with 23 data sets, although 22 studies were included,[11,14-34] because one study[22] presented two distinct data sets (one from microtensile test and one from push-out test). Characteristics of the 22 studies (23 data sets) are summarized in Table 2. In the global analysis, 148 comparisons were included.

In the first analysis using a fixed-effect model (Figure 2), the self-adhesive resin cements had higher *in vitro* bond strengths (1.25 MPa; $p \leq 0.01$). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 98%. In the subgroup analysis of self-adhesive resin cement vs regular resin cement with etch-and-rinse adhesive, the self-adhesive resin cements had higher bond strengths (0.9 MPa; $p \leq 0.01$). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 98%. In the subgroup analysis of self-adhesive resin cement vs regular resin cement,

Table 1: *Risk of Bias Considering Aspects Reported in the Materials and Methods Section*

	Teeth Randomization	Teeth Free of Caries or Restoration	Materials Used According to the Manufacturer's Instructions	Teeth With Similar Dimensions	Endodontic Treatment Performed by a Single operator	Sample Size Calculation	Blinding of the Operator of the Testing Machine	Risk of Bias
Bitter and others (2009)[11]	Y	N	Y	N	N	N	N	High
Bitter and others (2012)[14]	Y	N	Y	N	N	N	N	High
Calixto and others (2009)[15]	N	N	Y	Y	N	N	N	High
de Durão Mauricio and others (2007)[35]	N	Y	Y	Y	N	N	N	High
Erdemir and others (2010)[19]	Y	Y	Y	N	Y	N	N	Medium
Erdemir and others (2011)[18]	N	N	Y	N	Y	N	N	High
Farina and others (2011a)[16]	N	N	Y	Y	N	N	N	High
Farina and others (2011b)[17]	N	N	Y	Y	N	N	N	High
Goracci and others (2004)[22]	Y	N	Y	N	N	N	N	High
Goracci and others (2005)[21]	Y	N	Y	N	N	N	N	High
Kececi and others (2008)[25]	Y	N	Y	Y	Y	N	N	Medium
Leme and others (2011)[23]	Y	N	N	N	N	N	N	High
Lindblad and others (2010)[24]	Y	N	Y	Y	N	N	N	High
Mumcu and others (2010)[26]	Y	Y	Y	N	Y	N	N	Medium
Radovic and others (2008)[28]	N	N	Y	N	N	Y	N	High
Rathke and others (2009)[27]	N	Y	Y	N	N	N	N	High
Roperto and others (2010)[29]	Y	N	Y	N	N	N	N	High
Sadek and others (2006)[34]	Y	N	N	N	N	N	N	High
Soares and others (2012)[30]	Y	N	Y	Y	N	N	N	High
Xu and others (2011)[32]	Y	N	N	Y	N	N	N	High
Zaitter and others (2011)[31]	Y	N	Y	N	N	N	N	High
Zicari and others (2008)[33]	Y	Y	Y	N	N	N	N	High

Abbreviations: N, no; Y, yes.

the self-adhesive resin cements again had higher bond strengths (1.88 MPa; $p \leq 0.01$). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 96%.

The second global analysis using random-effects model showed no statistically significant difference between groups ($p=0.31$). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 98%. The subgroup analysis of self-adhesive resin cement vs regular resin cement with etch-and-rinse adhesive showed no statistically significant difference be-

Table 2:

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength	
Bitter and others (2009)[11]	37% phosphoric acid	ED Primer (one-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Not found*	24 h of water storage at 37°C	13.3 MPa	
		PermaFlo DC Primers (three-step, etch-and-rinse)	PermaFlo DC (dual-cure, regular)			9.9 MPa	
		Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)			9.5 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			20.4 MPa	
		New Bond (two-step, etch-and-rinse)	Clearfil Core (dual-cure, regular)			14.9 MPa	
Bitter and others (2012)[14]						**Before Aging**	**After Aging**
	.	ED Primer (one -step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post and into the root canal	Stored 7 d in water and after 5000 thermal cycles (58°C/ 558°C, 2 min each cycle) and 1.2 × 106 mastication cycles	13.2 Mpa	3.5 Mpa
	.	Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Around the post and into the root canal	Stored 7 days in water and after 5000 thermal cycles (58°C/558°C, 2 min each cycle) and 1.2 × 106 mastication cycles	13.2 Mpa	4.8 Mpa
	.	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule	Stored 7 days in water and after 5000 thermal cycles (58°C/558°C, 2 min each cycle) and 1.2 × 106 mastication cycles	18.3 Mpa	9.8 Mpa
Calixto and others (2009)[15]						**Quartz-ungsten-halogen unit**	
	37% phosphoric acid + silane + bond	ScotchBond Multi-Purpose (three-step, etch-and-rinse)	RelyX ARC (dual-cure, regular)	Around the post and into the root canal	Stored in distilled water for 24 h at 37°C	9.6 Mpa	
	37% phosphoric acid + silane + bond	ED Primer (one -step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)			8.4 Mpa	
	37% phosphoric acid + silane + bond	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			6.3 Mpa	
						Light-emitting - diode	
	37% phosphoric acid + silane	ScotchBond Multi-Purpose (three-step, etch-and-rinse)	RelyX ARC (dual-cure, regular)			8.8 Mpa	
	37% phosphoric acid + silane	ED Primer (one -step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)			8.2 Mpa	

Table 2: Continued.

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength
	37% phosphoric acid + silane	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			6.3 Mpa
de Durão Mauricio and others (2007)[35]	Ethanol + silane	ED Primer (one -step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post	None	21.8 MPa
		All Bond 2 (three-step, etch-and-rinse)	C&B Cement (self-cure, regular)	.		15.7 MPa
		Multilink Primer (one-step, self-etch)	Multilink (dual-cure, regular)	Around the post		21.9 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		12.2 MPa
		Excite DSC (tqo-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Around the post		22.2 MPa
Erdemir and others (2010)[19]	Ethanol	ED Primer (one -step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post	(TC; 5°C/55°C, 5000 cycles; dwell time, 30 s	9.8 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		8.9 MPa
		Single Bond (two-step, etch-and-rinse)	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		8.1 MPa
Erdemir and others (2011)[18]	Ethanol	ED Primer (one-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post	Distilled water for 7 days at 37°C	8.8 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		9.5 MPa
		No bonding agent used	Maxcem Elite (dual-cure, self-adhesive)	Around the post		8 MPa
		Adper Prompt L-Pop (one-step, self-etch)	RelyX Unicem (dual-cure, self-adhesive)	Around the post		9.9 MPa
		Obtibond all-in-one (one-step, self-etch)	Maxcem Elite (dual-cure, self-adhesive)	Around the post		8.2 MPa
Farina and others (2011a)[16]	37% phosphoric acid for 5 s + silane	Adper Scotchbond Multi-Purpose (three-step, etch-and-rinse)	Cement-Post (self-cure, regular)	Into the root canal with lentulo drill	None	3.3 MPa
		No bonding agent used	Rely-X Unicem (dual-cure, self-adhesive)	Into the root canal with lentulo drill		8.1 MPa
Farina and others (2011b)[17]	37% phosphoric acid for 5 s + silane	Adper Scotchbond Multi-Purpose (three-step, etch-and-rinse)	Cement-Post (self-cure, regular)	Into the root canal with lentulo drill	None	3.3 MPa

Table 2: Continued.

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength	
		No bonding agent used	Rely-X Unicem (dual-cure, self-adhesive)	Into the root canal with lentulo drill		8.1 MPa	
Goracci and others (2004)[22]	Not found	Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Into the root canal with lentulo drill	One wk in water	6.8 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		5 MPa	
Goracci and others (2005)[21]	Ethanol + silane	Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Into the root canal with lentulo drill	None	10.1 Mpa	
		ED Primer (one-step, self-etch)	Panavia 21 (self-cure, self-etch)	Around the post		5 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		5 MPa	
Goracci and others (2004)[22]	Not found	Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Into the root canal with lentulo drill	One wk in water	12.3 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		9.1 MPa	
Kececi and others (2008)[25]						**FRC Postec Plus**	**Ever-stick**
	Ethanol + silane	Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Around the post and into the root canal	None	3.7 MPa	3 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			2.7 MPa	1.9 MPa
Leme and others (2011)[23]						**One Mo**	**Nine Mo**
	37% phosphoric acid for 60 s + silane	Scotchbond Multi-Purpose Plus (three-step, etch-and-rinse)	RelyX ARC (dual-cure, regular)	Around the post and into the root canal	Stored in a light-proof container with 100% humidity at 37°C for 1 or 9 mo. The liquid used for 100% humidity aging was 0.9% thymol solution	2.5 MPa	1.3 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		5.4 MPa	3.9 MPa
Lindblad and others (2010)[24]						**With Chlorhex-idine**	**Without Chlorhex-idine**
	All-Bond Primer B	All-Bond 2 (three-step, etch-and-rinse, dual cure)	Duo-link cement (dual-cure, regular)	Not found*	Stored in artificial saliva in 37°C for 3–7 d	6.6 MPa	5 MPa
	None	PermaFlo DC Primers (three-step, etch-and-rinse)	PermaFlo DC (dual-cure, regular)	Not found*		12.6 MPa	11.5 MPa

Table 2: Continued.

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength	
	None	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		12.8 MPa	11.2 MPa
Mumcu and others (2010)[26]	Ethanol	ED Primer (one1-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post	Distilled water for 7 days at 37°C	10.6 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		10.6 MPa	
		No bonding agent used	Maxcem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		10.2 MPa	
Radovic and others (2008)[28]	Ethanol + silane	XPBond (two-step, etch-and-rinse)	Calibra resin cement (dual-cure, regular)	Around the post and into the root canal	None	12.7 MPa	
	Ethanol	XPBond (two-step, etch-and-rinse)	FluoroCore 2 (dual-cure, regular)	Around the post		8.1 MPa	
	34% phosphoric acid + Silane	Excite DSC (two-step, etch-and-rinse)	MultiCore Flow (dual-cure, regular)	Around the post		11.1 MPa	
	Ethanol	ED primer (one-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post		8.7 MPa	
	Ethanol	No bonding agent used	Experimental self-adhesive cement (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		10.6 MPa	
	Ethanol	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		12.5 MPa	
Rathke and others (2009)[27]						**With Silane**	**Without Silane**
	Ethanol in all specimens and in half of it, silane	Prime & Bond NT (two-step, etch-and-rinse)	Dyract Cem Plus (self-cure, self-adhesive)	Not found*	None	19.3 MPa	22.2 MPa
		Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)			29.7 MPa	32.4 MPa
		ED Primer II (one-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)			22.2 MPa	23.4 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			23.1 MPa	24.7 MPa
Roperto and others (2010)[29]						**EverStick**	**Reforpost**
	Immersed in 24% H_2O_2 for 10 min + silane	Clearfil SE Bond (two-step, self-etch)	Panavia F 2.0 (dual-cure, self-etch)	Around the post	Stored in water at 37°C and thermocycled for 3000 cycles (5°C to 55°C) for 60 s in each water bath	12.66 Mpa	11.2 Mpa

Table 2: Continued.

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength	
		No bonding agent used	Rely-X Unicem (dual-cure, self-adhesive)			11.09 Mpa	9.25 Mpa
		No bonding agent used	MaxCem (dual-cure, self-adhesive)			10.09 Mpa	6.46 Mpa
		No bonding agent used	BisCem (dual-cure, self-adhesive)			12.03 Mpa	8.89 Mpa
Sadek and others (2006)[34]						**Immediate**	**After 24 h**
	Ethanol + silane	All Bond 2 (three-step, etch-and-rinse)	Duo Link (dual-cure, regular)	Around the post	Immediate and after 24 h	5.6 MPa	7.9 MPa
		Optibond Solo Plus (two-step, etch-and-rinse)	Nexus 2 (dual-cure, regular)	Around the post		8.6 MPa	12.0 MPa
		Multilink Primer (one-step, self-etch)	Multilink (dual-cure, regular)	Around the post		8.3 MPa	11.0 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Around the post		5.1 MPa	9.2 MPa
Soares and others,(2012)[30]	Ethanol + silane	Scotchbond Multi-Purpose Plus (three-step, etch-and-rinse)	RelyX ARC (dual-cure, regular)	Into the canal	Distilled water for 24 h at 37°C	7.1 Mpa	
		Scotchbond Multi-Purpose Plus (three-step, etch-and-rinse)	Cement-Post (self-cure, regular)	Into the canal	Distilled water for 24 h at 37°C	8.7 Mpa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the canal	Distilled water for 24 h at 37°C	13.8 Mpa	
		No bonding agent used	Maxcem Elite (dual-cure, self-adhesive)	Into the canal	Distilled water for 24 h at 37°C	3.9 Mpa	
		Scotchbond Multi-Purpose Plus (three-step, etch-and-rinse)	RelyX ARC (dual-cure, regular)	Into the canal	Distilled water for 24 h at 37°C	7.3 Mpa	
		Scotchbond Multi-Purpose Plus (three-step, etch-and-rinse)	Cement-Post (self-cure, regular)	Into the canal	Distilled water for 24 h at 37°C	8.7 Mpa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the canal	Distilled water for 24 h at 37°C	13.4 Mpa	
		No bonding agent used	Maxcem Elite (dual-cure, self-adhesive)	Into the canal	Distilled water for 24 h at 37°C	4.2 Mpa	
Xu and others (2011)[32]						**Monobond - S (Silane)**	**Porcela - Bond Activator (Silane)**
	Silane	No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Not found*	None	9.5 Mpa	14.8 Mpa

Table 2: Continued.

Article	Pretreatment of Post	Bonding Agent	Cement	Cement Application	Aging/ Storage	Bond Strength	
		ED Primer (one-step, self-etch)	Panavia F (dual-cure,self-etch)			8.6 Mpa	9.8 Mpa
		All Bond 2 (three-step, etch-and-rinse)	Duo-Link (dual-cure, regular)			5.2 Mpa	5.7 Mpa
Zaitter and others (2011)[31]						**Exacto**	**Everstick**
	Immersed in 24% hydrogen peroxide for 10 min and two layers of silane-coupling agent	Clearfil-SE Bond (two-step, self-etch)	Panavia F (dual-cure, regular)	Into the root canal with lentulo drill	Thermocycled 1000 times in water baths between 5°C and 55°C and stored in distilled water at 37°C for 30 d	10.3 MPa	25.9 MPa
		Clearfil-SE Bond (two-step, self-etch)	NAC-100 (dual-cure, self-etch)			14 MPa	29.1 MPa
		No bonding agent used	BisCem (dual-cure, self-adhesive)			16.4 MPa	28.9 MPa
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)			19.8 MPa	30.5 MPa
Zicari and others (2008)[33]	Ethanol	ED Primer (one-step, self-etch)	Panavia 21 (self-cure, self-etch)	Into the root canal with centrix syringe	1 wk of water storage at 37°C	12.6 Mpa	
		ED Primer II (one-step, self-etch)	Clearfil Esthetic Cement (dual-cure, regular)	Into the root canal with centrix syringe		14.6 MPa	
		Excite DSC (two-step, etch-and-rinse)	Variolink II (dual-cure, regular)	Into the root canal with centrix syringe		11.1 MPa	
		No bonding agent used	RelyX Unicem (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		11.3 MPa	
		No bonding agent used	GC (dual-cure, self-adhesive)	Into the root canal with tip attached to the cement capsule		7.6 MPa	

tween groups (p=0.41). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 98%. The subgroup analysis of self-adhesive resin cement vs regular resin cement with self-etch adhesive showed no statistically significant difference between groups (p=0.63). The values of the Cochran's Q and I^2 tests were $p \leq 0.01$ and 96%.

Descriptive Analysis

From the studies included in the review, a total of 47 experimental groups testing regular resin cements were detected, including 13 studies using Panavia F 2.0 (Kuraray, Osaka, Japan) and eight studies using Variolink II (Ivoclar Vivadent, Schann, Liechtenstein). A total of 39 experimental groups testing self-adhesive resin cements were detected, including 27 studies with RelyX Unicem (3M ESPE, St Paul, MN, USA).

Several attempts to verify how pretreating the post influenced bond strength results were used: cleaning with ethanol,[18,19,26,33] silane application,[15-19,21,23,25-28,30-33,34,35] use of acids,[11] or even no pretreatment of the post.[14] Although no statistical analysis was performed, the retention of GPFs that had been pretreated with silane seemed to be higher compared with posts that were not pretreated or that were pretreated with other products.

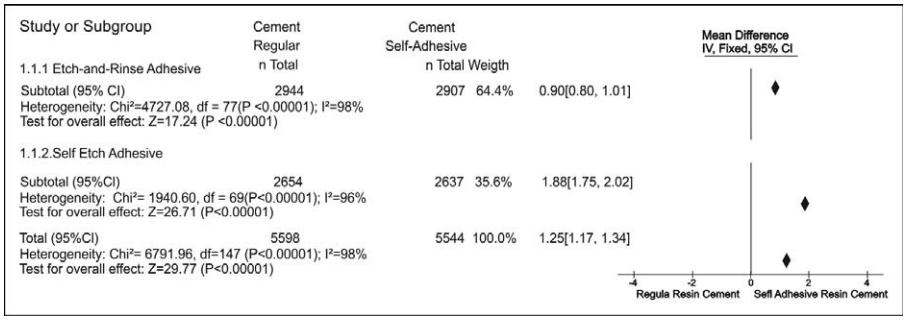

Figure 2. *Results for analysis using fixed-effect model. The analysis 1.1.1 represents the subgroup analysis between self-adhesive resin cement vs regular resin cement with etch-and-rinse adhesive, while the analysis 1.1.2 represents the subgroup analysis between self-adhesive resin cement vs regular resin cement with self-etch adhesive. The total analysis stands for the global results.*

Application of the resin cement was performed using three different approaches: inserting the cement into the root canal, inserting the cement around the post, or inserting the cement into the root canal and around the post. The studies that used mixed techniques showed lower bond strength values.[17,26,30] In two studies that did not perform endodontic treatment before luting,[23,25] the bond strength results were similar or higher than those for studies in which endodontic treatment was performed.

Each study used its own protocol for aging and storing the samples, including storage for 1 week in water,[18,22,26,33] storage in a light-proof container with 100% humidity at 37°C for 9 months,[23] or storage in water at 37°C + 3000 thermal cycles (between 5°C and 55°C) for 60 seconds in each water bath with a 6-second dwell time.[29] The overall results did not seem to be influenced by the aging protocol.

The type of post cementation failure was not taken into consideration in our analyses, that is, adhesive between the post and cement versus adhesive between the dentin and cement or cohesive within the different types of cement because of the wide variation between the classifications of failure modes in the different studies included. In the same way, we performed no statistical analysis regarding how different types of post pretreatment affected their retention because there were many confounding factors that could influence the results based on the heterogeneity among the studies.

DISCUSSION

This systematic review and meta-analysis is the first to verify the pooled effect of data from *in vitro* studies that tested the retention of GFPs using resin cements. Several cementation strategies and different bond strength tests were used; more consistent results could be obtained if data were analyzed together, giving support for the clinician on evidence-based decision-making.

The global result (regular vs self-adhesive resin cement) using a fixed-effect model favored the use of self-adhesive resin cement. This result could be explained by the different characteristics of the resin cements. The most commonly used self-adhesive resin cement was RelyX Unicem (3M ESPE),[7] which has adhesive properties based on acid monomers that demineralize and infiltrate the tooth substrate, creating micromechanical retention and chemical bonding to hydroxyapatite.[7] The water resulting from the acid-base interactions may improve the tooth-cement interaction and the cement moisture tolerance.[36,37] The consequent use of water available in the cement matrix and ionization of residual acidic methacrylates culminates in transformation to a hydrophobic material with neutral pH values.[7] In addition, the higher bond strength of self-adhesive cements may be a result of the lower polymerization stress compared with regular resin cements.[38] The high C-factor and the conical shape of the root canal are critical for the development of polymerization stress; thus, cements with higher stress values may present poorer bonding to the canal walls. Although the hypothesis was rejected, it is important to highlight that the study was conducted using *in vitro* studies (see the Limitations of the Study section).

Our analysis also demonstrated high heterogeneity (98%); thus, the subgroup analysis was carried out to verify the influence of the adhesive used (etch-and-rinse or self-etch) with regular resin cements in the heterogeneity. The two subgroup analyses favored the use of self-adhesive resin cement. Regular resin cements require multiple bonding

steps compared with self-adhesive materials. Etch-and-rinse adhesives require an accurate technique mainly concerning the control of dentin moisture and proper infiltration of the adhesive solution into the root canal, a procedure that might be considered critical and might affect post retention. The etch-and-rinse approach has been also reported to leave a non-encapsulated collagen zone beneath the hybrid layer, which could interfere with the longevity of the bonds.

The rationale of using self-etch adhesives and self-adhesive cements is based on the same principle of dental demineralization and simultaneous infiltration by methacrylate monomers. The bonding mechanism of these adhesive techniques has been linked to an additional chemical bond to tooth structures; the self-etch and self-adhesive strategies, however, have the same possible problem of poorer surface conditioning. Interestingly, the two subgroup analyses favored the use of self-adhesive resin cement; a possible explanation for these results is twofold. On the one hand, application of self-etch solutions into root canals is more complex than self-adhesive cements, particularly regarding proper solvent evaporation, excess adhesive removal, and photopolymerization in the apical areas. On the other hand, some studies use strong self-etch adhesives, which might lead to deposition of calcium phosphates on dentin that are not rinsed and are very unstable in an aqueous environment, thus interfering with the interfacial integrity and bonding ability.[7,39] Compared with the use of regular resin cements associated with conventional or self-etch adhesives, the self-adherence potential and dual-cure mechanism of self-adhesive resin cements seems to improve the bonding of GFPs into the confines of the root canal.

Nevertheless, the subgroup analyses showed high heterogeneity because there are great differences among studies. The articles included in this review demonstrated differences, particularly in such aspects as aging or storage of samples, cement application mode, and approaches used to pretreat the posts. The variability related to multiple steps in the bonding process could increase the retention of GFPs to intraradicular dentin in some cases; in other cases, however, the multiple steps might just make the procedures harder and more time consuming. In addition, the included studies generally had a small number of samples and consequently high standard deviation, favoring heterogeneity. This finding made it hard to identify the reasons and variables that influenced the high heterogeneity.

The global result (regular vs self-adhesive resin cement) using a random-effects model showed no difference between resin cements, although the data remained with high heterogeneity (98%). The subgroup analyses were carried out to verify the influence of the adhesive used (etch-and-rinse or self-etch) with regular resin cement in the heterogeneity. The results demonstrated no difference between groups and high heterogeneity, confirming the differences between methodologies used in the studies included in the review. This finding made it hard to identify the reasons and variables that influenced the high heterogeneity. Furthermore, the parameters the authors developed to assess risk of bias showed that the studies included had high or medium risk of bias, thus demonstrating that the variables that could influence the results of the studies were not controlled by researchers favoring the high heterogeneity of the findings of this study.

Yet, post debonding has been described as the most common mode of failure *in vitro*,[4] and this type of failure can be more related to inappropriate bonding techniques than to problems inherent to the materials themselves. The bonding techniques using either regular or self-adhesive resin cements can still be regarded as good options for the luting of GFPs into root canals. The use of self-adhesive resin cements, however, appears to be a suitable and perhaps less technique-sensitive option than luting strategies that involve pretreating the canals with adhesive solutions.

To date the literature has no clinical studies comparing different cementation strategies for GFPs, and clinical studies with self-adhesive resin cements are still scarce. The few clinical studies available[40,41] using regular or self-adhesive resin cements to lute GFPs show high survival rates in the short term. The differences between resin cements shown by *in vitro* studies could be clinically irrelevant, but longer clinical follow-ups are not available.

Limitations of the Study

The results of the present review should be interpreted with caution because laboratory studies have intrinsic limitations when trying to simulate *in vivo* conditions. In addition, there was a predominance of one particular self-adhesive resin cement (RelyX Unicem) in the studies included, and this should be taken into account when comparing regular resin cements with other self-adhesive cements. Well-designed randomized controlled trials with long follow-up periods are needed to provide the ultimate

answer as to whether self-adhesive resin cement will result in improved clinical success rates compared with regular resin cements.

CONCLUSION

Although the articles included in this meta-analysis showed high heterogeneity and high risk of bias, the *in vitro* literature seems to suggest that the use of self-adhesive resin cement could improve the retention of GFPs into root canals.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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