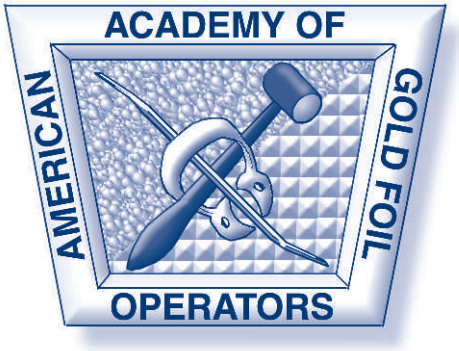
OPERATIVE DENTISTRY



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Operative Dentistry publishes articles that advance the practice of operative dentistry. The scope of the journal includes conservation and restoration of teeth; the scientific foundation of operative dental therapy; dental materials; dental education; and the social, political, and economic aspects of dental practice. Review papers, book reviews, letters, and classified ads for faculty positions are also published.

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Operative Dentistry
Indiana University School of Dentistry, Room S411
1121 West Michigan Street, Indianapolis, IN 46202-5186
Telephone: (317) 278-4800, Fax: (317) 278-4900
URL: http://www.jopdent.org/

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Editorial

Where Have All the Mentors Gone?

In the early days of dentistry, before the establishment of dental schools and colleges, training was primarily done on an apprenticeship basis. As with any apprenticeship, the novice would work for an experienced master craftsman in return for instruction and "hands-on" training. This was usually a "one-on-one" or very small group situation, and the master's role was that of mentor, which *Webster's New World Dictionary* defines as "a wise adviser, teacher or coach." The mentor would demonstrate a procedure for the apprentice, then watch carefully while the apprentice performed the technique, giving advice and criticism and evaluating the outcome. This would be repeated again and again until the student could demonstrate a thorough knowledge and the ability to apply that knowledge. Even today, individual or small group instruction, particularly in teaching manual dexterity skills, is recognized as one of the best methods for imparting knowledge. Unfortunately, the sheer size of dental school classes and the limited curricular time and number of faculty make true mentoring of every student extremely difficult, if not impossible. Because of this, a large percentage of our profession must rely on various types of continuing education courses to further their knowledge and improve their skills. The obvious question is if mentoring is an appropriate way to impart clinical skills, what role does it play in the modern continuing education process?

Dental continuing education is a vast arena of different types of programs. The majority are primarily lecture-format presentations that vary from an hour or two to several days in length. Practitioners often attend multiple sessions that encompass a variety of subjects during annual meetings of various professional organizations. The emphasis of this type of continuing education is usually on newer materials and equipment with some visual examples of clinical applications and, occasionally, some preliminary data on longevity and success. While this is certainly a very important part of continuing education, the mentor (lecturer) is essentially removed from the students (listeners) and has no way of knowing if the information delivered has been understood or how it will be applied. There is no opportunity to observe the student's clinical skills and offer constructive criticism. Conversely, attendees at this type of course are often impressed with the beautiful cases they are shown and then disappointed when the promoted material or technique does not give them the same result in their own office, and there is no follow-up to explain why. The natural tendency is to simply blame the new material and not recognize a possible lack of understanding or ability, so that the product is pushed to the back of a shelf or disposed of and the experience becomes a waste of valuable time.

More clinically oriented continuing education is offered as "hands-on" courses that provide laboratory and possibly clinical instruction. The best of these usually involve several days of attendance, encompassing lecture, laboratory and/or clinical demonstration, and finally, performance activity by the students under the observation, guidance and critique of instructors. These courses at least offer the opportunity to actually work with the products and receive advice and correction of errors. Unfortunately, this is still a "one-time" experience, often with no provision for continuing input and instruction related to individual clinical problems that arise or long-term development and improvement of necessary manual skills.

The best and most proven source of clinical continuing education is the operating study club. By this, I don't mean a social group of colleagues who meet once a month for dinner and drinks and have a guest lecturer make a one-hour presentation. I'm referring to a group of dedicated practitioners who meet on a regular basis and actually perform various types of restorative treatment on patients under the guidance of a knowledgeable and clinically proficient mentor. This is true "hands-on" education, where every session provides experience and the opportunity to make

mistakes and receive constructive criticism as well as advice and demonstration on how to recognize and correct problems as they arise. Ongoing sessions ensure that the clinical relevance and impact on performance and longevity of the skills, techniques and materials used will become evident. The goal of these groups is to constantly improve the level of treatment for their patients by evaluating materials, equipment and techniques and learning new clinical skills and refining them to their highest level.

There are two basic requirements for an operating study club. Members who are willing to devote the necessary time, effort and expense as well as accept the scrutiny and criticism of their work, and a mentor who has the knowledge, skills and dedication to earn the respect of the group and provide the instruction.

Herein lies the problem. Where are the mentors today? Who are the successors to the Blacks, Hollenbacks and Markleys of yesterday? All of us can name individuals who have made a tremendous impact on the profession through their unselfish mentoring (I won't insert any names myself, because it would take too much space and I would certainly miss some), and recite stories of their regular journeys across several states and to other countries to supervise different study clubs and promote excellence. Unfortunately, the world changes and motivations shift. The face of dentistry is in constant flux as the market is inundated with new products, while others disappear at the same rate. Continuing education has become big business for some and a reputation builder for others. This does not imply that they are not skilled or knowledgeable, merely that their time is spent in an attempt to reach as large an audience as possible. This certainly has merit and provides useful information to busy practitioners, but it does not really lead to improved clinical skills.

What the profession needs are more study clubs and more mentors. The Tucker Study Clubs have set up an excellent model of training "apprentices" whom they send to mentor new study groups. While there is a natural hesitation (feeling of inadequacy) in assuming a mentor's role, a good mentor recognizes when a student is ready to become a teacher and needs to encourage this step. Most good mentors continue to function as students in their original study group since continued learning can only improve their own teaching. For all of you who have enjoyed the experience of study club activity, I strongly encourage you to help expand the availability of this type of continuing education by starting new groups and encouraging your colleagues to participate. Considering all the changes and problems in dental education today, we sorely need to not only keep mentoring alive, but to increase its impact on the profession.

Michael A Cochran
Editor

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Clinical Research

Technique Sensitivity in Bonding to Vital, Acid-Etched Dentin

M Ferrari • FR Tay

Clinical Relevance

Technique sensitivity, previously reported *in vitro* using a moist bonding technique on acid-etched dentin, is applicable *in vivo* when bonding to vital dentin, in the small number of samples examined in this study.

SUMMARY

Just as vital dentin is moist after removing the smear layer, avoiding collapse of the collagen matrix after acid-etching requires *in vivo* validation. This study hypothesizes that there is no difference between moist bonding performed *in vitro* or *in vivo*, and that excessive drying or wetting of vital acid-etched dentin produces inferior results. Resin-dentin interfaces bonded with a moist bonding technique (control), either *in vitro* or *in vivo* with Excite DSC (Vivadent), were examined with and without tracer penetration using transmission electron microscopy. Specimens bonded *in vivo* under excessively dry and wet conditions were also examined. The patterns of silver deposition were similar within the adhesive and hybrid layers created *in vitro* or *in vivo*. No hybrid layer was observed *in vivo* after excessive drying. Excessive wetting *in vivo* resulted in more extensive nanoleakage and water tree formation along resin-dentin interfaces.

M Ferrari, MD, DDS, PhD, dean of School of Dental Medicine, chair and professor of Restorative and Dental Materials Department, Policlinico "Le Scotte," University of Siena, Italy

*Franklin R Tay, BDSc (Hons), FADM, PhD, honorary assistant professor, Departments of Pediatric Dentistry & Orthodontics, and Conservative Dentistry, The University of Hong Kong, The Prince Philip Dental Hospital, Hong Kong

*Reprint request: Faculty of Dentistry, 34 Hospital Road, Hong Kong SAR, China; e-mail: kfctay@hknet.com

INTRODUCTION

The moist bonding technique (Kanca, 1992) was introduced a decade ago for optimizing bonding of acetone- and ethanol-based dentin adhesives to acid-etched dentin. Moist bonding prevents collapse of demineralized collagen fibrils during resin-infiltration (Gwinnett, 1994). Interfibrillar spaces about 20 nm wide when fully extended must remain open to enable diffusion of resin monomers into the demineralized intertubular dentin (Eick & others, 1997; Wang & Spencer, 2002). Desiccation of acid-etched dentin diminishes the surface wettability of the bonding substrate (Rosales & others, 1999), increases the capacity for hydrogen bonding among amino acid residues of collagen fibrils (Miles & Ghelashvili, 1999; Pashley & others, 2001) and results in incomplete resin-infiltration within the hybrid layer (Tay & others, 1996; Nakajima & others, 2000). Manufacturers of total-etch dentin adhesives almost exclusively recommend using moist bonding or aqueous rewetting agents on air-

dried, acid-etched dentin (Perdigão & Frankenberger, 2001; Pashley & others, 2001; Saeki & others, 2001).

Despite numerous *in vitro* studies on the efficacy of the moist bonding technique (Nakabayashi & Hiranuma, 2000; Hashimoto & others, 2002), the necessity to avoid collapse of the collagen matrix after acid-etching of vital human dentin has not been substantiated *in vivo*. As vital dentin is inherently moist, with transudation of dentinal fluid after smear layer removal (Itthagarun & Tay, 2000), the presence of this intrinsic source of moisture (Pereria & others, 1999; Moll & Haller, 2000) may be all that is required to maintain the demineralized collagen matrix in its hydrated state, or even to cause regional disruption of resin-dentin bonds in some adhesive systems (Tay, Gwinnett & Wei, 1998; Pereria & others, 1999). Thus, the objective of this study was to examine the ultrastructure and extent of tracer penetration in resin-dentin interfaces created in deep, vital acid-etched dentin under different degrees of hydration of the demineralized collagen matrices using transmission electron microscopy (TEM). The null hypotheses tested were: a) there is no difference between moist bonding performed *in vitro* or *in vivo*, and b) there is no difference in the *in vivo* results produced with excessive drying or wetting of vital acid-etched when compared with the manufacturer's recommended technique for moist bonding.

METHODS AND MATERIALS

Sixteen teeth were used in this study. *In vitro* and *in vivo* specimens were restored by different operators. Four extracted anterior teeth were collected after the patients' informed consent had been obtained under a protocol reviewed and approved by the institutional review board from the University of Hong Kong. These teeth were assigned to the *in vitro* control group and restored by one operator (FRT). Twelve vital, periodontally-compromised, caries-free, unrestored anterior teeth scheduled for extraction, were selected. Informed consent of the subjects was obtained under an *in vivo* protocol reviewed and approved by an ethical committee from the University of Siena. These teeth were assigned to the three *in vivo* groups and restored by a second operator (MF).

Experimental Design

Tooth preparation was performed on the labial surface of each tooth with unbevelled cavosurface margins located occlusally in enamel and cervically beyond the cementodentinal junction. Cavities were etched with a 37% phosphoric acid gel for 20 seconds and rinsed for 20 seconds. Bonding was performed with Excite DSC (Vivadent, Schaan, Liechtenstein), an ethanol-based, two-step, dual-curable, single-bottle adhesive. The self-curing mode was activated by dipping the catalyst-impregnated microbrush tip into the light-cured adhesive and mixing for five seconds. One layer of the activated adhesive was applied with gentle agitation for 10 seconds, leaving a glossy adhesive film over the entire cavity surface after the solvent evaporated. The experimental groups represented different conditions of the acid-etched dentin prior to adhesive application:

1. *In vitro* control group (moist bonding). Acid-etched dentin of each extracted tooth was blot-dried with a piece of lint-free gauze immediately before placing the adhesive. Evaporation of the adhesive solvent was achieved by gentle air drying for five seconds with a triple syringe located 10 cm away from the dentin surface, followed by more aggressive air drying for another five seconds.
2. *In vivo* control group (moist bonding). Taking into account the higher intraoral relative humidity in the absence of rubber dam placement, and the intrinsic wetness of deep vital dentin after removal of the smear layer (Itthagarun & Tay, 2000), the wet, vital acid-etched dentin from each periodontally-compromised tooth was gently air dried for one second at a distance of 10 cm from the bonding surface to remove gross excess of water, leaving the etched dentin visibly moist. After applying the adhesive, evaporation of the adhesive solvent followed what had been described for the previous group.
3. *In vivo* excessively dry group. The wet acid-etched dentin was air dried for five seconds to collapse the demineralized collagen matrix prior to adhesive application. Drying was assessed clinically by observing frostiness over the adjacent acid-etched enamel. Evaporation of the adhesive solvent was performed in the same way as the other groups.
4. *In vivo* excessively wet group. After rinsing, the acid-etched dentin was not air dried, and a visible excess of surface moisture was present during adhesive application. Evaporation of the adhesive solvent was performed in the same way as the other groups.

For each group, the adhesive was light activated for 20 seconds, according to the manufacturer's instructions. Each bonded cavity was restored incrementally with Tetric Flow (Vivadent), a light-cured flowable resin composite, to facilitate ultramicrotomy. Each 2 mm composite increment was light activated for 40 seconds. The composites were finished using tungsten carbide finishing burs (Axis Dental Corp, Irving, TX 75038, USA), followed by diamond-impregnated polishing disks (Pogo, Dentsply Caulk, Milford, ME 19963, USA) to obtain a high luster. The teeth from the three *in vivo* groups were extracted one week after placing the restorations. Extracted teeth from all the

four groups were stored in distilled water at 22°C for three hours before laboratory processing.

Laboratory Specimen Preparation

A 0.9 mm slab of restored mid-coronal dentin that contained the bonded interface that was to be examined was sectioned mesial-distally from each tooth using a slow-speed saw (Isomet, Buehler Ltd, Lake Bluff, IL 60049, USA) under water lubrication. Half of the slabs from each group were completely demineralized in 0.1 M buffered ethylenediamine tetraacetic acid (pH=7.0) for morphological examination of the resin- dentin interfaces. The remainder of the undemineralized slabs were immersed in a tracer solution for examining the extent of tracer penetration within the bonded interfaces.

An aqueous solution of 50 wt% ammoniacal silver nitrate [pH=9.5] was used as a TEM tracer (Tay, Pashley & Yoshiyama, 2002). It was prepared by dissolving 50 g of silver nitrate crystals (Sigma Chemical Co, St Louis, MO 63178, USA) in 25 ml of distilled water. Concentrated (28%) ammonium hydroxide (Sigma) was used to titrate the black solution until it became clear as ammonium ions complexed the silver into diamminesilver (I) ions ($[Ag(NH_3)_2]^+$). This solution was diluted to 50 ml with distilled water to achieve a 50 wt% solution. Specimens were coated with fast-setting nail varnish applied 1 mm from the bonded interfaces. Without allowing the slabs to become dehydrated, they were immersed in the tracer solution for 24 hours. The silver-impregnated slabs were rinsed thoroughly in distilled water and placed into photodeveloping solution for eight hours under a fluorescent light to reduce the diamminesilver (I) ions into metallic silver grains within potential voids along the bonded interfaces.

Demineralized and undemineralized epoxy resin-embedded 70-90 nm thick sections were prepared according to the TEM protocol of Tay, Moulding & Pashley (1999). Demineralized sections were double-stained with uranyl acetate and lead citrate. Silver-impregnated, undemineralized sections were not additionally stained. They were examined using a transmission electron microscope (Philips

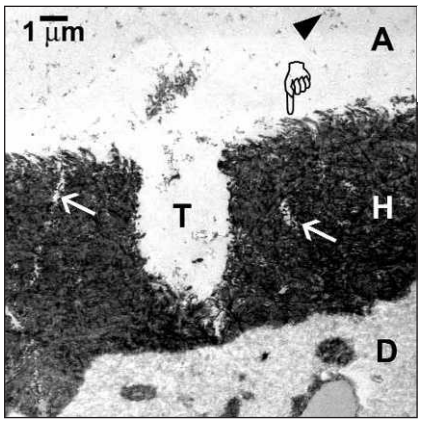

Figure 1A.

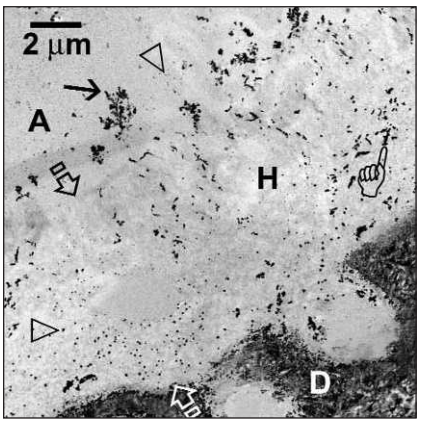

Figure 1B.

In vitro *control group bonded using a moist bonding technique with blot-drying of the acid-etched dentin. Figure 1A. Morphology of resin-dentin interface in stained, demineralized section. Collagen fibrils along the surface of the 6 µm-thick hybrid layer (H) exhibited a shag carpet-like appearance (pointer). Filler clusters (arrowhead) were sparsely distributed within the adhesive layer (A). D: intertubular dentin; T: resin tag within a dentinal tubule. Arrows: lateral branches of the dentinal tubules. Figure 1B. Extent of tracer penetration in unstained, undemineralized section. Demineralized, resin infiltrated collagen fibrils within the unstained hybrid layer (H, between open arrows) appeared electron-lucent. Two patterns of silver deposition could be identified within the hybrid and adhesive layers (A). The reticular pattern existed as fine, interconnecting silver deposits (nanoleakage) within the interfibrillar spaces of the hybrid layer (pointer) and "water trees" (arrow) within the adhesive layer. The latter originated from, and were perpendicular to, the surface of the hybrid layer. The spotted pattern (open arrowheads) consisted of isolated silver grains that were randomly distributed within both the hybrid and adhesive layers. D: intertubular dentin.*

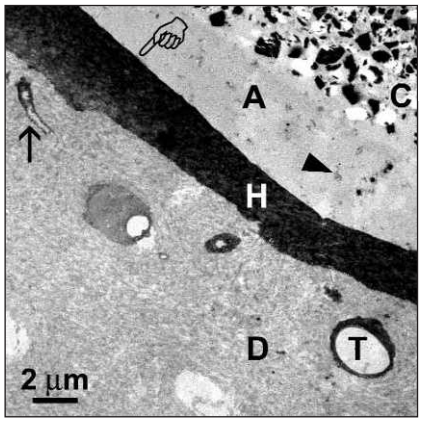

Figure 2A.

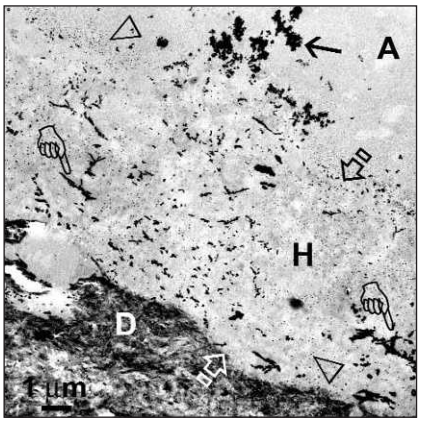

Figure 2B.

In vivo *control group bonded using a moist bonding technique with air drying of the acid-etched dentin for one second.* Figure 2A. *Stained, demineralized section. The thickness of the hybrid layer was more variable and ranged from 2-5 µm thick. The surface of the hybrid layer (H) was smooth. Lateral branches (arrow) were rarely observed within the hybrid layer. C: resin composite; A: adhesive; T: resin tag; D: intertubular dentin.* Figure 2B. *Extent of tracer penetration in the unstained, undemineralized section. Despite the difference in morphology of the hybrid layer between the* in vivo *and* in vitro *bonded specimens, there was no difference in the silver staining patterns observed in the hybrid layer (H; between open arrows) and adhesive layer (A) in both control groups. Pointer: reticular pattern of nanoleakage within hybrid layer, Arrow: "Water tree" extending from the surface of the hybrid layer into the adhesive layer; Open arrowheads: isolated silver grains within the hybrid and adhesive layers; D: intertubular dentin.*

EM208S, Philips, Eindhoven, The Netherlands) operating at 80 kV.

RESULTS

Hybrid layers created with moist bonding *in vitro* using the blot-drying method had a looser texture with the presence of tufted surface collagen fibrils and the frequent observation of lateral branches of the dentinal tubules (Figure 1A). Conversely, those created with moist bonding *in vivo* using air drying exhibited a smooth surface morphology, the absence of lateral branches and more variability in thickness (Figure 2A).

Despite these morphological differences, the patterns of silver penetration within the bonded interfaces were similar in both control groups. Two patterns of silver deposition were recognized in both the hybrid layer and adhesive layer (Figures 1B and 2B). The reticular pattern consisted of fine interconnecting strands of silver deposits and was manifested as nanoleakage (Sano & others, 1995) within hybrid layers and as "water trees" (Stepp & others, 1996; Tay & Pashley, 2002) within adhesive layers. The spotted pattern appeared as individual, unconnected silver grains in both the hybrid and adhesive layers.

Except for the presence of a thin, highly electron-dense, stained surface crust, no hybrid layer could be identified from vital dentin sections that were bonded under excessively dry conditions (Figure 3A). Bonded specimens that were immersed in aqueous ammoniacal silver nitrate revealed almost complete obliteration of the re-expanded, previously collapsed demineralized collagen matrix by silver deposits (Figure 3B).

The morphological appearance of hybrid layers in vital acid-etched dentin specimens bonded under excessively wet conditions (Figure 4A) was similar to the *in vitro* control group. However, there was a more profuse manifestation of the reticular pattern of silver deposits in both the hybrid and adhesive layers (Figure 4B). "Water treeing" (Ross, 1998) within the adhesive layer could be observed within the bulk of the adhesive, extending almost to the adhesive-composite interface (not shown).

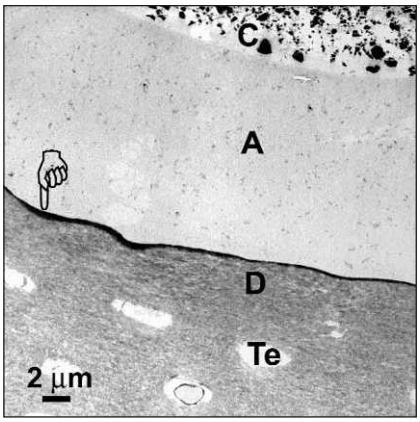

Figure 3A.

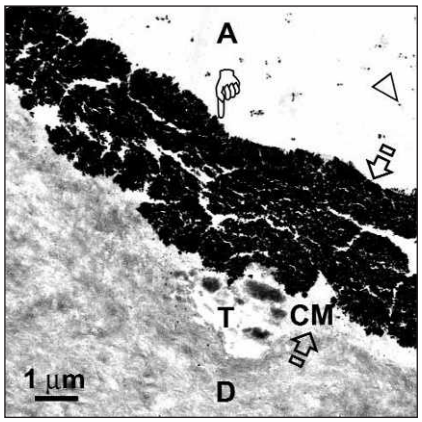

Figure 3B.

In vivo*, excessively dry group with acid-etched dentin air dried for five seconds.* Figure 3A. *Stained, demineralized section. No hybrid layer could be identified except for an electron-dense crust (pointer) on the surface of the acid-etched dentin. C: resin composite; A: adhesive layer; Te: empty dentinal tubule; D: intertubular dentin.* Figure 3B*. Unstained, undemineralized section. Re-expansion of the uninfiltrated, collapsed, acid-etched dentin during immersion in ammoniacal silver nitrate resulted in almost complete obliteration of the demineralized collagen matrix (CM; between open arrows) in most of the specimens examined. Additional isolated spots of silver grains (open arrowhead) could be identified within the adhesive layer (A). T: resin tag; D: intertubular dentin.*

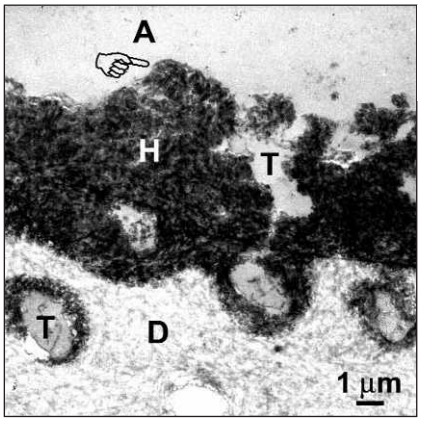

Figure 4A.

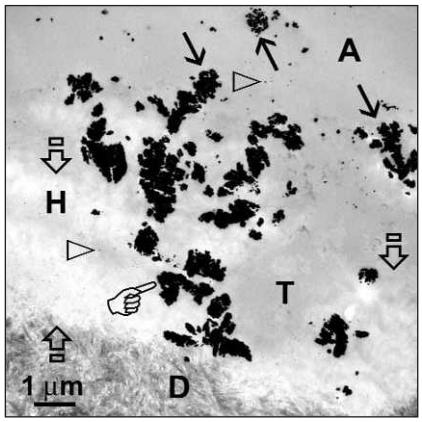

Figure 4B.

In vivo*, excessively wet group with the acid-etched dentin visibly over-wetted during adhesive application.* Figure 4A. *Stained, demineralized section. The hybrid layer (H) was looser in appearance and individual collagen fibrils could be identified along the surface (pointer). A: adhesive layer; T: resin tags; D: intertubular dentin.* Figure 4B*. Unstained, undemineralized section. Similar to the* in vivo *control group, both the spotted (open arrowheads) and the reticular patterns of silver deposits were observed within the adhesive (A) and hybrid layers (H; between open arrows). However, the reticular patterns were considerably denser in the hybrid layer (pointer) and "water tree" formation was more extensive (arrows) and penetrated deeply into the adhesive layer, almost reaching the composite-adhesive interface (not shown). T: resin tag; D: intertubular dentin.*

DISCUSSION

Using an adjunctive tracer penetration technique with unstained, undemineralized TEM sections provides complementary information on the efficacy of resin infiltration within interfaces that were examined with stained, demineralized sections. While the authors concede that using additional chemical-analytical techniques (Van Meerbeek & others, 2000) would be highly desirable in improving their understanding of the status of resin infiltration within hybrid layers (Spencer & others, 2000) and phase separations of resin components within the adhesive interfaces (Eliades, Vougiouklakis & Palaghias, 2001), some of the ultra-

structural features demonstrated in this study could only be observed with the resolution of transmission electron microscopy. Thus, within the limits of the small sample size in this study, the authors accept the first null hypothesis that there is no difference between moist bonding performed *in vitro* or *in vivo*, and reject the second null hypothesis that there is no difference when excessive drying or wetting of vital acid-etching was performed when compared with the manufacturer's recommended technique for moist bonding.

A slightly different moist bonding technique was used in the *in vitro* and *in vivo* procedures due to the anticipated increase in intraoral relative humidity and the possibility of transudation of dentinal fluid in vital dentin after removal of the smear layer. The shag carpet-like appearance of stained collagen fibrils in the *in vitro* specimens was the result of continuous agitation during adhesive application (Inoue & others, 2000). Air-drying for one second *in vivo* resulted in partial collapse of the demineralized collagen matrices. However, since an ethanol-based adhesive invariably contains a small amount of water, this extrinsic water, together with the increase in intrinsic moisture caused by removal of the smear layer, could have resulted in rehydration of the partially collapsed collagen matrix during the 10 seconds of adhesive application (Van Meerbeek & others, 1998).

The extent of silver penetration within adhesive interfaces was the least among the three *in vivo* groups when the manufacturer's recommended technique for moist bonding was followed. The spotted pattern of silver deposits could only be seen when basic ammoniacal silver nitrate was used. These silver grains increase in size with specimen aging and were absent when specimens were immersed in conventional acidic silver nitrate (Tay, Pashley & Yoshiyama, 2002). They probably represent microdomains within the adhesive and hybrid layers where an acid-base reaction occurs between resin monomers with acidic functional groups and the basic diamminesilver (I) ions. The reticular pattern of silver deposits within the hybrid layer in both control groups was similar to the nanoleakage previously reported using conventional acidic silver nitrate (Sano & others, 1995). As incomplete resin infiltration caused by a diffusion gradient of resin components usually occurs along the base of hybrid layers (Spencer & others, 2000); these randomly distributed interconnecting silver deposits more likely represent areas where water was incompletely removed from the interfibrillar spaces. Silver deposition within the adhesive layers had only been reported recently (Li, Burrow & Tyas, 2001). The occurrence of the reticular pattern of nanoleakage outside the hybrid layer cannot be attributed to incomplete resin infiltration and is likely to be related to water that was trapped within the adhesive layers during polymerization.

Similar to nanoleakage, the term "water tree" was first in introduced in Japan by Miyashita (1969). It is a well-known phenomenon that is responsible for the water-induced deterioration of polymer insulation of electrical cables after aging. Water trees in polyethylene- coated cables are submicroscopic, self-propagating, water-filled tracks that are formed electrochemically by the oxidation of the hydrophobic polymer into more hydrophilic moieties, with the condensation of moisture from the hydrophobic polymer into the hydrophilic, electro-oxidized regions (Dissado & Fothergill, 1992). The increase in water conductivity results in self-propagation along these tracks and the growth of a microscopic, tree-like pattern of water channels. In the context of dentin bonding, an electrochemical process is not required for water tree formation, as both hydrophilic resin monomers and water are present simultaneously in resin-dentin interfaces. "Water trees" along resin-dentin interfaces may act as stress raisers during functional stresses, or as channels that facilitate resin leaching during the degradation of resin-dentin bonds. This has to be investigated in future studies. There is initial evidence to show that "water treeing" can occur along the periphery of optimally-polymerized, non-solvented hydrophilic adhesive resins by water sorption and they propagate internally with increased time of water storage (Yiu & others, 2002).

CONCLUSIONS

Within the limits of the small sample size in this study, the technique sensitivity previously reported *in vitro* is also applicable *in vivo*. Excessive air drying of vital, acid-etched dentin resulted in a minimal hybrid layer along resin-dentin interfaces, confirming previous *in vitro* results (Nakajima & others, 2000). The complete obliteration of the demineralized collagen matrix with silver deposits could be explained by the re-expansion of the collapsed collagen matrix that was devoid of resin infiltration after immersion for 24 hours (Saeki & others, 2001) in aqueous silver nitrate. In this study, the authors did not observe blister formation (Tay & others, 1998) along resin dentin interfaces when bonding to excessively wet dentin *in vivo*. This could be explained by the use of an ethanol-based adhesive that has a milder potential in displacing water along the bonded interfaces compared to an acetone-based adhesive. However, it is notable that the density of the reticular silver deposits manifested as nanoleakage in hybrid layers and "water trees" in adhesive layers increased under the condition of bonding to excessively wet, vital, acid-etched dentin. It is unlikely that water can be completely removed from these interfaces due to the relatively high Hoy's solubility parameter for hydrogen bonding (δh) of the hydrophilic resin monomers and the ethanol solvent employed (Pashley & others, 2001). This may eventually result in an increase in the rate of degradation of resin-dentin bonds created in vital dentin.

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Laboratory Research

Voids and Porosities in Class I Micropreparations Filled with Various Resin Composites

NJM Opdam • JJM Roeters • T de Boer
D Pesschier • E Bronkhorst

Clinical Relevance

Small occlusal preparations are difficult to restore free of voids. The best results are achieved with a technique that uses a first layer of uncured flowable composite followed by a second layer of a medium-viscous composite injected into the cavity.

SUMMARY

In this *in vitro* study, voids inside a minimal occlusal restoration using different consistencies of resin composite and various application techniques were investigated.

One hundred and fifty-two simulated, minimally invasive preparations, including a prepared fissure and an excavated carious dentin lesion, were ground in perspex blocks. After applying an acrylic primer (Artglass Connector, Kulzer), the preparations were restored with the adhesive PhotoBond (Kuraray) and one of three resin composites: a packable composite (Prodigy Condensable-Kerr), a syringable composite (Clearfil Photo Posterior, Kuraray) and a flowable composite (Revolution, Kerr). The restorations were inserted according to eight protocols (n=19). In three groups, the composite was placed in bulk. In another three groups, a layer of flowable composite was placed first, then cured, followed by a second layer of one of the three composites. In two groups, the first layer of flowable composite was left uncured before a second layer of a packable or syringable composite was inserted. The perspex blocks were sectioned and inspected for the presence of voids. Statistical analysis was conducted using Fischer's exact tests at $p<0.05$.

The results showed that restoring minimal preparations in the absence of porosities and voids was very difficult to achieve. Placing a layer of flowable composite that was left uncured, directly followed by injecting a medium-viscous composite, was the technique that resulted in the most homogeneous restoration.

*Niek JM Opdam, DDS, PhD, assistant professor, University of Nijmegen, The Netherlands

Joost JM Roeters, DDS, PhD, associate professor, University of Nijmegen, The Netherlands

Tim de Boer, dental student, University of Nijmegen, The Netherlands

Dennis Pesschier, dental student, University of Nijmegen, The Netherlands

Ewald Bronkhorst, MSc, PhD, assistant professor, University of Nijmegen, The Netherlands

*Reprint request: University of Nijmegen, Department of Cariology and Endodontology, PO Box 9101, NL 6500 HB Nijmegen, The Netherlands; e-mail: N.Opdam@dent.kun.nl

INTRODUCTION

Adhesive techniques enable the clinician to save sound tooth tissue when caries is treated in such a way that only the decayed tooth substance is removed. Since the restorative material can strengthen weakened tooth structures after preparation (Ausiello & others, 1999), undermined enamel can be left in place. Therefore, treatment of occlusal caries may result in an occlusal opening of fissures that have a small dimension and local extension into the dentin at locations where decayed tissue has to be removed. These minimal preparation techniques may include using air-abrasion for preparation of occlusal caries (Goldstein & Parkins, 1994). After preparation, the clinician can restore the irregularly-shaped cavities with an adhesive technique using resin composite. Preparations with a narrow occlusal opening are more difficult to fill than larger cavities (Opdam & others, 2002a). Choosing a low or medium viscous composite helps to obtain a more completely filled cavity compared to high viscous composites (Opdam & others 1996; Opdam & others, 2002). Flowable composites with a low viscosity are also recommended as the material of choice for restoring small, narrow cavities, especially when a needle-shaped application tip that provides good access to the cavity is used (Peters & McClean, 2001b). However, due to low filler content, flowable composites have inferior physical properties, such as higher polymerization shrinkage and lower strength compared to normal hybrid composites (Bayne & others, 1998). Applying a lining of flowable composite under a resin composite restoration can result in less voids inside the restoration (Chuang, Liu & Jin, 2001b). However, no research is available to support claims of a superior adaptation for flowable composites when these materials are used as a restorative material for Class I restorations. On the other hand, some studies mention the risk of entrapment of air bubbles in flowable composites or sealants (Lekka, Papagiannoulis & Eliades, 1991; Chuang & others, 2001a). Also, the effect on the adaptation and the presence of voids in small micro-preparations, when a combination of a flowable composite with a syringable or packable composite is used, is unknown.

This study compared the adaptation and homogeneity of different types of composite in small occlusal preparations.

METHODS AND MATERIALS

To enable standardization of shape and size, preparations were made in eight blocks of clear polymethylmethacrylate. The dimensions of these blocks were 200 x 18 x 18 mm. Preparations were made according to a standardized protocol. First, a cylindrical cavity was ground 3 mm in diameter and 4 mm in depth with an industrial bur. To simulate an excavation procedure in dentin at the bottom of the cylindrical cavity, an extension was prepared using a stainless steel round bur (001-018, Meisinger, Düsseldorf, Germany). The bur was placed on the bottom of the cavity and used perpendicular to the ascending cavity wall to simulate an excavation procedure. The shaft of the bur acted during this procedure as a stopgap against further extension of the cavity. The cavity was further extended using a small fissure bur (HM132-008, Meisinger, Düsseldorf, Germany) that simulated a narrow fissure 3 mm in depth, 3 mm in length and 1 mm in width. Figures 1 and 2 show the final preparation simulating a minimal or micro-preparation, including a small fissure opened with a small bur or by air-abrasion, and a local deeper dentin cavity resulting from local excavation of carious dentin. All preparations were made in line through the center of the perspex blocks, so that after sectioning the bar, all restorations were available for inspection.

In order to bond to the perspex blocks and provide the operator with a surface that allows proper wetting by the composite, Artglass Connector (Kulzer, Wehrheim, Germany) was applied on the perspex surface followed by a layer of adhesive resin (Photo Bond, Kuraray, Osaka, Japan). Both materials were applied and cured according to the manufacturer's instructions.

The cavities were filled with one of three composites varying in consistency or with a combination of materials.

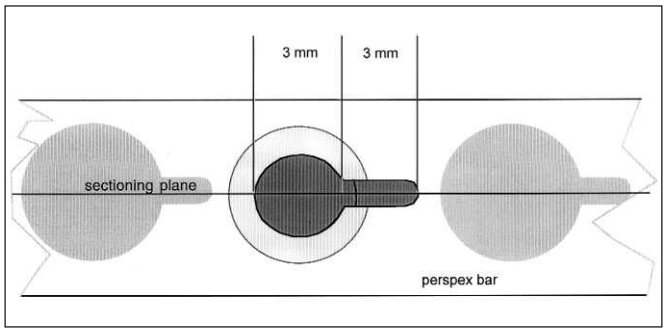

Figure 1. *Occlusal view from the experimental preparation.*

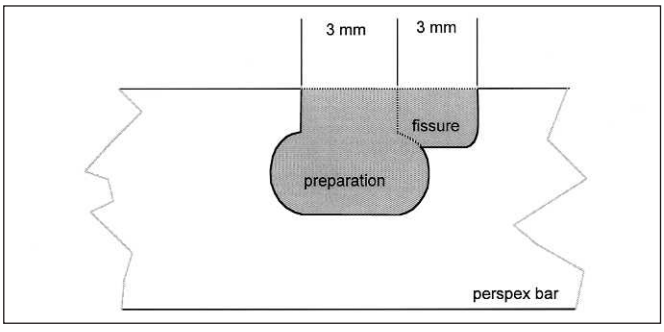

Figure 2. *Section of the experimental preparation design showing the preparation part and the fissure part.*

The following composites were used in the study:

- A highly viscous or packable composite supplied in pre-loaded tips; (Prodigy Condensable, Kerr, Romulus, MI 48174, USA)
- A medium-viscous or syringeable composite (Clearfil Photo Posterior, Kuraray, Osaka, Japan) inserted in tips by the operator (Centrix, Hawe Neos, Bioggio, Switzerland).
- A low viscous or flowable composite (Revolution, Kerr) injected by a needle tip into the cavity.

These composites were placed in bulk or in combinations. In two groups, a layer of flowable composite was injected on the cavity floor. This layer was left uncured and, subsequently, a second layer of a composite with higher viscosity was applied into the cavity. This resulted in the flowable composite being extruded from the cavity by the more viscous material. This technique was called the "snowplough-technique." After removing the excess material, the restoration was cured for 40 seconds from the occlusal surface. In another three groups, the initial layer of flowable composite was cured before one of the three composites was applied.

Finally, the composites were applied according to one of the following protocols:

Group 1. The cavities were filled in bulk with the packable composite and cured for 40 seconds.

Group 2. According to Group 1, however, a syringable composite was used.

Group 3. According to Group 1, however, a flowable composite was used.

Group 4. Placement of a flowable composite in the cavity leaving it uncured before injecting the syringable composite (snowplough technique). The restoration was cured for 40 seconds.

Group 5. Same as Group 4, but instead of a syringable composite, a packable composite was used.

Group 6: The initial layer of flowable composite was applied on the cavity floor and cured for 20 seconds. Subsequently, the restoration was completed with a second layer of flowable composite that was also cured for 20 seconds.

Group 7: The initial layer of flowable composite was applied on the cavity floor and cured for 20 seconds. Subsequently, the restoration was completed by injecting the syringable composite that was cured for 20 seconds.

Group 8: The initial layer of flowable composite was applied on the cavity floor and cured for 20 seconds. Then, the restoration was completed with the packable composite, which was packed with a hand-instrument and cured for 20 seconds.

Each group consisted of 19 restorations. All restorations were placed by one operator, a dental student close to graduation. All curing procedures were performed from the occlusal surface using a Kulzer Translux CL polymerization unit (Kulzer, Wehrheim, Germany, output 700mW/cm^2).

The perspex blocks with the restorations were stored for a minimum of 24 hours, then placed in a milling machine (Friedrich Deckel FP1, München, Germany) and sectioned through the middle of the restorations. The restorations were evaluated by two independent examiners using a light microscope (Carl Zeiss, Jena, Germany) at magnification 10x. Both the section with the preparation and excavation and the prepared fissure were inspected for voids and porosities.

Score 0 = voids or porosities absent, score 1 = voids or porosities present.

In the case of disagreement between the two examiners, the samples were examined again until a mutual agreement was obtained.

Differences between the groups were calculated for their statistical significance using Fischer's exact test at p=0.05. The p-value was corrected for multiple group testing.

RESULTS

Table 1 summarizes the results of the presence of voids inside the restorations. Based on the results, it is obvious that a restoration completely free of porosities and voids was hard to achieve. Only in Group 4, eight restorations were scored as free of voids. In Group 2, three restorations, and in Group 7, only one restoration was totally free of voids. All the other restorations had some porosities or voids, either in the fissure or in the preparation part of the restoration.

The best results were achieved in Group 4, where an uncured flowable was combined with a syringable composite. In the preparation portion of the sections, this technique was significantly better compared to all other techniques (p<0.05) except the syringable composite

Table 1: *Presence of Voids in the Total Restoration*

Group	Application Mode	No Voids (n)	Voids Present (n)
4	uncured flowable+syringable	8	11
2	syringable bulk	3	16
7	cured flowable + syringable	1	18
1	flowable bulk	0	19
5	uncured flowable +packable	0	19
8	cured flowable + packable	0	19
6	flowable in 2 layers	0	19
3	packable	0	19

Table 2: *Presence of Voids in the Preparation Part*

Group	Application Mode	No Voids (n)	Voids Present (n)	
4	uncured flowable+syringable	12	7	*
2	syringable bulk	8	11	
7	cured flowable + syringable	5	14	
1	flowable bulk	1	18	
5	uncured flowable +packable	1	18	*
8	cured flowable + packable	0	19	
6	flowable in 2 layers	0	19	
3	packable	0	19	

*p>0.05 (Fisher's exact test)

Table 3: *Presence of Voids in the Fissure Part*

Group	Application Mode	No Voids (n)	Voids Present (n)	
4	uncured flowable+syringable	14	5	
2	syringable bulk	5	14	
6	flowable in 2 layers	5	14	
3	packable	4	15	
5	uncured flowable +packable	3	16	*
7	cured flowable + syringable	1	18	
8	cured flowable + packable	1	18	
1	flowable bulk	0	19	

*p>0.05 (Fisher's exact test)

injected in bulk (Group 2) and the cured flowable combined with the syringable (Group 7). These findings are shown in Table 2. In the fissure part of the sections, Group 4 was significantly better than all the other techniques ($p<0.05$) as documented in Table 3.

DISCUSSION

This study compared the homogeneity of different types of composites in small occlusal preparations. For that purpose, a flowable, syringable and packable composite was used to restore standardized cavities. Only a few studies regarding consistencies of dental composites are available (Opdam & others, 1996b; Tyas & others, 1998), and the results of those studies are quickly outdated due to the ongoing introduction of newer products that replace older versions. The choice of syringable material was based on the results of a 1996 study (Opdam, & others, 1996b). The other materials were selected based on the information supplied by the manufacturers, which indicated that their materials were flowable or packable.

From other studies on homogeneity of restorations, it is known that injection of a syringable composite results in a better restoration with less voids compared to a packing technique with a highly viscous composite (Opdam & others, 1996a; Opdam & others, 2002). Furthermore, it has been shown that small Class I preparations are more difficult to restore adequately when compared to larger cavities (Opdam & others, 2002). In this study, small occlusal preparations were made, as this type of preparation is the most tooth-preserving technique for the treatment of primary caries lesions (Peters & McClean, 2001a). These preparations can be ground using a small diamond stone or alternately by using the air-abrasion technique. In all cases, this will result in narrow cavities of different shapes and form. The cavity design used in this study can be considered to be clinically representative of a small, occlusal dentin lesion that can be treated by an opening in the enamel followed by an enamel-undermining excavation procedure along the enamel-dentin junction. An adjacent, discolored fissure was ground to remove discolored caries tissue at the outline. As adhesion to enamel and dentin was not the subject of the study, it was possible to make the standardized preparations in perspex blocks. Applying a bonding agent ensured that a clinical representative surface of the cavity was present when applying the resin composite.

The results of this study show that it is almost impossible to restore a small, narrow preparation without including voids. The fact that only one operator placed all the restorations may have significance. In a study regarding the presence of voids inside Class II restorations, an experienced operator achieved better results (Chuang & others, 2001a). However, in another study with six operators, including a dental student, where Class I restorations with various types of composite were placed, it was concluded that the homogeneity was not influenced by the operators. In that study, preparations were larger than in the current study. Nevertheless, only a small number of sections of restorations were free of porosities, while it was concluded that small preparations were more difficult to restore free of voids than larger preparations (Opdam & others, 2002).

Therefore, it can be assumed that a micropreparation is even more difficult to fill properly, which is in accordance with the results of this study. It appears almost impossible to avoid any porosities inside the restoration. Light-curing resin composites taken directly taken from the syringe already contain porosities 0.05 to 1.4% by volume (Fano, Ortalli & Pozela, 1995). In the 1995 study, the highest amount of porosities was found in a highly viscous resin composite. Furthermore, injecting the light-curing materials out of a needle resulted in less porosities with the exception of stiff composites, which showed an increase in porosities. A study by Jörgensen & Hisamitsu (1983) recorded an increase of porosites in composites that were injected due to the composite sticking to the inside of the tip. However, by

coating the inside of the tip with a thin layer of resin before inserting the composite, the number of porosities was largely reduced. In this study, this procedure was followed when filling the tips with the syringable composite.

The clinical relevance of the current study is not clear. Large porosities at the tooth-restoration interface may result in gross microleakage and subsequent failure of the restoration due to caries. In a study by Estafan, Estafan & Leinfelder, 2000, Class I restorations made with a condensable composite without a first layer of flowable composite exhibited voids at the restoration-preparation interface, while the voids were reduced when combined with a flowable composite. Furthermore, large porosities and voids will have a weakening effect on the whole restoration, since an interface between improper adepted materials may act as a site where failure can start (Huysmans & others, 1996). Some clinical studies report the presence of porosities detected on radiographs (Kreulen & others, 1995). However, clinical failures due to such porosities are seldom reported, and the clinical relevance of a small porosity inside a minimal invasive restoration, as made in the current study, seems to be minimal. Nevertheless, voids and porosities appear to have a negative effect on the physical properties of the material and should be avoided as much as possible.

This study showed that the technique of placing an initial thin layer of flowable composite, left uncured, followed by injecting a syringable composite, is best suited to fill a micropreparation completely. With this so-called "snowplough-technique," the flowable composite helps to wet the cavity walls and will be pressed out of the cavity when injecting the more viscous syringable composite. One should expect that this technique would also be effective in combination with a packable composite. Nevertheless, this study demonstrated that this was not the case. It is possible that the stiff, packable composite contains irregularities that result in entrapment of air at the interface with the flowable composite. Furthermore, it is possible that the porosities were already present inside the composite material (Fano & others, 1995).

Another explanation could relate to the size of the tip in which the composites were placed. The end of the Hawe tip can be placed in the preparation and, therefore, the composite can be injected while in direct contact with the flowable composite. The packable composite is delivered in a tip with a large diameter to facilitate injection of the stiff material. The end of such a tip would not fit into the opening of the cavity. When injecting the composite, the opening of the tip is positioned above the occlusal surface and the composite does not fill the cavity from the cavity floor and may trap air. Other studies, looking in greater detail at the voids, found a reduction in the number of voids if a flowable composite is placed in advance of a packable composite (Chuang & others, 2001b). A flowable composite appeared to be beneficial in reducing microleakage of restorations made with stiff, packable composites (Tung, Estafan & Scherer, 2000) but failed to demonstrate the same positive effect in combination with a normal microhybrid composite (Jain & Belcher, 2000). Though the reduction of microleakage by combining a flowable with a packable composite is evident, microleakage was still greater than when a normal microhybrid composite was used without a flowable lining (Leevailoj & others, 2001).

Using a flowable composite may also have some disadvantages. The volumetric curing-shrinkage of flowable composites is considerably higher and most of the physical properties are less than from normal hybrid composites (Bayne & others, 1998). In case the initial layer of flowable composite is not cured before inserting the stiffer composite, most of the flowable composite will be pressed out of the cavity, avoiding thick layers of the flowable composite at the tooth-restoration interface in locations loaded by occlusion and articulation. It is often suggested that micropreparations are best restored using a flowable composite (Peters & McClean, 2001b). Advantages of these materials are their low viscosity, making it possible to let the material flow into a narrow cavity, and the application with a needle tip, which facilitates placement deep into the fissure. However, in this study, restorations placed with only flowable composite, either in bulk or in an incremental technique using the needle tip, resulted in the presence of voids in almost all cases, indicating that these materials are not as easy to manipulate as they appear. Chuang & others (2001a) already concluded that an experienced operator was more successful in placing a flowable composite without entrapping air. Others stated that flowable composites are difficult to manipulate and air is easily entrapped on removal of the syringe (Leevailoj & others, 2001). Wibowo & Stockton (2001) found it easy to let a flowable composite adapt to the deepest part of an approximal box but noted that after sectioning, incorporating porosities inside the restoration were frequent. Incorporating air bubbles is not only a problem of flowable composites but is also seen in other low, viscous materials such as pit and fissure sealants (Lekka & others, 1991). Flowable composites are also recommended as fissure sealants but are not always an improvement, as sealing with a flowable composite requires the use of an adhesive resin.

CONCLUSIONS

It can be concluded from this study that narrow occlusal preparations are difficult to restore completely free of voids. Flowable composites are sometimes recommended for this purpose but they showed disap-

pointing results in this study when used as the only restorative material. The most homogeneous restorations were obtained by combining an initial layer of uncured flowable composite with a second layer of medium-viscous composite injected into the cavity. Packable composites exhibited poor results even in combination with an uncured flowable composite.

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Effects of In-Office Bleaching Products on Surface Finish of Tooth-Colored Restorations

P Wattanapayungkul • AUJ Yap

Clinical Relevance

In-office bleaching systems that employ strong oxidizing agents are not detrimental to the surface finish of tooth-colored restorative materials.

SUMMARY

A number of "high power" in-office bleaching products have recently been re-introduced into the market. The use of such strong oxidizing agents has raised questions as to possible adverse effects on tooth structure and restorative materials. This study evaluated the effects of 35% carbamide peroxide (Opalescence Quick) and 35% hydrogen peroxide (Opalescence Xtra) on the surface finish of four tooth-colored restorative materials (Spectrum TPH, Dyract AP, Reactmer and Fuji II LC). Twenty-seven matrix-finished specimens of each material were fabricated, stored in distilled water at 37°C for seven days and randomly divided into three groups. Specimens in Group 1 were stored in distilled water at 37°C (control). Specimens in Groups 2 and 3 were treated with 35% carbamide peroxide and 35% hydrogen peroxide, respectively. A total of three 30-minute bleaching sessions were conducted at one-week intervals. Storage medium during the hiatus period was distilled water at 37°C. Surface roughness measurements were carried out using profilometry after each bleaching session. Data was analyzed using ANOVA/ Scheffe's test at a 0.05 significance level. No significant difference in surface roughness was observed between the bleached and the control groups for all materials. In-office bleaching products are not detrimental to the surface finish of composites, compomers, giomers and resin-modified glass ionomer cements.

*Pranee Wattanapayungkul, DDS, MSD, teaching fellow, Department of Restorative, Faculty of Dentistry, National University of Singapore

Adrian UJ Yap, BDS, MSc, PhD, FAMS, FADM, FRSH, associate professor, Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore

*Reprint request: Department of Restorative, Faculty of Dentistry, National University of Singapore, 5 Lower Kent Ridge Road, Singapore 119074, Republic of Singapore; e-mail: rsdwp@nus.edu.sg

INTRODUCTION

Over the last decade, home vital tooth bleaching has attracted the interest of patients and dentists due to its high success rates, ease of use and media publicity. This procedure utilizes low concentrations of hydrogen peroxide (3% to 7%) or carbamide peroxide (10% to 20%). Recently, new in-office bleaching products that utilize high concentrations of hydrogen peroxide or carbamide peroxide have been re-introduced. The latter procedure, which involves 30% to 35% carbamide peroxide or hydrogen peroxide, is totally under the dentist's control and has the potential for bleaching quickly in situations in which it is effective. High concentrations of hydrogen peroxide have been reported to cause surface roughening of teeth and etching-like patterns (Flaitz &

Hicks, 1996; Shannon & others, 1993; Zalkind & others, 1996).

The effects of such strong oxidizing agents on the physico-mechanical properties of restorative materials have, however, not been widely studied. Surface roughness of restorations is one clinically important physical property that warrants investigation. The surface finish of restorations influences aesthetics and oral health, as the presence of irregularities may influence appearance, plaque retention, surface discoloration and gingival irritation (Weitman & Eames, 1975; Dunkin & Chambers, 1983; Chan, Fuller & Hormati, 1980; Shintani & others 1985). Studies have shown that using home bleaching systems increases the surface roughness of some composite restoratives (Cooley & Burger, 1991; Bailey & Swift, 1992). Mor & others (1998) found that 10% carbamide peroxide and 10% hydrogen peroxide caused a significant increase in surface adherence of *S mutans* and *S sobrinus*, while a decrease in adherence of *Actimimyce viscosus* was found after treatment with 10% hydrogen peroxide. Little is known about the effects of in-office bleaching systems on the surface finish of composites, compomers, giomers or PRG composites and resin-modified glass ionomer cements. Giomer is a new category of hybrid aesthetic restorative material that employs the use of pre-reacted glass ionomer (PRG) technology (Yap & Mok, 2002). Unlike compomers, the fluoroalumino silicate glass is reacted with polyacrylic acid prior to inclusion into the resin matrix. The bonding and handling is similar to compomers. The manufacturer's claims include fluoride release and recharge, smooth surface finish, excellent aesthetics and clinical stability.

This study evaluated the effects of in-office bleaching systems on the surface finish of different tooth-colored restorative materials. The surface roughness of the different materials was also compared.

METHODS AND MATERIALS

Four tooth-colored restorative materials and two commercial bleaching agents were selected for this study. The restorative materials included a composite resin (Spectrum Dentsply/Detrey, Konstanz, Germany), a compomer (Dyract AP, Dentsply/Detrey, Konstanz, Germany), a giomer (Reactmer, Shofu Inc, Kyoto, Japan) and a resin modified glass ionomer (Fuji II LC Capsule, GC Corporation, Tokyo, Japan). The bleaching agents were 35% carbamide peroxide (Opalescence Quick, Ultradent Products, Inc, UT 84095, USA) and 35% hydrogen peroxide (Opalescence Xtra, Ultradent).

The restorative materials were placed in the rectangular recesses (4 mm long x 3 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate matrix strips (Hawe-Neos Dental, Bioggio, Switzerland) to achieve the smoothest surface finish (Bauer & Caputo, 1983; Pratten & Johnson, 1988; Yap, Lye & Sau, 1997) and to avoid problems of operator-induced variables during finishing and polishing. A glass slide was placed over the molds and pressure was applied to extrude excess material. The restoratives were light polymerized according to manufacturers' cure times with a Poly LUX II light cure unit (KaVo Dental, Warthausen, Germany). Mean intensity of the light source (597 ± 10 mW/cm^2) was determined with a radiometer (CureRite, EFOS INC, Ontario, Canada) prior to starting the experiment. Cure times were as follows: Spectrum–20 seconds; Dyract–40 seconds; Reactmer–30 seconds and Fuji II LC–20 seconds. The specimens were stored in distilled water at 37°C for seven days and randomly divided into three groups. Specimens in Group 1 were not exposed to any bleaching systems and served as the control group. Group 2 specimens were bleached with 35% carbamide peroxide (Opalescence Quick) for 30 minutes without any light activation or reapplication of bleaching gel. Group 3 specimens were bleached with 35% hydrogen peroxide (Opalescence Xtra) for 15 minutes with 20 seconds light activation. After 15 minutes, the gel was washed away, fresh gel was reapplied and the aforementioned treatment was repeated. The combination of the two cycles resulted in a total bleaching time of 30 minutes (Table 1). After bleaching, the specimens were washed and surface roughness measurements (R_a) were taken at the center of the specimens using a profilometer (Surftest SV-400; Mitutoyo, Kanagawa, Japan). The average surface roughness, R_a values is the arithmetic average height of roughness component irregularities from the mean line measured within the sampling length. Smaller R_a values indicate smoother surfaces. Four sampling lengths of 0.25 mm were used, giving a total evaluation length of 1 mm. The specimens were bleached for another two sessions at one-week intervals. Storage medium for all groups during the hiatus period was distilled water at 37°C. All statistical analysis was carried out at significance level 0.05. Multiple

Table 1: *Summary of Treatment Groups*

Groups	Bleaching Agents	Treatment Time	Light Activation	Reapplication of Gel
Group 1 (Control)	No treatment with bleaching agents	Not Applicable	Not Applicable	Not Applicable
Group 2	35% Carbamide Peroxide (Opalescence Quick)	30 minutes	No	No
Group 3	35% Hydrogen Peroxide (Opalescence Xtra)	30 minutes	Yes	Every 15 minutes

Table 2: *Mean Ra Values [10^{-2}] of Four Materials After the Various Bleaching Sessions (standard deviations in parenthesis)*

Materials	Spectrum TPH			Dyract AP			Reactmer			Fuji II LC		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Session 1	**5.00** (1.58)	5.22 (2.22)	4.78 (1.09)	5.57 (1.58)	6.00 (1.94)	6.11 (2.09)	8.44 (1.88)	7.22 (1.64)	8.89 (3.86)	10.89 (1.83)	10.11 (2.26)	10.89 (2.09)
Session 2	4.56 (0.5)	5.00 (0.70)	5.00 (1.50)	7.78 (2.54)	6.44 (1.81)	7.00 (2.17)	7.56 (2.92)	9.44 (4.44)	10.33 (3.00)	9.33 (2.45)	11.44 (2.04)	8.89 (1.27)
Session 3	4.78 (1.09)	5.00 (1.41)	4.56 (0.76)	8.22 (1.79)	6.22 (1.48)	6.44 (1.67)	8.78 (2.81)	8.37 (2.24)	9.33 (3.76)	9.11 (1.36)	9.67 (1.12)	8.33 (1.41)

Note: At all treatment sessions, there is no significant difference between Group 1, 2 and 3 for all materials.

Table 3: *Comparison of Ra Values Between Materials at the Various Treatment Sessions*

		Differences
Session 1	**Group 1**	Spectrum, Dyract < Reactmer < Fuji II LC
	Group 2	Spectrum, Dyract, Reactmer < Fuji II LC
	Group 3	Spectrum < Reactmer, Fuji II LC Dyract < Fuji II LC
Session 2	**Group 1**	Spectrum < Dyract, Fuji II LC
	Group 2	Spectrum, Dyract < Reactmer, Fuji II LC
	Group 3	Spectrum < Reactmer, Fuji II LC
Session 3	**Group 1**	Spectrum < Dyract, Reactmer, Fuji II LC
	Group 2	Spectrum < Reactmer, Fuji II LC Dyract < Fuji II LC
	Group 3	Spectrum < Reactmer, Fuji II LC Dyract < Reactmer

**Results of one-way ANOVA/Scheffe' test at significance level 0.05.*
< indicates statistically significant difference.

analysis of variance (ANOVA) was used to determine the interaction among various variables. One-way ANOVA and Scheffe's post-hoc test were used to establish the effects of bleaching systems on individual materials and to compare the surface roughness of the various materials after bleaching.

RESULTS

The mean Ra values of four materials after the various bleaching sessions are shown in Table 2, while Table 3 shows the results of statistical analysis comparing materials.

Multiple analysis of variance showed no significant interaction between materials, treatment groups and sessions. At all treatment sessions, no significant difference in surface roughness was observed between the control and the bleached groups for all materials. The use of in-office bleaching systems was therefore not detrimental to the surface finish of the tooth-colored restorative materials evaluated. Significant differences in surface roughness were, however, observed between materials. Differences between materials varied somewhat depending on the treatment session. For all treatment sessions and groups, Spectrum was significantly smoother than Fuji II LC. After the third treatment session, Spectrum was significantly smoother than Dyract, Reactmer and Fuji II LC for the control group. No significant difference was observed among the latter three materials. For the bleached groups, Spectrum was only significantly smoother than Reactmer and Fuji II LC. No significant difference in surface roughness was observed between Spectrum and Dyract. Ra values obtained with Dyract were significantly lower than Fuji II LC for Group 2 and Reactmer for Group 3.

DISCUSSION

Vital tooth bleaching using high concentrations of hydrogen peroxide was described as early as the 1900s (Henderson, 1910; Fisher, 1911; Ames, 1937). The procedures were both complicated and time-consuming; furthermore, gingival irritation was relatively frequent. The new in-office bleaching products being marketed also utilize high concentrations of carbamide peroxide or hydrogen peroxide. The delivery systems are, however, more friendly and the consistency more workable. The concentration of hydrogen peroxide and the pH of bleaching products is important to clinicians as they may have adverse effects on both tooth structure and restorations. Price, Sedarous & Hiltz (2000) measured the pH of 26 tooth-whitening products available in the market. They found that home bleaching products have a pH range from 5.66 to 7.35. The pH range of in-office bleaching systems was lower and ranged from 3.67 to 6.53. Among the systems evaluated, Opalescence Xtra had the lowest mean pH (3.67) and Opalescence Quick had the highest mean (6.53). These two bleaching systems were thus selected for the current study. With the exception of conventional glass ionomer cements, the materials selected represent the entire continuum of tooth-colored restorative materials currently available.

Surface alterations to resin composites and glass ionomer cements after exposure to bleaching agents have been reported (Bailey & Swift, 1992; Lee, Grimuado & Shen, 1999; Kilimitzoglou & Wolff, 2000; Turker & Biskin, 2000). The products used in these studies were "at-home" systems and over-the-counter bleaching products. Roughening was suggested to result from loss of matrix rather than filler particles (Bailey & Swift, 1992). Other studies (Burgess & others, 1991; Souyias, Hoelscher & Neme, 2000) have, however, demonstrated no significant increase in surface roughness. The apparent discrepancies may be explained, in part, by the differences in experimental methodologies and bleaching agents used. While some researchers have adopted clinically relevant protocols, others have employed continuous exposure of restorative materials to bleaching agents over stipulated time periods. The frequency of change of bleaching agents may also contribute to the disparity in results.

The contact time between bleaching products and teeth/restorations for home vital bleaching is much longer than that for in-office vital bleaching. In this study, three sessions of 30-minute bleaching treatment with one-week intervals were employed to simulate clinical conditions. At all treatment sessions, no significant difference in surface roughness was observed between the control and bleached groups for all materials. Using Opalescence Quick and Xtra are, therefore, not detrimental to the surface finish of the composite, compomer, giomer and resin-modified glass ionomer cements evaluated clinically. It is important to note that results may be material dependent, as some restorative materials are pH sensitive. For example, the surface finish of "smart" composites, such as Ariston pHc (Vivadent, Schann, Liechtenstein) that use a low oral pH to increase fluoride release (Combe & Douglas, 1998), may be affected by the low pH of some hydrogen peroxide-based bleaching systems. For all treatment sessions and groups, the composite (Spectrum) was significantly smoother than the resin-modified glass ionomer cement (Fuji II LC). This can be explained by the differences in microstructure. The mean particle size of Spectrum is under 1 μm, while that of Fuji II LC is 4.8 μm. Treatment with strong oxidizing agents appeared to stabilize the surface of the compomer evaluated. For the control group, a gradual increase in roughness was observed for Dyract specimens. The Ra values of bleached Dyract specimens, however, remained relatively stable over the experimental period. The aforementioned accounts of the significantly smoother surface of Dyract as compared to Reactmer/Fuji II LC for the bleached groups after three weeks storage in water at 37°C. Compomers are known to uptake water and expand (Yap & others, 2000). Water uptake is necessary for establishing an acid-based reaction and fluoride release (Yap, Khor & Foo, 1999). Water uptake may result in stress corrosion and complete or partial debonding of fillers leading to increased surface roughness (Söderholm, 1983). The exact mechanism for the stabilization effect of in-office bleaching agents is not known and warrants further investigation.

Although in-office bleaching systems are not detrimental to the surface finish of tooth-colored restoratives, care should still be taken when bleaching teeth with restorations. Hydrogen peroxide was found to have higher levels of penetration into the pulp chamber in restored teeth compared to sound teeth (Gokay, Tuncbilek, & Ertan, 2000). The mechanical properties and, durability of tooth-colored restoratives may also be affected by in-office bleaching agents. Dentists should, therefore, limit treatment time to as short as possible since extended bleaching treatment with such high concentrations of peroxide along with low pH may cause some alterations to both tooth structure and restorations.

CONCLUSIONS

1. The use of in-office bleaching systems that employ strong oxidizing agents is not detrimental to the surface finish of composite, compomer, giomer and resin-modified glass ionomer cements evaluated.
2. The surface finish of the composite Spectrum was significantly better than the resin-modified glass ionomer regardless of bleaching treatment.

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Effects of Regional Enamel and Prism Orientation on Resin Bonding

Y Shimada • J Tagami

Clinical Relevance

Within the limitation of this *in vitro* study, the bond strengths of the self-etching primer system and the one-bottle adhesive system were influenced by the anisotropic structure of enamel. The effect of the self-etching primer system was less influenced than that of the one-bottle adhesive system.

SUMMARY

Human enamel, with its prismatic, rod-like apatitic morphology, is an anisotropic material. Because of this structural anisotropy, variation in enamel bonding sites might influence the bonding ability of current adhesive systems. This study investigated the effects of regional enamel and the direction of enamel sectioning on the bonding ability of two commercially available resin adhesives: a self-etching primer system (Clearfil SE Bond) and a one-bottle adhesive system intended for use with a total-etch wet bonding technique (Single Bond). Two regions of enamel, cuspal and mid-coronal enamel, were chosen, then sectioned in three different directions, horizontally, axially and tangentially. Slices of the sectioned enamel were then bonded with each adhesive system and submitted to a micro-shear bond test. The results of a micro-shear bond testing showed that the bonding of a one-bottle adhesive system (Single Bond) to enamel was high at the surface perpendicular to the enamel prisms (40 MPa to 51 MPa) and low at the surface parallel to the enamel prisms (24 MPa to 27 MPa). In the case of a self-etching primer system (Clearfil SE Bond), 35 MPa to 45 MPa bond strengths were obtained from all surfaces. The bond strengths of the two adhesive systems were significantly influenced by the anisotropic structure of enamel ($p<0.05$). However, the effect of a self-etching primer system was less influenced by the orientation of the prismatic structure of enamel than that of a one-bottle adhesive system ($p<0.05$).

SEM and CLSM microphotographs showed that the self-etching primer effectively modified the smear layer without being excessively destructive to the enamel.

*Yasushi Shimada, DDS, PhD, instructor, Tokyo Medical and Dental University, Tokyo, Japan

Junji Tagami, DDS, PhD, professor and chair, Tokyo Medical and Dental University, Tokyo, Japan

*Reprint request: Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan; e-mail: shimada.ope@tmd.ac.jp

INTRODUCTION

Human enamel mainly consists of apatitic calcium phosphate arranged in a highly ordered prismatic array (Lees & Rollins, 1972; Rasmussen & others, 1976; Munechika & others, 1984; Carvalho & others, 2000). Because of this microstructural anisotropy, variation in enamel bonding sites might influence the bonding strength of direct restorative systems to this substrate (Munechika & others, 1984; Shimada & oth-

ers, 1999a). However, the effects of regional variations in tooth structure, such as the orientation of the enamel prisms, and the variability introduced by tooth sectioning (cavity preparation) on dental adhesion, are still not completely understood.

Today, two kinds of adhesive systems are commercially available; they are the so-called "one-bottle" and "self-etching" adhesives (Nakabayashi, 1984; Wang, Nikaido & Nakabayashi, 1991; Tay & others, 1996; Watanabe, Nakabayashi & Pashley, 1994). This study investigated how regional enamel microstructural variation and the effects of enamel sectioning (orientation of enamel prisms) influence the bonding ability of a self-etching primer system and an acid-etch, one-bottle adhesive system. In addition, surfaces with the bonding removed after the shear bond test for failure mode, the adhesive interface between the enamel and resin and the conditioned enamel surface without any bonding were studied morphologically using scanning electron microscopy (SEM) or confocal laser scanning microscopy (CLSM). CLSM has been widely used in biology for non-invasive and non-destructive imaging *in vivo* of many organ tissues and has found numerous applications in dental research (Watson, 1989; Shimada & others, 1999b). Specimens examined by CLSM do not require any special preparation and are not subjected to the distortions caused by dehydration that results from procedures such as SEM.

METHODS AND MATERIALS

Two bonding systems were evaluated: Clearfil SE Bond system, which includes a self-etching primer and a bonding agent (Kuraray Co, Osaka, Japan), and Single Bond system, which uses an etching gel with 35wt% phosphoric acid and a one-bottle adhesive (3M, St Paul, MN 55144, USA). All the materials were handled according to manufacturers' instructions.

Micro-shear bond tests were used to measure the bonding in this study (Shimada & others, 1999a).

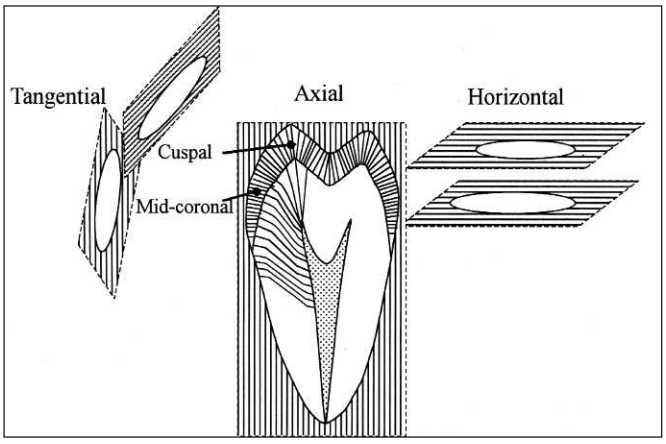

Figure 1a: *Tooth regions and sectioning directions.*

Tooth Slices

One hundred and ninety-two human molars were stored under refrigeration in a preservative solution containing 0.2 g sodium azide 100 mL distilled water before sectioning. The cuspal and mid-coronal enamel regions chosen as substrates for micro-shear bond test were sectioned in one of three ways, horizontally, axially or tangentially (Figure 1a). Horizontal slices were cut perpendicular to the tooth axis, axial slices were cut parallel to the tooth axis and tangential slices were cut parallel to the dentino-enamel junction. Because each of the two regions of enamel was directionally sectioned three ways, a total of six kinds of slices were examined. Thirty-two slices each, approximately 1.0 mm thick, were obtained from every six kinds of enamel (192 slices total) by cutting with a slow rotating diamond blade (Struers Minitom, Struers, Copenhagen, Denmark) under a flow of water. The enamel surfaces were then resurfaced with wet 280-grit SiC paper until a depth half way between the dentin enamel junction and outer surface was obtained.

Micro-Shear Bond Test

Twenty enamel slices from the 32 slices, each corresponding to the six kinds of enamel slices, were randomly chosen (120 slices total) and further divided into two groups (10 slices each) according to the adhesive system used. Each slice underwent one of the following treatments:

Group 1 (Single Bond system): Etched with Single Bond etchant for 15 seconds, thoroughly rinsed for 15 seconds and blot-dried with absorbent paper for removal of excess water, leaving a moist surface. Two coats of Single Bond Adhesive were consecutively applied, air thinned and light cured for 20 seconds.

Group 2 (Clearfil SE Bond system): Treated with Clearfil SE Bond Primer for 20 seconds and dried. Clearfil SE Bond was applied, air thinned and light cured for 10 seconds.

Prior to the irradiation of bonding resin, an iris cut from microbore Tygon tubing (R-3603, Norton Performance Plastic Co, Cleveland, OH, USA) with an internal diameter and a height of approximately 0.8 mm and 0.5 mm, respectively, was mounted on the enamel to restrict the bonding area. A hybrid restorative resin composite, shade A3 (Clearfil AP-X, Kuraray Co, Osaka, Japan) was placed into the cylinder and a clear celluloid sheet was placed over the resin and gently pressed flat and irradiated for 40 seconds. In this manner, very small cylinders of resin, approximately 0.8 mm in diameter and 0.5 mm in height, were bonded to the surface. The specimens were stored at room temperature (23°C) for one hour prior to removing the tygon tubing. The specimens were then stored in water at 37°C for 24 hours.

After the specimens were cooled to room temperature, their shear bond strength was measured by micro-shear testing (Figure 1b). The tooth slice with the resin cylinders was adhered to the testing device (Bencor-Multi-T, Danville Engineering Co, San Ramon, CA 94583, USA) with a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA 92882, USA), which, in turn, was placed in a universal testing machine (Ez-test-500N, Shimazu Co, Kyoto, Japan) for shear bond testing. A thin wire (diameter 0.20 mm) was looped around the resin cylinder, making contact with half of the cylinder base, and it was held flush against the resin/enamel interface. A shear force was applied to each specimen at a crosshead speed of 1.0 mm/min until failure occurred.

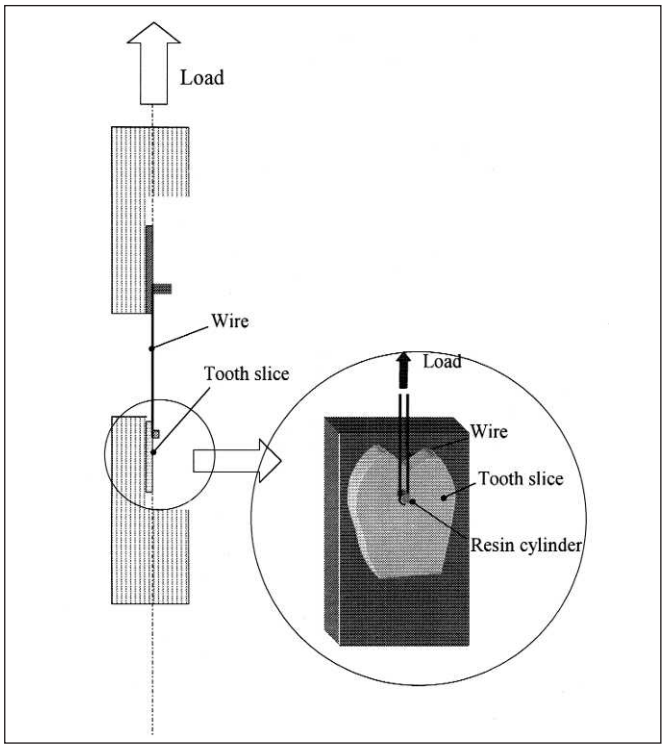

Figure 1b: *Micro-shear bond test.*

The adhesive systems (SE Bond and Single Bond), enamel regions (cuspal and mid-coronal regions) and direction of sectioning (horizontally, axially and tangentially) were the three factors analyzed using three-way analysis of variance (ANOVA). After three-way ANOVA, one-way ANOVA and multiple comparisons were made using Fisher's PLSD test. Statistical significance was defined as $p<0.05$.

All the debonded enamel surfaces after the shear bond test were examined under an optical microscope at 30x magnification and SEM (JXA840, JEOL Ltd, Tokyo, Japan) so that the mode of failure and orientation of enamel prisms could be identified.

Morphological Study Using SEM and CLSM

Six additional slices, each corresponding to one of the six kinds of enamel slices (36 slices total), were divided into two subgroups (three slices each) and conditioned or primed (but not bonded) in the same manner as the shear bond test specimens. The slices treated with the self-etching primer were given an additional 60-second acetone rinse to remove any crystals or other residue remaining from the primer. The surfaces were sputter-coated with gold and observed in a SEM.

Also, the remaining six slices that corresponded to the six kinds of enamel slices (36 slices total) were used for interfacial observations and bonded in the same manner as that employed for the shear bond test. The bonded specimens were cut in half, then ground and polished using wet silicon carbide papers and diamond pastes of decreasing particle size down to 0.25 µm. One of the polished surfaces was sputter-coated with gold and observed under SEM. The other half of the polished pair surface was viewed under CLSM (1LM21H/W, Lasertec Co, Yokohama, Japan).

Table 1: *Micro-Shear Bond Strength (MPa) and Mode of Failure on Enamel*

Area	Direction	Bond Strength		Failure Mode		
		Mean (SD)	N	A*	C**	AC***
Single Bond						
Cuspal	Horizontal	51.7 (5.2)	10	10	0	0
	Axial	24.9 (3.5)	10	0	10	0
	Tangential	40.1 (3.6)	10	10	0	0
Mid-coronal	Horizontal	27.3 (5.3)	10	0	7	3
	Axial	26.4 (3.9)	10	0	10	0
	Tangential	42.7 (8.4)	10	8	0	2
Clearfil SE Bond						
Cuspal	Horizontal	45.5 (5.2)	10	10	0	0
	Axial	36.6 (4.9)	10	0	10	0
	Tangential	41.9 (5.4)	10	10	0	0
Mid-coronal	Horizontal	39.6 (3.9)	10	0	8	2
	Axial	35.7 (5.2)	10	0	10	0
	Tangential	42.9 (7.5)	10	10	0	0

***100% adhesive failure between enamel or hybrid enamel layer and overlying adhesive resin; **100% cohesive failure in enamel; ***Mixed failure with adhesive failure (A) and cohesive failure in enamel (C)*

RESULTS

Micro-Shear Bond Test

The mean shear bond strength and standard deviations in MPa and mode of failure are shown in Table 1. The results of the statistical analysis are shown in

Table 2: *Results of Statistical Analysis*

ANOVA and Interactions	Sum of Squares	Mean Squares	F Value	p Value
1. SE Bond * Single Bond	713.310	713.310	24.876	<.0001
2. Cuspal * Mid-Coronal	568.624	568.624	19.830	<.0001
1 * 2	171.607	171.607	5.985	0.160
3. Horizontal * Tangential * Axial	3085.660	1542.830	53.804	<.0001
1 * 3	465.327	232.663	8.114	.0005
2 * 3	1855.050	927.525	32.346	<.0001
1 * 2 * 3	637.756	318.873	11.120	<.0001

	Adhesive system	SE Bond > Single Bond
Enamel region	Cuspal > Mid-coronal	
Sectioning direction	Horizontal & Tangential > Axial	

> indicates statistically significant difference (Fisher's PLSD test, p<0.05)

Single Bond vs SE Bond		**SE Bond**					
		Cuspal			Mid-Coronal		
		H	A	T	H	A	T
Single Bond							
Cuspal	Horizontal	S	S	S	S	S	S
	Axial	S	S	S	S	S	S
	Tangential	S	NS	NS	NS	NS	NS
Mid-Coronal	Horizontal	S	S	S	S	S	S
	Axial	S	S	S	S	S	S
	Tangential	NS	S	NS	NS	S	NS

S indicates statistical significance. NS indicates no statistical significance (Fisher's PLSD test, p<0.05)

Table 3: *Statistical Analysis of Single Bond*

Enamel Region	Cuspal > Mid-Coronal
Sectioning Direction	Horizontal & Tangential > Axial

> indicates statistically significant difference (Fisher's PLSD test, p<0.05)

Single Bond		Mid-Coronal			Cuspal	
		T	A	H	T	A
Cuspal	Horizontal	S	S	S	S	S
	Axial	S	NS	NS	S	
	Tangential	NS	S	S		
Mid-Coronal	Horizontal	S	NS			
	Axial	S				

S indicates statistical significance. NS indicates no statistical significance (Fisher's PLSD test, p<0.05)

Tables 2, 3 and 4. The ANOVA indicated that there were statistically significant interactions between the adhesive systems and the directions of sectioning (p=0.0005), as well as the enamel regions and the directions of sectioning (p<0.0001). However, no significant interaction was observed between the adhesive systems and the enamel regions (p=0.160). Fisher's PLSD test indicated that significant differences existed between the adhesive systems (SE Bond versus Single Bond, p<0.05) and the enamel regions (cuspal versus mid-coronal, p<0.05). In the case of directions of sectioning, only the axial slices showed significantly lower bond strength values (p<0.05).

The enamel bonding of one-bottle adhesive system (Single Bond) was significantly influenced by the direction of sectioning (One way ANOVA, df=5, 54, F=2.386, p=9.47 x 10^{-18}). Even though the mean shear bond strength values also tended to be lower at the axial slice (Fisher's PLSD test, p<0.05), the effect of the self-etching primer system (Clearfil SE Bond) was less influenced by the direction of sectioning than it was in the test with Single Bond (One way ANOVA, df=5, 54, F=2.386, p=0.00076).

Morphological Study Using SEM and CLSM

The SEM part of this study showed that the axially sectioned cuspal and mid-coronal regions and the horizontally sectioned mid-coronal regions mostly contained longitudinally cut enamel prisms, whereas the tangentially sectioned cuspal and mid-coronal regions and the horizontally sectioned cuspal region mostly contained crosscut enamel prisms. SEM photomicrographs of enamel surfaces etched with phosphoric acid gel or the self-etching primer are shown in Figure 2. The self-etching primer showed a less distinct pattern than phosphoric acid etchant. SEM and CLSM images of adhesive interfaces between the enamel and the resin are shown in Figure 3. When the parallel prismatic zone was etched by phosphoric acid gel, not only the apatite crystals but also the subsurface enamel prisms separated from the deeper part of the enamel (Figure 3b). In the case of the self-etching primer, the formation of etched enamel tags was not as evident compared to that of the phosphoric acid etching (Figures 3c, d).

Table 4: *Statistical Analysis of SE Bond*

Enamel Region	Cuspal NS Mid-Coronal (p=0.0574)
Sectioning Direction	Horizontally & Tangentially > Axially

> indicates statistically significant difference.

NS indicates no statistically significant differences (Fisher's PLSD test, p<0.05).

SE Bond		Mid-Coronal			Cuspal	
		T	A	H	T	A
Cuspal	Horizontal	NS	S	S	NS	S
	Axial	S	NS	NS	S	
	Tangential	NS	S	NS		
Mid-Coronal	Horizontal	NS	NS			
	Axial	S				

**S indicates statistical significance. NS indicates no statistical significance (Fisher's PLSD test, p<0.05)*

Figure 2: *SEM Images of Conditioned Tooth Surfaces*

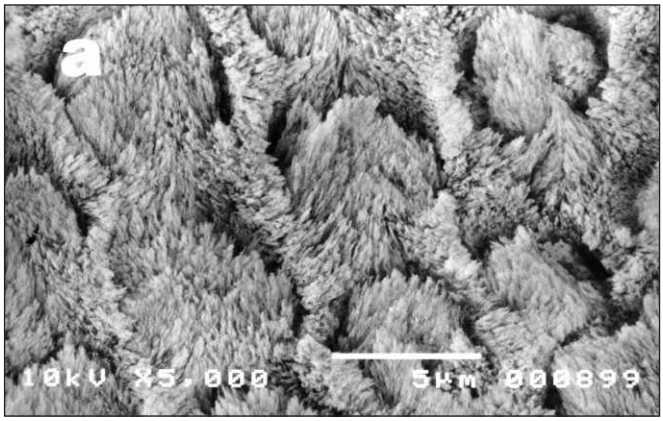

Figure 2a: *Horizontally sectioned cuspal enamel etched by 35% phosphoric acid gel for 15 seconds. Enamel surface is roughened and microirregularity based on apatite crystals is apparent.*

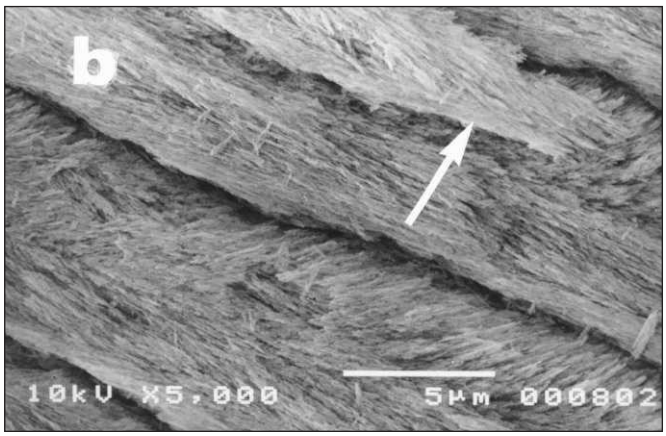

Figure 2b: *Axially sectioned cuspal enamel etched by 35% phosphoric acid gel for 15 seconds. Unsupported apatite crystals were observed at the etched surface (arrow).*

DISCUSSION

Microfractures of longitudinally cut enamel prisms have been described (Lees & Rollins, 1972; Rasmussen & others, 1976). Munechika & others (1984) reported higher tensile bond strengths for crosscut etched enamel than for longitudinally cut enamel. In this study, similar results were obtained with the total-etch wet-bonding treatment with phosphoric acid. An examination of bond failure at the enamel surface indicated that enamel fracture generally occurred, especially at the parallel prismatic zone, while adhesive failure between enamel or hybrid enamel and overlying adhesive resin generally occurred at the crosscut prismatic zone. Even though it has been reported that this mode of failure is due to the non-uniform stress distribution generated in the shear test arrangement (Van Noort & others, 1991; DeHoff, Anusavice & Wang, 1995), the bonding to the parallel-prismatic zone seems to contribute to the strength of enamel and the inherent strength of the enamel might be the weak link (Munechika & others, 1984; Shimada & others, 1999a; Carvalho & others, 2000). This is because enamel failure did not occur as much in the area of crosscut prismatic zone and because these surfaces produced significantly higher bond strengths (Fisher's PLSD, p<0.05). On the other hand, the fracture toughness of crosscut enamel prisms seems to be higher than that of the bonding resin or the bonding between the bonding resin and enamel (Munechika & others, 1984; Shimada & others, 1999a; Carvalho & others, 2000).

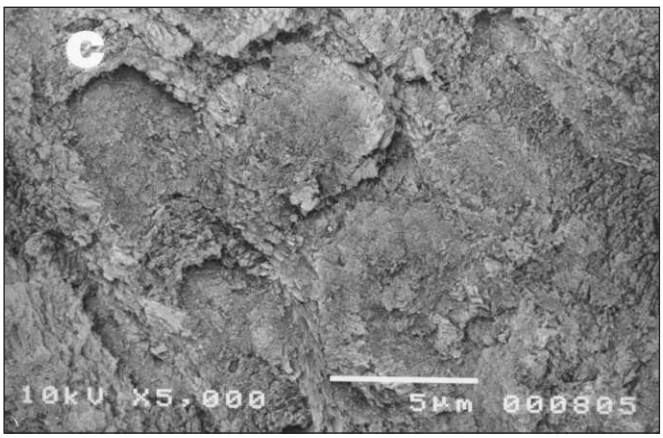

Figure 2c: *Horizontally sectioned cuspal enamel conditioned by Clearfil SE Bond primer for 20 seconds. The smear layer was removed, revealing slight porosity at the enamel surface.*

Figure 3: *SEM and CLSM Images of Adhesive Interface*

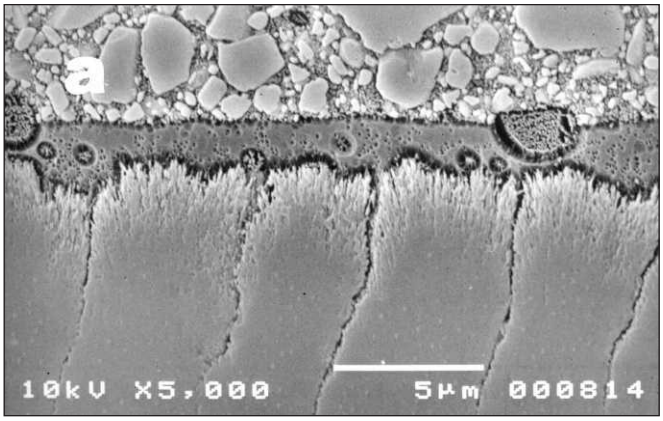

Figure 3a: *SEM image of Single Bond to the crosscut prismatic zone. Bonding resin flows and interlocks to the interprismatic and intercrystalline spaces. The etched zone is approximately 10 µm deep.*

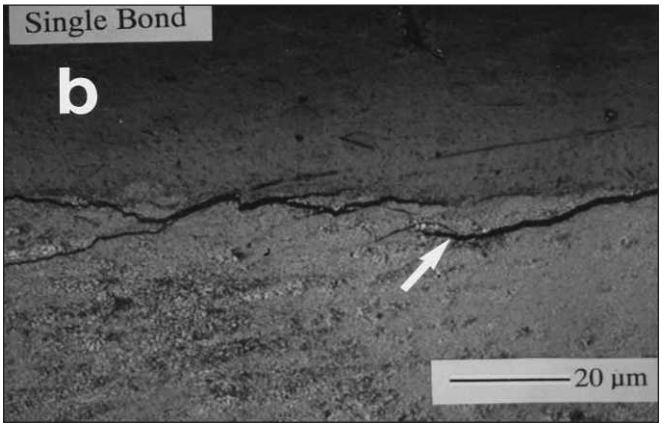

Figure 3b: *CLSM image of Single Bond to the longitudinally sectioned prismatic zone. Separation of superficial enamel prism was observed (arrow).*

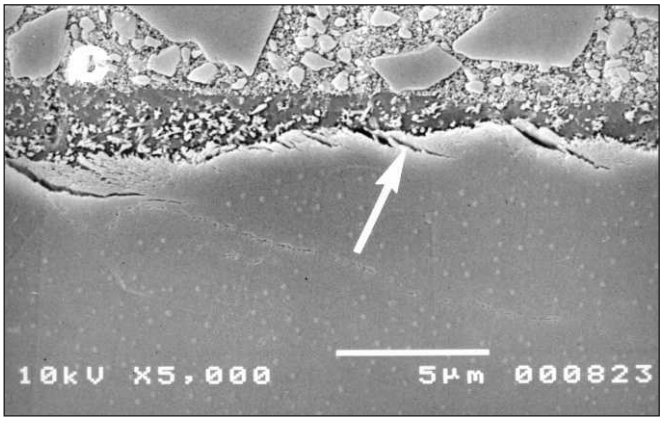

Figure 3c: *SEM image of the Clearfil SE Bond to the longitudinally sectioned prismatic zone. Superficial apatite crystals were partially separated (arrow).*

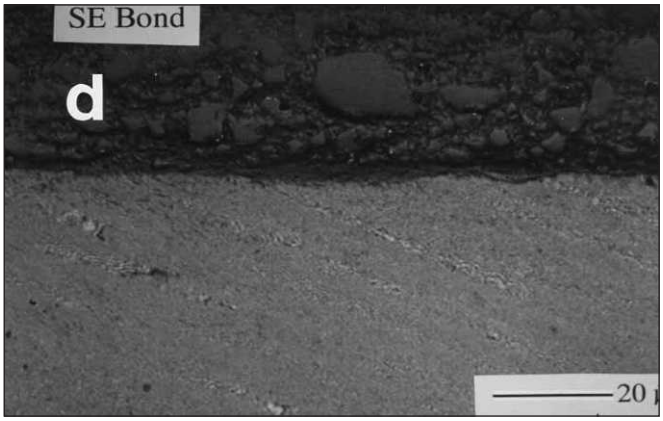

Figure 3d: *CLSM image of Clearfil SE Bond to the longitudinally sectioned prismatic zone.*

Resin composites shrink as they polymerize, and contraction stresses grow within the resin (Davidson, de Gee & Feilzer, 1984). The lower bond strength of Single Bond obtained from the parallel prismatic zone may be attributed to the intrinsic weakness of the anisotropic substrate. It is highly likely that polymerization shrinkage stress produced during the light curing of adhesive caused the enamel to crack, especially when an unfilled adhesive such as Single Bond system was used (Figure 3b). On the contrary, the adhesive of Clearfil SE Bond is a filled adhesive that might cause less shrinkage stress. The inclusion of filler particles in the composition of the adhesive may result in a stress-breaking behavior (Davidson & Abdalla, 1994). A variety of factors may influence the cuing stress value and the development of stress with time. Further study regarding the effect of curing stress on enamel is needed (Aarnts, Akinmade & Feilzer, 1999).

The depth of enamel demineralization caused by phosphoric acid etching has been reported to be approximately 5 to 50 µm and the depth of the porous zone to be 5 to 20 µm (Silverstone & others, 1975; Shinchi, Soma & Nakabayashi, 2000). In this study, the authors observed an interprismatic space approximately 10 µm deep caused by phosphoric acid (Figure 3a). The phosphoric acid etching of 10 µm depth might also be aggressive for the parallel-prisms site, to the point where it could cause the shearing off of the subsurface enamel prisms or apatite crystals.

In the case of the self-etching primer system, the effect on enamel bonding was less influenced by prism orientation and enamel (Table 1). Compared to the results obtained with the one-bottle adhesive system, the bond strengths of this system were comparable at the crosscut enamel surfaces (tangentially sectioned cuspal and mid-coronal regions and the horizontally sectioned cuspal region) and significantly higher at the parallel-prisms site (axially sectioned cuspal and mid-coronal regions and the horizontally sectioned mid-coronal regions; Fisher's PLSD, $p<0.05$). The bonding to

enamel is reportedly achieved by micromechanical adhesion resulting from the diffusion of resin monomers into the pretreated enamel and polymerization, therein, creating a hybrid layer in enamel (Nakabayashi, 1984; Kanemura, Sano & Tagami, 1999; Shinchi & others, 2000). The depth of enamel demineralization and the penetration depth of the monomer seem to be identical, since the processes run parallel to each other (Watanabe & others, 1994). The self-etching primer may provide optimal demineralization of enamel not only for the crosscut prismatic zone but also for the parallel zone (Watanabe & others, 1994; Kanemura & others, 1999; Shimada & others, 1999a; Hannig, Reinhardt & Bott, 1999).

Previous studies of the properties of enamel show different values of stiffness for occlusal, cuspal and side enamel (Stanford & others, 1960; Ng & others, 1989). In this study, no significant differences in bond strengths existed except in the case of the horizontal sections. The discrepancy observed with the horizontal sections also seemed to be dependent on the prism orientation, as horizontal cuspal slices involved crosscut prisms and resulted in higher bond strengths, while the mid-coronal site created almost parallel prisms that yielded lower bond strength (Table 1). In particular, phosphoric acid treatment produced a high bond strength value (51 MPa) at the horizontally sectioned cuspal enamel.

The formation of the Hunter-Schreger bands was reported to result from a change in the direction of the enamel prisms between successive groups of prisms (Hirota, 1982). Close to the central axis of the cuspal enamel, the enamel prisms were arranged in a tight spiral, which is oppositely directed with adjacent groups around the central axis of the tooth (Hirota, 1982). The reason for the high bond strength of horizontally sectioned cuspal enamel is probably the complexity of prism orientation plus the high density of enamel prisms (Hirota, 1982; Shimada & others, 1999a).

Enamel crack or gap might occur even with an enamel margin cavity because of the low bond strengths obtained in the parallel-prismatic zone. If lower bond strengths develop in the parallel prismatic zone in cavities with high c-factors, then the stress that develops during polymerization may produce debonding that is localized to these regions (Brännström & Nyborg, 1973; Davidson & others, 1984). Marginal integrity of composite resin restorations has been demonstrated to improve when enamel margins are beveled (Hinoura, Setcos & Phillips, 1988; Munechika & others, 1984; Shimada & others, 1999). Thus, enamel margins should be beveled, especially when phosphoric acid is used as an enamel conditioner for parallel prismatic walls. Although it seems that the self-etching primer system could reduce the crack of enamel margins, the long-term stability of the bonds needs to be evaluated. Further study is needed, especially under occlusal function that might fatigue the bonding. It has also been reported that an intact, unground enamel surface, where the margin of the restoration is placed, is prismless and hypermineralized, which reduces the effect of bonding of a self-etching primer system (Kanemura & others, 1999; Pashley & Tay, 2001). The effect of cavity depth on a direct restorative system should be studied with respect to microgap formation, as well.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. The bond strengths of the two adhesive systems were influenced by the anisotropic structure of enamel ($p<0.05$).
2. When phosphoric acid etching was applied to the parallel prismatic enamel, the enamel surface appeared to be over-etched, resulting in lower bonding.
3. The self-etching primer system produced higher bond strength to parallel prismatic enamel compared to the one-bottle adhesive system ($p<0.05$).

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The Effect of a "Resin Coating" on the Interfacial Adaptation of Composite Inlays

PR Jayasooriya • PNR Pereira • T Nikaido
MF Burrow • J Tagami

Clinical Relevance

The application of a "resin coating" consisting of a dentin bonding system and a low viscosity microfilled resin was shown to improve the interfacial adaptation of composite inlays when using a dual-cured resin cement.

SUMMARY

The relatively low bond strengths of resin cements to dentin may result in poor interfacial adaptation of composite inlays. This study determined whether the interfacial adaptation of composite inlays could be improved by applying an adhesive system and a low viscosity microfilled resin to the prepared cavity walls before making an impression. Ten MOD cavities were prepared on extracted human premolars with gingival margins located above and below the cemento–enamel junction. A "resin coat" consisting of a self-etching primer system (Clearfil SE Bond) and a low viscosity microfilled resin (Protect Liner F) was applied to the cavities of half of the prepared teeth, while the remaining teeth served as non-coated control specimens. All the teeth were restored with composite inlays (Estenia) fabricated by the indirect method and cemented with a dual-cured resin cement (Panavia F). After finishing the margins with superfine burs, the bonded inlays were thermocycled between 4°C and 55°C for 400 cycles. Specimens were sectioned with a diamond saw and the tooth-restoration interfaces were observed with a confocal laser scanning microscope. The data were analyzed with two-way ANOVA and Fisher's PLSD test ($p<0.05$). The percentage length of gap formation at the dentin-restoration interface of the "resin coated" teeth (7.1 ± 3.5) was significantly less than that of the non-coated teeth (85.7 ± 6.7) ($p<0.05$). The concept of coating the prepared cavity with an adhesive system and a low viscosity microfilled resin resulted in observing fewer gaps at the internal dentin-restoration interface compared with the non-coated specimens.

*Primali R Jayasooriya, BDS, graduate student, Tokyo Medical and Dental University, Tokyo, Japan

Patricia NR Pereira, DDS, PhD, assistant professor, University of North Carolina-School of Dentistry, Chapel Hill, NC

Toru Nikaido, DDS, PhD, senior lecturer, Tokyo Medical and Dental University, Tokyo, Japan

Michael F Burrow, MDS, PhD, associate professor, School of Dental Science, University of Melbourne, Melbourne, Australia

Junji Tagami, DDS, PhD, professor and chairman, Tokyo Medical and Dental University, Tokyo, Japan

*Reprint request: Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School, Tokyo Medical and Dental University, 1-5-45, Yushima, Bunkyo-ku, Tokyo 113-8549, Japan; e-mail: nikaido.ope@tmd.ac.jp

INTRODUCTION

Posterior composite restorations have risen in popularity as a result of the development of improved resin composites, bonding systems and operating techniques. In

posterior restorations, direct placement composites are the preferred treatment over indirect composite restorations because they require minimal intervention and cavity preparation (Tyas & others, 2000). However, a major limitation of direct composites is the inability to control polymerization shrinkage and depth of cure (Versluis & others, 1996). This, in turn, may lead to marginal gap formation and microleakage resulting in secondary caries (Fontana & others, 1996) and subsequent failure of the restoration. In posterior proximal restorations with enamel gingival margins, different incremental filling techniques (Versluis & others, 1996) and inserts (Ferderlin, Thonemann & Schmalz, 2000) provide some means to control polymerization shrinkage. However, these methods may be inadequate for teeth that require larger restorations (Cheung, 1990).

To overcome the polymerization shrinkage of posterior composite restorations, the indirect fabrication of a composite inlay and cementation with a resin cement has been advocated (Reeves & others, 1992). However, current dual-cured resin cements do not bond as strongly to the tooth as do resin adhesives that are designed for direct composite restorations (Burrow & others, 1996). Moreover, the inability of the resin cement to attain high bond strengths shortly after insertion of the restoration (Kitasako & others, 1995) and contamination from temporary filling materials, saliva and blood may lead to reduced bond strengths (Xie, Powers & McGuckin, 1993; Nikaido & others, 1998; Kaneshima & others, 2000) and it may adversely affect the longevity of the restorations. A relatively weak bond may lead to gap formation, producing post-operative sensitivity (Christensen, 2000) that results in premature failure of the indirect composite restorations.

By applying a resin coating that consists of a dentin bonding system and a low viscosity microfilled resin immediately following cavity preparation prior to making an impression, the prepared tooth surface is sealed to protect the pulp from mechanical trauma, thermal stimuli and bacterial invasion during impression making, provisional restoration fabrication and final cementation (Satoh & others, 1994). Moreover, the same method has been shown to improve the early bond strength of resin cement to dentin (De Goes & others, 2000).

This study evaluated gap formation at the internal tooth–restoration interface of MOD cavities bonded using a preliminary "resin-coat" by means of a confocal laser scanning microscope (CLSM) to determine whether a "resin-coating" technique could reduce gap formation at the interface of the indirect composite inlay (CI). The null hypothesis tested was that applying a resin coating immediately following cavity preparation does not affect the interfacial adaptation of CI.

METHODS AND MATERIALS

The materials used for this study and their restorative procedures are presented in Table 1. Recently extracted, non-carious, human maxillary premolars stored in water at 4°C were used. Ten mesio-occluso-distal (MOD) cavities with slightly rounded internal line angles were prepared using a superfine bur (SF 145, Shofu Co, Kyoto, Japan) mounted on a high-speed handpiece under water coolant (Figure 1). Dimensions of the cavity preparation were approximately 3 mm wide bucco-lingually, 3 mm deep (occlusal cavity), while the depth of the proximal boxes depended on the crown length of each tooth. The mesial and distal margins of each cavity were located 1 mm above and below the cemento-enamel

Table 1: *Material Used and Summary of Restorative Procedure*

Materials	Batch #	Composition	Directions
Dentin bonding system *Clearfil SE Bond*	003A	Primer: MDP, HEMA, water, photo-initiator Bond: Multi-functional methacrylates, microfillers, photo-initiator	Primer: 20 seconds apply, dry Bond: apply, dry, 20 seconds polymerize
Low viscosity micro-filled resin *Protect Liner F*	003	BIS-GMA, TEGMA, micro-fillers, photoinitiator	Mix with opaquer, apply, 20 seconds polymerize
Indirect resin composite *Estenia*	0019B	Hydrphobic methacrylates, 72wt% micro-fillers, 16wt% superfine fillers	Apply separator on stone cast, prepare inlay, three minutes polymerize in alpha-light, 15-minute heat cure
Resin cement *Panavia F*	0075B	ED primer: Primer A-MDP, HEMA, 5-NMSA, chemical initiator	Resin coated teeth+ all inlays: apply mixture of ED primer+ porcelain activator 60 seconds, dry
		Primer B- 5-NMSA, water	Non-coated teeth: apply ED primer 60 seconds, dry
		A paste-Quatz glass, micro-filler, MDP, methacrylate, photoinitiator. B paste-Barium glass, NaF, methacrylates, chemical initiator	Mix cement pastes, seat inlays, remove excess, polymerize 60 seconds

All materials were manufactured by Kuraray Co, Tokyo, Japan.
MDP- 10 metacylxydecyle dihydrogen phosphate, HEMA- 2 hydroxy ethyl methacrylate
5-NMSA- N methacryloyl 5 amino salicylic acid, NaF-sodium fluoride, TEGMA- tri ethylene glycol methacrylate

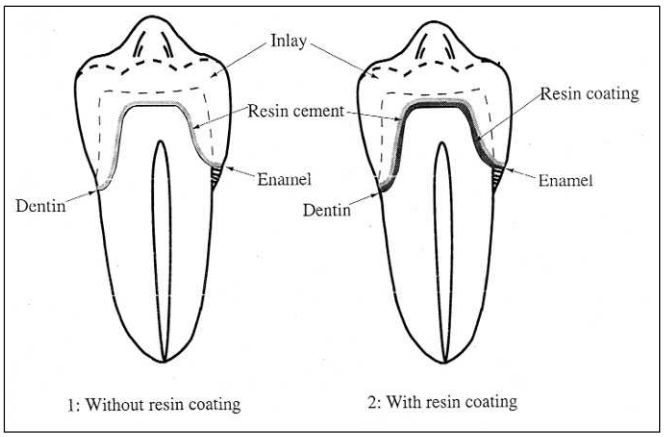

Figure 1: *Schematic illustration of the specimens.*

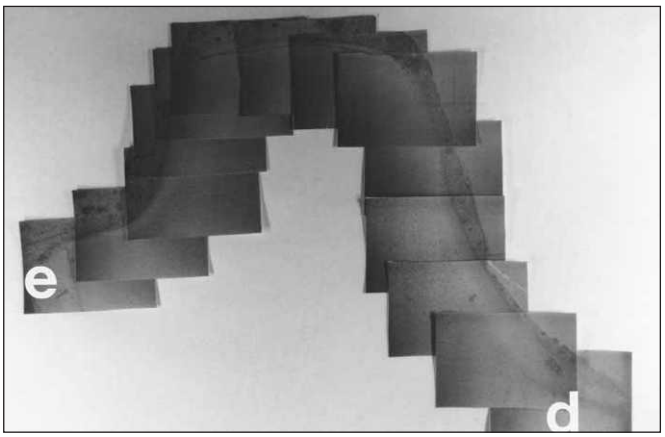

Figure 2: *Acquired tooth-restoration interface (10x). The total length of gap formation was evaluated on this image.*

junction, which means an enamel and dentin margin was created for each restoration, respectively. The prepared teeth were randomly divided into two groups, that is, the experimental group (n=5) that received the "resin -coating" and the control group (n=5) without the "resin coating."

Immediately following cavity preparation, the teeth were stabilized by embedding the roots in utility wax. For the specimens in the resin-coat group, the cavity surface was prepared using a self-etching primer bonding system (Clearfil SE Bond, Kuraray Medical, Tokyo, Japan) following the manufacturer's instructions. The specimens were then coated with a low viscosity microfilled resin (Protect Liner F, Kuraray Medical Co, Tokyo, Japan) and were polymerized for 20 seconds (New light-VLII, GC Co, Tokyo, Japan). To distinguish the two layers of "resin coating" under the CLSM, a small amount (5% wt) of opaque resin (Clearfil Opaquer, Kuraray Medical Co, Tokyo, Japan) was added to the low viscosity microfilled resin. An agar (Aromaloid, GC Co, Tokyo, Japan) and or irreversible hydrocolloid (Aromafine DF II, GC Co, Tokyo, Japan) combination impression (Takano, Nikaido & Tagami, 2001) was made of each cavity. The impressions were cast in a Type III stone (Zo Gypsum, GC Co, Tokyo, Japan). The next day, the composite inlays (Estenia, Kuraray Medical Co, Tokyo, Japan) were fabricated on casts according to the manufacturer's instructions. Trial insertion prior to cementation was performed to ensure a good fit for each inlay. For the cementation procedure, the enamel and dentin cementing surfaces of non-coated teeth were primed with ED primer for 60 seconds and dried. The cavities for the resin-coated teeth were etched with 37% phosphoric acid gel (K-etchant, Kuraray Medical Co, Tokyo, Japan) for 5-to-10 seconds, rinsed and dried in order to remove debris. A mixture of resin cement priming agent and a silane-coupling agent (Porcelain activator, Kuraray Medical Co, Tokyo, Japan) was applied for 60 seconds to the etched surface and fitting surfaces of the inlays, then dried. Equal amounts of two pastes of the dual-cured resin cement (Panavia F, Kuraray Medical Co, Tokyo, Japan) were mixed and placed in the cavities and the inlays were seated and polymerized for 60 seconds in total, 20 seconds each from occlusal, buccal and palatal directions. The teeth were placed in water at 37°C for 24 hours, then the margins were finished with superfine burs (V16ff, GC Co, Tokyo, Japan). The teeth were thermocycled between 4°C and 55°C for 400 thermal cycles (each cycle containing a 55 seconds dwell time and five seconds transfer time). The teeth were kept well hydrated at 37°C in a humidifier throughout the restorative procedure to prevent desiccation.

The teeth were sectioned mesio-distally along the long axis using a slow rotating diamond saw (Isomet, Buehler Co, Lake Bluff, IL 60044, USA) and polished to a high gloss with diamond pastes (grit 6, 3, 1, 1/4 µm; DP paste, Struers Co, Denmark). Gaps at the tooth-restoration interfaces were observed directly using a CLSM (Laser Tech, Tokyo, Japan) at 10x magnification and hard copy images were printed directly from the CLSM, forming a montage of the cavity-tooth interfacial region (Figure 2). The length of gap formation at the following three segments of the interface: gingival enamel and axial dentin on mesial wall (Enamel margin wall), occlusal dentin (Occlusal wall) and gingival dentin and axial dentin on distal wall (Dentin margin wall) were measured from the hard copy images. The percentage of length of gap formation was calculated by dividing the total length of gap by the total length of each segment of the interface (Belli & others, 2001). Areas with gap formation were also observed under high magnification and recorded. The data were analyzed by two-way ANOVA at 5% level of significance. The factors analyzed were region of cavity floor and with and without resin coating. The percentage of length of gap formation for each region with and

without coating was then analyzed by one-way ANOVA and Fisher's PLSD test at the confidence level of 95%.

The gap width and maximum thickness of the bonding agent, low viscosity microfilled resin and resin cement were also measured for each segment. The data were analyzed with one-way ANOVA and Fisher's PLSD test ($p<0.05$).

RESULTS

The percentage of length of gap formation is summarized in Table 2. Two-way ANOVA revealed that the percentages of gap formation were influenced by resin coating ($F=31.3$; $p<0.0001$) and the region of the cavity floor ($F=8.9$; $p<0.05$). Extensive gap formation was observed in the three segments in the non-coated group, while the gap formation was significantly reduced at each segment in the resin-coated group ($p<0.05$). The percentage of length of gap formation at the occlusal wall was significantly higher than the enamel margin wall and the dentin margin wall in both the non-coated and resin coated groups ($p<0.05$). However, there was no difference in the gap formation between the enamel and dentin margin walls ($p>0.05$). The maximum gap width ranged from 10-12 µm for both groups, and no statistically significant differences in the gap width between groups or sites ($p>0.05$) were observed (Table 3). The minimum gap width was 7 µm.

Maximum thickness of the bonding agent, low viscosity microfilled resin, the resin cement for the three segments and the statistical outcomes are shown in Table 4. The maximum thickness of resin cement for both methods ranged from 150 to 300 µm. Moreover, the thickness of resin cement at the dentin margin wall was significantly less than both the enamel margin walls and the occlusal walls in both groups. In the resin-coated group, the maximum thickness of Clearfil SE Bond and Protect Liner F were 145 and 93 µm at the enamel margin walls, 62 and 58 µm at the occlusal walls and 85 and 152 µm at the dentin margin walls, respectively. The maximum thickness of both Clearfil SE Bond and Protect Liner F at the occlusal wall was significantly lower than both the enamel and dentin margin walls.

CLSM photomicrographs of the interfaces with and without resin coating are shown in Figures 3 and 4, respectively. For the conventional method, no gaps were observed at the enamel margin (Figure 3a), while gap formation was observed at the dentin margin, parts of the proximal box surfaces (Figure 3b) and the whole occlusal wall. For the resin-coated teeth, good interfacial adaptation with significantly fewer gaps was observed at both the enamel and dentin margins (Figures 4a,b). However, gaps were present at the occluso-mesio and occluso-distal angles, where a thin layer of SE Bond and Protect Liner F were observed (Figure 4c).

DISCUSSION

To date, CLSM has been used to evaluate caries (Fontana & others, 1996), collagen shrinkage (Nakaoki & others, 2000) and tooth–restoration interfaces (Watson & Wilmot, 1992; Griffiths, Watson & Sherriff,

Table 2: *The Length of Gap Formation (%) of Composite Inlay–MOD Cavity Interface*

	Enamel Margin Wall	Occlusal Wall	Dentin Margin Walls
With Resin Coating	4.3 (4.0)[a]	13.3 (7.4)[b]	4.5 (4.1)[a]
Without Resin Coating	73.9 (8.3)[c]	100.0 (0.0)[d]	77.8 (10.1)[c]

**n=10, Mean (SD)*
The same superscript letters among figures represent no statistically significant difference (p>0.0001)

Table 3: *The Maximum Gap Width for Composite Inlay MOD Cavity Interface (µm)*

	Enamel Margin Wall	Occlusal Wall	Dentin Margin Wall
With Resin Coating	10.5 (2.5)[a]	11.5 (2.3)[a]	11.0 (2.4)[a]
Without-Resin Coating	10.0 (2.4)[a]	11.6 (2.4)[a]	11.5 (2.3)[a]

N=10, mean (SD)
The same superscript letter among figures represents no statistically significant difference (p>0.05).

Table 4: *The Maximum Thickness of the Materials Used in the Resin Coating and Resin Cement*

	Enamel Margin Wall	Occlusal Wall	Dentin Margin Wall
With Resin Coating			
1. SE Bond	145.0 (85.4)[a]	62.7 (60.3)[b]	134.7 (67.3)[a]
2. Protect Liner F	93.3 (66.5)[c]	58.3 (54.8)[c]	85.5 (41.1)[c]
3. Panavia F	241.1 (65.1)[d]	243.4 (87.2)[d]	152.9 (50.7)[e]
Without Resin Coating			
1. Panavia F	96.8 (52.3)[f]	266.9 (81.0)[f]	194.4 (51.5)[g]

n=10, mean (SD)
The same superscript letters among materials within each group represent no statistically significant difference (p>0.05.)

Figure 3: *Photomicrographs to show the tooth-restoration interface of a non-coated tooth (50x).*

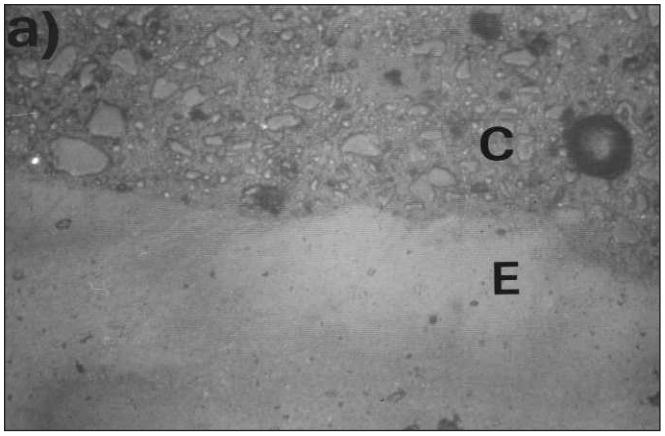

Figure 3a: *Enamel-restoration interface. No gap formation is visible between enamel (E) and resin cement (C).*

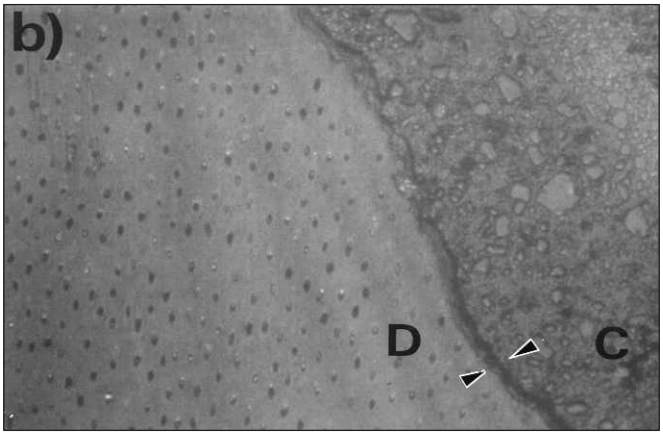

Figure 3b: *Dentin-restoration interface. Note the presence of gap (arrow) between dentin (D) and resin cement (C).*

Figure 4: *Photomicrograph to show the tooth-restoration interface of a resin-coated tooth (50x).*

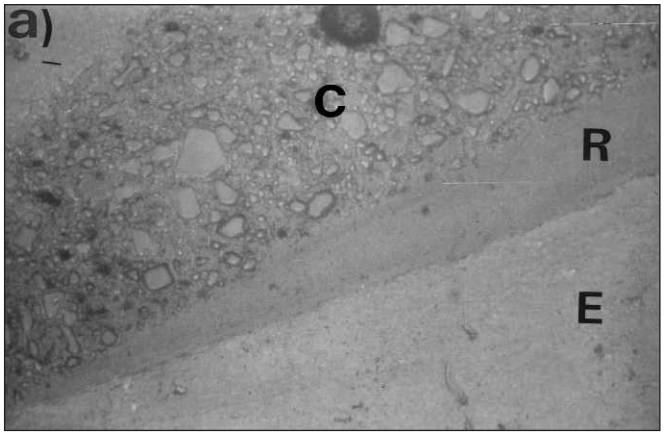

Figure 4a: *Enamel-restoration interface. Note the absence of gaps between enamel (E), resin coating (R) and resin cement (C) at the interfaces.*

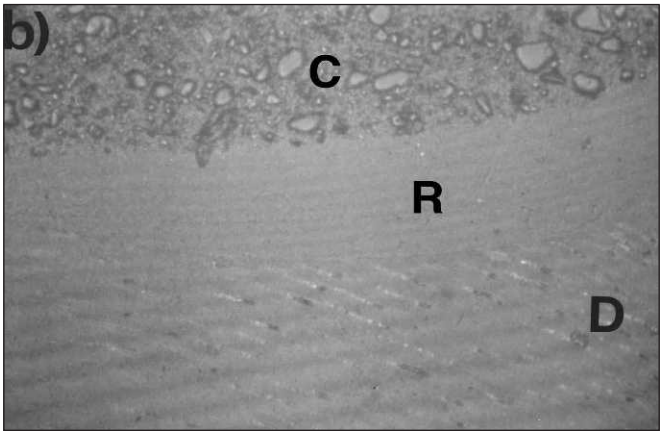

Figure 4b: *Dentin-restoration interface. Note the absence of gaps between dentin (D), resin coating (R) and resin cement (C) at the interfaces.*

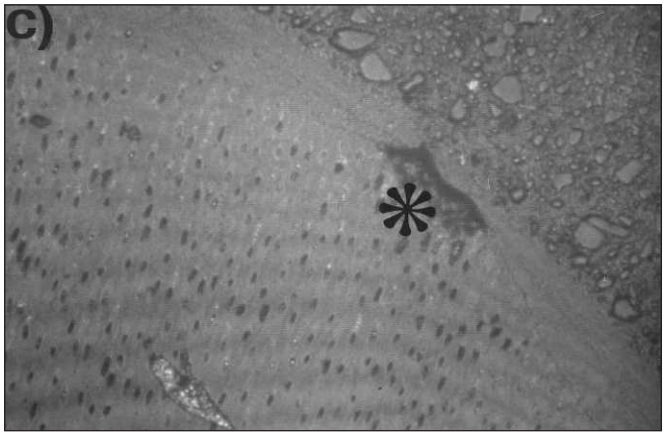

Figure 4c: *Disto-occlusal angle. Also, note the presence of gap (star) at disto-occluso proximal line angle and the thin resin coating.*

1999). Though studies have documented the use of CLSM simultaneously with the fluorescent-labeled dyes, only limited information is available in the literature regarding the use of CLSM to identify gaps without fluorescent-labeled dyes (Belli & others, 2001). The main advantage of CLSM is that it requires simple preparation of specimens without subjecting them to desiccation and high vacuum. Therefore, the destruction and artifacts that occur as a result of these procedures are reduced. In addition, the specimens can be observed under ambient conditions.

A resin-coating technique has recently been developed in which both a hybrid layer and a tight sealing film are produced on the dentin surface with a dentin adhesive system and a low-viscosity microfilled resin (Nikaido & others, 1992; Otsuki, Yamada & Inokoshi, 1993). It enables coverage and protection of the pre-

pared dentin immediately after cavity preparation to provide high bond strength of resin cement (De Goes & others, 2000) and good adaptation of composite inlays (Otsuki & others, 1993). Therefore, this technique has the potential to minimize pulp irritation and post-operative sensitivity (Satoh & others, 1994). The selection of appropriate materials for impressions and provisional restorations after using the resin coating technique has been reported and is important for the success of the final restoration (Takano, Nikaido & Tagami, 2001; Takada & others, 1995).

In this study, the two-step self-etching primer system, Clearfil SE Bond, and the low-viscosity microfilled resin, Protect Liner F, were used for the resin coating. An acidic monomer in the primer, such as MDP in Clearfil SE Bond, dissolves the smear layer and demineralizes the underlying dentin, resulting in mild surface etching. Good bonding performance with a self-etching primer system for a direct resin composite has already been shown in a previous laboratory study (Nikaido & others, 2002). The additional application of the low-viscosity microfilled resin can protect and promote polymerization of the underlying adhesive, resulting in an increase in bond strength (Jayasooriya & others, 2001).

Significantly more gaps in the resin-dentin interface were observed without resin coating than with resin coating for each site (Table 2). The early bond strengths of resin cement, Panavia F, to dentin without resin coating was reported to be significantly lower than with resin coating, using the combination of Clearfil Liner Bond 2V and Protect Liner F (De Goes & others, 2000). Moreover, considering the shape of the MOD cavity, a relatively high configuration factor (Feilzer, de Gee & Davidson, 1989) may contribute to high polymerization stress during cementation with the conventional method, while resin coating may act as a stress absorber (Kemp-Scholte & Davidson, 1990) and reduce polymerization shrinkage stress in the resin coated group. These factors may explain the significant differences in gap formation with and without resin coating. A previous study (Dietschi & Herzfeld, 1998) reported extensive gap formation, similar to the current study, at the resin-dentin interface of composite inlays with the conventional method. However, relatively few gaps were observed at the enamel margins in both groups (Figures 3a and 4a). Good marginal adaptation at enamel was also observed by Reeves & others (1992) and is supported by Kitasako & others (1995), who reported high bond strengths of resin cement to enamel.

The site within the cavity also influenced the gap formation. For occlusal walls, significantly greater gap formation was observed compared to the other segments in both the coated and non-coated groups. For the coated group, the maximum thickness of the adhesive and the low-viscosity microfilled resin at the occlusal site was significantly thinner than that at the enamel and dentin margin walls (Table 3). The relatively thin layers were created due to the gentle air blowing of the bonding agent prior to polymerization. The thinnest layer of the bonding agent was observed at the mesial and distal occluso-proximal line angles, where gap formation was often observed (Figure 4c). Zheng & others (2001) reported that reducing the thickness of the adhesive layer decreased the bond strength to dentin when the self-etching primer system, Clearfil Liner Bond 2 V, was used. Therefore, care should be taken not to create very thin layers of bonding agent so as to provide good interfacial adaptation. The maximum thickness of the resin cement at different walls ranged from 150-to-300 μm. Sorensen & Munksgaard (1995) reported cement film thickness in the range of 50-to-300 μm for ceramic inlays. Therefore, the thickness of the resin cement observed in this study is consistent with other studies. However, the thickness of the resin cement along the dentin margin wall was significantly less than both the enamel and occlusal walls in both groups. The reason is unclear; however, the dentin margin wall was longer than other walls and tended to taper out to the margin (Figure 2), hence, providing a "slip-joint" effect that allowed for better flow of the cement and, thus, better seating.

Considering the shape of the MOD inlay, air entrapment might occur at the occlusal wall during cementation. The presence of air at the interface may inhibit polymerization of the resin cement, which could cause gap formation especially in the non-coated group. Furthermore, the presence of air by itself may also appear as a gap. However, it was not possible to differentiate air entrapment from gap formation that occurs as a result of polymerization shrinkage when using CLSM and it can be considered a limitation of this study. Nevertheless, any space formed can be deleterious, as it permits the restoration to deform under the occlusal load and may result in premature failure of the composite inlays.

In addition, regional variability of dentin (Pereira & others, 1999; Bouillaguet & others, 2001), the depth of the cavity (Burrow & others, 1994), the burs selected for cavity preparation (Ogata & others, 2001) and the distance from a curing unit (Hansen & Asmussen, 1997) may also contribute to the differences observed.

Applying a "resin coating" on the prepared cavities was shown to reduce the number of gaps at the interface. However, it was not possible to completely seal all internal cavity surfaces of the restoration. Therefore, further improvement of techniques and materials is necessary to achieve gap-free interfacial adaptation of a restoration. Moreover, the oral environment may also adversely influence the bonding performance of the materials used due to contamination from blood and saliva (Xie & others, 1993). Therefore, in a clinical situ-

ation, a rubber dam should be used to isolate the prepared tooth and prevent contamination during the restorative procedure. However, as performance of the material in a clinical situation was not considered, there is a need for a clinical trail that involves the resin coating technique to further confirm the validity of this procedure.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Using a "resin coating" reduced the percentage length of gap formation between the interface of composite inlays and the preparation cavity surface.
2. Site within the cavity was shown to influence gap formation at the interface of the composite inlays, as the highest percentage of gap formation was observed at the occlusal walls in both groups.
3. A confocal laser scanning microscope is useful in observing gap formation at internal cavity surfaces of a restoration.

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Effects of Finishing/Polishing Techniques on Microleakage of Resin-Modified Glass Ionomer Cement Restorations

AUJ Yap • WY Yap • EJC Yeo
JWS Tan • DSB Ong

Clinical Relevance

The effect of finishing/polishing techniques on microleakage of resin-modified glass ionomer cements are tissue and material dependent. Wet finishing/polishing techniques that employ the use of one or two-step rubber abrasives at speeds between 10,000 and 12,000 rpm generally resulted in less leakage.

SUMMARY

This study investigated the effect of finishing/polishing techniques on the microleakage of resin-modified glass ionomer restorations. Class V preparations were made on the buccal and lingual/palatal surfaces of freshly extracted teeth. The cavities on each tooth were restored with Fuji II LC (FT [GC]) and Photac-Fil Quick (PF [3M-ESPE]) according to manufacturers' instructions. Immediately after light-polymerization, gross finishing was done with eight-fluted tungsten carbide burs. The teeth were then randomly divided into four groups and finishing/polishing was done with one of the following systems: (a) Robot Carbides (RC); (b) Super-Snap system (SS); (c) OneGloss (OG) and (d) CompoSite Polishers (CS). The sample size for each material-finishing/polishing system combination was eight. After finishing/polishing, the teeth were stored in distilled water at 37°C for one week. The root apices were then sealed with acrylic and two coats of varnish was applied 1 mm beyond the restoration margins. The teeth were subsequently subjected to dye penetration testing (0.5% basic fuchsin), sectioned and scored. Data was analyzed using Kruskal-Wallis and Mann-Whitney U tests at a significance level of 0.05. Results of statistical analysis were as follows: Enamel margins: PF–OG<SS; FT-OG<RC; Dentin margins: PF–no significant difference; FT–OG & CS<RC. Regardless of the finishing/polishing technique, leakage at dentin margins was significantly greater than at enamel margins for FT. For PF, no significant difference in leakage scores was observed between dentin and enamel with the exception of finishing/polishing with OG. FT restorations had significantly less enamel and dentin leakage than PF restorations when treated with OG. The effect of finishing/polishing techniques on microleakage was both tissue and material dependent.

*Adrian UJ Yap, BDS, MSc, PhD, FAMS, FADM, FRSH, associate professor, Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore

WY Yap, student, Faculty of Dentistry, National University of Singapore

Egwin JC Yeo, student, Faculty of Dentistry, National University of Singapore

Jane WS Tan, student, Faculty of Dentistry, National University of Singapore

Debbie SB Ong, student, Faculty of Dentistry, National University of Singapore

*Reprint request: 5 Lower Kent Ridge Road, Singapore 119074, Republic of Singapore; e-mail: rsdyapuj@nus.edu.sg

INTRODUCTION

Glass ionomer cements are comprised of a basic glass and an acidic polymer that are set by an acid-base reaction when mixed. These cements are popular as restorative materials due to their numerous desirable properties, including fluoride release, adhesion to dentin and enamel, similar thermal expansion to dentin and low solubility in oral fluids when set. Resin-modified glass ionomer cements (RMGICs) were introduced to help overcome the problems of moisture sensitivity and low early mechanical strength associated with conventional glass ionomer cements, while maintaining their clinical advantages (Sidhu & Watson, 1995). Setting characteristics are also improved and finishing/polishing of resin-modified glass ionomer restorations can be carried out almost immediately after photo curing (Mount, 1993).

Microleakage can be defined as the passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material (Kidd, 1976). Clinically, it may lead to staining, postoperative sensitivity and/or recurrent caries. RMGICs, as with all other restorative materials, exhibit some degree of microleakage (Yap, Tan & Teh, 2000; de Magalhaes, Serra & Rodrigues, 1999; Yap, Lim & Neo, 1995). Variations in finishing/polishing techniques have been shown to affect the ability of composite restorations to resist leakage (Owens, Halter & Brown, 1998; Brackett, Gilpatrick & Gunnin, 1997; Barkmeier & Cooley, 1992; Yu & others, 1990). The effect of finishing/polishing techniques on microleakage of RMGICs has, however, not been widely investigated (Yap & others, 2000; Wilder & others, 2000). In addition, most manufacturers have been ambiguous regarding their recommendations for finishing/polishing of their RMGICs. Vague statements like "finish under water spray using standard techniques" are frequently used. This study evaluated the effect of different finishing/polishing systems on the microleakage of RMGICs. The relative ability of the RMGICs to seal enamel and dentin margins after the various finishing/polishing procedures was also compared.

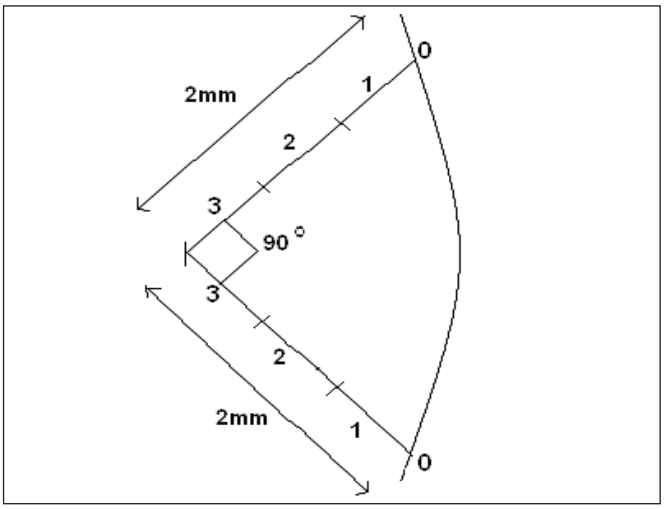

Figure 1: *Grading scale used to evaluate the degree of dye penetration at the tooth-restoration interface.*
0 : no evidence of dye penetration
1 : dye penetration up to one-third cavity wall
2 : dye penetration more than one-third but less than two-thirds cavity wall
3 : dye penetration more than two-thirds to full cavity wall

METHODS AND MATERIALS

The resin-modified glass ionomer cements investigated and their technical profiles are shown in Table 1. Thirty-two freshly extracted, non-carious premolars were selected for this study. The teeth were disinfected with 2% formaline-saline, cleaned and stored in distilled water at 4°C until use. Wedge-shaped Class V preparations were made on the buccal and lingual/palatal surfaces of each tooth. The cavity dimensions were approximately 4 mm mesio-distally and 3 mm occluso-gingivally. An internal line angle of 90° was maintained such that length of both the occlusal and gingival walls was about 2 mm (Figure 1). The occlusal cavosurface margin was located in enamel, while the gingival cavosurface margin was located in dentin. The cavities on each tooth were restored with capsulated Fuji II LC (GC) and Photac-Fil Quick (3M-ESPE, St Paul, MN 55144, USA). Cavities that were to be restored with Fuji II LC were first treated with Cavity Conditioner (GC) for 10 seconds, while cavities to be restored with Photac-Fil were treated with Ketac Conditioner (3M-ESPE) for 10 seconds. The cavities were then washed for 30 seconds and gently air dried. The resin-modified glass ionomer cements were mixed according to manufactur-

Table 1: *Technical Profiles of the Resin-Modified Glass Ionomer Cements Evaluated*

Material	Manufacturer	Powder	Liquid	Filler Particle Size (μm)
Fuji II LC	GC Corp, Tokyo, Japan Lot #9912202	Aluminosilicate glass, pigments	Polyacrylic acid, distilled water, HEMA (17%). dimethacrylate monomer, camphoroquinone	4.5
Photac-Fil Quick	ESPE Dental AG, Seefeld, Germany Lot #0065231	Calcium aluminium fluorosilicate glass, freeze-dried copolymers of polyacrylic and maleic acids, tartaric acid, activator, pigments	HEMA (40%), difunctional monomers, water, camphoroquinone	7.0

Table 2: *Finishing/Polishing Systems and Sequences*

Product	Finishing/ Polishing System	Usage	Handpiece Speed	Manufacturer
Robot Carbide				
SH134F	Graded carbide	Wet, 12 strokes	300,000 rpm	Shofu Inc,
SH134UF		Wet, 12 strokes	300,000 rpm	Kyoto, Japan
Super-Snap				
Coarse	Graded abrasive	Dry, 6 strokes	12,000 rpm	Shofu Inc,
Medium	discs	Dry, 6 strokes	12,000 rpm	Kyoto, Japan
Fine		Dry, 6 strokes	12,000 rpm	
Extra fine		Dry, 6 strokes	12,000 rpm	
OneGloss				
	One-step rubber abrasive	Wet,12 heavy strokes	10,000 rpm	Shofu Inc,
		Wet,12 heavy strokes	10,000 rpm	Kyoto, Japan
CompoSite Polishers				
CompoSite	Two-step rubber	Wet, 12 strokes	12,000 rpm	Shofu Inc,
CompoSite Fine	abrasive	Dry, 12 strokes	12,000 rpm	Kyoto, Japan

Table 3: *Distribution of Dye Penetration Scores for Photac-Fil Quick*

	Enamel				Dentin			
Finishing/Polishing System	0	1	2	3	0	1	2	3
Shofu Robot	2	0	0	6	0	0	0	8
Super-Snap	0	0	0	8	0	0	0	8
OneGloss	4	0	0	4	0	0	0	8
CompoSite	3	0	0	5	1	0	0	7

Table 4: *Distribution of Dye Penetration Scores for Fuji II LC*

	Enamel				Dentin			
Finishing/Polishing System	0	1	2	3	0	1	2	3
Shofu Robot	4	0	0	4	0	0	0	8
Super-Snap	6	0	1	1	0	0	3	5
OneGloss	8	0	0	0	1	0	3	4
CompoSite	5	1	2	0	1	0	3	4

ers' instructions and injected into the cavities. Transparent preformed cervical matrixes (Hawe-Neos Dental, Bioggio, Switzerland) were placed over the filled cavities and pressure was applied to extrude excess material. The cements were then light polymerized for 20 seconds using a curing light (Spectrum; Dentsply Inc, Milford, DE 19963, USA) with an output intensity ≥ 420 mW/cm^2, as assessed with a curing radiometer (Cure Rite, EFOS Inc, Ontario, Canada).

Immediately after light-polymerization, the cervical matrixes were removed and gross finishing was done with 8-flute tungsten carbide burs (Robot Carbide SH134, Shofu, Kyoto, Japan). Gross finishing was performed in one direction under water spray using a high-speed handpiece at 300,000 rpm. The burs were replaced after gross finishing of every eight restorations. The restored teeth were then randomly divided into four groups and finished/polished with the following systems: (a) Robot Carbides (RC); (b) Super-Snap system (SS); (c) One-gloss (OG) and (d) CompoSite Polishers (CS). Details of the finishing/polishing sequences are reflected in Table 2. The restored teeth were then stored in distilled water at 37°C for one week. After the one-week storage period, the apical third of the roots of each tooth were sealed with acrylic resin. Two layers of nail varnish were painted, staying clear of the restoration margins by 1 mm. The teeth were then soaked in 0.5% basic fuchsin dye at 37°C for 24 hours. The nail varnish and excess dye were removed after dye penetration testing. The teeth were then sectioned bucco-lingually/palatally with a Microslice 2 precision saw (Cambridge Instrument Ltd, Cambridge, England). The degree of dye penetration was then graded at 10x magnification with a stereomicroscope (Nikon SE, Nikon, Tokyo, Japan) using the following scale (Figure 1):

0: No evidence of dye penetration.

1: Dye penetration up to one-third cavity wall.

2: Dye penetration more than one-third but less than two-thirds cavity wall.

3: Dye penetration more than two-thirds to full cavity wall.

Data was subjected to non-parametric statistical analysis at a significance level of 0.05.

The Kruskal-Wallis test was used to determine significant differences between finishing/polishing techniques, and the Mann-Whitney U-test test was used to evaluate inter-technique, material and tissue differences.

RESULTS

Tables 3 and Table 4, respectively, show the distribution of dye penetration scores for Photac-Fil Quick and Fuji II LC. Results of statistical analyses are shown in Tables 5 to 7. The effect of the finishing/polishing system on microleakage was both material and tissue dependent. At the enamel margins of Photac-Fil restorations, finishing/polishing with OneGloss resulted in significantly less leakage than with Super-Snap. No significant difference in dentin leakage was observed among the various finishing/polishing sys-

Table 5: *Comparison of Microleakage Scores Among the Different Finishing/Polishing Systems*

Tissue	Photcal-Fil Quick	Fuji II LC
Enamel	OneGloss < Super-Snap	OneGloss < Robot Carbide
Dentin	NS	OneGloss, CompoSite < Robot Carbide

< indicates statistical significance and NS indicates results no statistical significance (Results of Kruskall-Wallis and Mann-Whitney U tests at p<0.05)

Table 6: *Comparison of Leakage Score Among Materials*

Finishing/Polishing System	Enamel	Dentin
Robot Carbide	NS	NS
Super-Snap	Photac-Fil > Fuji II LC	NS
OneGloss	Photac-Fil > Fuji II LC	Photac-Fil > Fuji II LC
CompoSite	NS	NS

> indicates statistical significance and NS indicates results no statistical significance (Results of Mann-Whitney U tests at p<0.05)

Table 7: *Comparison of Leakage Score Between Enamel and Dentin Margins*

Finishing/Polishing System	Phototac-Fil Quick	Fuji II LC
Robot Carbide	NS	Dentin > Enamel
Super-Snap	NS	Dentin > Enamel
OneGloss	Dentin > Enamel	Dentin > Enamel
CompoSite	NS	Dentin > Enamel

> indicates statistical significance and NS indicates results no statistical significance (Results of Mann-Whitney U tests at p<0.05)

tems. At the enamel margins of Fuji II LC restorations, finishing/polishing with OneGloss resulted in significantly less leakage than with Robot Carbide. Finishing/polishing with OneGloss and CompoSite resulted in significantly less dentin leakage than with Robot Carbide (Table 5). Fuji II LC restorations had significantly less enamel and dentin leakage than Photac-Fil restorations after finishing/polishing with OneGloss. Fuji II LC restorations also had significantly less enamel leakage than Photac-Fil restorations when treated with Super-Snap. Regardless of the finishing/polishing technique, leakage at dentin margins was significantly greater than at enamel margins for Fuji II LC. For Photac-Fil, no significant difference in leakage scores was observed between dentin and enamel with the exception of finishing/polishing with OneGloss.

DISCUSSION

Finishing refers to the gross contouring of restorations to obtain the desired anatomy. Polishing refers to the reduction of roughness and scratches created by finishing instruments. The two procedures are, however, interdependent and cannot be clearly delineated from each other and, hence, use of the term finishing/polishing. Research has shown that the smoothest surface imparted to resin-modified glass ionomer cements occurs when they are allowed to set against a cellulose strip or matrix (Hoelscher & others, 1998; Yap, Lye & Sau, 1997). However, despite the careful placement of matrixes, removal of excess material or re-contouring of restorations is often necessary clinically. The finishing/polishing systems evaluated included carbide burs (Robot Carbide), graded abrasive disks (Super-Snap), and one-step (OneGloss) and two-step (CompoSite Polishers) rubber abrasives.

The effect of finishing/polishing systems on microleakage was both material and tissue dependent. At the enamel margins of Photac-Fil restorations, finishing/polishing with Super-Snap resulted in grade 3 leakage scores for all specimens. Super-Snap, being a totally dry finishing/polishing system, could generate substantial heat. In view of the significant difference in thermal coefficients of expansion between RMGICs and teeth (Sidhu & Watson, 1995), finishing/polishing with Super-Snap could result in stress at the restoration-tooth interface, creating microgaps that allow microleakage to occur. In addition, contraction under desiccating conditions could also lead to increased microleakage (Bouschlicher, Vargas & Denehy, 1996; Wilson & Paddon, 1993). The lack of statistical significance in dentin leakage between finishing/polishing systems is not due to the resistance of Photac-Fil to finishing/polishing procedures but to the generally poor dentin seal of Photac-Fil. Grade 3 leakage was observed for almost all specimens regardless of the finishing/polishing system employed. Although the enamel seal of Fuji II LC restorations was not susceptible to the effect of dry finishing/polishing (Super-Snap), it was susceptible to the detrimental effect of ultra high-speed finishing/polishing. Finishing/polishing with Robot Carbide (300,000 rpm) resulted in significantly greater enamel leakage than treatment with OneGloss. A similar trend was observed at the dentin margins. Finishing/polishing with OneGloss and CompoSite resulted in significantly less leakage than with Robot Carbide (Table 5). The mechanical stresses generated with ultra high-speed finishing/polishing could disrupt the bond of Fuji II LC to enamel and dentin. Results suggest that wet finishing/polishing techniques that employ the use of one or two step rubber abrasives at speeds between 10,000 and 12,000 rpm generally resulted in less leakage. The fact that leakage was present even after one week's storage in water showed that the effect of finishing/polishing techniques on microleakage cannot be compensated by water sorption in the short-term (Kanchananvasita, Anstice & Pearson, 1997; Yap, 1996).

Compared to conventional materials, RMGICs may offer a better seal to enamel/dentin due to their reduced water content, immediate adhesion and superior wetting ability resulting from the use of HEMA (hydroxyethyl methacrylate) (Yap & others, 2000; Martin & O'Rourke, 1993). Results of microleakage tests have, however, shown that not all RMGICs display significantly less leakage than their conventional counterparts (Hallett & García-Godoy, 1993). This has been attributed to thermal expansion mismatches with tooth substance and polymerization shrinkage arising from the inclusion of resin (Sidhu & Watson, 1995). Yap & others (2000) reported that the sealing ability of conventional and resin-modified glass ionomer cements to enamel was significantly better than dentin regardless of the type of finishing/polishing employed. As glass ionomer cements bond by polar and ionic attraction, the lower microleakge observed in enamel can be attributed to the greater inorganic content and homogeneity of enamel (Anusavice, 1996). The aforementioned observations might, however, be material specific. In the current study, Fuji II LC displayed significantly less leakage in enamel regardless of the finishing/polishing systems employed. This corroborated the findings of Yap & others (2000), who also assessed Fuji II LC. On the other hand, no significant difference in enamel and dentin leakage was observed for Photac-Fil, with the exception of treatment with OneGloss. The enamel seal of Photac-Fil, therefore, appears to be compromised by immediate treatment with most finishing/polishing systems. One possible hypothesis for this observation is the use of freeze-dried copolymers of polyacrylic acid in Photac-Fil. As the anhydrous polyacrylic acid needs to be hydrated and activated prior to reaction with the aluminosilicate glass, the ionic exchange mechanism may take more time to become established. Immediate finishing/polishing of Photac-Fil might disrupt the weak ionic bonds formed early in the setting reaction. This also explains the significantly greater enamel and dentin leakage observed with Photac-Fil as compared to Fuji II LC for some of the finishing/polishing systems evaluated.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The effect of finishing/polishing techniques on microleakage of resin-modified glass ionomer cements were tissue and material dependent.
2. At the enamel margins of Photac-Fil restorations, finishing/polishing with OneGloss resulted in significantly less leakage then with Super-Snap.
3. At both the enamel and dentin margins of Fuji II LC restorations, finishing/polishing with OneGloss resulted in significantly less leakage than with Robot Carbide. The dentin seal after treatment with CompoSite was also significantly better than with Robot Carbide.
4. Regardless of the finishing/polishing technique employed, leakage at dentin margins was significantly greater than at enamel margins for Fuji II LC. For Photac-Fil, no significant difference in leakage scores was observed between dentin and enamel with the exception of finishing/polishing with OneGloss.
5. Fuji II LC restorations had significantly less enamel and dentin leakage than Photac-Fil restorations when treated with OneGloss.

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The Effect of Flowable Resin Composite on Microleakage in Class V Cavities

AR Yazici • M Baseren • B Dayangaç

Clinical Relevance

The use of a flowable resin composite as both a restorative material and a liner combined with a hybrid composite in Class V cavities can be advocated as a means of minimizing microleakage at dentin margins.

SUMMARY

This *in vitro* study investigated the microleakage of flowable resin composite as a restorative material and as a liner (either light cured separately or co-cured with hybrid resin composite) in Class V cavities. A light-cured hybrid resin composite was used as a control. Twenty extracted human premolars were prepared with standardized Class V cavity outlines on the buccal and lingual surfaces. The occlusal margin of the cavities was on enamel and the gingival margin was on dentin. One bottle adhesive system (Single Bond) was used after etching enamel and dentin with 34.5% phosphoric acid for 15 seconds. The cavities were randomly divided into four groups of 10 each and restored according to the manufacturers' instructions: Group I–Hybrid resin composite (Z100); Group II–Flowable resin composite (Filtek Flow); Group III–Flowable resin composite (Filtek Flow)+Hybrid resin composite (Z100); light cured separately; Group IV–Flowable resin composite (Filtek Flow)+ Hybrid resin composite (Z100); co-cured. The samples were thermocycled 200 times with a 30-second dwell time. They were then immersed in a 0.5% basic fuchsin solution for 24 hours, sectioned and analyzed by stereomicroscopy. The degree of dye penetration was recorded and analyzed with the Kruskal-Wallis and Mann-Whitney U tests.

The results of this study indicate that there was no leakage at the occlusal margin for either restoration. Statistically significant differences were found among the groups at the gingival margin. No statistically significant difference was observed between the occlusal and gingival margins except in Group IV.

The combination of flowable resin composite and hybrid composite light cured separately yielded the best result in this study. The most leakage was observed when this combination was co-cured. The resistance to microleakage of flowable resin composite as a restorative material is similar to that of hybrid resin composite.

*A Rüya Yazici, DDS, PhD, teaching fellow, Hacettepe University, Ankara, Turkey

Meserret Baseren, DDS, PhD, associate professor, Hacettepe University, Ankara, Turkey

Berrin Dayangaç, DDS, PhD, professor, Hacettepe University, Ankara, Turkey

*Reprint request: Faculty of Dentistry, Dept of Conservative Dentistry, Hacettepe University, 06100, Sihhiye, Ankara, Turkey; e-mail: ruyay@hacettepe.edu.tr

INTRODUCTION

Resin composites are widely used for restoring cervical lesions, as they are esthetic, mercury free and bond to

tooth structure with the use of bonding systems. Unfortunately, the coefficient of linear thermal expansion of resin composites is three or four times that of tooth structure. In addition to the differences in thermal expansion coefficients, the shrinkage of composites during curing induces stresses at the tooth/restorative interface and generally results in gap formation. Therefore, polymerization shrinkage and the thermal expansion coefficient of these restorative materials have been suggested as major causes of microleakage (Craig, 1989; Feilzer, de Gee & Davidson, 1988; Puckett & others, 1992). Restoring cervical lesions with resin composites has always been a problem, especially where no enamel is present for bonding to the gingival margin. The higher organic component, tubular structure, fluid pressure and the lower surface energy of dentin make bonding to dentin more difficult than to enamel (Barkmeier & Cooley, 1991; Pashley & Carvalho, 1997). Poor adhesion between dentin and restorative material predisposes gap formation. Marginal gap formation leads to leakage, which may be responsible for secondary caries, marginal discoloration, pulpal inflammation and hypersensitivity (Going, 1972; Kidd, 1976; Bauer & Henson, 1984). Many attempts have been made to limit the microleakage of composites in dentin. Dentin bonding agents are used to improve the marginal seal of resin composite restorations at the composite/tooth interface. They have been proven to be effective at reducing but not eliminating microleakage (Hansen & Asmussen, 1989; Prati, Nucci & Montanari, 1991).

In late 1996, an alternative filling material, flowable composite, was introduced for restoring Class V cavities. Its modulus of elasticity is low, thereby, it has the ability to undergo plastic deformation to flex and absorb polymerization shrinkage stress (Bayne & others, 1998). On the other hand, since it has less filler content, the coefficient of thermal expansion of flowable composites is close to that of the tooth structure (Bayne & others, 1998; Chuang & others, 2001). The use of a flowable composite as a liner is another recently recommended technique for overcoming the shortcomings of resin composites. These resins are used as an initial thin layer under composites and function as a stress breaker (Unterbrink & Liebenberg, 1999). Researchers have used flowable composites as lining materials and have obtained favorable results in reducing microleakage (Payne, 1999; Leevailoj & others, 2001). Belvedere (2001) has recommended placing flowable composites without curing separately under resin composite restorations. However, no research has determined the effect of the co-curing of flowable resin composite with hybrid resin composite on microleakage. This *in vitro* study evaluated the microleakage performance of light cured flowable resin composite as a restorative material and as a liner (either light cured separately or co-cured with hybrid resin composite) and light cured hybrid resin composite as a control in Class V cavities.

METHODS AND MATERIALS

Twenty extracted human mandibular premolars stored in tap water at room temperature were used within one week of extraction. Only teeth that were free of caries and restorations and showed no evidence of white spots or cracks on buccal or lingual surfaces were selected. Forty Class V cavities (one on the buccal and one on the lingual surface of each tooth) were prepared with a high-speed diamond flat end cylinder bur (835-008-3 Diatech Dental AG, Heerbrugg, Switzerland) using water as a coolant. The bur was replaced after every fifth preparation. Preparation included an occlusal margin in enamel and a gingival margin in dentin. The preparation was approximately 3 mm wide, 2 mm high and 1.5 mm deep. After the enamel and dentin were etched with 34.5% phosphoric acid for 15 seconds, the cavities were thoroughly rinsed with water for 15 seconds. They were then air dried gently approximately 10 cm away from the cavity surface for five seconds, avoiding complete desiccation. Two consecutive coats of Single Bond (3M Dental Products, St Paul, MN 55144, USA) were applied to the whole cavity surface, followed by gentle air drying to remove excess solvent and light cured for 10 seconds. All preparations, etching and bonding procedures were conducted by the same operator. The teeth were then randomly distributed into four groups (Table 1).

Group I: Z100 resin composite (3M Dental Products) was inserted in bulk, with special attention given to marginal adaptation. Resin was light cured for 40 seconds with a calibrated visible-light curing unit (Optilux 400, Demetron Research Corp, Danbury, CT 06810, USA) from a distance of 1 mm from its outer surface.

Group II: The cavities were bulk filled with flowable resin composite, Filtek Flow (3M Dental Products), which was cured for 20 seconds.

Group III: A thin layer (0.5 mm) of flowable composite (Filtek Flow) was lined at the axial wall of the cavity preparation. After curing flowable resin composite for 20 seconds, hybrid resin composite (Z100) was placed over the lining and cured for 40 seconds.

Group IV: A thin layer (0.5 mm) of flowable composite (Filtek Flow) was lined at the axial wall of the cavity

Table 1: *Materials Tested*

Group	Restorative Material
I	Hybrid resin composite(Z 100)
II	Flowable resin composite(Filtek Flow)
III	Flowable + Hybrid resin composite(light cured separately)
IV	Flowable + Hybrid resin composite(co-cured)

preparation. Without curing flowable resin composite, hybrid resin composite (Z100) was placed over the lining, then co-cured for 40 seconds, which means the flowable composite and hybrid resin composite were cured at the same time.

All restorations were finished after 24 hours with fine-grit finishing diamond burs (Edenta AG-Dental Produkte, AU/SG, Switzerland) and Hawe-Neos disks (Hawe-Neos Dental CH6934 Bioggio, Switzerland) of decreasing abrasiveness. After storing the specimens at 37°C for seven days, the teeth were subjected to 200 cycles between temperature baths at 5°C and 55°C. The cycles lasted 30 seconds in each bath, with a 10-second transfer time. The root apices were occluded with resin composite, and the teeth were painted with two coats of acid resistant varnish to within 1 mm of the margins of the restorations. The specimens were immersed in 0.5% basic fuchsin solution and stored for 24 hours at 37°C, after which they were washed for one minute in running water and dried. An Isomet (Buehler Ltd, Lake Bluff, IL 60044, USA) diamond saw cooled with water was used to section each tooth longitudinally through the center of the restorations. Each restoration was observed under a binocular stereomicroscope (M5 Wild Herrbrugg, Switzerland) with a magnifying loupe of X18. Two examiners scored the restorations independently, and any discrepancies between the two examiners were reevaluated by both and a consensus reached. Enamel and dentin margins were scored separately. For each restoration, the section with greater leakage was selected for scoring.

The degree of marginal leakage was evaluated using a standardized scoring system similar to that used by Munro, Hilton & Hermesch (1996). A zero value was assigned where there was no evidence of microleakage. Dye penetration up to half the cavity depth scored a value of 1. When the dye penetration was more than half of the cavity depth, a value of 2 was recorded, and when it had spread to involve the axial wall, the microleakage was assigned a value of 3. Mean leakage scores for all groups were also calculated.

The results of the dye penetration scores were analyzed with Kruskal-Wallis non-parametric analysis followed by Mann-Whitney U test to evaluate differences among the experimental groups at a significance level of p=0.05. Combined occlusal and gingival scores within each restoration were compared using the Mann-Whitney U test.

RESULTS

Microleakage and mean leakage scores of all groups are presented in Table 2. The Kruskal-Wallis test showed no statistically significant differences in microleakage at the enamel margins among the groups (p=1). All groups resisted microleakage completely at the enamel margin. However, statistically significant differences in microleakage were observed among the groups at the dentin margins (p<0.001). Dye penetration scores in dentin margins differed significantly between Groups I and IV (p=0.005), II and IV (p=0.005), III and IV (p=0.0017).

When flowable composite was placed as a liner and co-cured with hybrid resin composite (Group IV), five samples exhibited microleakage involving the axial wall (score 3), two exhibited microleakage up to half of the cavity depth (score 1) and three exhibited no degree of microleakage (score 0) at the dentin margins. No dye penetration was observed at the dentin margins in samples restored with the combination of flowable composite as a liner and hybrid resin composite (Group III) cured separately. Hybrid resin composite (Group I) and flowable resin composite (Group II) used as a restorative material exhibited equal leakage patterns in the dentin; only one sample from each group showed minimal leakage (score 1) at the dentin margins.

Comparison of the microleakage scores between enamel and dentin margins within each group showed that there was more leakage in the dentin in all groups but a statistically significant difference was only seen in Group IV (p=0.002).

DISCUSSION

Marginal seal is one of the most important factors for the success of a restoration. The restoration of cavities having margins partly or totally located in the dentin is an unsolved problem in resin composites. Many studies have shown that bonding of restorative material to enamel is adequate (Al-Hamadani & Crabb, 1975; Retief & Denys, 1989; Swift, Perdigão & Heymann, 1995). In this investigation, all restorations completely resisted microleakage at the occlusal margins, proving the effectiveness of the acid-etch technique in sealing cavity margins in enamel. However, varying degrees of microleakage occurred along the gingival margins that were placed in the dentin. On the other hand, no statistically significant difference was detected between

Table 2: *Microleakage and Mean Leakage Scores*

Group		Leakage Scores				
		0	1	2	3	Mean
I	Enamel	10	0	0	0	0
	Dentin	9	1	0	0	0.1
II	Enamel	10	0	0	0	0
	Dentin	9	1	0	0	0.1
III	Enamel	10	0	0	0	0
	Dentin	10	0	0	0	0
IV	Enamel	10	0	0	0	0
	Dentin	3	2	0	5	1.7

the enamel and dentin margins except in Group IV, as microleakage at the dentin margins was only slightly greater than at the enamel margins. These results show that a good bond to dentin is achieved with new generation dentin bonding systems (Nikaido & others, 1997; Swift & Bayne, 1997). These new adhesives may seal dentin margins better than previous adhesives and, therefore, may have more effectively prevented leakage at the dentin margins. They have the ability to resist the contraction stress generated by polymerization shrinkage, thereby, establishing a good bond to dentin without gap formation (Davidson, de Gee & Feilzer, 1984; Eick & others, 1997).

Several authors have reported encouraging results in reducing microleakage with the use of flowable composite restorative materials (Ferdianakis, 1998; Estafan & Estafan, 2000). This study also obtained good results with a flowable composite in Class V cavities. Mazer & Russell (1998) have reported that flowable composites and hybrid composites performed equally well in terms of microleakage. The results of this study were consistent with these findings. Only one sample in the hybrid resin composite and one sample in the flowable resin composite group showed minimum leakage. This suggests that as flowable composites are more resin-rich, they have low viscosity and flow and adapt at least as well as hybrid composites to cavity margins. Their low modulus of elasticity allows for plastic deformation, acts as an elastic buffer and compensates for contraction shrinkage stress (Kemp-Scholte & Davidson, 1990; Van Meerbeek & others, 1993; Estafan & Estafan, 2000). In a SEM study by Estafan, Estafan & Leinfelder (2000), flowable composites had better marginal integrity than hybrid and condensable composites, and flowable composites showed no evidence of marginal gaps. In another study, Ferdianakis (1998) compared the microleakage performance of flowable resin composite with that of hybrid resin composite and found significantly less leakage in cavities restored with flowables. From these results, it can be concluded that flowable composites can be used to restore Class V cavities.

In this study, the combination of flowable resin composite and hybrid composite that were light-cured separately completely eliminated microleakage. This confirms other investigations that proved that flowable composites under resin composite restorations can efficiently reduce microleakage (Tung, Estafan & Scherer, 2000; Leevailoj & others, 2001). The complete resistance to microleakage found in this combination could be related to the lower modulus of elasticity of flowables (Estafan & Estafan, 2000). The use of low modulus flowable composite may also increase the flexibility of the bonded assembly and might act as a shock absorber and relieve the stress induced by the polymerization shrinkage of resin composites (Kemp-Scholte & Davidson, 1990; Van Meerbeek & others, 1993). Materials with high elastic modulus destroy the bond between the restorative material and the tooth structure and lead to poor marginal adaptation (Unterbrink & Liebenberg, 1999).

Although the manufacturer recommended curing the flowable composite prior to applying the restorative materials, Belvedere (2001) reported that the hydraulic pressure of heavier viscosity composite would help uncured flowable composite to penetrate better and improve the sealing of margins. Therefore, he suggested placing flowable resin composite without curing, separately. The authors of this study thought that it would be of interest to observe whether co-curing flowable resin and hybrid composite would have any effect on microleakage. Contrary to suggestions, in this group, the greatest leakage was found in dentin. Even five samples showed leakage along the axial wall. Leakage probably occurred up to an intact resin-enamel bond. This finding may be attributed to the fact that polymerization shrinkage of a resin composite may create contraction forces that may disrupt the bond of uncured flowable composite from cavity walls. On the other hand, many composites are sticky and may have a tendency to pull back the uncured flowable composite from the cavity wall as the instruments used to place them are being removed. Moreover, it has been reported that as flowable composites are separately cured and serve as a well-adapted first increment, they resist disturbance and absorb polymerization shrinkage of the overlying composites (Bertolotti & Laamanen, 1999).

It should be noted that these results are based on *in vitro* data; therefore, future studies that evaluate the clinical performance of flowable composites are necessary.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following statements can be made:

1. No leakage was observed in the enamel margins of hybrid, flowable and flowable/hybrid-combined restorative materials.
2. The resistance of flowable resin composite as a restorative material to microleakage is similar to hybrid resin composite at the dentin margins.
3. The use of flowable composite with hybrid composite cured separately prevented leakage completely. Leakage was observed at the dentin margins when flowable resin composite was co-cured with hybrid composite.

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Effects of Instrumentation Time on Microleakage of Resin-Modified Glass Ionomer Cements

AUJ Yap • EJC Yeo • WY Yap
DSB Ong • JWS Tan

Clinical Relevance

The effects of instrumentation time on microleakage of resin-modified glass ionomer cements are material, finishing/polishing system and tissue dependent. Finishing/polishing of resin-modified glass ionomers should be delayed where possible.

SUMMARY

This study investigated the effect of instrumentation time on the microleakage of resin-modified glass ionomer cements (RMGICs). Class V cavities were prepared on buccal and lingual/palatal surfaces of 64 freshly extracted non-carious premolars. The cavities on each tooth were restored with Fuji II LC (FT [GC]) and Photac-Fil Quick (PF [3M-ESPE]). The restored teeth were randomly divided into two groups of 32 teeth. Finishing/polishing was done immediately after light-polymerization in one group and was delayed for one week in the other group. The following finishing/polishing systems were evaluated: (a) Robot Carbides (RC); (b) SuperSnap (SS); (c) OneGloss (OG) and (d) CompoSite Polishers (CS). The sample size for each instrumentation time, material and finishing/polishing system combination was 8. Storage medium for both immediate and delayed instrumentation groups was distilled water at 37°C during the hiatus period. The teeth were subsequently subjected to dye penetration testing (0.5% basic fushcin), sectioned and scored. Data were analyzed using Kruskal-Wallis and Mann-Whitney U tests at significance level 0.05. For PF, significant difference in enamel leakage was observed between immediate and delayed instrumentation with SS and CS. Significant differences in dentin leakage were also observed between the two instrumentation times for SS. For FT, significant differences in leakage between instrumentation times were observed only in dentin and with RC. Where significant differences in dye penetration scores existed, delayed finishing/polishing resulted in less microleakage.

*Adrian UJ Yap, BDS, MSc, PhD, FAMS, FADM, FRSH, associate professor, Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore

Egwin JC Yeo, student, Faculty of Dentistry, National University of Singapore

WY Yap, student, Faculty of Dentistry, National University of Singapore

Debbie SB Ong, student, Faculty of Dentistry, National University of Singapore

Jane WS Tan, student, Faculty of Dentistry, National University of Singapore

*Reprint request: 5 Lower Kent Ridge Road, Singapore 119074, Republic of Singapore; e-mail: rsdyapuj@nus.edu.sg

INTRODUCTION

The favorable adhesive and fluoride-releasing properties of glass ionomer cements (GICs) have led to their widespread use as luting, lining and restorative mate-

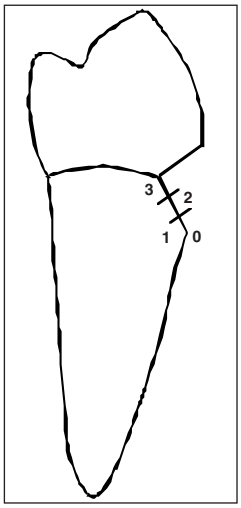

Figure 1: *Scoring scale used to measure microleakage.*

rials. Resin-modified glass ionomer cements (RMGICs) were introduced to help overcome the problems of moisture sensitivity and low early mechanical strengths associated with conventional GICs, and at the same time, to maintain their clinical advantages (Sidhu & Watson, 1995). In RMGICs, the fundamental acid-base curing reaction is supplemented by a second curing process that was light-initiated. In their simplest form, they are GICs with the addition of small amounts of resin, such as hydroxyethyl methacrylate (HEMA) or BisGMA. More complex materials have been developed with polyacid side chains, which can polymerize by light-curing mechanisms.

Although laboratory tests show that RMGICs are not any stronger than conventional ones (Burgess, Norling & Summitt, 1994), strength is developed more quickly, making it possible to begin finishing and polishing almost immediately after light curing. This is a distinct advantage over conventional materials where finishing and polishing must be delayed for at least 48 hours (Mount, 1993). It is, however, important to note that the resin components form only 4.3% to 6% of RMGICs (Toledano & others, 1999) and light curing only sets the resin components. The fundamental acid-base reaction is therefore relatively immature following removal of the light source. To make matters worse, the acid-base reaction is retarded due to the replacement of water (which serves as the reaction medium) with water/resin mixtures in RMGICs (Wan, Yap & Hastings, 1999). While the acid-base complexation reaction is essentially complete after 24 hours for conventional materials, it levels off only after 168 hours in RMGICs. Immediate finishing/polishing after light curing may therefore result in disruption of the weak early chemical bonds, leading to gap formation at the tooth-restoration interface. The latter may lead to microleakage, which contributes to staining, postoperative sensitivity and/or recurrent caries clinically.

The effects of instrumentation time on microleakage of RMGICs have not been widely investigated (Lim, Neo & Yap, 1999). This study investigated the effects of instrumentation time on the microleakage of resin-modified glass ionomer cements (RMGICs). The possibility of microleakage being material, finishing/polishing system and tissue dependent was also determined.

METHODS AND MATERIALS

The RMGICs that were investigated and their technical profiles are shown in Table 1. Sixty-four freshly extracted, non-carious premolars were selected for the study. The teeth were disinfected with 2% formaline-saline, cleaned and stored in distilled water at 4°C until use. Wedge-shaped Class V preparations (approximately 4 mm wide mesio-distally), 3 mm long (occluso-gingivally) and 2 mm (deep) were made on the buccal and lingual/palatal surfaces of each tooth. The cavities on each tooth were restored with capsulated Fuji II LC (GC) and Photac-Fil Quick (3M-ESPE, St Paul, MN 55144, USA) of A2 shade. Cavities restored with Fuji II LC were first treated with Cavity Conditioner (GC) for 10 seconds, while cavities restored with Photac-Fil Quick were treated with Ketac Conditioner (3M-ESPE) for 10 seconds. The cavities were then washed for 30 seconds and gently air dried. The RMGICs were mixed according to manufacturers' instructions and injected into the cavities. Transparent preformed cervical matrixes (Hawe-Neos Dental, Bioggio, Switzerland) were placed over the filled cavities and pressure was applied to extrude excess material,

Table 1: *Technical Profiles of the Resin-Modified Glass Ionomer Cements Investigated*

Material	Manufacturer	Components	Mean Particle Size (μm)	Lot #
Fuji II LC	GC Corporation, Tokyo, Japan	*Powder:* Alumino silicate glass, pigments *Liquid:* Polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone	4.5	9912202
Photac-Fil Quick	3M-ESPE, Seefeld, Germany	*Powder:* Calcium aluminium fluorosilicate glass, copolymers of acrylic and maleic acids, tartaric acid, activator, pigments *Liquid:* HEMA (40%), difunctional monomer, water, camphoroquinone	7.0	0065231

Table 2: *Finishing/Polishing Systems and Sequences*

Product	Usage	Handpiece Speed	Manufacturer
Robot Carbides			
SH134F	Wet, 12 strokes	300,000 rpm	Shofu Inc,
SH134UF	Wet, 12 strokes	300,000 rpm	Kyoto, Japan
SuperSnap			
Coarse	Dry, 6 strokes	12, 000 rpm	Shofu Inc,
Medium	Dry, 6 strokes	12, 000 rpm	Kyoto, Japan
Fine	Dry, 6 strokes	12, 000 rpm	
Extra fine	Dry, 6 strokes	12, 000 rpm	
OneGloss	Wet, 12 heavy strokes	10,000 rpm	Shofu Inc,
	Wet, 12 light strokes	10,000 rpm	Kyoto, Japan
CompoSite Polishers			
CompoSite	Wet, 12 strokes	12,000 rpm	Shofu Inc,
CompoSite Fine	Dry, 12 strokes	12,000 rpm	Kyoto, Japan

Table 3: *Distribution of Microleakage Scores for Photac-Fil Quick*

System	Enamel								Dentin							
	Immediate				Delayed				Immediate				Delayed			
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Robot Carbides	2	0	0	6	5	1	0	2	0	0	0	8	0	0	0	8
SuperSnap	0	0	0	8	7	0	0	1	0	0	0	8	3	0	2	3
CompoSite	3	0	0	5	7	0	0	1	1	0	0	7	0	1	4	3
OneGloss	4	0	0	4	6	0	1	1	0	0	0	8	2	0	1	5

Table 4: *Distribution of Microleakage Scores for Fuji II LC*

System	Enamel								Dentin							
	Immediate				Delayed				Immediate				Delayed			
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Robot Carbides	4	0	0	4	5	1	2	0	0	0	0	8	1	0	3	4
SuperSnap	6	0	1	1	7	0	0	1	0	0	3	5	2	1	1	4
CompoSite	5	1	2	0	8	0	0	0	1	0	3	4	3	0	1	4
OneGloss	8	0	0	0	7	0	1	0	1	0	3	4	2	0	3	3

which was subsequently removed. The cements were then light polymerized for 20 seconds using a curing light (Spectrum; Dentsply Inc, Milford, DE 19963, USA) with an output intensity ≥ 420 mW/cm^2, and assessed with a curing radiometer (Cure Rite, EFOS Inc, Ontario, Canada).

The cervical matrixes were removed after light curing and gross contouring was done with 8-flute tungsten carbide burs (Robot Carbide SH134; Shofu, Kyoto, Japan) under water spray using a high-speed handpiece at 300,000 rpm. The restored teeth were then randomly divided into two groups of 32 teeth. Specimens in the first group were finished/polished immediately after light curing/gross contouring and stored in distilled water at 37°C for one week. In the second group, finishing/polishing was delayed for one week. Storage during the hiatus period was again in distilled water at 37°C. The following finishing/polishing systems were evaluated: (a) Robot Carbides, (b) SuperSnap, (c) OneGloss and (d) CompoSite Polishers. Details of the finishing/polishing sequences are reflected in Table 2. The sample size for each instrumentation time, material and finishing/polishing system combination was 8.

The apices of the teeth were subsequently sealed with acrylic. Two coats of nail varnish were applied, leaving a 1-mm margin from the restoration free of varnish. The teeth were then soaked in 0.5% basic fuschin dye at 37°C for 24 hours. After dye penetration testing, the nail varnish was removed with an ultrasonic scaler and excess dye was washed off. The aforementioned was done to prevent residual dye contamination of the sectioned surfaces. The teeth were subsequently sectioned longitudinally (bucco-lingually) at the center using a Microslice II Precision Saw (Cambridge Instruments Ltd, Cambridge, England) and scored. Dye penetration was assessed using an optical stereomicroscope (SE, Nikon, Tokyo, Japan) at 10x magnification. The degree of dye penetration for both the enamel and dentin margins was graded using the following scale (Figure 1):

0 = No evidence of dye penetration

1 = Dye penetration to 1/3 the cavity depth

2 = Dye penetration to 2/3 the cavity depth

3 = Dye penetration to the full cavity depth

Microleakage data were subjected to non-parametric statistical analysis (Kruskal-Wallis and Mann Whitney U tests) at significance level 0.05.

RESULTS

The distribution of microleakage scores for the different instrumentation times and materials are shown in Tables 3 and 4. Results of the statistical analyses are reflected in Tables 5 to 7. The effects of instrumentation time on microleakage were found to be material, finishing/polishing system and tissue dependent. For Photac-Fil, immediate instrumentation with SuperSnap and CompoSite resulted in significantly more enamel leakage than delayed instrumentation. Significantly more dentin leakage was observed with immediate instrumentation with SuperSnap (Table 5). For Fuji II LC, no significant difference in microleakage was observed

Table 5: *Comparison of Microleakage Scores Between Immediate and Delayed Finishing/ Polishing*

Photac-Fil Quick				
Tissue	**Robot Carbides**	**SuperSnap**	**OneGloss**	**CompoSite**
Enamel	NS	Immediate > Delayed	NS	Immediate > Delayed
Dentin	NS	Immediate > Delayed	NS	NS
Fuji II LC				
Tissue	**Robot Carbides**	**SuperSnap**	**OneGloss**	**CompoSite**
Enamel	NS	NS	NS	NS
Dentin	Immediate > Delayed	NS	NS	NS

NS denotes no statistical significance while > indicates statistically significant differences (Results of Mann Whitney U test at p<0.05).

Table 6: *Comparison of Microleakage Scores Between Finishing/Polishing Systems*

Photac-Fil		
Tissue	**Immediate**	**Delayed**
Enamel	OneGloss < SuperSnap	NS
Dentin	NS	SuperSnap, CompoSite < Robot Carbides
Fuji II LC		
Tissue	**Immediate**	**Delayed**
Enamel	OneGloss < Robot Carbides	NS
Dentin	OneGloss, CompoSite < Robot Carbides	NS

NS denotes no statistical significance while < indicates statistically significant differences (Results of Kruskal Wallis and Mann Whitney U test at p<0.05).

Table 7: *Comparison of Microleakage Scores Between Material*

Immediate Finishing				
Tissue	**Robot Carbides**	**SuperSnap**	**OneGloss**	**CompoSite**
Enamel	NS	PF > FT	PF > FT	NS
Dentin	NS	NS	PF > FT	NS
Delayed Finishing				
Tissue	**Robot Carbides**	**SuperSnap**	**OneGloss**	**CompoSite**
Enamel	NS	NS	NS	NS
Dentin	PF > FT	NS	NS	NS

PF = Photac-Fil and FT = Fuji II LC. NS denotes no statistical significance while > indicates statistically significant differences (Results of Mann Whitney U test at p<0.05).

between the two instrumentation times with the exception of finishing/polishing with Robot Carbides. Immediate instrumentation with Robot Carbides resulted in significantly more dentin leakage (Table 5).

Although significant differences in enamel and dentin microleakage were generally observed between finishing/polishing systems with immediate instrumentation, no significant difference was observed with delayed instrumentation with the exception of leakage at the dentin margins of Photac-Fil restorations (Table 6). A similar trend was observed when leakage scores of the materials were compared (Table 7). The leakage scores of Photac-Fil were significantly greater than Fuji II LC for several finishing/polishing systems with immediate instrumentation. With delayed instrumentation, Photac-Fil only had significantly greater dentin leakage than Fuji II LC when finishing/polishing was done with Robot Carbides.

DISCUSSION

A wide spectrum of commercially available finishing/polishing systems was evaluated. These included tungsten carbide (Robot Carbides), abrasive disk (SuperSnap), one-step (OneGloss) and two-step (CompoSite Polishers) rubber abrasive finishing/polishing systems. Among the various finishing/ polishing systems, abrasive disks provided the best surface finish (Yap & others, 2002; Hoelscher & others, 1998; Yap, Lye & Sau, 1997). Although it has been stated that RMGICs are resistant to water uptake after light activation (Mount, 1990), they have been shown to absorb substantial amounts of water after light curing (Kanchananvasita, Anstice & Pearson, 1997; Yap, 1996). This has been attributed to water uptake by the polyHEMA complex and the formation of a hydrogel of calcium and aluminum polyacrylates in RMGICs (Yap, 1996; Wilson, 1990). Water sorption may allow for some degree of relaxation of polymerization/setting stresses and reduce microleakage (Thonemann & others, 1997; Carvalho & others, 1996). As such, the duration of water storage was standardized at one week for both the immediate and delayed instrumentation groups.

Although significant differences in microleakage scores were observed for some material-finishing/polishing system-tissue combinations, a general reduction in enamel and dentin microleakage was observed with delayed instrumentation for both RMGICs. Findings were consistent with those of Irie & Suzuki (2002) and Lim & others (1999), who found decreased gap formation and microleakage with delayed finishing/polishing of RMGICs. The greater leakage observed with imme-

diate instrumentation may be attributed, in part, to the disruption of the weak ionic (chemical) bonds of RMGICs immediately after light curing as stated earlier. The latter might be aggravated by the desiccation of restorations during finishing/polishing with "dry" systems. This was evidenced by the significant differences in leakage scores between the two instrumentation times for Photac-Fil with SuperSnap and CompoSite. Wilder & others (2000), however, found no statistically significant difference in microleakage between wet and dry polishing of RMGICs. Setting shrinkage of RMGICs may also contribute to the observed phenomena. The setting shrinkage of RMGICs is higher than conventional glass ionomer cements (Tay, 1995). This is due to the fact that while slow setting conventional materials permit stress relief within the restoration, RMGICs exhibit more rapid setting contraction through polymerization of the resin component. RMGICs shrink 3.28% to 4.78 % within five minutes after light curing and shrinkage can continue up to 12 hours (Crim, 1993). If restorations are finished/polished to the cavity margins immediately after light curing, the inherent contraction could lead to increased gap formation, resulting in increased microleakage. Ninety percent of the equilibrium water uptake of RMGICs occurs within one week (Kanchanavasita & others, 1997). As leakage was present even after one week's storage in water, it could be concluded that water sorption is insufficient to compensate for gap formation resulting from shrinkage and instrumentation. As Yap & others (2001) also reported that the maximum properties of RMGICs are achieved at one week, it could be suggested that finishing/polishing should be delayed and not conducted immediately after light polymerization.

Delayed instrumentation also appeared to reduce the influence of finishing/polishing systems on microleakage of RMGICs. With immediate instrumentation, significant differences between finishing/polishing systems were observed for most material-tissue combinations. In general, treatment with OneGloss resulted in significantly less leakage compared to the other finishing/polishing systems. With delayed instrumentation, no significant difference was observed between OneGloss and the other finishing/polishing systems. Significant differences in microleakage were, however, observed at the dentin margins of Photac-Fil restorations where the use of SuperSnap and CompoSite resulted in significantly less leakage than Robot Carbides. The latter may be attributed, in part, to the chemistry of Photac-Fil and the large mechanical stresses generated by ultra high-speed finishing/polishing. Photac-Fil employs the use of freeze-dried co-polymers of polyacrylic acid. As the anhydrous polyacrylic acid needs to be hydrated and activated prior to reaction with the aluminosilicate glass, the ionic exchange mechanism may require more time to mature. Enamel microleakage was not affected by the use of Robot Carbides when instrumentation was delayed, as the seal of RMGICs to enamel is superior to dentin (Yap, Tan & Teh, 2000). This is due to the higher inorganic content and homogeneity of enamel (Anusavice, 1996). The aforementioned also explains the significantly greater dentin leakage associated with Photac-Fil when compared to Fuji II LC after finishing/polishing with Robot Carbides.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The effects of instrumentation time on microleakage of resin-modified glass ionomer cements are material, finishing/polishing system and tissue dependent.
2. Delayed finishing/polishing of resin-modified glass ionomers generally resulted in less leakage.
3. Delayed finishing/polishing also reduces the influence of finishing/polishing systems on microleakage of resin-modified glass ionomer cements.

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Surface Geometry of Three Packable and One Hybrid Composite After Finishing

M Jung • S Voit • J Klimek

Clinical Relevance

Finishing with a 30 µm diamond caused a considerable roughening of the surfaces. After finishing in two steps, roughness was reduced significantly. A 30 µm diamond cannot be recommended for use on Definite (Degussa) surfaces due to destructive effects. Solitaire (Heraeus-Kulzer) was finished efficiently by two diamonds.

SUMMARY

This study compared the effects of different finishing techniques on the surface of a traditional hybrid composite and three packable composites.

Four composites were used in the study (Herculite XRV/Kerr, Definite/Degussa, SureFil/Dentsply and Solitaire/Heraeus-Kulzer). Fifty specimens were made of each material, sized 7 x 7 x 4 mm. Fifteen specimens of each material were subjected to the following finishing procedures: (1) a 30 µm diamond, (2) a 30 µm and a 20 µm diamond and (3) a 30 µm diamond followed by a tungsten carbide finishing bur. As a reference, five specimens of each material were treated by Sof-Lex discs (3M). For quantitative surface evaluation, laser-stylus profilometry was used. Roughness parameters included average roughness (R_a) and profile-length-ratio (LR). Statistical analysis was performed with one- and two-way Anova and Scheffé post-hoc tests. Qualitative surface evaluation in SEM was performed at a tension of 25kV.

Significant effects were found with both the composites and the finishing methods with respect to surface roughness ($p<0.001$ for R_a and LR). A 30 µm diamond caused the greatest roughness on all composites, with R_a ranging from 2.015 - 2.079 µm ($p<0.001$). After finishing using methods 2 and 3, the Solitaire surfaces were significantly smoother ($p<0.001$ for LR). The lowest roughness values were achieved after using disks; again, the Solitaire specimens yielded the lowest R_a and LR values ($p<0.001$ except for Sure-Fil). With scanning electron microscopy, surface areas with signs of destruction were found after using a 30 µm diamond on Definite specimens.

*Martin Jung, priv-doz, Policlinic for Operative and Preventive Dentistry, Justus-Liebig-University, Giessen, Germany

Stefan Voit, dentist, Policlinic for Operative and Preventive Dentistry, Justus-Liebig-University, Giessen, Germany

Joachim Klimek, DDS, professor, Policlinic for Operative and Preventive Dentistry, Justus-Liebig-University, Giessen, Germany

*Reprint request: Schlangenzahl 14, D-35392 Giessen, Germany; e-mail: martin.jung@dentist.med.uni-giessen.de

INTRODUCTION

In recent years, packable composites have been introduced to the spectrum of direct restorative materials as an alternative to dental amalgam in posterior teeth. Packable composites show great variations with respect to their matrix and filler composition. Mechanical properties such as diametral tensile strength, compressive

Table 1: *Details and Properties of the Composites Evaluated (based on information by manufacturers)*

Material	Lot #	Matrix	Fillers	Filler Size in µm	Filler Content % by Weight	Filler Content % by Volume	Vickers Hardness VHN
Herculite XRV	902844	Bis-GMA TEGDMA EBADM	Ba-Al-Borosilicate SiO_2 ZnO TiO_2	0.6	78	59	82*
Definite	CHB 224	Inorganic-Organic Siloxane Polymers	Ba-Glass Aerosils Apatite	1-1.5	77	61	65.8‡
SureFil	981027	UDMA TEGDMA	Ba-Al-B-F-Si-Glass SiO_2 Nanofiller	0.8	82	66	70.14‡
Solitaire	010029	HPMA ETMA Bis-GA Tetrafunctional Molecules	Ba-Al-B-F-Si-Glass Porous SiO_2	3-22	66	90	41.7‡

** VHN 0.5/30 (Hofmann & others, 2000)*
‡ VHN 0.2/40 (Manhart, Chen & Hickel, 2001)

Table 2: *Details of the Rotary Instruments*

Type of Bur	Manufacturer	Order #	Particle Size/# of Blades
Finishing diamond	Brasseler,Savannah, Georgia 31419, USA	806 314 166 514 014	24-40 µm
Finishing diamond	Brasseler,Savannah, Georgia 31419, USA	806 314 166 504 014	15-30 µm
Tungsten carbide	Brasseler,Savannah, Georgia 31419, USA	500 314 166 041 014	16-fluted
Sof-Lex Discs finishing bur	3M ESPE Dental Products, St Paul, MN 55144, USA	1982 C 1982 M 1982 F 1982 SF	100 µm 29 µm 14 µm 5 µm

and flexural strength or fracture toughness varied considerably among the different packable composites and were not superior or even lower in quality than those of traditional hybrid composites (Cobb & others, 2000; Kelsey & others, 2000; Leinfelder, Bayne & Swift, 1999; Manhart & others, 2000). In an effort to facilitate clinical handling, packable composites were promoted as being capable of minimizing polymerization shrinkage and assuring an increased depth of cure. Scientific documentation of these properties indicate that this has actually not been satisfactorily accomplished (Chen & others, 2001; Cobb & others, 2000; Yap, 2000).

Although packable composites may offer some technical advantages and a more convenient placement, there is no convincing evidence that these materials are clinically superior to traditional hybrid composites (Loguercio & others, 2001; Oberländer & others, 2001).

When placing composite restorations, rotary instrumentation is inevitable. The novel matrix formulation and filler composition of packable composites might influence the state of the surface after finishing and polishing. Therefore, a re-evaluation of the new composites with respect to surface quality was deemed necessary.

The trimming of composite surfaces comprises two different steps, that is, finishing and polishing. Finishing includes the gross removal of overhangs, anatomical contouring and the initial smoothing of surfaces. Polishing aims to reduce surface roughness to the lowest possible level.

This study examined the effect of different finishing procedures on the surface quality of three packable and one traditional microhybrid composite. The evaluation of polishing methods will be the subject of an additional study.

METHODS AND MATERIALS

Three packable composites were used for this study. Definite (Degussa AG, 63403 Hanau, Germany) belongs to the group of ormocers (organically modified ceramic) by virtue of novel inorganic-organic copolymers in the matrix formulation. SureFil (Dentsply/Caulk, Milford, DE 19963, USA) is characterized by a special interlocking filler technology. Solitaire (Heraeus Kulzer, 61273 Wehrheim, Germany) consists of an organic glass matrix combined with large, porous silicon-dioxide filler particles. For com-

parison, Herculite XRV (Kerr Manufacturing Company, Romulus, MI 48174, USA), a traditional hybrid composite, was also used in the study. Details and properties of the four composites are summarized in Table 1.

Fifty specimens sized 7 x 7 mm and 4-mm thick were made of each composite using glass molds. The specimens were polymerized for 40 seconds on both sides with the light curing unit Optilux 400 (VCL 401; Demetron, Danbury, CT 06810, USA). The output was verified using a curing radiometer (Model 100, P/N 10503, Demetron) to ensure a power density >600 mW/cm^2. After fabrication of the specimens, the surface layer was removed by sandpaper discs of 400 and 600 grit (Leco Corporation, St Joseph, MI 49085, USA) for 30 seconds, each under running water (automatic polishing apparatus A 250, Jean Wirtz, Duesseldorf, Germany). Using the stereomicroscope Stemi SV6 (Carl Zeiss, 37081 Goettingen, Germany) at a magnification 4x, the surfaces of the specimens were examined for irregularities.

Three rigid rotary instruments were chosen for finishing the composite surfaces. Also, the specimens were treated with Al_2O_3-coated flexible Sof-Lex discs. Details of the rotary instruments are specified in Table 2.

The finishing of specimens was performed following three different protocols:

- Finishing method 1 (FM 1; one step): a 30 µm finishing diamond.
- Finishing method 2 (FM 2; two steps): a sequence of a 30 µm and a 20 µm finishing diamond.
- Finishing method 3 (FM 3; two steps): a 30 µm diamond followed by a 16-fluted tungsten carbide finishing bur.
- Clinical standard (CS; four steps): the consecutive use of four flexible Sof-Lex discs from coarse to extra-fine.

Fifteen randomly selected specimens of each composite were finished according to FM 1, 2 and 3. Five specimens were treated with Sof-Lex discs (CS). Finishing was performed manually with a red-ring handpiece (24 LN Intramatic Lux 2, KaVo, 88400 Biberach, Germany) at 40,000 rpm under three-way water-cooling. The flexible discs were mounted in a blue-ring handpiece (Intramatic Lux 20L with head 68G, KaVo) and used at 4,000 rpm under two-way water-cooling. The number of revolutions was verified electronically (Moviport C 117.11, Braun, 71334 Waiblingen, Germany). After application on five surfaces, a new finishing bur was used. A new flexible disc was used for each surface. Time was limited to 30 seconds per instrument. The selection of the finishing methods and the composite specimens was accomplished according to a randomized protocol; during finishing, the type of composite was blind.

After rotary instrumentation, the composite surfaces were evaluated quantitatively and qualitatively. Quantitative examination was performed by optical profilometry. A laser stylus (Focodyn, Rodenstock, 80469 Munich, Germany), focused to a diameter of 1 µm, was used for scanning the finished surfaces. Profile data were transmitted to the processing unit S8P (Mahr, 37073 Goettingen, Germany). Each surface was scanned by nine parallel tracings that were generated automatically, ensuring a constant side shift (D_Y) of 0.22 mm. Transverse length (L_T) was set to 1.75 mm; the distance used for calculating roughness parameters (sampling length L_M) was 1.25 mm. The complete profilometric settings were:

L_T = 1.75 mm; L_M = 1.25 mm

D_Y = 0.22 mm; n (scans per surface) = 9;

L_Y = 1.76 mm

λ (cut-off) = 0.25 mm (Gauss profile-filter)

The surface area on each specimen evaluated quantitatively was 1.25 mm x 1.76 mm.

Surface quality was characterized by average roughness (R_a) and profile-length-ratio (LR). R_a is defined as the arithmetic mean of the absolute ordinate values within the sampling length (ISO 4287 [ISO-Standards, 1997]). LR represents the length of a profile tracing drawn out to a straight line (true profile length) in relation to the sampling length (DIN 4762 [DIN-Normen, 1996]). LR is dimensionless; an ideally smooth surface yields an LR=1.

Statistical analysis of the quantitative results was carried out using SPSS for Windows (version 10.07). The R_a and LR data were distributed normally and differences between the methods were analyzed with one- and two-way ANOVA and Scheffé post-hoc tests at a significance level $p<0.001$.

Qualitative examination was carried out with scanning electron microscopy (PSEM 500, Philips Electronics, 5600 MD Eindhoven, Netherlands) at a working tension of 25 kV. Two specimens each were randomly selected for the SEM study, representing the three finishing methods and the disc group. This resulted in a total of 32 specimens for the four composites. During the qualitative evaluation, both the type of composite and the finishing method were blind. From each surface, a photomicrograph was taken at an original magnification of 80x. Photoprints sized 16 cm x 12 cm were divided into 48 squares. Each square was evaluated according to the following grading system:

Grade 1 - smooth, homogeneous surface.

Grade 2 - minor roughness.

Grade 3 - severe roughness.

Grade 4 - detrimental surface area.

RESULTS

Quantitative Evaluation

Analyzing the results by two-way ANOVA revealed significant effects both on the finishing methods and on the different composites on surface roughness with respect to R_a and LR ($p<0.001$ for R_a and LR). The use of a 30 µm finishing diamond caused the greatest roughness on all composites ($p<0.001$ for R_a and LR, Figure 1 and 2). A sequence of two finishing diamonds (FM 2) led to a considerable reduction in average roughness below the level of 1 µm ($p<0.001$). LR values were also reduced significantly ($p<0.001$), but the corresponding decrease in LR was only moderate compared to R_a. When the 30 µm diamond was followed by a tungsten carbide bur (FM 3), roughness was slightly reduced (with respect to R_a) or slightly increased (with respect to LR), compared to FM 2, but the differences were not statistically significant.

The use of Sof-Lex discs achieved the lowest roughness on all composites ($p<0.001$ for LR). With respect to R_a, the differences to FM 2 and FM 3 were only significant on SureFil surfaces.

After using a 30 µm diamond, there were only minor differences among the composites evaluated. The greatest roughness data were recorded for Definite surfaces (R_a=2.08 µm; LR=1.782). After finishing according to FM 2 and FM 3, Solitaire surfaces showed the lowest roughness compared to the other composites. The differences were significant with respect to LR for both finishing methods ($p<0.001$) and with respect to R_a only for FM 2.

After using Sof-Lex discs, again the Solitaire surfaces yielded the lowest roughness values (R_a=0.5 µm, LR=1.214); the differences to Definite and Herculite surfaces were significant ($p<0.001$).

Qualitative Evaluation

The SEM evaluation largely corroborated the profilometric results. The use of a 30 µm diamond caused large areas of severe roughness on all composites (Figure 3). Moreover, Definite specimens showed more than 10% surface irregularities of Grade 4, indicating the destructive effects of the 30 µm diamond (Figure 4). Using the 20 µm finishing diamond (FM 2) achieved a complete reduction of the severely roughened surfaces to minor roughness on Solitaire specimens. The other composites had remaining areas of severe roughness ranging from 19 to 36%. After finishing with a tungsten carbide bur (FM 3), the amount of severe roughness was reduced to between 4 and 18%. Solitaire surfaces revealed small amounts of smooth areas. The use of Sof-Lex discs resulted in an increase in the amount of homogeneous areas on the surface of the packable composites. Solitaire specimens yielded more than 50% smooth areas. Despite the use of flexible discs, Definite surfaces retained areas of severe roughness amounting to almost 42%.

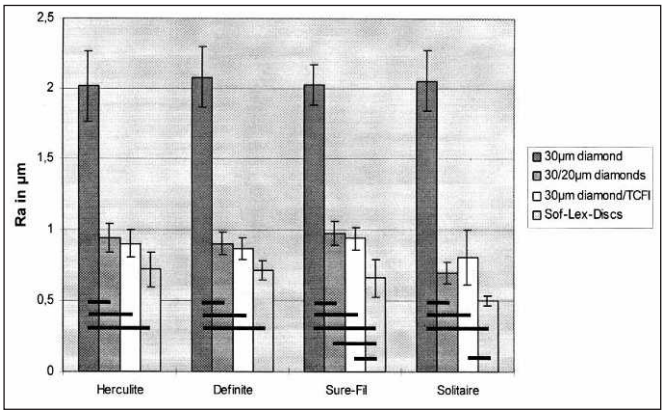

Figure 1: *Average roughness (Ra) of one hybrid and three packable composites after finishing (each vertical bar represents 15 specimens) and after treatment with flexible discs (mean ± SD; n=5 each); the horizontal bars characterize statistically significant differences (*p*<0.001).*

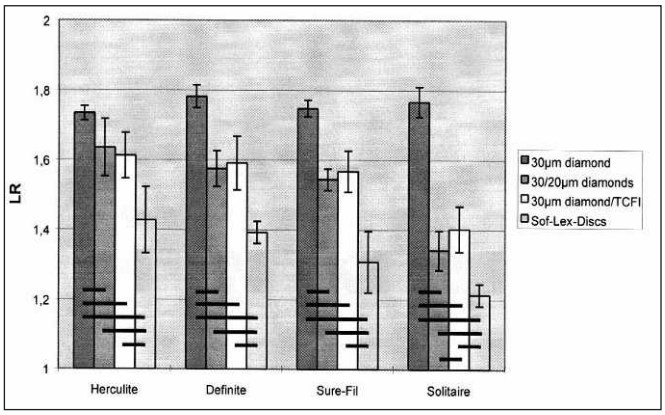

Figure 2: *Profile-length-ratio (LR) of one hybrid and three packable composites after finishing (each vertical bar represents 15 specimens) and after treatment with flexible discs (mean ± SD; n=5 each); the horizontal bars characterize statistically significant differences (*p*<0.001).*

DISCUSSION

Surface quality is an important parameter that influences the behavior of dental restorations in the oral environment in different ways. Rough surfaces accumulate more plaque and plaque components compared to smooth surfaces (Kawai & Urano, 2001). The surface state affects the fracture resistance of brittle material such as composites and ceramics (De Jager, Feilzer & Davidson, 2000; Graf & others, 1998). Restorations that are well polished are less abrasive toward antagonistic surfaces and show greater wear resistance (Tjan & Clayton, 1989). Finishing and polishing influences the surface hardness of composites (Yap, Lye & Sau, 1997). Smooth surfaces attribute to a natural appearance of tooth-colored restorations. Polishing reduces susceptibility to staining (Dietschi & others, 1994). The

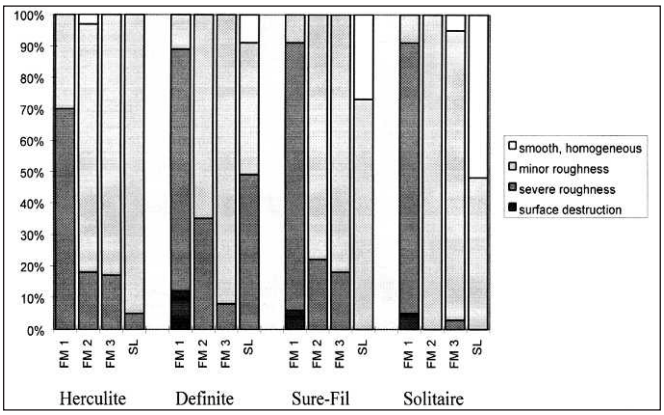

Figure 3: *The portion of different surface chararcteristics of one hybrid and three packable composites in SEM after finishing (each bar represents 15 specimens) and disc treatment (n=5 each).*

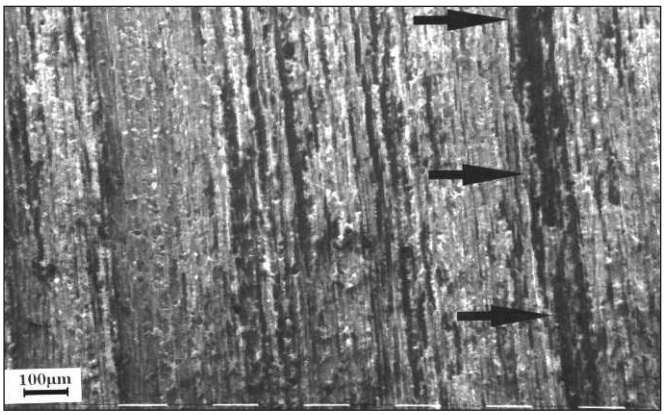

Figure 4: *Areas of surface destruction (≠) on Definite after finishing with a 30 µm diamond.*

state of a surface affects the patient's comfort with respect to perception of surface irregularities (Van Noort & Davies, 1984).

Packable composites were designed as an alternative to amalgam for the restoration of posterior teeth. Class I or II restorations usually include structured surfaces caused by the presence of cusps and fissures. Flexible discs are accepted as a clinical standard for trimming and polishing composites (Hoelscher & others, 1998; Tjan & Clayton, 1989; Wilson, Heath & Watts, 1990). Because of their shape, their use is confined to convex surfaces (Chen, Chan & Chan, 1988; Tjan & Clayton, 1989). Therefore, it was important to evaluate rigid rotary instruments that permit the finishing of structured surfaces. Rotating stones produce rough surfaces on composite materials and should be avoided for this use (Yap & others, 1997). Finishing diamonds and tungsten carbide finishing burs are recommended for trimming composites (Kaplan & others, 1996; Lutz, Setcos & Phillips, 1983); for this reason, these burs were chosen for this study.

To avoid the training effects caused by increasing manual skill when finishing the composite specimens, a randomized protocol was followed. This was done with respect to selecting the different composites and the finishing method used.

The samples were evaluated by optical profilometry. This permitted a touch-free scanning of the composite surfaces. The size of the stylus tip, which is commonly used for mechanical profilometry, is regarded as being too large to penetrate the irregularities of finished or polished surfaces (Joniot & others, 2000; Jung, 1997; Whitehead & others, 1999). The laser stylus of the Focodyn pick-up is focused to a diameter of 1 µm, thus, providing great accuracy for the profilometric evaluation.

Roughness parameters such as R_{max}, R_t, R_z or R_a are vertical parameters since they describe surface irregularities only by their amplitudes. The shortcomings of these parameters have been pointed out in dental literature (Jung, 1997; Whitehead & others, 1995). The authors, therefore, included the profile-length-ratio (LR) for the characterization of roughness because this parameter reflects both the vertical and the horizontal dimensions of surface irregularities.

Several authors have stressed the importance of supporting quantitative evaluation of surface roughness by qualitative methods (Goldstein & Waknine, 1989; Northeast & van Noort, 1988; Tjan & Clayton, 1989). For this reason, additional examination of the specimens with the SEM was performed. This enabled a discrimination between surface roughness and the destructive effects caused by rotary instrumentation.

The roughest surfaces on all composites were caused by the 30 µm finishing diamond. The subsequent use of a 20 µm diamond reduced roughness significantly. The corresponding decrease in LR was only moderate compared to R_a. This can be attributed to the fact that the 20 µm diamond not only reduced the amplitude of profile irregularities but also increased their number. In contrast to LR, average roughness does not reflect the change in the number of profile peaks. LR represents both the height of surface irregularities and their number.

For three of the four composites tested, there were no significant differences between the use of two finishing diamonds or the sequence of a diamond and a tungsten carbide bur with respect to R_a and LR. The specimens treated with two diamonds were significantly smoother only for Solitaire. This might indicate that a tungsten carbide finishing bur is not recommendable for use on Solitaire surfaces.

Sof-Lex discs caused a significant reduction in roughness with respect to LR compared to each of the finishing methods. This emphasizes the necessity of a final polishing with rigid rotary instruments after finishing.

Finishing, according to FM 2 and FM 3, can only achieve an initial smoothing of roughened surfaces.

When comparing composite materials, there were no significant differences between the hybrid composite Herculite and the packables Definite and SureFil with respect to surface quality. When finishing according to FM 2 and FM 3, and (with one exception) after the use of flexible discs, Solitaire surfaces yielded significantly lower LR values than the other composites. These differences might arise from the special filler technology of Solitaire. The large and porous SiO_2 particles facilitate penetration and embedding by the matrix constituents, which could attribute to a more homogeneous surface behavior when rotary instrumentation is performed. Another point might be the reduced hardness of Solitaire compared to the other composites. Clinical studies must show whether the mechanical properties of Solitaire will be sufficient for the restoration of posterior teeth. Currently, controversial results relating to the clinical behavior of Solitaire have been published (Farah & Powers, 1998; Klinge & others, 2000).

The SEM evaluation revealed destructive effects of the 30 µm diamond on Definite surfaces. After treatment with flexible discs, about 40% severe roughness remained on Definite specimens. This indicates the detrimental effect of rotary instruments with a large grain size on the ormocer surface. With respect to the filler composition, there are only minor differences to SureFil and Herculite. Therefore, the destructive effect of coarse rotar instrumentation might result from the special composition of the ormocer matrix and could indicate a weak adhesion of the filler particles and the siloxane polymer network.

The R_a values of this study are in agreement with a prior study on Herculite surfaces with respect to the finishing diamonds and Sof-Lex discs (Jung, 1997). Both studies utilized the same type of laser-stylus-based profilometry. Comparing the roughness data with that of other authors is problematic. This arises from the fact that there are several factors influencing the results of quantitative roughness evaluation. One of these factors is the type and design of the pick-up system. The Focodyn laser stylus is very precise compared to a mechanical stylus; this can explain the fact that the R_a values of this study are mostly greater than those of similar studies in the literature. Pratten & Johnson (1988) reported R_a values of 1.5 µm and 0.8 µm on composite surfaces after using a fine or x-fine diamond, respectively. Berastegui & others (1992) examined Herculite surfaces after finishing and reported an R_a of 0.7 µm when using a finishing diamond and an R_a of 0.3 µm after treatment with Sof-Lex discs. Of special interest are the results of a study examining the surface quality of three packable composites (Roeder, Tate & Powers, 2000). SureFil and Solitaire finished with a 30 µm diamond had an R_a ranging from 1.3-2.2 µm; Sof-Lex discs reduced average roughness to 0.2-0.24 µm. A tungsten carbide bur was only tested on SureFil and caused an R_a of 0.4-0.6 µm. The absolute R_a-values, thus, are lower compared to this study, but the relation of the results among the different finishing methods are similar.

CONCLUSIONS

1. The use of a 30 µm diamond caused a similar roughening of the surfaces of all composites to an R_a level of 2 µm. On Definite surfaces, the 30 µm diamond caused large amounts of detrimental effects and cannot be recommended for finishing this type of composite.
2. The subsequent use of two finishing diamonds or a finishing diamond followed by a tungsten carbide bur reduced initial roughness significantly to more than half the amount on all composites.
3. With respect to LR, Solitaire surfaces were significantly smoother when finishing was performed with two diamonds compared to a diamond and a tungsten carbide bur.
4. The lowest roughness values were achieved after using discs; the Solitaire specimens yielded the lowest R_a and LR values.
5. Overall, there were only minor differences in surface quality between the hybrid composite Herculite and the packable composites Definite and SureFil. Solitaire surfaces were significantly smoother after finishing according to FM 2 and FM3 compared to the other materials.

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Relationship Between Nanoleakage and Microtensile Bond Strength at the Resin-Dentin Interface

S Guzmán-Armstrong • SR Armstrong • F Qian

Clinical Relevance

The main goal of bonding a restorative material to dental tissue is to achieve a strong, durable bond and an impervious seal. The correlation between laboratory measurements of physical properties representing clinical performance, that is, nanoleakage—(secondary caries, pulpal reactions and marginal integrity) and microtensile bond strength—(restoration retention), could not be confirmed in this study.

SUMMARY

To evaluate the correlation between microtensile dentin bond strength (μTBS) and silver ion penetration, two total-etch 3-step and one self-etch 2-step system were investigated. OptiBond FL adhesive was applied to flat occlusal dentin on six non-carious human molars, and a resin composite "crown" was formed in 2 mm increments. After 24-hour water storage, the teeth were sectioned with a low-speed diamond saw to obtain four-square sticks (~2 mm X 2 mm) per tooth. Cylindrical tensile test specimens were formed with an 0.5 mm² cross-sectional area. Nail varnish was applied to the dentin within 0.5–1.0 mm of the interface before immersing in 50% silver nitrate for 15 minutes. Following silver fixation, tensile testing was performed in a Zwick UTM at 1 mm/minute using a passive gripping fixture to obtain 72-hour μTBS [23.9 MPa]. The percentage area of silver penetration was measured on debonded specimens using light microscopy and Image-Pro Plus Software [89%]. The procedures were repeated using Scotchbond Multi-Purpose Plus [μTBS =27.8 MPa; nanoleakage = 67%] and Clearfil SE bond [μTBS = 36 MPa; nanoleakage = 55%]. No significant correlation between microtensile bond strength and nanoleakage was found for all systems. A weak-to-moderate negative relationship was found between μTBS and nanoleakage for OptiBond FL (Spearman r = -0.3844). No correlation was found for the remaining adhesive systems. The correlation between these two common laboratory measurements appears to be adhesive-system dependent.

*Sandra Guzmán-Armstrong, DDS, MS, assistant professor, Operative Dentistry Department, The University of Iowa

Steven R Armstrong, DDS, PhD, assistant professor, Operative Dentistry Department, The University of Iowa

Fang Qian, PhD, senior research assistant, Department of Preventive & Community Dentistry, The University of Iowa

*Reprint request: S-229 Dental Science Building, College of Dentistry, Department of Operative Dentistry, University of Iowa, Iowa City, IA 52242; e-mail: sandra-guzman-armstrong@uiowa.edu

INTRODUCTION

High bond strength and a complete marginal seal at the resin composite-dentin bonded interface are required for clinically successful restorations. *In vitro* measurements of dentin bond strength and marginal integrity

are commonly viewed as indicators of adhesive system potential and are used by clinicians as important selection criteria for dental adhesives. The relationship between bond strength and leakage is not clearly understood.

Countless studies have individually evaluated marginal integrity or bond strength of the adhesive dentin-bonded interface; however, few studies have evaluated the relationship between these two different outcomes (Prati & others, 1992; Retief, Mandras & Russell, 1994; Fortin & others, 1994; Pereira & others, 2001; Paul & others, 1999; Neme, Evans & Maxson, 2000). Munksgaard, Irie & Asmussen (1985) demonstrated an inverse relationship between shear bond strength and gap formation, while Retief & others (1994) found an inverse relationship between shear bond strength and microleakage. However, many more studies have failed to demonstrate a correlation between SBS and marginal gap or microleakage (Kemp-Scholte & Davidson, 1990a,b; Uno & Finger, 1995; Finger & Fritz, 1996; Prati & others, 1992; Hammesfahr, Huang & Sjaffer, 1987; Fortin & others, 1994).

In general, these studies have demonstrated a tendency toward high bond strength related to low leakage but were rarely statistically significant. Staninec & Kawakami (1993) concluded that the amount of leakage observed was correlated to early shear bond strength. Fortin & others (1994) also evaluated microleakage and bond strength using the same tooth but different specimens. However, the trend was materials with high bond strength also had the lowest microleakage. This study is in agreement with Neme & others (2000), who demonstrated an inconsistent relationship between the two methodologies. In a different study, Paul & others (1999) found no correlation between bond strength and etching time.

The correlation between leakage and bond strength is most appropriately determined within the same test specimen. Prati & others (1992) found that high bond strength was associated with low microleakage and vice versa. Pereira & others (2001) investigated the relationship between μTBS and nanoleakage on alternate specimens within the same tooth and found no significant correlation between the two tests. Okuda & others (2001a), testing both μTBS and nanoleakage on the same specimen, confirmed that a correlation existed only for one adhesive system (self-etch two-step) after three, six and nine months of storage. This same group also reported no correlation for two total-etch two-step systems (Okuda & others, 2001b). Also, Guzmán-Ruiz & others (2001) found no association between leakage and bond strength using the same specimen in Class II indirect resin composite restorations.

This study determined the correlation between microtensile bond strength (μTBS) and silver ion leakage (% area) in the same specimen for two total-etch 3-step and one self-etch 2-step system.

METHODS AND MATERIALS

Six intact, non-carious extracted human third molars were stored in 2% thymol at 4°C solution for less than two months. Each tooth was hand scaled, then placed in water for at least 24 hours prior to mounting in 1x1 inch dental stone blocks using a custom fabricated tooth-mounting device. Flat occlusal dentin was prepared with constant water spray at equivalent speed rates using a #56 carbide bur mounted in the University of Iowa Microspecimen Former. Light microscopy was used to verify removal of all enamel remnants. Immediately after preparation, the specimens were restored with OptiBond FL (Kerr Corporation, Orange, CA 92867, USA) adhesive resin according to manufacturer's instructions (Table 1). A resin composite (Prodigy, Kerr, Danbury, CT 06810, USA) "crown" of at least 6 mm in height was formed in 2 mm increments. The resin composite was built up freehand and each increment was light cured for 40 seconds using Optilux 400 (Demetron/Kerr, Danbury, CT 06810, USA) light curing unit. The output for the curing light unit was verified at >400 mW/cm^2 and the laboratory conditions were 22±1°C and 54±1% relative humidity throughout the bonding procedure. After storage in water for 24 hours, the mounted "crown"/teeth were sectioned with a low-speed diamond saw (Isomet 1000, Buehler, Lake Bluff, IL 60044, USA) to obtain four square sticks (~2 mm x 2 mm x 10-12 mm) per tooth. Each stick was trimmed in the Iowa Microspecimen Former using an eight micron diamond cutting instrument in a high-speed hand piece creating cylindrical tensile test specimens with 0.5 mm^2 cross sectional area and a 2 mm gage length. The samples were stored in water in individual containers for 48 hours. Nail varnish was applied to the dentin within 0.5 mm–1 mm of the adhesive interface before immersing in 50% silver nitrate in a light-proof container for 15 minutes, then rinsed with water for five minutes and placed in a photodeveloper solution for 12 hours to precipitate silver ions in areas of leakage. Following silver fixation, 72-hour microtensile bond strength was determined in a universal testing machine (Zwick 1445 Materials Testing Machine, Zwick GmbH & Co, Ulm, Germany) and a Dirck's passive gripping fixture at 1 mm/minute until failure.

The percentage area of silver penetration was determined at the interface in all debonded specimens using light microscopy at 0.6X x 4.0X (Olympus BX-50, Japan) and Image-Pro Plus Software.

The study was repeated with a different total-etch three-step adhesive system, (Scotchbond Multi-Purpose, 3M, St Paul, MN 55144, USA) using five

Table 1: *Dental Adhesive Systems*

Material	Components	Batch #	Manufacturer	Clinical Steps
Optibond FL	*Etch:* 37.5% Phosphoric Acid	001642	Kerr	15 seconds, rinse, leave moist
	Primer: HEMA, GPDM, mono (2-methacryloxy ethyl) phthalate (PAMM), ethyl alcohol, CQ, and water	25881		10 seconds, gentle agitation, air-dry gently 5 seconds
	Adhesive: BIS-GMA, HEMA,	25882		Brush application, Light cure 20 seconds
	barium aluminum borosilicate glass, fumed silica, disodium hexafluorosilicate, glycerol dimethacrylate, and CQ			
ScotchBond Multi-Purpose	*Etch*: 35% Phosphoric Acid	7523	3M-ESPE	15 seconds, rinse, leave moist
	Primer: Water, HEMA, and polycarboxylic acid copolymer	7542		20 seconds, scrubbing, add primer every 5 seconds, air-dry gently 5 seconds
	Adhesive: BIS-GMA, HEMA, CQ, EDMAB, DHEPT	7523		Brush application Light cure 10 seconds
Clearfil SE Bond	*Primer*: 10-MDP, HEMA, DHEPT, hydrophilic dimethacrylate, CQ, water	00110A	Kuraray Co Ltd	Apply and allow to stand for 20 seconds Air-dry gently
	Adhesive: 10-MDP, HEMA, BIS-GMA, hydropholic dimethacrylate, CQ, DHEPT, silanated colloidal silica	00046B		Apply and gently air thin Light cure 10 seconds

Abbreviations: CQ = camphorquinone, DHEPT = N,N-diethanol p-toluidine; EDMAB = ethyl 4-dimethyl amino benzoate; HEMA = 2-hydroxyethylmethacrylate; GPDM = glycerol phosphate dimethacryate; BIS-GMA = bisphenyl glycidyl methacrylate; 10-MDP = 10-Methacryloyloxydecyl dihydrogen phosphate

Table 2: *Means, Standard Deviations and Results of Correlation Between Microtensile Bond Strength and Nanoleakage Over Each Adhesive System Tested*

Dental Adhesive System	N	μTBS MPa	Ag+ Penetration %	Spearman Correlation	P-Value
Optibond FL (Kerr)	22	23.9(10.3)	89(17)	-0.3844	0.0773
ScotchBond Multi-Purpose (3M ESPE)	15	27.8(18.4)	67(23)	0.0107	0.9697
Clearfil SE Bond (Kuraray)	16	36.0(16.7)	55(32)	0.06825	0.8017

teeth and a self-etch, two-step adhesive (Clearfil SE, Kuraray, Japan) using four teeth.

STATISTICAL ANALYSIS

SAS software was used to conduct the data analysis. Spearman correlation was used to test whether there were any apparent increasing or decreasing relationships between microtensile bond strength and silver ion penetration for each adhesive system. All tests have a 0.05 level of statistical significance.

RESULTS

In the OptiBond FL group, one specimen fractured during μTBS specimen preparation and one specimen failed in resin composite during μTBS testing, therefore, the leakage percentage area could not be measured. Also, four specimens fractured during specimen preparation in the Scotchbond Multi-Purpose group and one specimen failed in the dentin substrate during μTBS testing, and leakage area, again, could not be measured.

Table 2 reports the means, standard deviations and correlation statistics for μTBS and leakage over each adhesive system tested. Based on the Spearman's correlation test, the data showed no evidence of significant relationships between microtensile bond strength and leakage for each of the three adhesive systems: Scotchbond Multi-Purpose (p-value=0.9697), Clearfil SE (p-value=0.8002) and Optibond FL (p-value=0.0773). The highest μTBS=36.0 (16.7) and the lowest leakage=55% (32%) were found in the Clearfil SE adhesive system group. Figure 1 shows the relationship between μTBS and silver penetration area for each adhesive system.

The correlation coefficient r=-0.3844 between μTBS and leakage for the OptiBond FL group is relatively high, which showed an apparent decreasing relationship between μTBS and leakage at 0.10 significance level. Further investigation was performed based on the distribution of percentage leakage areas. Twenty-two specimens were divided into two groups: seven with 47%-86% leakage (Group 1) and 15 with 100% leakage

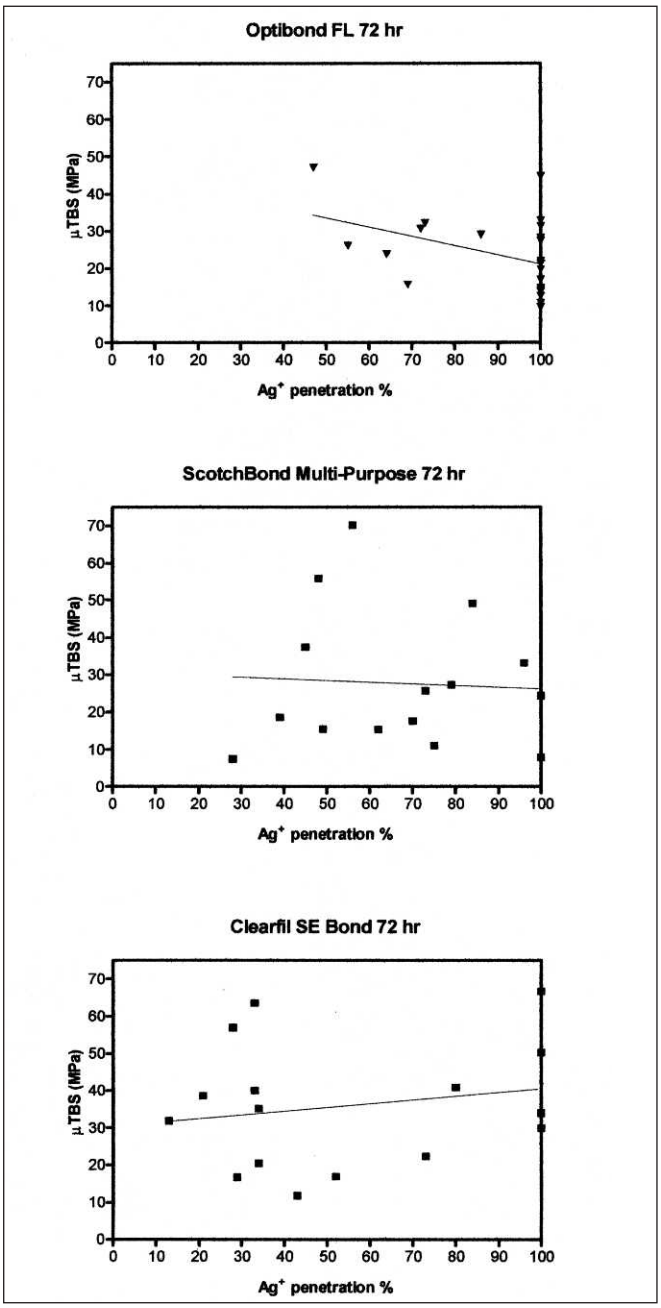

Figure 1: *X-Y plot of mTBS (MPa) and silver penetration (%) with regression line for adhesive systems tested.*

(Group 2). The Wilcoxon Rank-Sum test revealed a significant difference between mean levels of bond strength in the two groups with one-sided *p*-value=0.046. The mean strength 29.28 for Group 1 with lower percentage leakage areas is significantly higher than the mean strength 21.37 for Group 2 with higher percentage leakage areas.

DISCUSSION

The main goal of bonding a restorative material to dental tissue is to achieve high bond strength and a good, long lasting seal. It has been suggested that the bond between tooth and adhesive material could persist in spite of minimal leakage (Neme & others, 2000). However, bond strength alone may not adequately address issues more directly related to microleakage, such as secondary caries, pulpal reactions and marginal integrity.

If both bond strength and microleakage tests are needed to best predict the clinical behavior of an adhesive dental material, some correlation of data is expected since both methodologies are intended to evaluate marginal integrity. In fact, such a relationship has been reported to be inversely related and predictive of clinical performance (Prati & others, 1992; Retief & others, 1994; Fortin & others, 1994; Neme & others, 2000; Okuda & others, 2001a).

No correlation between silver penetration area and bond strength was demonstrated in this study using Scotchbond Multi-Purpose, Clearfil SE bond and OptiBond FL dental adhesive systems. However, an inverse relationship of the two measured variables was weak-to-moderate at best (Spearman=-0.3844) when OptiBond FL was used. This adhesive system showed the lowest bond strength and the highest leakage. These findings are dissimilar to the results presented by Fortin & others (1994) that showed using OptiBond, produced the highest bond strength and the lowest leakage within all adhesives tested. These results could differ due to test methods and/or operator variability (Sano & others, 1998; Finger & Balkenhol, 1999). However, in general, both studies demonstrated that bond strength and microleakage were related, showing an inverse relationship between the methodologies where the dental adhesive material with the highest bond strength had the lowest leakage.

The relationship between bond strength and leakage is complex and poorly understood, as demonstrated by the limited number of publications dedicated to the topic. Prati & others (1992) reported a negative correlation between bond strength and microleakage using Scotchbond Dual-Cure and Scotchbond 2, suggesting that high bond strength was associated with low leakage. The method for measuring microleakage was based on fluid filtration rather than dye penetration. Staninec & Kawakami (1993) found that the amount of leakage observed was correlated to early shear bond strength. Also, in a previous study, the authors evaluated bond strength and leakage in the same specimen using indirect resin composite restorations. No correlation was found; however, a feasible method for evaluation of both tests at the joint interface within the same specimen was demonstrated (Guzmán-Ruiz & others, 2001).

On the other hand, Neme & others (2000) evaluated dentin and enamel bonded interface using amalgam

and resin composite. They found an inconsistent relationship between bond strength and microleakage using different specimens for each test. The results also showed that using an adhesive system would both increase the bond strength and decrease microleakage. These results were confirmed in this study when it was observed that the group with the higher bond strength also had the lower leakage percentage area and vise verse. They also highlighted the importance of additional investigations comparing methodologies for both bond strength and microleakage evaluation.

Long-term storage is also considered an important factor for evaluation of these two tests. Some studies have demonstrated a progressive decline in bond strength over time (Kiyomura, 1987; Sano & others, 1994, 1999) and an increase in microleakage (Grieve, Saunders & Alani, 1993; Crim, 1993; Haller & others, 1993). Paul & others (1999) suggested that microleakage might rise over time, caused by the slow hydrolytic degradation of the resin and the collagen fibers in the submicron spaces of the hybrid layer. A distinction between microleakage and nanoleakage and the effects of each on long-term bond stability was recently reviewed by Pioch & others (2001).

Staninec & Kawakami (1993) evaluated bond strength using different adhesive systems and some of the groups showed an increase in bond strength over time (three minutes, one hour, 24 hours). The increases may be due to further polymerization at the interface or stress relaxation by hygroscopic expansion of the composite. Early bond strength is particularly important when the restorative margins are placed under stress (resin composite polymerization shrinkage stress, contouring and finishing, masticatory loading and thermal fatigue). As mentioned, short-term studies failed to demonstrate a relationship between nanoleakage and μTBS (Pereira & others, 2001), whereas, longer-term studies found an apparent adhesive system-dependent relationship (Okuda & others, 2001a; 2001b). Other studies have shown deterioration at the resin-dentin bonded interface due to hydrolytic degradation over long-term storage (one year) (Blunk & Roulet, 1999). More research is indicated on degradational progresses within the dentin-adhesively-bonded interface.

Pashley & others (1999) concluded that the microtensile bond testing methods give great potential for providing insight into the strength of adhesion dental restorative materials. DeHoff, Anusavise & Wang (1995) state that most dental researchers use tensile and shear tests to predict the effects of technique and material variable on clinical performance of bonding systems, though there is no evidence of clinical relevance. In this study, Clearfil SE bond adhesive system showed the highest bond strength 36 (16.7) MPa. It has been reported that self-etching primer adhesive systems produce high bond strength to normal dentin (Yoshiyawa & others, 1998, 1999; Pereira & others, 1999) theoretically due to simultaneous collagen fiber network exposure and monomer infiltration, which may create a sufficient retentive strength and an adequate seal. Whether this ideal can be achieved remains to be determined through long-term clinical trials.

The relative low bond strength obtained with OptiBond FL and Scotchbond Multi-Purpose groups may be due to incomplete removal of all water/solvent within the interdiffusion zone, possibly interfering with the polymerization of the resin. OptiBond FL, an intermediately filled adhesive resin layer (48% filled adhesive), had the lowest bond strength 23.9 (10.3) MPa in this study, in contrast with other laboratories' findings (Bouillaguet & others, 2001; Prati, Chersoni & Pashley, 1999; Wilder & others, 1998). This study is in general agreement with Tanumiharja, Burrow & Tyas (2000) who evaluated microtensile bond strength of several conventional and self-etching primer systems. They concluded that generally the self-etching priming systems had higher bond strengths than the other three-step adhesive systems. However, laboratory bond strength (Miyazaki & others, 1995), microleakage (Fortin & others, 1994) and clinical (Van Meerbeek & others, 1994; Alhadainy & Abdalla, 1996) studies all provided evidence for the theory that intermediately-filled adhesive resin system, by providing an elastic buffer zone, may be superior to unfilled systems.

Sano & others (1994; 1995a,b) reported the presence of nanometer-sized spaces that permitted silver nitrate to penetrate the resin-dentin interface. They explain that the porosity may be the result of an incomplete resin infiltration into the demineralized dentin, poor polymerization of the adhesive resin and the existence of low-molecular-weight oligomers that allow water to penetrate the bonded interface. According to the results of this study, Clearfil SE Bond presented low leakage penetration. It is presumed that no gap or voids exist since the resin infiltration into the collagen fibers occur simultaneously to the same depth of the demineralized dentin when self-etching primer adhesive system is used. The acidic conditioning of these self-etching primer systems dissolves the smear layer and incorporates it into the primers and the demineralized dentin (Nishida & others, 1993). Self-etching adhesive systems may efficiently penetrate both dry and wet dentin. This may explain why Clearfil SE demonstrated lower leakage penetration and the three-step adhesive system showed higher leakage penetration.

Interestingly, the main reasons that could contribute to high bond strength are similar to the reasons that may contribute to a low leakage penetration, that is, adequate penetration into the demineralized dentin, tolerance to dry and wet dentin substrates, residual solvent, extent of polymerization, gap and void formation. Intuitively, a relationship between bond strength and leakage is expected.

Previous studies suggest the importance of evaluating both tests using the same specimen to predict the clinical performance of dental adhesive systems. During this study several factors were not evaluated and could have led to different findings: variation in the dentin substrate, (location, degree of demineralization, wetness, amount of solid substrate, caries affected dentin; long-term storage, thermal stress, simulated occlusal loading or tooth flexure, simulated pulpal pressure, three-dimensional cavity preparations). No clear relationship between bond strength and marginal leakage was demonstrated under the condition of this study.

CONCLUSIONS

To date, no strong evidence exists demonstrating a reasonable relationship between these extremely common laboratory assessments of dental adhesive performance; however, the possibility that a relationship exists cannot be discounted. This study demonstrates the feasibility of measuring both nanoleakage and microtensile bond strength of dentin bonding systems in the same specimen. Future long-term studies should focus on developing these methods to better investigate this relationship.

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Effects of Er:YAG and Nd:YAP Laser Irradiation on the Surface Roughness and Free Surface Energy of Enamel and Dentin: An *In Vitro* Study

V Armengol • O Laboux • P Weiss
A Jean • H Hamel

Clinical Relevance

This study investigated the morphological changes and free surface energy of enamel and dentin following laser irradiation and their role in the resin-composite adhesion process.

SUMMARY

Sixty-seven extracted molars were selected (134 samples). Dentin and enamel samples were prepared by buccal and lingual surface sectioning to expose a planar enamel or dentin surface.

For the roughness study, 80 samples were randomly assigned to eight groups. Enamel and dentin surfaces were etched with a 37% phosphoric acid solution, irradiated with an Er:YAG laser or irradiated with a Nd:YAP laser. Samples were then observed in SEM using BSE.

For the free-surface energy study, 54 samples received the same treatment as above. Two contact angle measurements were made on each surface using a goniometer. Data were analyzed by a non-parametric statistical test.

Morphological changes on enamel and dentin were greater with acid-etch and Er:YAG laser than with Nd:YAP laser. Free surface energy was significantly greater with acid-etch or Er:YAG laser than with Nd:YAP laser ($p<0.001$).

*Valerie Armengol, DDS, PhD, Centre de Recherche sur les Matériaux d'Intérêt Biologique, Département d'Odontologie Conservatrice-Endodontie, France

O Laboux, DDS, PhD, Centre de Recherche sur les Matériaux d'Intérêt Biologique, Département d'Odontologie Conservatrice-Endodontie, France

P Weiss, DDS, PhD, Centre de Recherche sur les Matériaux d'Intérêt Biologique, Département d'Odontologie Conservatrice-Endodontie, France

A Jean, DDS, PhD, professor, Centre de Recherche sur les Matériaux d'Intérêt Biologique, Département Biomatériaux-Biophysique, France

H Hamel, DDS, professor, Centre de Recherche sur les Matériaux d'Intérêt Biologique, Département d'Odontologie Conservatrice-Endodontie, France

*Reprint request: UFR d'Odontologie, 1 Place Alexis Ricordeau, 44042 Nantes Cedex 01, France; e-mail: Valerie.Armengol@sante.univ-nantes.fr

INTRODUCTION

Lasers have been proposed for use in clinical dentistry since 1960, and several studies have investigated applications for removal of dental hard tissues prior to applying restorative materials. These studies showed that the effects of laser irradiation are dependent on wavelength specificity and energy density. As the laser energy absorbed by dental tissues produces surface modifications, it has been suggested that lasers could be used for the pretreatment of enamel and dentin to enhance the bonding of restorative adhesive material (Khan & others, 1998; Niu & others, 1998; Visuri & others, 1996).

During the bonding process, roughness and free surface energy play a key role by interacting with each other. The adhesion of composite materials depends on the adhesive's ability to spread on a surface, which is referred to as wettability. To improve wettability and

bonding, the free surface energy (or critical surface tension) of enamel and dentin must be increased, which involves using conditioners and primers (Attal, Asmussen & Degrange, 1994; Buonocore, 1955; Erickson, 1992; Pashley, 1990; Van Meerbeek & others, 1992). Surface topography also plays an important role. A more or less roughened surface is indicative of the degree to which mechanical anchorage is involved in the bonding process. Buonocore (1955) showed that acid-etch of enamel increases resin retention, that is, the micromechanical component is essential in adhesion to enamel. On dentin, acid-etch causes physicochemical changes in the surface conducive to micromechanical and possibly chemical attachment to a dentin bonding. The most effective approach appears to be the formation of a dentin-resin inter-diffusion zone or hybrid layer (Erickson, 1992; Pashley, 1990; Van Meerbeek & others, 1992).

Many studies, often with conflicting results, have evaluated the shear bond strength and microleakage of composite restorations on enamel and dentin surfaces treated by laser irradiation compared to acid-etch. However, no studies have yet assessed the roughness and free surface energy of lased enamel and dentin relative to the effects obtained in mechanical bond strength and microleakage studies.

This study determined the influence of surface roughness and free surface energy on the adhesion process and elucidated the results obtained in previous studies (Armengol & others, 1999; Armengol & others, 2002).

METHODS AND MATERIALS

Specimen Preparation

Sixty-seven freshly extracted, healthy (without caries and restoration-free) third molars were cleaned with a rotary brush and pumice, stored in a 1% aqueous solution of chloramine-T at 4°C for one week (decontamination), then stored in physiological serum at 4°C until experimentation (one to eight weeks).

The teeth were inserted into a resin block (self-curing methacrylate resin, Meliodent, Gema, ACD, Toulon, France) in a cubical aluminum mold 17 mm wide and 14 mm high (inner dimensions) leaving the upper portion of the crowns exposed. Lingual and buccal faces were as parallel as possible to the respective sides of the cube. The general axis of the tooth was parallel to the height of the block.

Specific sample preparation was performed on a bench that allowed reproducible positioning of samples and the handpiece. A standard flat, reproducible surface was produced on buccal and lingual faces using a cylindrical diamond bur on enamel (ref 837 KR 314 014, Komet Germany) and a cylindrical carbide bur on dentin (ref H 21 L 014, Komet Germany). These burs were used in clinical practice for cavity preparation. The teeth were then rinsed in a distilled water ultrasonic system for five minutes and stored in physiological serum at 37°C until treatment (24 hours).

For the laser treatment, only one set of irradiation parameters (Er:YAG = 200mJ and 4Hz on enamel, 140mJ and 4Hz on dentin; Nd:YAP = 310mJ and 10Hz on enamel, 240mJ and 10Hz on dentin) was chosen based on pilot data specifying the energies that would cause no discoloration, charring or cracks.

Roughness Study

Forty teeth were randomly distributed into eight groups. Groups 1, 2, 3 and 4 included 10 enamel surfaces, and Groups 5, 6, 7 and 8 included 10 dentin surfaces. Treatment for the groups was as follows:

Groups 1 and 5:

Samples were gently air dried and a 37% phosphoric acid gel (ref 60615208, Dentsply De Trey conditioner 36, France) was placed on the enamel and dentin surfaces for 30 seconds and 15 seconds, respectively. Samples were then thoroughly rinsed with water and air dried.

Groups 2 and 6:

Surfaces were irradiated by an Er:YAG laser (Key laser 1242, KaVo, Germany) at 200 mJ and 4 Hz on enamel and 140 mJ and 4 Hz on dentin for 12.5 seconds (50 pulses). Energy density was 83.16 J/cm^2 for enamel and 72.76 J/cm^2 for dentin. Laser irradiation scanned the surface with a perpendicular orientation at a focal distance of 10 mm. Irradiation was performed through a metallic matrix 0.5 mm thick with a central opening 3.5 mm in diameter.

Groups 3 and 7:

Surfaces were irradiated with an Nd:YAP (Lokki$_{Dt}$, France) at 310 mJ and 10 Hz on enamel and 240 mJ and 10 Hz on dentin for 12.5 seconds (100 pulses). Energy density was 322 J/cm^2 for enamel and 299.37 J/cm^2 for dentin. The irradiation laser was moved above the surface in contact mode and in tangential position for the optic fiber/surfaces with an angle of 45°C (fiber diameter=320 µm).

Groups 4 and 8:

These control samples received no acid-etch or laser treatment and were air dried.

All specimens were then prepared for scanning electron microscopy (SEM) studies (using back-scattered electrons: BSE; JEOL JSM 6300, 10kV, 15 mm, Japan) according to a standard technique: dehydration in increasing ethanol solutions, embedding in methylmethacrylate and sectioning in a bucco-lingual plane through the center of the treated surface using an Isomet low-speed diamond saw (Isomet, low-speed saw 11-1180, Buehler Ltd, Lake Bluff, IL 60049, USA). Specimens were polished successively with 600-, 1,200, 2,500- and 4,000-grit wet silicon-carbide sandpaper,

then rinsed copiously with water before being coated with gold-palladium.

Free Surface Energy Study

Twenty-seven teeth were randomly distributed into nine groups. Groups 1, 2, 3 and 4 included six enamel surfaces, and Groups 5, 6, 7, 8 and 9 included six dentin surfaces. Treatments for Groups 1 to 8 were the same as for the roughness evaluation.

In Group 9, dentin surfaces were acid-etched by a 37% phosphoric acid conditioner (Dentsply De Trey conditioner 36, ref 60615208) for 15 seconds, rinsed with water and air dried before the primer (Scotchbond MultiPurpose, 3M Dental Products, St Paul, MN 55144, USA) was applied with a clean brush and allowed to sit for 30 seconds.

Free surface energies were estimated from contact angle measurements (Center of Transfer Technology, CTTM, Le Mans, France).

Free surface energy (γ) possesses two components: one (γ^{LW}) is non-polar and refers to the apolar Lifshitz-Van der Waals forces often called "dispersive forces" and gives information mainly on hydrophobic interaction. The other (γ^{AB}) involves the polar interaction, acid-base interactions often called "non-dispersive forces" and refers to hydrophilic interactions.

$\gamma S = \gamma S^{LW} + \gamma S^{AB}$ where γS is free surface energy of solid

This study investigated the wettability of enamel and dentin by calculating their free surface energy after applying different treatments. The wettability of a surface depends on its free surface energy and is defined by the contact angle between the surface of the solid and the liquid. With appropriate liquids (polar and non-polar) and the contact angle measured, both components (dispersive and non-dispersive) of the free surface energy could be calculated.

This experimentation consisted of depositing drops of reference liquids on the different treated surfaces where free surface energy was known, then measuring the contact angles (θ represented the angle of the surface of the teeth with the tangent of the drop to the interface). The closer the contact angle was to zero, the better the wettability.

Distilled water was used as the reference polar liquid and diethyleneglycol and formamide served as the reference non-polar liquid. All contact angles were advancing, and direct measurements were conducted with a goniometer (Kyowa Contact Angle Meter, model CAS 150, Japan). Two measurements were performed for each surface and liquid and were processed by computer (with a software Young-Dupré/Owens-Wendt equation) to determine the free surface energy in mJ/m^2.

Data were analyzed using Bartlett's test for homogeneity of variance and a non-parametric statistical test (Kruskal-Wallis one-way analysis of variance).

RESULTS

Roughness Study

In the control groups, the enamel surfaces were smooth, with relief resulting from the burs (Figure 1). On dentin, the surfaces were also smooth and covered by a smear layer that obliterated the tubules (Figure 2).

Acid-etch enamel specimens were roughened, showing regular, perpendicular microporosities (1 to 2 µm and 10 to 20 µm in depth) (Figure 3). On dentin, phosphoric acid removed the smear layer and exposed the open tubules to a depth of 10 µm (Figure 4).

Er:YAG laser treatment caused alterations to a depth of 70 µm of the enamel surface (Figure 5). Surface profiles were irregular and had large anfractuosities. Some enamel projection debris remained on the surface, with cracking noted under rugosities. Dentin was similar in appearance but the irregularities were less marked. The volatilization of dentin differed in the irradiated surface areas (Figure 6).

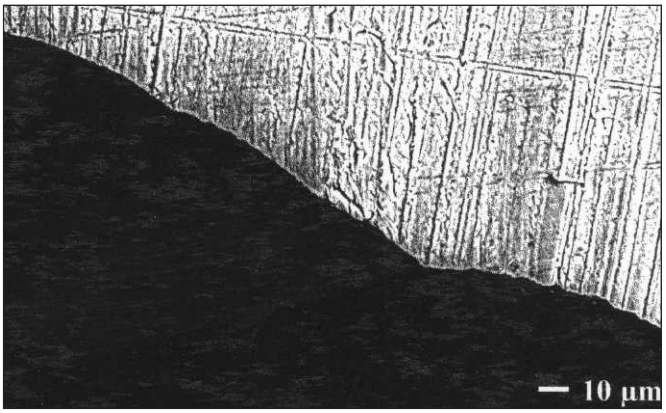

Figure 1: *Scanning electron micrograph of enamel treated with diamond bur (original magnification x500).*

Figure 2: *Scanning electron micrograph of dentin treated with carbide bur (original magnification x500).*

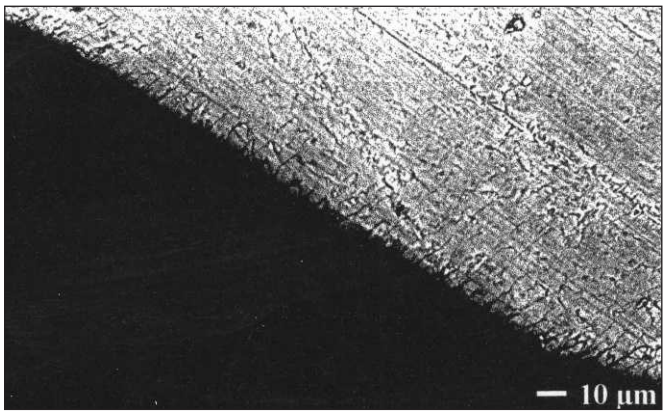

Figure 3: *Scanning electron micrograph of acid-etch enamel (original magnification x500).*

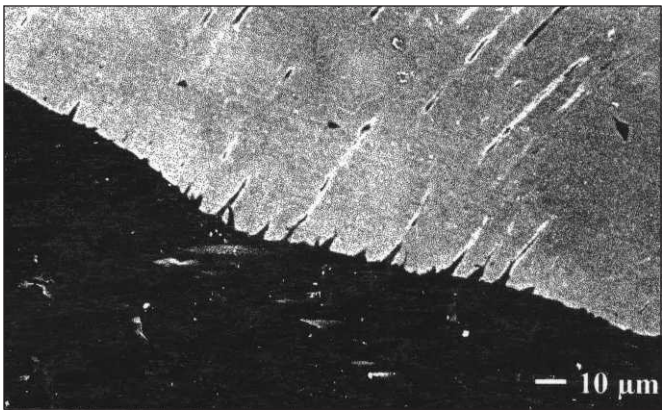

Figure 4: *Scanning electron micrograph of acid-etch dentin (original magnification x500).*

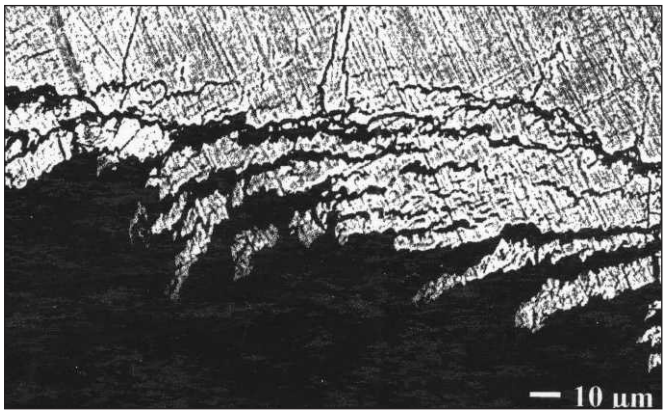

Figure 5: *Scanning electron micrograph of enamel treated with Er:YAG laser (original magnification x500).*

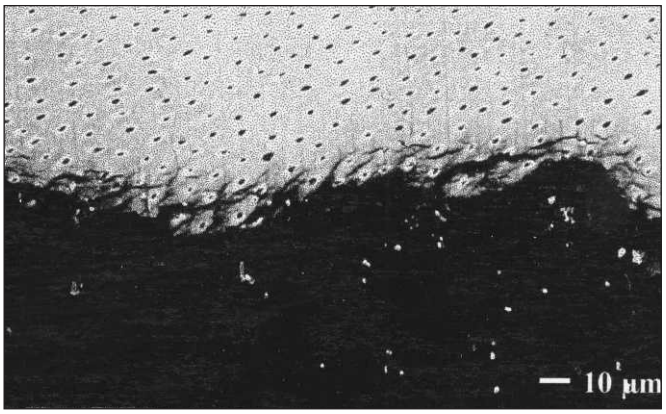

Figure 6: *Scanning electron micrograph of dentin treated with Er:YAG laser (original magnification x500).*

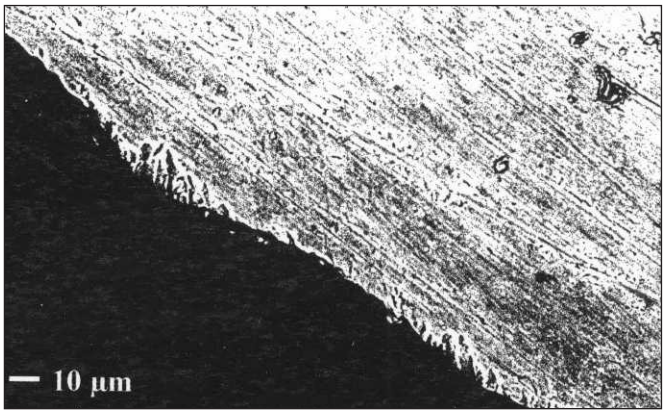

Figure 7: *Scanning electron micrograph of enamel treated with Nd:YAP laser (original magnification x500).*

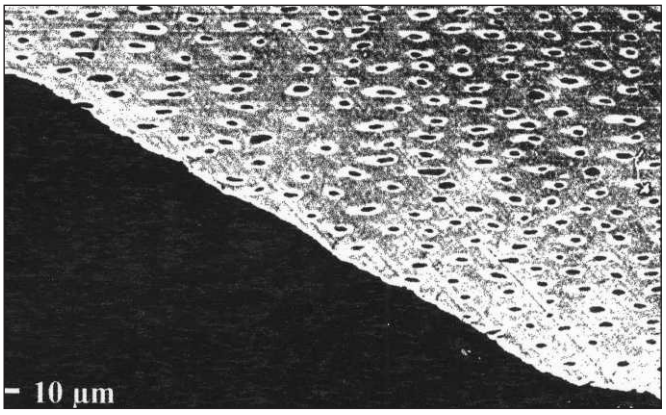

Figure 8: *Scanning electron micrograph of dentin treated with Nd:YAP laser (original magnification x500).*

Following Nd:YAP laser treatment, enamel surfaces showed a macrorelief similar to normal abraded enamel except for some cracking to a depth of 1 to 3 µm (Figure 7). Dentin surfaces were smooth, with a 1-µm thick, white line identified in back-scattered electron studies as a modification of dentinal chemical structure (Figure 8).

Free Surface Energy

Mean-free surface energy and standard deviations for each group are shown in Figures 9 and 10. Statistical analyses are indicated in Tables 1 and 2.

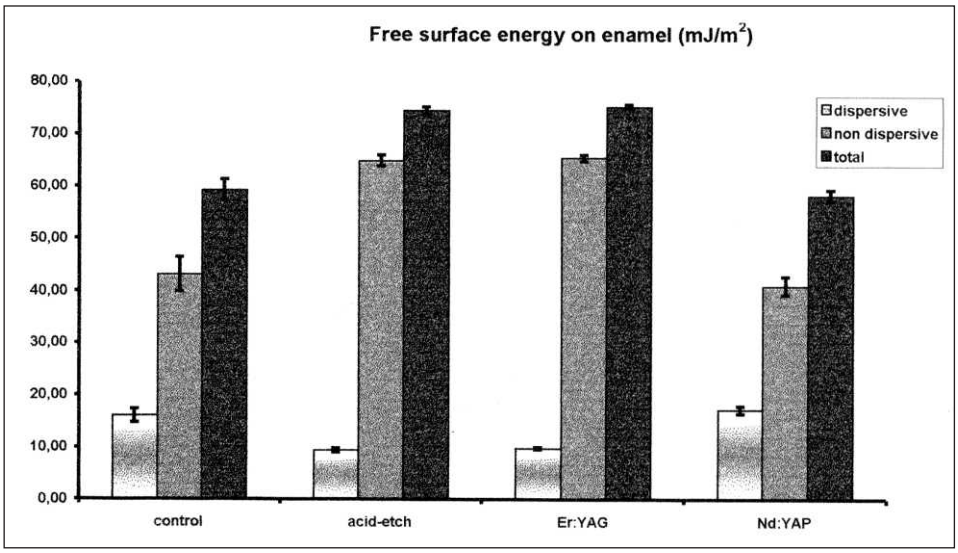

Figure 9: *Free surface energy on enamel (means and standard deviations).*

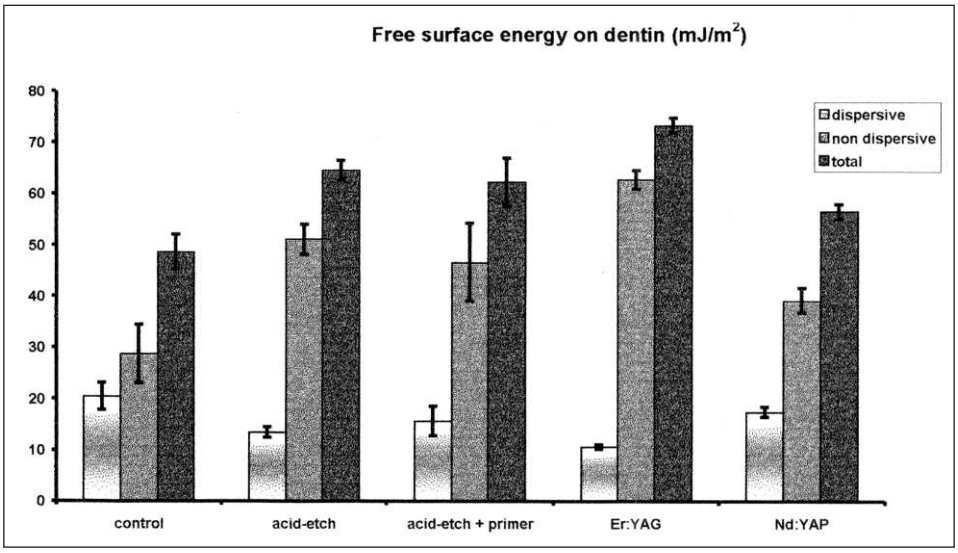

Figure 10: *Free surface energy on dentin (means and standard deviations).*

Enamel Surfaces

For enamel groups, free surface energy values were very high and standard deviations were relatively low, corresponding to homogeneous surfaces. The main component of the surface energy appeared to be polar, corresponding to hydrophilic interactions.

The highest free surface energy was obtained following Er:YAG laser- and acid-etch treatment, and the difference was significant from other groups ($p<0.05$). Nd:YAP laser-treated enamel had a free energy surface similar to control enamel ($p>0.05$).

Dentin Surfaces

The hydrophilic component of free surface energy was greater than the hydrophobic component with or without treatment. The different treatments involved a decrease in dispersive energy and an increase in non-dispersive energy. Total surface energy was significantly increased in all treatment groups compared to the control group ($p<0.05$), thus, enhancing surface wettability. Er:YAG laser treatment resulted in the greatest increase in surface energy, followed by acid-etch, acid-etch/primer and Nd:YAP laser. No significant difference was found between acid-etch and acid-etch/primer treatment ($p>0.05$).

DISCUSSION

Different factors influence the adhesion of resin-composite to dental tissues, namely, surface energy and wettability, roughness of the dental surface and adhesive viscosity. Wettability is essential for good bonding of an adhesive on a surface. Benedicktsson & others (1991) found that an increase in critical surface tension or free surface energy of enamel and dentin with an enamel-dentin bonding system (use of a surface conditioner such as acid and primer) resulted in an increase in shear bond strength. The extent to which a liquid wets the enamel or dentin surface depends on the chemical interactions between the liquid and the surface, physical considerations such as capillary action on dentin and surface roughness. However, it seems necessary to increase these energies, that is, to activate enamel and dentin to enhance surface wettability and optimize adhesion.

The free surface energy of enamel and dentin following Er:YAG or Nd:YAP laser treatment versus acid-etch was evaluated by measuring the contact angles of three standard liquids. The superficial tension of the adhesive was not determined, which would have required the use of a larger quantity than was provided by 3M Dental Products (St Paul, MN 55144, USA).

The free surface energies obtained in the control and acid-etch groups during this study's experimentation were higher than those reported in the literature (Attal & others, 1994; Cognard, 1987). These differences may have resulted from various experimental conditions: acid-etch time, the different reference liquids used and

the conservation time between processing and measurements of the contact angle (which should be short to avoid atmospheric contamination and a resulting reduction in free energy surface). The energy differences observed between enamel and dentin could have resulted from the difference in mineral and organic content. Hydroxyapatite has high energy and shows considerable reactivity.

Laser irradiation had an influence on the polar and dispersive components of free surface energy of enamel and dentin. Er:YAG laser irradiation significantly increased free surface energy on enamel and dentin compared to the untreated group, with values being similar to those obtained after acid-etch. However, Nd:YAP laser induced little or no change in free surface energy on either substrate. Previous studies have also indicated that laser treatment modifies free surface energy. Walsh (1996) suggested that laser irradiation on enamel produced physicochemical modifications that influenced surface energy and wettability, decreasing tissue humidity by dehydration due to the thermal effect of laser irradiation. Rohanizadeh, Jean & Daculsi (1999) showed that laser irradiation on dentin induces physicochemical changes, particularly in organic and aqueous components that can also influence the topography and surface energy.

Regarding surface roughness, the adhesion of resin-composite has clearly been established as depending on surface topography, that is, greater or lesser roughness affects the degree of mechanical anchorage. Roughness studies provide a good estimation of the developed surface of the substrate and, therefore, the contact area with adhesive (Degrange, Attal & Theimer, 1994). Roughness can be assessed in different ways: macroscopic observation, SEM studies, use of a profilometer, digital texture analyses based on computer scanning imagery and more (Arcoria & others, 1991; Arcoria, Lippas & Vitasek, 1993; Ariyaratnam & others, 1997; Ariyaratnam, Wilson & Blinkhorn, 1999; Degrange & others, 1994).

According to some authors, laser etching produces a qualitatively different surface profile and roughness significantly different from untreated enamel and dentin. Laser ablation produces a variety of surface alterations and transformations ranging from a slightly roughened surface without cracks or fissures to a highly roughened terraced or tiered surface with occasional cracks. The enamel surface alterations with Er:YAG laser in this study were morphologically similar to those obtained after acid-etch and agree with the authors' findings in a previous study (Armengol & others, 1999; Armengol & others, 1999). Some studies on enamel have reported a higher surface roughness after acid-etch than Nd:YAG laser or coaxial CO_2/Nd:YAG laser treatment (Arcoria & others, 1991; Arcoria & others, 1993). Other studies (Ariyaratnam & others, 1997; Ariyaratnam & others, 1999) found that Nd:YAG laser produced a roughened surface on enamel and dentin similar to that of acid-etch. However, despite these similar values, bonding of resin composite to laser-treated enamel or dentin was significantly poorer than to acid-etched tissues.

This study's SEM observations showed that the surface roughness of Er:YAG-lased enamel and dentin was greater than that of untreated and acid-etched specimens, whereas irregularities following Nd:YAP laser irradiation were very limited on both enamel and dentin.

This study's results elucidate and confirm the hypothesis concerning shear bond strength and microleakage values obtained in previous studies (Armengol & others, 1999; Armengol & others, 2002). Er:YAG laser induced the greatest increase in surface roughness and free surface energy on enamel and dentin. The bonding process should therefore have been as effective as, if not better than, that of acid-etch, which was not the case. These differences may be due to the surface topography. On enamel, acid-etch induced the dissolution of hydroxyapatite inter- or intraprismatic substance, resulting in regular microporosities that increased the surface area and surface energy. On dentin, acid-etch removed the smear layer completely, opened tubules and demineralized the surface layer to a certain depth.

Table 1: *Statistical Test (Kruskal-Wallis) for Free Surface Energy on Enamel*

	Control	**Acid-Etch**	**Er:YAG**	**Nd:YAP**
Control		*p*=0.009	*p*=0.0022	**NS *p*=0.465**
Acid-etch	*p*=0.009		*p*=0.017	*p*=0.009
Er :YAG	*p*=0.0022	*p*=0.017		*p*=0.0022
Nd :YAP	**NS *p*=0.465**	*p*=0.009	*p*=0.0022	

Table 2: *Statistical Test (Kruskal-Wallis) for Free Surface Energy on Dentin*

	Control	**Acid-Etch**	**Acid-Etch + Primer**	**Er:YAG**	**Nd:YAP**
Control		*p*=0.009	*p*=0.009	*p*=0.0022	*p*=0.009
Acid-Etch	*p*=0.009		**NS *p*=0.464**	*p*=0.0022	*p*=0.009
Acid + Primer	*p*=0.009	**NS *p*=0.464**		*p*=0.0022	*p*=0.0163
Er:YAG	*p*=0.0022	*p*=0.0022	*p*=0.0022		*p*=0.0022
Nd:YAP	*p*=0.009	*p*=0.009	*p*=0.0163	*p*=0.0022	

Subsequent application of effective primers containing hydrophilic monomers probably altered the collagen-fiber arrangement, elasticity and wettability, allowing for better penetration of the adhesive resin. Formation of a hybrid or resin-infiltrated layer between the deeper dentin structures and filling material has been clearly established as being the most effective approach for achieving better bonding. This transition layer offers bonding sites for copolymerization with the resin composite restorative material due to the presence of suitable monomers inside the interdiffusion area (Attal & others, 1994; Erickson, 1992; Van Meerbeek & others, 1992). This layer may also have a protective potential because it blocks the normal passage of microorganisms and toxins (Van Meerbeek & others, 1992) and allows for a micromechanical interlocking effect.

Surface morphology following Er:YAG laser treatment showed highly roughened enamel and dentin, with considerable relief. SEM showed evidence of cracks and fissures. The formation of microcracks, fissures or chipped surfaces may occur because of rapid thermal cycling of the surface during pulsed laser irradiation (Ariyaratnam & others, 1997). There was no continuity between relief features or anfractuosities and underlying areas, and these elements probably weakened the surface layer. Moreover, as Er:YAG laser removed all organic components, formation of a hybrid or resin-impregnated dentin layer was not possible. The penetration of resin tags into dentinal tubules contributes only slightly to overall dentin bond strength. The involvement of intertubular dentin was, in fact, the major element in bond stability that agreed with findings in other studies (Pashley, 1990; Tagami, Tao & Pashley, 1990). Although the wettability of a surface improves its adhesive characteristics, surface topography and roughness are probably the most important factors in the adhesion process.

Nd:YAP laser treatment has little influence on free surface energy compared to other treatments and, therefore, does not enhance wettability. The adhesive cannot spread adequately on enamel and dentin and does not penetrate irregularities. Nd:YAP laser also produces a slightly roughened surface on enamel and dentin. The surface is covered by a thin, smooth, fused, glaze-like surface layer. In fact, ND:YAP laser produces superficial modifications that destroy the normal architecture. Once the collagen has disappeared, the formation of a hybrid layer is not possible. The low, free surface energy and poor retention induced by the Nd:YAP laser accounts for the very weak shear bond strength and sealing.

CONCLUSIONS

In summary, Er:YAG laser treatment increased free surface energy and roughness surface, whereas, Nd:YAP laser had little influence on the free surface energy and roughness surface.

And, if these results are correlated to those of the previous studies (Armengol & others, 1999; Armengol & others, 2002), this study revealed two important points: an increase in free energy surface does not always lead to an increase in shear bond strength and efficient sealing. It facilitates the spread of adhesive on tooth tissues and intimate contact between adhesive and tissues. This was the case for Er:YAG laser treatment. However, micromechanical interlocking should be regarded as the main component in the adhesion process. Also, Er:YAG and Nd:YAP lasers, operated under the conditions described in this study, may not produce a desirable enamel and dentin surface morphology and cannot be recommended as a viable alternative to the conventional acid-etch technique.

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Effects of Cavity Size on Apoptosis-Induction During Pulp Wound Healing

C Kitamura • Y Ogawa
T Morotomi • M Terashita

Clinical Relevance

The over-induction of pulpal apoptosis may lead to irreversible pulpal reaction by severe cavity preparation.

SUMMARY

The effects of mechanical stress on apoptosis induction during pulp wound healing were examined. Mechanical stress cavities of two different sizes were prepared on individual rat molars, one twice the size of the other in the occlusocervical direction. The authors compared the distribution pattern and number of apoptotic cells of the two groups by terminal deoxynucleotidyl transferase-mediated labeling assay. At one hour and one day, significant differences were observed in the distribution patterns and number of apoptotic cells between the single-size and double-size group. Four days after injury, apoptosis still existed on pulp cells in the double-size group but not in the single-size group. At 14 days, no difference in the number of apoptotic cells between the two groups was observed. These results suggest that the magnitude of mechanical stress, such as cavity preparation, may modulate the induction of apoptosis during pulp wound healing.

*Chiaki Kitamura, DDS, PhD, assistant professor, Department of Operative Dentistry, Kyushu Dental College, Japan

Yukio Ogawa, DDS, postgraduate student, Department of Operative Dentistry, Kyushu Dental College, Japan

Takahiko Morotomi, DDS, PhD, assistant professor, Department of Operative Dentistry, Kyushu Dental College, Japan

Masamichi Terashita, DDS, PhD, professor and chair, Department of Operative Dentistry, Kyushu Dental College, Japan

*Reprint request: 2-6-1 Manazuru, Kokurakita, Kitakyushu 803-8580, Japan; e-mail: chi-aki-k@kyu-dent.ac.jp

INTRODUCTION

Wound healing of dental pulp after caries progression and cavity preparation involves odontoblast survival, differentiation of pulp cells to odontoblast-like cells and the cell-death process of damaged odontoblasts and pulp cells. Odontoblast survival results in reactionary dentinogenesis have been established in humans and other animals (Smith & others, 1995; Bjørndal, Darvann & Thylstrup, 1998; Smith, Tobias & Murray, 2001; About & others, 2001a), and the recruitment of odontoblast-like cells results in reparative dentinogenesis (Ohshima, 1990; Tziafas, 1995; Mitsiadis, Fried & Goridis, 1999). The area and volume of reactionary and reparative dentin formation are dependent on the magnitude of mechanical stress, such as cavity preparation (Lee, Walton & Osborne, 1992; Murray & others, 2000). On the other hand, the aspect of cell death has been previously studied. Several parameters are indicated as steps toward cell necrosis after caries progression and cavity preparation, which include the calciotraumatic line and the aspiration of odontoblasts after acute injuries (Brännström, 1968; Trowbridge, 1981; Mjör, 2001).

Apoptosis, one type of cell death, is distinct from necrosis and is recognized by morphological criteria such as cell shrinkage, nuclear chromatin condensation, the formation of apoptotic bodies and the rapid removal of apoptotic cells by scavenger cells (Earnshaw, 1995; Kerr & others, 1995). The hallmark of apoptosis is enzymatic splicing of DNA that can be visualized in tissue sections by using various methods, including terminal deoxynucleotidyl transferase-mediated labeling assay. The apoptotic regulation of damaged odontoblasts and pulp cells was noted in some reports (Bronckers & others, 1996; Vermelin & others, 1996). Recently, the authors reported that two waves of apoptosis were induced on dental pulp as one of the cell death regulation processes during wound healing (Kitamura & others, 2001 accepted). This apoptotic phenomenon consists of the primary apoptosis induced on odontoblasts and the secondary apoptosis induced on subodontoblastic pulp cells. Previously, the relationship between cavity size and pulpal inflammatory responses was suggested (About & others, 2001b). However, it is not clear whether inducing apoptosis is affected by the magnitude of mechanical stress and whether this apoptotic phenomenon is associated with the pulpal reaction against severe stress.

In this study, cavities of different sizes were prepared on rat molars, and their distribution pattern and number of apoptotic cells was compared between two different cavity size groups during pulp wound healing.

METHODS AND MATERIALS

Preparation of Cavities on Rat Molars

The animal protocol followed the guidelines for animal care of Kyushu Dental College and ethical approval was obtained from the institutional panel for animal care of Kyushu Dental College.

Twelve Wistar-specific pathogen free rats (nine weeks old) weighing 250-350 g were cared for and used under barrier system conditions. Under this controlled condition, the rats were deeply anesthetized by intraperitoneal injection of 5% pentobarbital sodium (Nembutal, Dainippon Pharmaceutical Co, Suita, 564, Japan) at a dose of 30 mg/kg. Two different sizes of Class V cavities were prepared on the mesial aspects of maxillary bilateral first molars with a #1/2 round bur under water-cooling. One cavity was prepared into approximately half the thickness of dentin and the occlusocervical length of the cavity matched the diameter of the #1/2 round bur (single-size group). The other cavity was prepared at the same depth as the single size but the occlusocervical length was twice (double-size group). To avoid the effects of materials on the pulp wound healing process in this study, the cavities were not filled with materials and the rats were cared for under the barrier system condition until they were sacrificed. Postoperative intervals of sacrifice were one hour, and one, four and 14 days, based on the results of previous investigations (Taylor & Byers, 1990; D'Souza & others, 1995). The authors used three individual molars for the each cavity size in each interval. After each interval, the rats were anesthetized using the above method and killed by transcardial vital perfusion with 4% paraformaldehyde-phosphate buffer, pH 7.3 (4% PFA). The maxillary segments, including first molars, were carefully dissected and immersed in 4% PFA at 4°C overnight for further fixation. The first molars dissected from maxillary segments were then demineralized in 10% EDTA-phosphate buffered saline (1xPBS), pH 7.3 at 4°C.

Terminal Deoxynucleotidyl Transferase-Mediated Labeling (TUNEL) Assay

The demineralized molars were dehydrated with graded ethanol and embedded in paraffin. Serial 5 µm-sections were cut and mounted on three aminopropyltriethoxysilane-treated object slides. To indicate two different cavity sizes, one section from each group was stained with hematoxylin and eosin. After deparaffinization and dehydration, sections were subjected to terminal deoxynucleotidyl transferase-mediated labeling (TUNEL) assay using "*In Situ* Cell Death Detection Kit, Fluorescein" (Roche Molecular Biochemicals, D-68298, Mannheim, Germany) according to the manufacturers' instructions. Sections were treated with proteinase K (20 µg/ml) for 15 minutes at 37°C, washed with 1xPBS and incubated with 100 µl of terminal deoxynucleotidyl transferase (TdT) mixture that consisted of 5 µl of TdT, 45 µl of TdT buffer containing fluorescein-labeled nucleotide mixture and 50 µl of 10% bovine serum albumin for one hour at 37°C. The sections were then rinsed with 1x PBS, and observed under fluorescence microscopy.

Statistical Analysis of the Number of Apoptotic Cells

Two serial sections were selected, including the deepest area of cavities from each molar (six sections for each

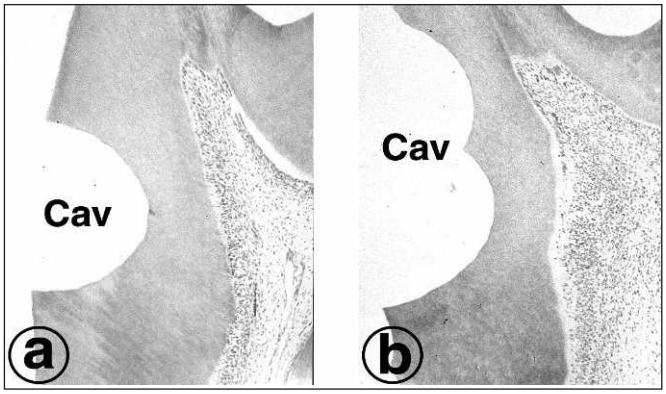

Figure 1: *Preparation of two different cavity sizes on rat molars. The diameter of the single-size cavity (a) was same as that of the #1/2 round bur. The occlusocervical length of the double-size cavity (b) was almost twice the diameter of the round bur (magnification x100). Cav, cavity.*

group) and used for semi-quantitative analysis. After counting TUNEL-positive cells under the cavity in each section, all data were compared using Student's *t*-tests.

RESULTS

Figure 1 shows representative sections from the single-size groups and the double-size groups. TUNEL assay was implemented on each group from each time interval. Figures 2 to 5 show representative distribution patterns of apoptotic cells in all groups. One hour after injury, apoptotic odontoblasts were detected in contact with dentin underneath cavities both in the single and the double-size group (Figure 2). Some apoptotic odontoblasts appeared to be located within the injured dentin in both groups. The distribution pattern of apoptotic odontoblasts in the double-sized group more broadly spread toward the occlusocervical direction than the single-size group. One day after injury, apoptotic pulp cells were detected in the mesiocoronal pulp area in both groups (Figure 3). In the single-size group, the distribution of apoptotic cells was limited to the subodontoblastic area underneath the cavity. In contrast, apoptotic cells in the double-size group broadly spread from the mesiocoronal area to the center of the coronal pulp and the upper area of the mesial root pulp. Four days after injury, prolongation of the apoptosis-induction was observed in the double-size group but most apoptotic pulp cells were absent in the single-size group (Figure 4). After 14 days, apoptotic pulp cells markedly decreased in both groups (Figure 5). Only a few apoptotic cells in the double-size group were detected.

The authors counted the apoptotic cells in each group and examined differences in the number of apoptotic cells between the two groups. Figure 6 shows the statistical data of the number of apoptotic cells in each group at each time interval. In one hour, one day and four days,

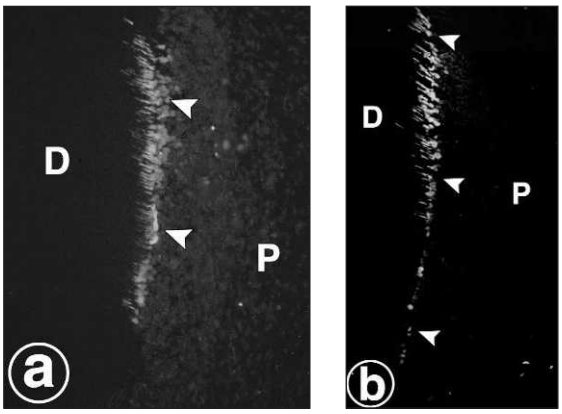

Figure 2. *One hour after cavity preparation. Apoptotic odontoblasts in the double-size group (b) more broadly spread in the occlusocervical direction than those in the single-size group (a). Arrowheads indicate representative apoptotic odontoblasts (magnification x200). D, dentin; P, pulp.*

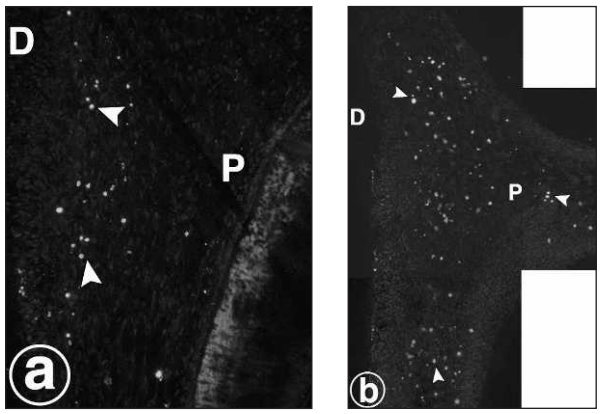

Figure 3. *One day after cavity preparation. Apoptotic pulp cells in the double-size group (b) broadly spread in mesiocoronal pulp compared with the single-size group (a). Arrowheads indicate representative apoptotic pulp cells (magnification x200). D, dentin; P, pulp.*

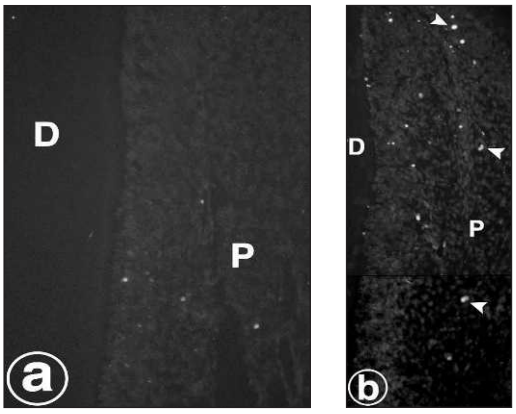

Figure 4. *Four days after cavity preparation. Apoptosis were still induced on pulp cells in the double-size group (b), almost none in the single-size group (a). Arrowheads in (b) indicate representative apoptotic pulp cells (magnification x200). D, dentin; P, pulp.*

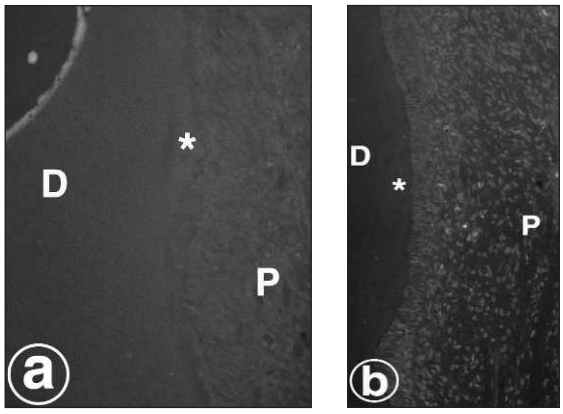

Figure 5. *Fourteen days after cavity preparation. Few apoptotic cells were detected in both the single-size groups (a) and the double-size group (b) (magnification x200). D, dentin; P, pulp; *, reparative dentin.*

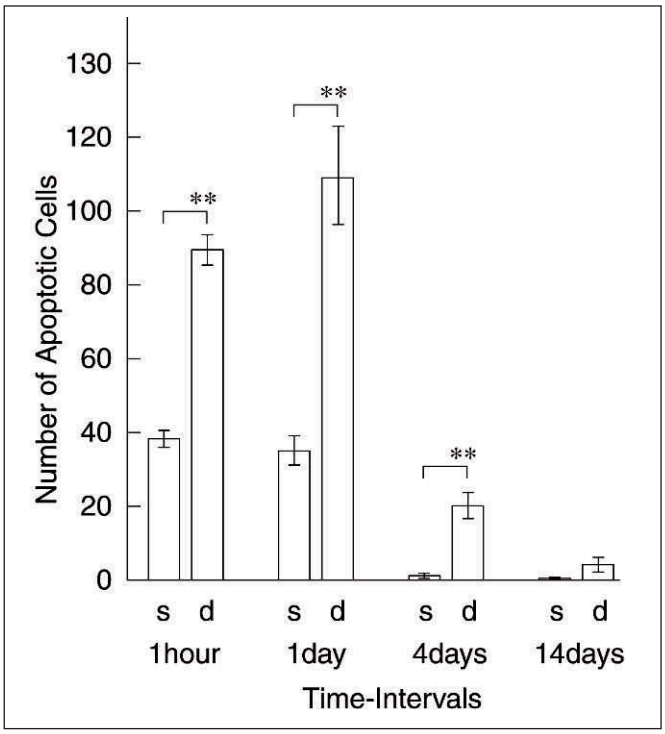

Figure 6: *Statistical comparison of the number of apoptotic cells between the single-size group and the double-size group in each time interval. One hour, one day and four days after injury, the number of apoptotic cells in the double-size group was significantly larger than the single-size group. No significant difference was observed between the double-size group and the single-size group. s, single-size group; d, double-size group. ** Significance of difference,* p*<0.01.*

there were significant differences in the number of apoptotic cells between the single and double-size group. The number of apoptotic cells in the double-size group was significantly larger than the single-size group ($p<0.01$). Fourteen days after injury, however, there was no statistical difference in the number of apoptotic cells between the two groups.

DISCUSSION

The effect of mechanical stress on the apoptosis induction during pulp wound healing was examined. As the mechanical stress, the authors prepared two different sized cavities (single-size and double-size) on sound rat molars in the burrier system condition to minimize other effects. Primary-induced apoptotic odontoblasts distributed according to cavity size and the number of apoptotic odontoblasts was significantly larger in the double-size group than in the single-size group. These results suggest that the primary-induction of apoptosis on odontoblasts may directly depend on the size of the injured dentin area. The localization of some apoptotic odontoblasts within the injured dentin also suggests that the aspiration of odontoblasts into dentin by the cavity preparation procedure may be a factor that induced primary apoptosis on odontoblasts. Induction of secondary apoptosis more broadly spread and prolonged in the double-size group than in the single-size group. These findings reveal that secondary apoptosis induced on pulp cells is affected by the magnitude of mechanical stress. Apoptosis plays an essential role in controlling various biological systems, including homeostasis in several diseases (Jacobson, Weil & Raff, 1997; Willingham, 1999). The increment of apoptosis induction by severe stress raises the potential role of apoptosis in maintaining pulpal homeostasis against the increment of stress. The enhancement and prolongation of apoptosis induction by severe stress also raises the possibility that over-induction of two waves of apoptosis by over-cutting may result in disruption of the pulpal homeostasis and can lead to irreversible pulpal reaction. In this study, nearly apoptotic cells of both groups were eliminated 14 days after injury, indicating that dental pulp has a tolerance or can recover from the damage inflicted.

Recently, chemical stress, such as capping agents that affects the induction of apoptosis during pulp wound healing, has been indicated (Kitamura & others, 2001 accepted). Based on previous data and current results, the authors suggest that two waves of apoptosis induced on odontoblasts and pulp cells during wound healing may be modulated from mechanical and chemical stress.

CONCLUSIONS

The primary-induction of apoptosis on odontoblasts is dependent on the size of the injured dentin area. The secondary apoptosis induced on pulp cells is affected by the magnitude of mechanical stress. Taken together, double-sized cavities have more significantly enhanced and prolonged the induction of pulpal apoptosis during wound healing compared to single-size cavities. These results suggest that the increased induction of pulpal apoptosis may be a response that leads to irreversible pulpal reaction after the extensive cutting of the dentin/pulp complex.

Acknowledgements

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The Effect of Placement of Glass Fibers and Aramid Fibers on the Fracture Resistance of Provisional Restorative Materials

G Saygili • SM Sahmali • F Demirel

Clinical Relevance

The effectiveness of glass-fiber reinforcement is most evident in interim long-span fixed partial dentures. The resins used in this study showed superior fracture resistance.

SUMMARY

The fracture resistance of provisional restorations is an important concern for the restorative dentist. The fracture resistance of a material is directly related to its transverse strength. Six specimens of similar dimensions were prepared from three resins (PMMA, PEMA and BIS acryl-composite). The resins were reinforced with glass and aramid fibers. The samples were tested immediately after the material set, following seven days of wet storage using three-point compression loading. The results were analyzed with an analysis of variance (ANOVA). Fracture resistance of the specimens was statistically different ($p<0.001$) among the materials. Specimens reinforced with glass fibers showed higher transverse strength (149.82 MPa). The fiber reinforcement of resin materials increased the strength values (20-50%). Within the limitations of this study, the transverse strengths of PMMA, PEMA and BIS acryl-resin composites were improved after reinforcement with glass and aramid fibers.

*Gülbin Saygili, DDS, PhD, associate professor, Department of Prosthodontics, Hacettepe University, Faculty of Dentistry, Ankara, Turkey

Sevil M Sahmali, DDS, PhD, associate professor, Department of Prosthodontics, Hacettepe University, Faculty of Dentistry, Ankara, Turkey

Figen Demirel, DDS, PhD, associate professor, Department of Prosthodontics, Hacettepe University, Faculty of Dentistry, Ankara, Turkey

*Reprint request: Hacettepe Üniversitesi, Dishekimligi Fakültesi, Protetik Dis Tedavisi ABD, 06100 Ankara–Türkiye; e-mail: sahmali@isbank.net.tr

INTRODUCTION

Provisional restoration is an important stage of therapy prior to placing final fixed prostheses (Amsterdam & Fox, 1959; Shillingburg, Hobo & Whitsett, 1997; Powell & others, 1994).

These prostheses are made indirectly in a dental laboratory. Several days or weeks are usually required for completion. During this period, the patient must wear a provisional restoration that provides pulpal protection, positional stability, maintenance of occlusal function, ease of cleansability, strength, retention and esthetics for the prepared teeth (Shillingburg & others, 1997; Powell & others, 1994; Larson & others, 1991; Hazelton & Brudvik, 1995). A catastrophic fracture could necessitate lengthy chairtime for repair or replacement (Shillingburg & others, 1997). Hence, structural reinforcement is desirable if it can prolong clinical life expectancy.

Tooth-colored acrylic resin is the material of choice for the provisional coverage of teeth that have been pre-

pared for fixed prosthodontic restorations. Acrylic resin is convenient to use and provisional restorations can be made by a variety of techniques (Sotera, 1973; Frederick, 1975; Preston, 1976; Kaiser, 1978; Kaiser & Cavazos, Jr, 1985; Koumjian & Nimmo, 1990). Polymers used in interim fixed partial dentures (FPDs) are often based on poly(methyl methacrylate) (PMMA), poly (ethyl methacrylate) (PEMA) or n-poly (butyl methacrylate) (PBMA). However, some alternative resins have been used for provisional restorations. Two alternatives include visible light-cured microfilled resin composites (Wood, Halpern & Lamb, 1984) and urethane dimethacrylate resin (Koumjian & Nimmo, 1990; Haddix, 1988).

In long-span restorations, strength is a critical property. When masticatory forces are applied to a long-span provisional restoration, fracture of the restoration is more likely than with a short-span restoration (Koumjian & Nimmo, 1990).

Different types of fibers have been added to polymer materials to improve their mechanical properties. Orthopedic acrylic resin-based bone cements have successfully been reinforced with glass, carbon and aramid fibers (Vallittu, Lassila & Lappalainen, 1994). In periodontics, glass fibers have been tested as additives to BIS-GMA resin in temporary splints to immobilize teeth (Friskopp & Blomlöf, 1984). In orthodontics, the use of aramid fibers has been found to be useful in reinforcing orthodontic appliances (Mullarky, 1985).

In prosthodontics, fibers have been used to improve the fracture resistance or the moduli of elasticity of polymer materials. Glass fibers have been studied as a strengthening material added to polymethyl methacrylate, and carbon fibers have been used to reinforce prosthodontic restorations (Vallittu & Lassila, 1992; Solnit, 1991). The usefulness of glass fiber rovings as strengtheners of dental resins has been established (Vallittu & Lassila, 1992; Friskopp & Blomlöf, 1984).

This study compared the effect of polyaramid fibers (Kevlar) and glass fibers (E-glass) on the fracture resistance of three provisional resin materials.

METHODS AND MATERIALS

A stainless steel mold was used to make resin specimens measuring 65 x 10 x 3 mm. Six specimens each were made from a poly (methylmethacrylate) resin, a poly (ethylmethacrylate) resin and BIS-acryl resin composite. The provisional resin materials used are listed in Table 1 and include the product names and manufacturers.

During a pilot study, a 2.0:1.2 polymer to monomer ratio provided the best viscosity during stainless steel mold placement for the Dentalon Plus acrylic resin (Heraus Kulzer, Gmbh, 61273, Wehrheim, Germany). A 2.5:1 ratio was found to be appropriate for Jet acrylic resin (Lang Dental Mfg Co, Wheeling, IL 60090, USA) and a 1:1 catalyst paste to base material was best for Protemp (ESPE Premiere, Norristown, PA 19404, USA). These ratios were used throughout this investigation. Each acrylic resin was prepared by the same investigator and placed in the mold.

To improve adhesion, the surface of the fibers used were coated with the silane solution Silicer (Heraeus Kulzer GmbH 961273, Wehrheim, Germany) by dipping the glass and aramid fiber roving in a silane solution (Valittu & others, 1994).

The fibers were air dried for 20 minutes, then dipped into a methacrylate monomer. The fibers were added to the mixture when the mold was two-thirds full. The remainder of the mold was then filled, covered and allowed to polymerize under 20 psi pressure for 10 minutes. All the fibers studied were used in roving (continuous) form. The glass fibers used were E-glass (Ahlstrom, 48810 Karhula, Finland) and the aramid fibers were Kevlar (DuPont, Wilmington, DE 19898, USA). Each group consisted of six specimens. All of the fibers were placed longitudinal to the specimen and perpendicular to the loading force. The size of the specimens was measured by micrometer (NSK Max-cal, Japan Micrometer Co, 541 Osaka, Japan). Grinding the specimens to the predetermined dimensions eliminated differences in the dimensions of the test specimens used. The control group had no reinforcement. Specimens used in the first group were tested immediately after the specimens set. The second group was tested after seven days of storage in water at 37°C.

Each specimen was loaded with an Instron Testing Machine (Instron Corp, Canton, MA 02021, USA) with a crosshead speed of 0.5 cm per minute. The specimens were supported by two stainless steel rods 8 mm in diameter and 50 mm apart. The force applied to fracture the specimens was diagrammed (Figure 1).

The fracture resistance of resins is related to their transverse strength. The transverse strength of each sample was calculated using the formula (Koumjian & Nimmo, 1990):

Table 1: *Technical Profiles of the Resin-Modified Glass Ionomer Cements Investigated*

Product	Content	Manufacturer
Dentalon Plus	Polyethylmethacrylate	Heraus Kulzer GmbH, 61273, Wehrheim Germany
Jet	Polymethylmethacrylate	Lang Dental Mfg Co, Wheeling, IL 60090, USA
Protemp	BIS-acryl resin composite	ESPE Premiere, Norristown, PA 19404, USA
Kevlar	Polyaramid fiber	Du Pont, Wilmington, DE 19898, USA
E-glass	Glass fiber	Ahlstrom Corp, 48810, Karhula Finland
Silicer	Silane – solution	Heraus Kulzer GmbH 961273, Wehiheim-Germany

$$S = \frac{3PI}{2bd^2}$$

P: fracture load
I: distance between the supports
b: width of the specimen
d: thickness of the specimen

The mean values of the transverse strength and standard deviations were calculated and compared between the groups with analysis of variance (ANOVA).

The Newman-Keuls Multiple-Comparison test revealed significant differences between the means of the fracture load values ($p<0.001$).

RESULTS

ANOVA showed statistically significant effects for the variables in Table 2.

The materials tested, and the mean values and standard deviations of transverse strength for time and treatment groups and their interactions with each other are shown in Tables 3-6.

The Newman-Keuls Multiple Comparison test was performed, revealing significant differences ($p<0.001$) among the materials, time and treatment groups (Table 7).

Jet acrylic resin with glass fibers exhibited a significantly higher mean transverse strength (127.06 MPa) than the other two resins, and Protemp without fibers demonstrated a significantly lower mean transverse strength (48.17 MPa) than the other specimens.

The highest transverse strength value, 149.82 MPa, was achieved by reinforcement of PMMA with glass fibers.

In the group tested immediately, Jet resin showed the highest strength followed by Dentalon Plus and Protemp. Protemp demonstrated significantly lower strength.

In the wet-storage group, the values were higher than the initial values.

The fiber reinforcement of resin materials increased strength values (20-50%).

DISCUSSION

Tooth-colored resin is the material of choice for fabricating provisional restorations. However, fracture of the restoration may occur during function because of poor transverse, impact and flexural strength of resins (John, Gangadhar & Shah, 2001). Fatigue is one of the most common causes of breakage of provisional restorations (Stafford & Smith, 1970).

This study compared the transverse strengths of PMMA, PEMA and BIS-acryl resin composites and the same resins reinforced with glass and aramid fibers.

The crown and fixed partial denture acrylic resins used in this study were not pressure-packed or heat-cured, nor were they cross-linked to a significant degree. As a result, these resins may have had an increase in the number of microporosities, monomer retention and a large polarity that would enhance the rate of water sorption (Larson & others, 1991). Theoretically, these acrylic resins may have already reached their maximum water sorption within a few hours as a result of monomer retention and high polarity. For these reasons, the strength of the acrylic resins may have remained uniform. To simulate oral condi-

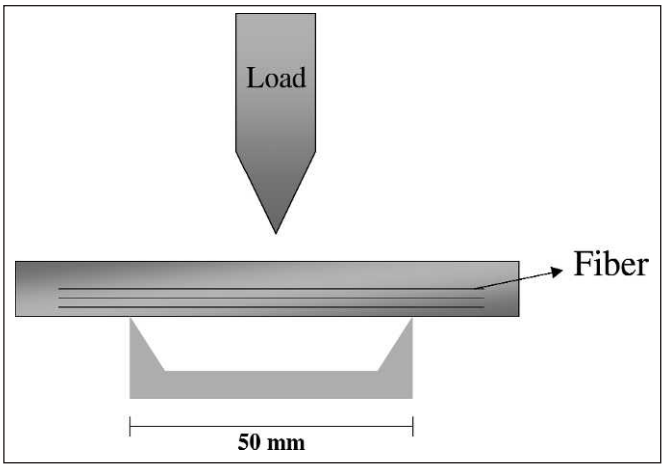

Figure 1: *Diagrammatic representation of the test specimen.*

Table 2: *Results of ANOVA for Transverse Strength Values (Dependent: Transverse strength (MPa)) (Significant p<0.001)*

Effect	df Effect	SS	MS Effect	F	P-Level
1	2	38.999.11	19499.56	41051.99	0.000000
2	1	6789.349	6789.349	7732.17	0.000000
3	2	24226.46	12113.23	12247.08	0.000000
1x2	2	288.2585	144.1293	164.14	0.000000
1x3	4	1477.178	369.2945	373.38	0.000000
2x3	2	48.563	24.2815	35.09	0.000000
1x2x3	4	21.21102	5.302754	7.66	0.000223

Effect: 1 = Material; 2 = TIme; 3 = Treatment
df: Degrees of freedom
SS: Sum of Squares
MS: Mean Square
F: F-ratio
p: probability

tions, the resins were tested immediately after the material set and after seven days of wet storage.

Water has a plasticizing effect resulting from an interaction with the polymer structure (Valittu, Ruyter & Ekstrand, 1998). Many studies on water sorption of denture base polymers have been carried out, and it has been concluded that sorption decreases the mechanical properties of denture base polymers. In contrast, Koumjian & Nimmo (1990) found that Triad, Protemp, Snap and Trim resins exhibited a significant increase in transverse strength after seven days of wet storage. In this study, water sorption did not adversely affect transverse strength.

As the provisional restoration should provide pulpal protection, positional stability, occlusal function, access for cleaning, esthetics, strength and retention (Shillingburg & others, 1997), during this stage of clinical treatment, periodontally involved abutment teeth are assessed. The functional occlusion, vertical dimension, prognosis of questionable teeth and the esthetic and phonetic acceptability of the tooth position may be evaluated (Amsterdam & Fox, 1959; Shillingburg & others, 1997). It may take months or years to make such assessments and a provisional restoration must be durable (Shillingburg, & others, 1997).

Different procedures for reinforcing these resins have been recommended but they have met with limited success. Adding glass fibers to dental resins to improve their strength has been studied by many investigators (Solnit, 1991; Vallittu & others, 1994; Powell & others, 1994; John & others, 2001).

Different types of fibers are produced commercially. In this study, glass fiber and aramid fiber were selected to reinforce the acrylic resins. Glass is an organic substance that has been cooled to a rigid state without crystallization (John & others, 2001). Different types of glass fibers are available. These include E-glass, S-glass, R-glass, V-glass and Cemfil. Of these, E-glass fiber, which has high alumina and low alkali and borosilicate, claims to be superior in flexural strength (Solnit, 1991).

Aramid is a generic term for wholly aromatic fibers. These fibers are resistant to chemicals, thermally stable and have a high mechanical stability, melting point and glass transitional temperature. They also have pleated structures (molecules are radially arranged in the form of sheets) that make aramid weak in terms of flexural, compression and abrasion behavior (John & others, 2001).

Fibers can most easily be placed longitudinally inside the specimen by using fiber rovings instead of woven fibers. If fibers are used to strengthen a polymer material, optimal adhesion between the fibers and the polymer matrix is essential. To improve adhesion, the surface of the fibers can be silane-treated (Clark & Ploedmann, 1963).

The accepted engineering beam theory (Powell & others, 1994) states that when a beam is loaded mid-span between two supporting points, the applied load induces tension in the bottom fibers and compression in the top fibers. In this study, the treated PMMA, PEMA and BIS-acryl composite bars would not be a catastrophic failure. In fact, a crack would occur on the tension side but would

Table 3: *Mean Values and Standard Deviations of Transverse Strength, Material x Time Interaction (1 x 2) (mean, SD) (MPa)*

Material	Time			
	Immediate		7-Day Wet	
	Mean	SD	Mean	SD
Protemp	61.81	0.54	73.72	0.54
Dentalon Plus	81.98	0.54	97.74	0.54
Jet	104.33	0.54	124.24	0.54

Table 4: *Mean Values and Standard Deviations of Transvers Strength, Material x Treatment Interaction (1 x 3) (mean, SD) (MPa)*

Material	Treatment					
	No Fibers		Kelvar		E-Glass	
	Mean	SD	Mean	SD	Mean	SD
Protemp	53.87	0.68	69.07	0.68	80.35	0.68
Dentalon Plus	72.21	0.68	89.98	0.68	107.39	0.68
Jet	90.06	0.68	114.37	0.68	138.44	0.68

Table 5: *Mean Values and Standard Deviations of Transvers Strength, Time x Treatment Interaction (2 x 3) (mean, SD) (MPa)*

Time	Treatment					
	No Fibers		Kelvar		E-Glass	
	Mean	SD	Mean	SD	Mean	SD
Immediate	64.83	0.46	83.40	0.46	99.9	0.46
7-Day Wet	79.27	0.46	98.88	0.46	117.55	0.46

Table 6: *Mean Values and Standard Devations of Transverse Strength, Material x Time x Treatment Interaction (1 x 2 x 3) (mean, SD)*

Material	Time	Treatment					
		No Fibers		Kelvar		E-Glass	
		Mean	SD	Mean	SD	Mean	SD
Protemp	Immediate	48.17	0.81	63.01	0.81	74.24	0.81
	7-Day Wet	59.57	0.81	75.12	0.81	86.45	0.81
Dentalon Plus	Immediate	64.87	0.81	82.69	0.81	98.39	0.81
	7-Day Wet	79.55	0.81	97.28	0.81	116.39	0.81
Jet	Immediate	81.44	0.81	104.51	0.81	127.06	0.81
	7-Day Wet	98.68	0.81	124.23	0.81	149.82	0.81

Table 7: *For Transverse Strength Values Evaluation of Differences Among the Means of Materials, Time and Treatment Groups by Newman-Keuls Multiple Comparison Test (mean, significance) (MPa)*

Materials		Mean	Difference Among Groups
Protemp	(1)	67.76	2, 3
Dentalon Plus	(2)	89.86	1, 3
Jet	(3)	114.29	1, 2
Time		**Mean**	**Difference Among Groups**
Immediate	(1)	82.71	2
7-day wet	(2)	98.57	1
Treatment Groups		**Mean**	**Difference Among Groups**
No fibers	(1)	72.05	2, 3
Kevlar	(2)	91.14	1, 3
E-Glass	(3)	108.72	1, 2

not propagate through to the compression point. The embedded fiber could not be stretched enough for the crack in the resin to continue. The fiber appeared to hold the two pieces together. Because a fracture failure is usually related to the initiation of a crack and its subsequent propagation until displacement (Gegauff & Pryor, 1987), if a provisional FPD fractures in the mouth, it is difficult if not impossible to repair. This presents an inconvenience to both the dentist and the patient because the provisional prosthesis often must be remade.

The same technique for measuring fracture resistance was used in earlier studies (Powell & others, 1994; Koumjian & Nimmo, 1990; Friskopp & Blomlöf, 1984; Ramos, Runyan & Christensen, 1996; Vallittu, 1998). The results of separate studies carried out earlier and those of this study closely agree (Nohrström, Vallittu, Yli-Urpo, 2000; Vallittu & others, 1998).

All the materials tested showed a significant increase in transverse strength after seven days of wet storage. The transverse strength values were higher following wet storage compared to those tested immediately after the material set. Protemp was consistently weaker than the other two resins tested with or without fiber reinforcement, immediately after setting and in the wet storage groups. Cross-linking has little influence on tensile strength, transverse strength or hardness. Jet was found to be the strongest resin material immediately after setting and following seven days of wet storage. The fiber reinforcement of the materials tested caused 20-50% increases in transverse strength.

These tests are *in vitro* and other factors, such as marginal integrity, color stability, and ease of manipulation, should also be considered.

CONCLUSIONS

The fibers incorporated in the acrylic resin material enhanced the fracture resistance of PMMA, PEMA and BIS-acryl resin composite test specimens.

The information presented in this study will aid the restorative dentist in selecting a provisional material. To determine whether the fibers incorporated into PMMA, PEMA and BIS-acryl resin composite also have relevance clinically, other testing methods, such as impact testing and fatigue testing, should be used.

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Literature Review

Tooth-Colored Post Systems: A Review

AJE Qualtrough • F Mannocci

Clinical Relevance

Tooth-colored fibre posts have several advantages over conventional metal posts. They are aesthetic, they must be bonded to tooth tissue, they have a modulus of elasticity similar to that of dentin and they appear to perform well in clinical studies without the risk of fracture.

INTRODUCTION

Restoration of the root filled tooth by a post to retain a crown dates back more than 200 years, when Fauchard used posts constructed from gold or silver (Fauchard, 1880). Over the next century, post crowns became the most popular method of restoration of roots. Opinions differed among those who favored wooden posts and those who preferred the metal variety. Wooden posts were more retentive due to water absorption, but there were no suitable cements to aid in the retention of metal posts. Gold and platinum were considered to be of superior quality compared with brass, silver and copper, which tended to corrode (Harris, 1839). As early as 1849, when there was little emphasis on cleaning and shaping endodontic procedures, Tomes proposed the principles of post dimensions. These procedures still closely conform with those used today (Tomes, 1848).

Ever since the early days, the provision of a post is still regarded as the accepted method of core retention for restoration of significant loss of coronal tooth tissue (Schillingburg & Kessler, 1982; Rosensteil, Land & Fujimoto, 1995). A further consideration was that a post was thought to render the root-filled tooth more resistance to fracture, although opinions now vary. For example, in a study of 59 endodontically-treated teeth with and without post-reinforcement, Guzy & Nicholls (1979) were unable to demonstrate any difference in fracture resistance between the two groups. However, when other factors were taken into account, the propensity for root fracture due to the wedging effect of tapered posts was considered a cause for concern by Standlee & others (1972).

Conventionally, endodontic posts can be categorized into two groups: custom-made and prefabricated. Prefabricated posts may be divided into those retained actively or passively. A wide range of posts have been developed, the main differences are usually related to taper and surface configuration. Systems that incorporate the use of matched parallel-sided preparation burs, casting posts for indirect use and stainless steel/titanium posts for direct placement are popular.

For success, a metal post must satisfy certain criteria (Johnson & Sakumara, 1978):

a) it should be as long as the prosthetic crown.

b) the sides should be as parallel as possible.

c) there should be a precision fit of the post within the canal.

d) the apical 4 mm of the gutta-percha root canal filling should not be removed.

*AJE Qualtrough, Unit of Operative Dentistry and Endodontology, University Dental Hospital of Manchester, UK

F Mannocci, Department of Restorative Dentistry, University of Siena, Italy

*Reprint request: Higher Cambridge Street, Manchester M15 6FH, UK; e-mail: alison.qualtrough@man.ac.uk

The crown may be constructed from a porcelain or ceramic material or from ceramic bonded to metal. Posts and cores may be made in the laboratory or pre-manufactured. The advantage of laboratory-constructed posts is that an accurate representation of the root canal is possible, hence, the fit of the post should be optimal. However, two appointments are required since this is an indirect procedure. Directly placed posts have the advantage that the canal may be prepared and the post bonded directly. They are also usually stronger and may be more retentive but are constructed from non-precious metals, therefore, the potential risk for corrosion leading to microleakage and root fracture exists.

The shape of metal posts may vary according to operator preference and canal shape and may be categorized as follows:

- Smooth tapered
- Smooth parallel-sided
- Threaded tapered
- Threaded parallel-sided

On rare occasions there may be insufficient space within the crown of the tooth for a retentive core and a separate crown. Under these circumstances, a crown bonded to a core may prove to be the best solution.

Destined for use in teeth that are already broken down, the hazards associated with post placement are not insignificant and include the risk of perforation. There is also the risk of a generation of stresses within the root dentin (Ross, Nicholls & Harrington, 1991), and the failure rate of post-retained restorations has been considered to be greater than any other indirect restoration in vital teeth (Roberts, 1970; Turner, 1982). Failure can also be attributed to fracture or bending of the post, loss of retention, core fracture or root failure. Corrosion is also considered a significant cause of failure (Silness, Gustavsen & Hunsbeth, 1979). However, there are few clinical studies of metal post crown successes and failures. Sorensen & Martinoff (1984) reported 8.6% failures due to post loss, root fractures or post perforations. Weine, Wax & Wenckus (1991) reported 6.5% failure after 10 years or more and Torbjöner, Karlsson & Odman (1995) recorded a failure rate of 8.3% after two to three years. There are other problems associated with conventional metal post and core systems, one being the aesthetics of the final restoration, as the restored crown cannot possess the optical properties of natural tooth structure. The metal core decreases the depth of translucency of the coronal restoration and the post may shine through in the cervical region, thus, altering the appearance of thin gingival tissues. However, the final aesthetic result is dependent on the relationship between the opacity of the ceramic core material and the degree of metal shine through. For example, some aluminous core materials can be as effective as porcelain fused to metal in blocking metal core effects. Another problem with metal posts relates to the difference in elasticity between dentin (18.6 MPa Young's modulus) and metal (200 MPa). This difference results in unequal distribution of strains on the dentin surface and a tendency to create stress concentration areas. Carbon fiber posts are primarily made of carbon fibers immersed in an epoxy resin matrix and show a different pattern of elastic behavior depending on the direction of applied stress. When a load was applied at an angle of approximately 35° to the long axis of the post, the modulus of elasticity of carbon fiber posts was approximately 21 GPa, while dentin is approximately 21 GPa. More recently, similar results were achieved when the load was applied at 45° to the long axis of the post (Asmussen, Peutzfeldt & Heitzmann, 1999).

As a consequence of the above considerations and following significant developments in dental materials science, including the introduction of reliable bonding systems (Mannocci & others, 1999), improved fiber reinforced resin composites and strengthened ceramics, a new generation of tooth-colored post systems have been proposed.

THE CERAMIC POST AND CORE

Historically, the main disadvantage of ceramic materials has been principally associated with their low flexural strength compared with metals, and in function, ceramic materials have a record of frequent failure in high-stress situations (Anusavice, 1996). Theoretically, ceramic post and cores should have good aesthetic and biological properties and, with advances in dental materials science, a resurgence of interest has emerged related to using these newer, reinforced ceramic materials as an alternative to metal, especially with successful bonding systems. In 1989, Kwiatkowski and Geller described the clinical application of glass-ceramic posts and cores and, in 1991, Kern and Knode introduced posts and cores made from glass infiltrated aluminum oxide ceramic (Koutayas & Kern, 1999). In 1995, Pissis proposed that a post and core could be constructed as a single component made from a glass ceramic material. Other ideas have included the introduction of pre-fabricated zirconia endodontic posts to be used in conjunction with a direct resin composite core build-up (Sandhaus & Pasche, 1994) and Ahmad (1998) described the practical application of zirconia posts as a support to leucite-reinforced cores in practice. In a study by Purton, Love & Chandler (2000), preformed ceramic posts were reported to be significantly more rigid than parallel-sided stainless steel posts. The metal posts were also significantly more retentive than ceramic posts bonded using a variety of luting/bonding agents and surface preparation techniques. However, Rosentritt & others (2000) demonstrated that typical failure of metal systems was marked by loosening compared with fracture of ceramic

posts. This could be interpreted as being disadvantageous, as removal of a ceramic post is notoriously difficult. On the other hand, it is preferable that the post fractures, rather than the root.

THE FIBER-REINFORCED POST AND CORE

The properties of fiber-reinforced materials not only depend on the nature of the matrix and fiber, but also on the interface strength and geometry of reinforcement (Isaac, 1997). The addition of fibers to a polymer matrix can result in a significant improvement in the mechanical properties of strength, fracture toughness, stiffness and fatigue resistance (Drummond, 2000). Fibers may be composed of woven polyethylene, glass or carbon. In a study of different resin composite materials (Viguie & others, 1994), the modulus of elasticity of a material containing short, randomly distributed fibers was concluded to be similar to that of radicular dentin and, hence, should be suitable for post and core construction.

Carbon fiber-reinforced resins are considered viable alternatives to metals when strength, stiffness, lightness and resistance to corrosion and fatigue are considered. Carbon compounds in various forms have been studied in several dental and surgical applications and have proved to be biocompatible and mechanically satisfactory for many purposes. In 1990, Duret, Reynaud & Duret introduced a non-metallic material based on the carbon-fiber reinforced principle. In a later report (Duret, Reynaud & Duret, 1992), the absence of corrosion was also mentioned as an advantage of fiber posts, but this statement was challenged in a study by Fovet, Pourreyron & Gal (2000) in which the involvement of carbon fiber posts in corrosion reactions was found. Purton & Payne (1996) suggested that carbon fiber posts could potentially replace stainless steel and other metal posts in many clinical situations due to their inherent rigidity, which allows smaller sizes to be used for equivalent strength. They also suggested that improved bond strength between post and root would permit the potential replacement of stainless steel with carbon fiber in post systems. The tensile bond strength of adhesive systems to stainless steel, titanium, carbon-fiber and zirconium dioxide root canal posts was evaluated by O'Keefe, Miller & Powers (2000). Bonds to carbon fiber posts were weaker than to stainless steel and titanium but stronger than to zirconium dioxide. The potential problem associated with water sorption must also be considered. Miettinen, Narva & Vallittu (1999) reported that water sorption and solubility of fiber composites vary according to the brand and homogeneity of polymer matrix and may affect the hydrolytic stability of the composite structure. High sorption rates were associated with microscopic voids and composition of the polymer matrix.

Fiber-reinforced posts have exhibited a significant decrease in flexural strength following thermocycling (Torbjorner & others, 1996; Drummond, 2000; Mannocci, Sherriff & Watson, 2001). This has been attributed to degradation of the fibers or the matrix and to the difference in thermal expansion coefficients between the two.

Although considered as having significant advantages compared to metal posts, especially with respect to mechanical properties, the carbon fiber post is gray in appearance. Replacing carbon with quartz fibers results in a tooth-colored restoration. Recently, new quartz fiber post-systems, such as Light-Post DT (RTD, St Egreve, France), with a tapered design, were introduced to the market to obtain better adaptation to the root canal preparation.

Although posts and cores used to restore pulpless teeth should be strong in the face of mechanical stress, it is preferred that the post, regardless of construction material, should fail in preference to tooth tissue. In a study comparing the fracture resistance of teeth restored with prefabricated carbon-fiber posts and composite cores to cast dowel-core restored teeth, Martinez-Insua & others (1998) reported the failure threshold of the carbon fiber posts was significantly lower than that of cast posts and cast cores commonly resulting in tooth fracture at failure. Comparable results were noted by Mannocci, Ferrari & Watson (1999), who reported that fiber posts reduced the risk of root fractures of teeth restored to a minimum with quartz fiber, carbon quartz fiber and zirconium dioxide ceramic posts. Similar trends have been reported by Dean, Jeansonne & Sarkar (1998) and Isidor, Odman & Brondum (1996). Early retrospective studies indicate that the clinical performance of fiber posts is promising (Fredriksson & others, 1998; Ferrari & others, 2000; Ferrari, Vichi & García-Godoy, 2000). In an *in vivo* study of carbon fiber and quartz fiber posts luted using four different bonding-luting material combinations over a period of up to four years, a failure rate of 3.2% was recorded. Failures were due to debonding during removal of the temporary restoration or the presence of a periapical lesion at the radiographic examination. There was no significant difference in the type of failure between the groups (Ferrari & others, 2000).

The success of 59 nine carbon-fiber post-composite core restorations covered with full ceramic crowns was evaluated in a prospective study (Glazer, 2000). The average observation was 28 months. There were no root fractures and the overall failure rate was 7.7%. The failure modes observed were two due to periapical pathology, one core debonded and one crown debonded.

Although destined to be permanent restorations, on occasion, a post must be removed, which can prove to be a challenging procedure. For fiber posts, the parallelism of the stretched fibers in a resin matrix is said to facilitate the guidance of removal drills. This is significant with respect to safe re-treatment (de Rijk, 2000).

GENERAL RECOMMENDATIONS

Indicators for provision of a non-metal post must be considered for each case on an individual basis as factors such as attachment loss and tooth type must be considered. Currently, there is insufficient evidence-based clinical data to permit meaningful comparisons to be made between studies related to aesthetic posts.

However, careful review of the literature suggests:

1. Generally, placement of a post is indicated whenever the coronal tooth structure is insufficient in quality or quantity to support a core build-up.
2. Tooth-colored fiber posts are useful because they provide an aesthetic means of building up a post and core at the chairside. There is also the advantage of compatibility between the flexibility of the tooth and post structure.
3. Adhesive techniques should be used in combination with all non-metal fiber posts to maximize retention and conserve tooth tissue.
4. Ceramic posts should not be used in cases of extensive tooth tissue loss, as the rigidity of the ceramic material tends to transfer stresses to the compromised tooth structure, thereby, enhancing the risk of root fracture.
5. Posts constructed from different fiber types have similar flexural strength, therefore, quartz fiber and other "aesthetic" fiber posts may be used with equal confidence.
6. The results of clinical studies to date indicate that even the smallest diameter fiber posts appear to perform well without the risk of fracture.

CONCLUSIONS

There have been significant developments in post systems in recent years with respect to post and core construction materials, post shape and design, bonding systems and techniques for removal. Carbon fiber posts have generally been superceded by quartz, silica and glass fiber-reinforced materials. One advantage of fiber-reinforced systems is that the modulus of elasticity of the post is similar to tooth tissue; hence, post failure should occur before root fracture under conditions of stress. The flexural strength of fiber posts was found to be similar to metal posts as long as contact with water was avoided. As a consequence, many systems, including posts of small diameters (such as 0.8 or 1 mm), have replaced older systems and have been recommended for use in roots with narrow mesio-distal diameters, such as mandibular premolars. An area of concern may be related to the finding that fiber posts can undergo degradation in the face of repeated mechanical loading and under conditions of moisture; this degradation may lead to a reduction in the modulus of elasticity and flexural strength with an increased risk in debonding. This is not likely to occur if stiff materials such as ceramics are used. The nature of the bond between resin composite and fiber or ceramic post to root dentin and post must also be taken into account. If the bond fails at either interface, transference of forces to the root dentin will be affected. As indicated above, bonds of composite to carbon fiber post materials have been found to be stronger than to zirconium dioxide. Failure of this bond may prevent root fracture of teeth restored with ceramic posts. It follows that the question of whether posts of high modulus of elasticity should be used compared to those of a lower modulus cannot be answered in light of the current clinical and laboratory research. The retention rate of fiber-reinforced posts appears to be similar to other post systems and early clinical findings are favorable.

A range of ceramic post systems has been described; the main disadvantage of these relates to the inherently brittle nature of ceramics and it can be difficult to remove a fractured ceramic post. There are a variety of construction methods, some involve exacting laboratory procedures.

With the introduction of ceramic and fiber-reinforced posts, there has also been a trend away from the parallel-sided post preparation previously associated with the need for retentive mechanical features required for metal posts and more towards a shorter, tapered design in harmony with the canal morphology.

An additional advantage to the newer systems from the patient's perspective is that metal post and cores may be realistically avoided. However, long-term, evidence-based clinical studies are required before the performance of fiber-reinforced and ceramic post and core systems can be fully assessed.

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Invited Paper

Minimal Intervention Dentistry: Rationale of Cavity Design

GJ Mount

Clinical Relevance

This discussion draws attention to a growing understanding of adhesion of restorative materials that is leading to possible modifications in cavity design. The original designs postulated by GV Black were designed for non-adhesive materials and have not been substantially modified in recent years despite improvements in adhesive dentistry. It is accepted that these designs lead to a weakening of the tooth crown and a continuing need for replacement and repair.

It is suggested that if cavity designs for new lesions are limited, the potential for retention of significant amounts of natural tooth structure avoids or at least delays the need for more extensive restorations. However, it is essential to eliminate disease in the first place if this strategy is to succeed. Caries is a bacterial disease, and methods of control have been improved to the extent that eliminating bacteria and remineralization and healing demineralized tooth structure is now a real possibility.

Modified cavity designs are suggested to treat new lesions based upon a new classification of carious lesions. This is a departure from the original GV Black classification that defined a series of cavities of specific design based on the requirements for specific restorative materials. It is suggested that the cavity's design should be dictated solely by the extent of the lesion with retention of the restoration being dependent upon adhesion to the remaining tooth structure.

INTRODUCTION

Black (1917) laid down the basic tenets for the design of cavities prescribed for restoring carious lesions nearly 100 years ago. At that time a limited range of materials was available for restoration and there was little understanding of the disease, itself. Some degree of bacterial involvement in the development of a carious lesion became apparent in the 1880s (Miller, 1883), however, the concept of preventive dentistry was in its infancy. The involvement of fermentable carbohydrate was not fully understood, with another 50 years passing before the influence of fluoride became apparent (Brudevold, 1974).

At the time of Black's writing, he was working in an era of rampant caries. He laid down a series of principles that set a standard that has continued to this day. He suggested that convenience form or access to the lesion was a primary need. He defined the outline form, which included all areas of the tooth that were at risk, such as the remaining, uninvolved areas of fissures and extending the outline into areas that were expected to be free of further caries attack.

As the materials that Black worked with were not adhesive, it became necessary for him to describe retention form in order for the restoration to not fall out.

*Graham J Mount AM, BDS, DDSc, FRACDS

*Reprint request: 13 MacKinnon Parade, North Adelaide, South Australia 5006; e-mail: gjmount@ozemail.com.au

Then, he had to consider the relative strength of the restorative material itself. There was also a need for resistance form, which meant that on some occasions, more tooth structure needed to be removed in order to lend strength to the filling so that it could resist occlusal stresses.

One of the greatest problems that Black faced was a lack of understanding of how rapidly the lesion progressed through enamel and, subsequently, through dentin. He worked on the basis that once demineralization had commenced on the surface of the crown of the tooth, it was not possible to reverse it. That is, it was not possible to heal a lesion. The result of this misunderstanding was that treating even the smallest lesion detectable on a radiograph would lead to destruction of a significant amount of natural tooth structure, much of which was still in perfect health.

It is interesting to note that more than 100 years later, following considerable change in dental materials, clinician's understanding of the caries process and the rate of speed at which the carious lesion progresses, we continue to use the cavity designs that Black specified. There have been modifications in design toward conservation of tooth structure and a better understanding of materials suggested over the years (Markley, 1966) but too much emphasis has been placed on the surgical approach to eliminating the disease. There is a need to reevaluate the use of surgery as the primary approach to eliminating what is essentially a bacterial disease.

HEALING OF THE CARIOUS LESION

For many years caries has been recognized as a bacterial disease, so that in the absence of the relevant bacteria, caries cannot be initiated or continue (Balakrishnan, Simmonds & Tagg, 2000). If, in the early stages of a caries attack, the bacterial flora can be modified, then it is possible to overcome the initial demineralization and heal the lesion through remineralization. If the lesion has progressed to the extent that there is actual cavitation on the otherwise smooth surface of the tooth crown, then it becomes necessary to reinstate that smooth surface by placing some form of restoration (Mount & Hume, 1998a).

Streptococcus mutans is acknowledged as the bacteria most involved in the reduction of the pH of plaque on tooth surface to the extent that demineralization can occur (Silverstone & others, 1981). In the presence of fermentable carbohydrate, these bacteria can reduce the pH of plaque fluid to levels below 5.5, which is the critical pH for demineralizing hydroxyapatite *in vitro*. *In vivo*, the level of saturation will have a bearing on the critical pH. This defines the fact that fermentable carbohydrate is a significant factor in the development of caries. Both factors have been known and understood for many years and provide some basis for good preventive dentistry.

Control of fermentable carbohydrate is a very personal factor, and patients need to understand the significance of the role they play in its control. On the other hand, control of the bacterial flora is relatively straightforward but not often recommended to patients. The profession needs to identify the patient who is at risk with a high Streptococcus mutans count and prescribe chlorhexidene in the correct manner to assist the patient in taking control (Walsh 2000). Using 0.2% chlorhexidene as a water-based gel or an alcohol-based mouthwash twice a day for two weeks will offer a significant reduction in streptococcus mutans and lactobaccilus and provide the patient with an increased opportunity to overcome infection. Following this, chlorhexidene can be used as a mouthwash at weekly intervals for long periods if the patient is incapacitated.

Obviously, this alone will not be sufficient to gain total control, and all the usual measures that limit the intake of fermentable carbohydrates and oral hygiene will also be essential. The patient, in fact, is the only one who can overcome the problem, leaving the profession with the responsibility of seeing that patients are fully educated in these areas.

The real significance for having a better understanding of the progress of the carious lesion lies in the fact that it is now obvious that the disease should be controlled through preventive measures first, prior to any restorative measures being undertaken. Surgery will only be necessary in the case where the tooth surface has been cavitated because, in the presence of surface defects, it will not be possible to completely control plaque accumulation. However, the concept of extension for prevention is out of date because the remaining, partially demineralized enamel that surrounds the cavity can be remineralized and healed. It is only necessary to control the bacterial flora in order for the disease to be controlled. The significant factor that cannot be overlooked is that, if the disease is allowed to continue unchecked, no restorative material or technique can, by itself, bring about control.

THE PLACE OF FLUORIDE IN CARIES CONTROL

Fifty years ago it became apparent that in the presence of free fluoride ions the progress of the carious lesion could be slowed down (Silverstone, 1982). It was decided that if fluoride were to be included in the developing tooth structure, there would be a degree of resistance to demineralization imparted onto the enamel. Fluoridating water supplies and introducing fluoride into toothpaste made a significant difference in the caries rates in children at a community level (Axelsson, 1999). Subsequently, adults also derived benefit, particularly following topical applications (Axelsson, Lindhe

& Nystrom, 1991). It is now recognized that in the continuing presence of low levels of fluoride in plaque fluid, demineralization of tooth surface can be slowed down, prevented or reversed (Clarkson & others, 1996).

It appears that fluoride can act as a catalyst for preventing demineralization in the first place and stimulating remineralization of tooth structure following the initiation of caries (Ten-Cate, 1990; Kidd & Jayston-Bechal, 1987). In a substitution reaction, fluoride can be incorporated into enamel and form fluorhydroxyapatite; this shows a greater resistance to acid attack because the critical pH of this form of enamel is pH 4.5 in contrast to hydroxyapatite, which is pH 5.5. It has been shown that fluoride is more effective post-eruption than pre-eruption.

The formation of some fluorhydroxyapatite can occur during tooth development if a level of about 1-ppm of fluoride is available in the water supply for the growing infant. However, it is also possible to modify the surface of the tooth and develop a layer of fluorhydroxyapatite at any time following eruption. This is significant because, in the presence of a restorative material that is capable of releasing fluoride ions, it may be possible to exert some degree of influence on further demineralization of tooth structure adjacent to the restoration (Serra & Cury, 1982).

It was recognized many years ago that silicate cement released a certain amount of fluoride, leading to some degree of defense against further demineralization as the restoration broke down. Now, the modern glass ionomer has been shown to have the same capability and is therefore a useful material in the defense of the tooth against further caries attack (Hicks, 1986). The transfer of fluoride from the restoration to the adjacent tooth surface will help in the formation of fluorhydroxyapatite, making this area more resistant to further acid attack. The modification of enamel will not, by itself, prevent new lesions but will make the tooth structure surrounding a glass-ionomer restoration more resistant to further demineralization.

ADHESIVE WITH RESIN COMPOSITE

Since dental caries is a bacterial disease, it is apparent that any situation in the oral environment that encourages the accumulation and retention of bacterial colonies is undesirable. The problem of microleakage forming between the restoration and the cavity wall has demanded much attention and a high level of clinical skill has been required to prevent it. When completely neutral materials such as amalgam and gold are used for restoration, it is essential to pay attention to both cavity design and placement of the restoration. Fortunately, amalgam corrodes to a degree (Mahler & Nelson, 1984) and the corrosion products themselves tend to occlude the interface. Over time, they will completely seal the restoration. A gold restoration will be placed and retained with a luting cement and, providing this is not soluble in the oral fluids, will prevent microleakage for the long-term.

The advent of adhesive materials has made it easier to seal the cavity margin but there is still a need to pay attention to cavity design. Adhesion with resin composite is based primarily on a micro-mechanical attachment between the enamel and the restoration. Fifty years ago, it was shown that following acid etching of the enamel surface, the tooth would be sufficiently porous to allow a low viscosity resin to penetrate some distance into the enamel (Buonocore, 1955). Once the resin had set, there was a very strong union between the two.

However, there are certain limitations in this technique because the union may be under stress from setting shrinkage of the resin. It is essential that the marginal enamel be fully mineralized. It has been noted that adhesion will be enhanced if the margins are beveled so that the resin can bond to the ends of the enamel rods rather than along their long axis (Ikeda & others, 2002).

Considerable research into the concept of adhesion between resin composite and dentin has been conducted. The current concept is to clean the cavity floor down to completely healthy dentin, then etch the surface of the dentin, leaving demineralized collagen fibers standing free on the floor (Sano & others, 1999). A low viscosity resin is then flowed over the surface and, when set, it will engage the collagen in a micro-mechanical union. There are some clinical and scientific problems with this system and long-term success has not yet been proven (Van Meerbeek & others, 1994). It can also be argued that removing all demineralized dentin from the floor of the cavity will often lead to an over-extension of the cavity because some of this dentin could be remineralized and healed (Ten Cate & van Duinen, 1995).

ADHESION WITH GLASS IONOMER

Adhesion with glass ionomer is the result of an ion exchange between the cement and both enamel and dentin. There can also be a degree of chemical union with exposed collagen fibers (Mount, 1991; Ngo, Mount & Peters, 1997; Akinmade, 1994; Ferrari & Davidson, 1998). This suggests that even in the presence of demineralized tooth structure, there will still be a degree of union. It will therefore only be necessary to extend the cavity outline to the point where the enamel surface is smooth and non-cavitated even though it may be partially demineralized. In addition, partly demineralized, non-infected dentin that remains on the floor of the cavity can be assisted to remineralize (Ngo & others, 2001). Extension of the cavity outline can therefore be very conservative, leading to retention of natural tooth structure and limitation of the aesthetic and physical problems that arise from the larger cavity preparation.

There are further advantages to be gained from using glass ionomer even if it serves only as a base for another restorative material. Glass ionomer has been shown to be bioactive and have a long-term ion exchange with tooth structure to the extent that it can assist in the remineralization of dentin and enamel (Ngo, Marino & Mount, 1998). It will exchange fluoride and calcium and strontium and phosphate, as well. This means that it is not necessary to remove all softened, partially demineralized dentin from the floor of the cavity, which allows for even more conservative cavity designs. The concept is to gain access to the carious lesion in the most conservative manner possible. The axial wall or pulpal floor can remain as demineralized dentin provided the surface infected layer has been removed. The enamel margin should be extended out only far enough to remove all completely degenerated enamel rods.

Glass-ionomer materials allow clinicians to be more conservative in their cavity preparations. Currently, its only limitation appears to be a relative lack of fracture resistance to shear and tensile stresses to the extent that it is not indicated for rebuilding marginal ridges or incisal corners. However, provided that glass ionomer is well supported by surrounding tooth structure, it has a satisfactory history of longevity. In fact, it remains bioactive throughout its life, continuing to absorb and release fluoride (Nicholson, Czarnecka & Limanowska-Shaw, 1999; Ngo & others, 1998).

CAVITY DESIGN MODIFICATIONS

It is apparent from the above discussion that it should now be possible to review the GV Black approach to cavity design and be far more conservative in removing natural tooth structure. There is no doubt that introducing the rapid reduction of sound tooth structure with the air rotor handpiece has led to excessive extension of cavities.

Minimal intervention cavity designs have been discussed for more than 20 years (Knight, 1984; Hunt, 1984), and a new classification that encourages the profession to see operative dentistry in a new light has been proposed (Mount & Hume, 1997). The GV Black classification does not address this new philosophy, thus, it is in the interest of both the patient and operator to adopt a new method.

The proposed classification takes into account the fact that there are only three surfaces of the crown of a tooth that can be subject to caries attacks. These surfaces are:

Site 1 - pits and fissures on the occlusal surface of posterior teeth and other defects on otherwise smooth enamel surfaces.

Site 2 - contact areas between any pair of teeth, anteriors or posteriors.

Site 3 - cervical areas related to gingival tissues, including exposed root surfaces.

A neglected lesion will continue to extend as an area of demineralization in relation to one of the sites noted above. As it extends, so will the complexities of the restoration increase. The sizes that can be readily identified include:

1. Size 0 - initial lesion at any site can be identified but has not yet resulted in surface cavitation. It can possibly be healed.
2. Size 1 - smallest minimal lesion requiring operative intervention. The cavity is into dentin just beyond healing through remineralization.
3. Size 2 – moderate-size cavity. There is still sufficient sound tooth structure to maintain the integrity of the remaining crown.
4. Size 3 – the cavity needs to be modified and enlarged to provide some protection for the remaining crown from the occlusal load. There is already a split at the base of a cusp or, if not protected, a split will likely develop.
5. Size 4 – the cavity is now extensive, following the loss of a cusp from a posterior tooth or an incisal edge from an anterior.

The Size 0 lesion represents identifying an area of demineralization on any of the three surfaces, and, with normal preventive measures as discussed above, the lesion is expected to be arrested and healed. The problem then becomes significantly greater when the classification moves to a Size 1 because it is acknowledged that healing is no longer a proposition and some form of surgical intervention is required. However, it is suggested that in the presence of adhesive, bioactive restorative materials, it should not be necessary to do much more than simply seal the lesion from further bacterial activity so that the lesion will no longer progress.

As the lesion extends and the classification moves into Size 2 and beyond, other problems will be superimposed. It will become necessary to take into account the occlusal load, the intrinsic strength of the restorative material, the strength of the remaining tooth structure and its ability to accept functional load. The larger the cavity, the greater the need to use the stronger restorative materials. There will come a point where the cavity design has to be modified to the extent that the restoration, rather than the remaining tooth structure, will accept the entire occlusal load. These modifications apply particularly to replacement dentistry, where a failed restoration needs to be replaced.

However, in treating the early, new lesion, it is usually possible to minimize removing tooth structure, thus, maintaining the natural strength of the crown and

keeping the load off the restoration. Suitable designs for the Size 1 and Size 2 cavities are discussed below because this is where adhesive materials can be used to their optimum potential.

Site 1, Size O

The concept of the fissure seal, as discussed by Simonsen (1989) and others, is particularly sound in a newly erupted tooth. Sealing a deep fissure before it becomes partially occluded by plaque and pellicle, and in advance of demineralization into dentin, has an acceptable clinical history (Feigal, 1998; Ekstrand & others, 1998). The earliest fissure sealants were unfilled or lightly filled resins, but recent research has shown that there are some doubts about the integrity of the acid etch union between resin and enamel in these regions. It has been shown that a glass ionomer will successfully occlude such a fissure (Wilson & McLean, 1988). This is now being termed "fissure protection" to differentiate it from a "resin seal."

The anatomy of enamel within a fissure differs from that of other surfaces in that it is covered with a layer of enamel rods that appear to run parallel with the surface rather than at right angles. This means that when it is etched with orthophosphoric acid, it will not develop the usual pattern of porous enamel that allows penetration of the unfilled resin that is normally relied upon to provide the micromechanical attachment (Burrow, Burrow & Makinson, 2001). The presence of this type of enamel may well account for loss of the resin seal in many cases. Neither a resin nor a glass ionomer will flow into a fissure beyond the point where the fissure narrows down to approximately 200 µm in width. Therefore, retention of both materials appears to be dependent on adhesion to enamel at the entrance to the fissure rather than mechanical interlocking into the complexities of the fissure. Recent work suggests that even though the enamel rods lie in a different orientation, glass ionomer will still develop ion exchange adhesion and show acceptable longevity (Mount & Hume, 1998b).

Site 1, Size 1

As the fissure walls become demineralized, the dentin will become involved as well. This may pose a rather dangerous situation because there is often some difficulty in diagnosing the presence of a dentin lesion. Radiographs will not show this early lesion very clearly and laser detector and electrical impedance machines have limitations. In the presence of strong, fluoridated enamel, the occlusal surface entry to the lesion will remain limited, and bacteria-laden plaque can be forced down into a defective fissure. Under these circumstances, dentin involvement can become advanced before symptoms are noted.

The fissure system is a complex series of pits and fissures, therefore, a carious defect will often be limited to a very restricted area, leaving the remaining fissure system sound and uninvolved. This means that only the carious defect needs to be instrumented. However, prudence suggests that minor apparent defects should be explored in a very conservative manner before sealing the fissure system.

Site 1, Size 2

In this classification, the lesion will either have progressed to some degree or it may represent replacement of a failed Class I restoration. The same conservative principles should apply, as discussed above, in as much as it is only necessary to deal with the carious lesion and there is no need to open up the remaining fissures any further. If there is any part of the fissure system that is in doubt, it can be explored very conservatively, but there is no doubt that it is sufficient to seal the fissures and any carious process below will be arrested. It will progress no further until there is again access to the usual nutrients required by the bacteria (Mertz-Fairhurst & others, 1992). That is, if there is any marginal leakage, there will be further bacterial activity, which is very unlikely when using glass ionomer because of ionic adhesion and the presence of fluoride release. Instrumentation and restoration techniques for these lesions will be the same as for a Size 1 lesion. However, the occlusal involvement will be more extensive and, if there is any doubt about the ability of the glass ionomer to withstand the occlusal load, it can be cut back conservatively and laminated with resin composite.

It should be noted that glass ionomer has been recommended for the restoration of both Size 1 and Size 2 lesions in this category. The restoration is well supported by the remaining tooth structure and the ion exchange adhesion will ensure complete sealing of the remainder of the cavity. This means that if there is any demineralized dentin remaining on the floor of the cavity, there will be no further carious activity and there is a potential for remineralization (Ngo & others, 2001). It is possible to use a resin composite for the restoration but that would also mean cleaning the floor down to sound, healthy dentin to develop an acid-etch union with fully mineralized tooth structure. This may mean removing dentin that could otherwise be remineralized and healed.

Site 2, Size 0

It should be noted that radiographic evidence of demineralization at the contact area does not necessarily mean that there is cavitation on the proximal surface and, in the absence of cavitation, it is often possible to heal the lesion. In fact, proximal lesions progress very slowly because that surface is not under masticatory load and is, to a degree, protected from traumatic damage (Pitts, 1983; Shwartz & others, 1984). In contrast to the occlusal fissure lesion, it may take up to four years to penetrate the full thickness of the enamel and an

additional four years to progress through the dentin to the pulp.

It is desirable to differentiate between the Size 0 and Size 1 lesion before surgery because, at least theoretically, it should be possible to heal the Size 0 and it is only when cavitation is established that a surgical technique is required. It is essential to avoid the use of a probe to explore the proximal surface because this is the quickest way to actually damage the enamel and cause a cavity.

Site 2, Size 1

Once it has been established that there is cavitation on the proximal surface, a surgical approach to its repair becomes essential and some alternative methods are available. First, determine the position of the damage in relation to the crest of the marginal ridge. If it is more than 2.5 mm below the crest, then it may be possible to approach the lesion through the occlusal fossa and design a "tunnel" cavity (Hasselrot, 1998; Wilson & McLean, 1988). On the contrary, if it is less than this distance, a tunnel will only undermine the marginal ridge and weaken it still further. Under these circumstances, it is better to design a small box or "slot" cavity beginning on the outer slope of the ridge, retaining as much of the enamel as possible. Occasionally, a further alternative will present itself when a large Site 2, Size 3 or 4 lesion is being repaired or replaced and a small Size 1 lesion is revealed on the side of the adjacent tooth. These three alternatives will be discussed in more detail.

Site 2, Size 1 - "Tunnel"

As discussed above, the early proximal lesion on a posterior tooth will commence in enamel immediately below the contact area because this is where plaque will accumulate and mature. Initially, the contact itself will remain plaque-free due to movement between the teeth. The level and depth of fluorapatite already in the enamel may help to control the speed at which the enamel will actually undergo demineralization. Often, particularly in fluoridated communities, the enamel, although demineralized, will remain relatively intact until the dentin lesion is quite advanced. It will take up stain and become disfigured, but in the presence of further fluoride, it may remineralize.

As the lesion develops, some degree of breakdown and cavitation of the enamel will eventually occur, but this will remain confined to the area below the contact until it is quite advanced. There will generally be a zone of demineralized enamel surrounding the cavitation, but as long as the surface is smooth, this remains capable of remineralization in the presence of fluoride (Serra & Cury, 1992). The contact area may remain sound and the marginal ridge may be quite strong, provided the lesion is more than 2.5 mm below the crest of the marginal ridge (Wilson & McLean, 1988). Access to the lesion through the occlusal surface should be limited to the extent required to achieve visibility and, where possible, should be undertaken from an area that is not under direct occlusal load (Knight, 1984). For most patients, there is a fossa immediately medial to the marginal ridge that is the most suitable position for initial entry and, in a normal occlusion, is often not an area of occlusal contact.

It should be noted that resin composite is not indicated for restoration of these lesions because it will not be possible to access the proximal lesion to a sufficient degree to be able to reliably remove all demineralized enamel. Also, it will not be possible to provide a beveled margin to ensure proper adaptation of the resin to the enamel. On the other hand, glass ionomer will flow readily into a small cavity and has the ability to remineralize the enamel margins and any dentin on the axial wall that may be demineralized.

Site 2, Size 1 - "Slot"

A slot cavity could be used when the lesion is less than 2.5 mm below the crest of the marginal ridge. Generally, the lesion will be obvious both radiographically and to visual examination due to discoloration under the marginal ridge. The basic principles of cavity design remain the same, with the objective of removing only that tooth structure that has broken down beyond the possibility of remineralization. If this is allowed to dictate the extent of the cavity, there will be many occasions with this design where there is still a sound contact with the adjacent tooth in one part or another. It is desirable to retain this to ease the problems of maintaining a good, firm contact area, thus minimizing the dangers of food impaction and retention.

The outline form will be dictated entirely by the extent of the breakdown of the enamel, removing only that which is friable and easily eliminated without applying undue pressure. Remaining demineralized enamel will generally heal satisfactorily. Retention will again be through adhesion, so it is only necessary to clean the walls around the full circumference of the lesion, leaving the axial wall because it will be affected by dentin only.

For such a lesion, resin composite may be a useful material because on many occasions there will be an enamel margin around the full circumference. This will allow for the potential of placing a bevel and, therefore, good sound adhesion. If resin is used, any affected dentin should be removed so that proper etching of the dentin with exposure of collagen will occur. However, glass ionomer is still a sound option because the occlusal load will not be great and the ion exchange will remain valuable both for adhesion and remineralization.

Site 2, Size 1 - "Proximal Approach"

A further, very conservative approach to restoring a proximal lesion can be achieved on limited occasions only when the proximal surface of a tooth becomes accessible at the time of cavity preparation in an adjacent tooth. The lesion may have been revealed through radiographs or it may be noted only during cavity preparation. The larger cavity in the adjacent tooth will normally need to be of reasonably generous proportions to allow room to manoeuver, but when such an approach is possible, it leads to considerable conservation of natural tooth structure.

In view of the normal direction of the progress of a carious lesion through the enamel and down the dentin tubules, it is not difficult to clean the cavity, trim the enamel walls and eliminate infected dentin. Note that it is only necessary to remove enamel that is broken down beyond remineralization. There will often be a residual area of demineralized enamel around the circumference of the lesion and this should be retained because it is quite capable of being remineralized and healed. As this entire restoration will probably be hidden and disguised by the restoration in the adjacent tooth, it is essential to use a radiopaque material.

Resin composite can be useful for a very small lesion but glass ionomer is preferred because the limited access will make it difficult to assure full polymerization of the resin through light activation. When resin is used, it would be appropriate to use a dual-cured resin.

CONCLUSIONS

It is apparent that the advent of adhesive and bioactive restorative materials has opened the way for a review of the surgical approach to restoring cavitated carious lesions. The micromechanical adhesion between enamel and resin composite is strong and very valuable but, to be fully effective, it depends upon the availability of sound, fully mineralized enamel that is well supported by healthy dentin. Occasionally, this may mean removing some areas of enamel that could otherwise have been remineralized and healed. For current techniques, it also requires complete removal of all demineralized dentin from the floor of a cavity, some of which can generally be remineralized and healed. The use of glass ionomer allows for a more conservative approach.

Glass ionomer is the most conservative of the restorative materials but requires good support from the remaining tooth structure. It has a bioactive ion exchange union with tooth structure that has been shown to last for long periods (Mount, 1997). There is also sufficient ion exchange with both enamel and dentin to assist in healing demineralized tooth structure so that it is now possible to be very conservative in extending the dimensions of a cavity.

In the presence of these changes, it is possible to review the approach to the control and the restoration of all new lesions, thus, retaining the strength and aesthetics of teeth in spite of the presence of carious lesions.

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Awards

American Academy of Gold Foil Operators
Clinician of the Year Award

Dr Mark J Modjean

Mark J Modjean

It is a distinct pleasure to present this year's AAGFO Clinician of the Year Award to Dr Mark J Modjean, who exemplifies the qualities that this award recognizes. Mark is an outstanding practitioner, educator, study club member and supporter of excellence in dentistry including the use of gold in all forms. He is also active in organized dentistry.

Mark is a native of Minnesota. He was born in St Paul and earned both his BS (1973) and DDS (1977) from the University of Minnesota. Mark married his lovely wife, Dr Suzanne Drost, while in dental school and they celebrated their 26th anniversary this August. Mark is licensed in both Minnesota and Florida (I assume in hopes of someday escaping all the snow he has lived with his entire life).

Mark has divided his professional time between private practice and teaching since his graduation from dental school. He taught two days per week at the University of Minnesota Dental School for 15 years in the departments of Oral Anatomy, Occlusion and Restorative Dentistry, during which time he attained the rank of Associate Professor. In 1992, Mark decided to devote full time to private practice but, until recently, continued providing one day per week to the community clinic sponsored by the Dental School. Now, after celebrating his 50th birthday, he still donates a day per month to the clinic.

Dr Modjean's involvement in study club activity began when he joined the GV Black study club in 1981. He was an extremely active member, serving as Secretary/Treasurer from 1985 to 1987 and then as President in 1988. His study club activity introduced him to the American Academy of Gold Foil Operators and he became an active member in 1996 after operating at the annual session in San Antonio. Mark also served as local arrangements host for the 1998 AAGFO meeting in Minnesota. He provided excellent support as well as arranging an outstanding presentation on the history of the GV Black Study Club, which was celebrating its 100th Anniversary at the time.

Despite his obvious dedication to his profession, Dr Modjean does manage some personal life. He raced formula cars for eight years and now enjoys restoring cars as a hobby. Mark also mentioned that his most current project is losing large sums of money in the stock market, which may adversely affect his ultimate goal of retiring and living long enough to enjoy it!

Again, it is a pleasure to present the 2002 American Academy of Gold Foil Operators Clinician of the Year Award to a well-rounded and dedicated professional. Congratulations, Dr Mark Modjean!

Alan Osborne

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The School of Dentistry at the Oregon Health & Science University is seeking an energetic, progressive, qualified individual for a full-time, tenure-track position as Chair of the Department of Operative Dentistry. The Chair will hold the rank of associate or full professor. The duties of the Chair are to support the missions, goals and objectives of the School of Dentistry. Specifically, the Chair will be responsible for strategic planning, budgeting and staffing the department and fostering the development of junior faculty. The Chair will have ultimate responsibility for the pre-doctoral program in Operative Dentistry. The successful candidate is expected to have demonstrated significant achievement in teaching, research, service, patient care and academic management, as well as possess excellent interpersonal and communication skills. Advanced training in general or operative dentistry or having an advanced degree in biomedical sciences is highly desired. One day per week (0.2 FTE) will be devoted to participation in the Faculty Dental Practice. OHSU is an Equal Employment Opportunity institution. Interested candidates should submit a letter, curriculum vitae and references to Dr Jack L Ferracane, Department of Biomaterials and Biomechanics, Oregon Health & Science University, 611 SW Campus Drive, Portland, OR 97239-3097 (ferracan@ohsu.edu).

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The University of Iowa's College of Dentistry is conducting a search for a full-time clinical or tenure track faculty member in the Department of Operative Dentistry. Major responsibilities include teaching operative dentistry to predoctoral/postdoctoral students, research and intramural practice. Position available July 1, 2003; screening begins immediately. Must have DDS/DMD from an ADA-accredited institution or a foreign dental degree with certification or Master's degree in operative dentistry from an ADA-accredited institution. Desirable qualifications include teaching experience in operative dentistry, background in clinical esthetic dentistry, dental research/training experience and clinical practice experience. Rank/track/salary commensurate with qualifications/experience. Submit CV and three letters of recommendation to Dr Gerald Denehy, 229 Dental Science Building South, College of Dentistry, University of Iowa, Iowa City, IA 52242. *AA/EEO employer; women/minorities encouraged to apply.*

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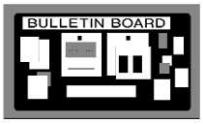

32nd ANNUAL MEETING of the
ACADEMY OF OPERATIVE DENTISTRY
26-28 February 2003
Fairmont Hotel, Chicago, IL

The Academy of Operative Dentistry's 32nd Annual Meeting once again offers an incredible group of essayists, an outstanding table clinic session and a wonderful social program.

SCIENTIFIC SESSION: Thursday begins with Dr Sasha Jovanovic speaking on "Optimal Esthetics with Implant Dentistry," followed by Dr Jimmy Eubanks discussing "Occlusion and Restoration Design." This year's Buonocore Memorial Lecturer is Dr Bart Van Meerbeek, who will present "Bonding to Tooth Tissue: Current Status and Challenges of the Future." Thursday afternoon features Dr William "Buddy" Mopper's presentation on "The Efficacy of Veneering with Direct Bonding" and Dr Shane White explains the new model of enamel microstructure in "Enamel and DEJ: Structure, Function and Why We Need to Preserve It."

Dr Richard D Tucker leads off on Friday morning with "Cast Gold Restorations with Integral Pins," and Dr. Edward McLaren follows with "Ceramic Systems:

Material Considerations and Selection Criteria." Finally, Dr Bruce W Small wraps up the essay sessions with an evidence-based protocol for restorative dental practice titled "Putting it All Together." Friday afternoon's exceptional group of table clinics organized by Dr Richard Kloehn will complete the 2003 Scientific Session.

COMPANION PROGRAM: The Companion Activities Program offers participants an opportunity to enjoy some of Chicago's unique and delicious attractions. On Thursday, a tour bus will whisk registered guests to a "Chef Demo and Lunch" provided by chef Erwin Dreshsler at his very popular Erwin Restaurant. Chef Dreshsler has reserved his entire restaurant for the Academy and will demonstrate the preparation of a three-course lunch that will then be served to attendees.

Friday morning features a "Continental Buffet Breakfast at the Fairmont with Barbara Rinella." Ms Rinella's presentation, "Dramatizing Current Literature—Academic Entertainment" is a fascinating and witty program of history in which she becomes many recent First Ladies to tell their stories of power and perspective.

RECEPTION: Finally, our Gala Reception on Thursday evening will once again provide a wonderful, once-a-year, platform for socializing with all our friends and colleagues from across the country and around the world.

Please do not miss this fantastic opportunity for education, information exchange and fun. See you in Chicago in February!

For more meeting information, please contact Dr Gregory Smith, PO Box 14996, Gainesville, FL 32604-2996; Fax (352) 371-4882.

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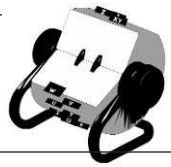

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❒ Supply complete names, degrees, titles and affiliations for all authors (include addresses that are different from the corresponding author's).

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