OPERATIVE DENTISTRY

july-august 1995 • volume 20 • number 4 • 129-172

(ISSN 0361-7734)

OPERATIVE DENTISTRY

JULY-AUGUST 1995 • VOLUME 20 • NUMBER 4 • 129-172

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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 and letters also are published.

OPERATIVE DENTISTRY (ISSN 0361-7734) is published bimonthly for $55.00 per year in the US and Canada (other countries $65.00 per year) by University of Washington, Operative Dentistry, Health Sciences Bldg., Rm D-775, Seattle, WA 98195-7457. Second class postage paid at Seattle, WA, and other selected points. **POSTMASTER:** Send address changes to: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

CHANGE OF ADDRESS: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457 USA.

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EDITORIAL

Is It Too Late to Modify Reality?

In the Volume 2(2), 1977, issue of *Operative Dentistry*, editor A Ian Hamilton stated that state examinations for dental licensure ensured that fundamentals of sound clinical dentistry were taught adequately and that faculty were stimulated to teach at the highest level because of these external examinations. He encouraged improving and strengthening board examinations rather than abandoning them. In the Volume 16(3), 1991 issue, editor David J Bales clearly explained the disparity in the quality of training that dental graduates had when they graduated from dental school. He concluded that examining boards were essential to monitor and influence dental curricula. The reality today is that although the preceding reasons for having external dental examinations are as valid today as they were in the past, the examination process has deteriorated to a level where minimum competency is the standard.

At the state level the increasing cost of maintaining a Board of Dental Examiners and continual legal problems have caused all but a few states to join forces with regional dental examination bodies. The Central Regional and Northeast Regional boards have merged into a large regional body that has been accepted by 24 states, while Texas and Washington have joined the Western Regional board, making that board accepted by 10 states. Although they are valiantly trying to comply, regional examination boards are finding it more and more difficult to adequately verify candidates' suitability to practice given the increasingly diverse curricula of dental schools. The Western Regional board found this out when they gave their first set of examinations in Texas after that state joined their regional examination schedule. The very conservative, valid approach to cavity preparation taught at Texas schools created an enigma for the board members, resulting in a high percentage of failures. The goal of the examiners to be fair and evaluate all applicants based on their fundamental dental school training became an impossible dream. The diversification of curricula being taught at dental schools is substantially growing. For example, there are dental schools that teach no partial coverage cast restoration techniques other than a crash laboratory course to help students pass board examinations *when* their board requires the procedure. Other schools would consider this action the equivalent of malpractice!

Can regional board examinations be devised to be fair to all while still providing a meaningful evaluation? In reality, they can't. The Northeast/Central Regional combined board has initiated simulation laboratory examinations for cast restorations, while the Western Regional board has broadened its definition of "acceptability" to the point where candidates can present unacceptable final restorations to the examiners but still pass the licensure examination. The stated philosophy is that since 95% of graduating students pass the examination by the end of their second try (usually around 65% on the first try and 30% on the second), they have devised an examination that would allow 95% of candidates to pass on the first try. What has this done? In reality, this type of examination has further decimated the original reasons for having an external examination and thus will accomplish nothing more than to be another stressful exercise for graduating students.

The one positive aspect of these examinations, even in their decimated state, is that board requirements will still help clinical disciplines retain valuable curriculum time, for success in these licensure examinations still casts a direct reflection on a school's reputation. Once this is gone, the rape of curriculum time of the clinical disciplines, primarily operative and fixed prosthetics, is inevitable. Does this direction of a watered-down regional dental licensure examination format have a meaningful place in our profession? Unfortunately, the external pressures being exerted are having massive effects, and we are heading toward a single national examination or no examination at all. Will this be good for dentistry? Absolutely not!

What we must do is forget the past and re-establish an examination process that will encourage quality fundamentals to be taught adequately, will stimulate faculty to teach at the highest level, and that will be structured in such a way that enhancement of teaching basic clinical dentistry will result. If organized dentistry cannot or will not join forces to achieve this goal, there will no longer be any useful purpose for retaining external dental licensure examinations. The reality of the situation is that it may already be too late!

RICHARD B McCOY
Editor

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CLINICAL ARTICLE

Coolant Evacuation: A Solution for Students Working without Dental Assistance

J M CHILDERS • T D MARSHALL

INTRODUCTION

This article will be of interest primarily to those individuals who have instructional or administrative responsibility for restorative dentistry being performed in dental school clinics or other institutional settings where dental assisting personnel are in short supply or nonexistent.

The stimulus for the coolant evacuation system to be discussed was supplied by an earlier article published in this journal by Ruiz Benavides and Vásquez Herrera (1992).

THE PROBLEM

The benefit of washed-field technique when utilizing high-speed rotary instrumentation was documented early on by Thompson (1955). Rotary instruments can be expected to maintain their efficiency for longer periods, and the teeth being treated are in less jeopardy from increased thermal temperature.

If the advantages of washed-field operation are to be taught and appreciated, there must be an efficient evacuation method to remove the water. Adequate evacuation of coolant can be a major problem in the typical dental school clinic where the number of operating students can make it prohibitive to supply comparable numbers of dental assistants.

The consequences of this dilemma are the avoidance of coolant use by students whenever possible, inadequate efforts to position and evacuate with a saliva ejector resulting in water dripping on the patient, or diversion of the student operator's attention to handpiece control by holding the high-velocity evacuation tube in the nonhandpiece hand. This can deprive the student of retraction and additional illumination with the dental mirror and will prohibit indirect vision, thereby contributing to poor operator posture.

SYSTEM EVALUATION AND COST DETERMINATION

It should first be stated that the solution to be suggested will be of no benefit if rubber dam isolation is not utilized. It is assumed that rubber dam isolation is a common practice in essentially all dental school clinics.

Recognizing the clinical potential suggested by the Ruiz Benevides and Vásquez Herrera article, the current authors proceeded to secure the recommended system components. Pilot systems were assembled that would allow for evaluation of efficiency, student acceptance, and cost.

The system was found to be entirely adequate, and was enthusiastically endorsed by the students chosen to experience the system. Cost for an individual

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system was determined to approximate $5.50.

To avoid duplication of narrative, the interested reader is referred to the Ruiz Benavides and Vásquez Herrera article for the descriptive assembly of the system and its application and associated pictures that illustrated their technique.

ADMINISTRATIVE CONSIDERATIONS

When the Director of Clinics was approached regarding full implementation of the system in both junior and senior clinics, he expressed concern regarding the annual expense of the units. This was understandable in view of the increased infection control costs that all school clinics are experiencing, and also since it was planned that the units should be disposable after a single use.

In response to these concerns, the possibility of an assembly of simpler components that could be secured in bulk supply at much less cost was investigated. This required some time and many contacts, but resulted in a successful solution. The components are as follows:

In lieu of plastic barb "Y" connectors: PVC clear vinyl tubing, Part #C1003S, I D 1/8", O D 1/4", wall thickness 1/16". Bulk purchase 200 feet. Manufactured by Mojak Plastic, Inc, Vernon, CA 90058.

In lieu of neonatal feeding tubes: clear vinyl tubing, Part #C1001A, I D 1/16", O D 1/8", wall thickness 1/32". Bulk purchase 500 feet. Manufactured by Mojak Plastic, Inc.

The products were secured through Home Depot, a local building supply dealer. The bulk materials allow production of unit systems at *pennies per unit.*

PREPARATION OF THE SYSTEMS FOR USE

The bulk tubings are assigned to dispensary or other staff personnel for preparation. The larger tubing is cut into 2-inch segments. The smaller tubing is cut into 12-14-inch segments. An end of the smaller tubing is inserted snugly into the orifice of the larger tubing segment. The prepared units are then packaged and stocked in the clinic dispensaries for issue to students upon request.

PREPARATION AND APPLICATION BY THE STUDENT

The student uses the largest hole of the rubber dam punch to produce a series of aspiration holes in the terminal end of the small tubing (Figure 1). The holes should involve 1 1/2 inches of the terminal end of the tubing. As the holes are punched, the tubing should be "rolled" so that the holes will be randomly located.

Related to the field of planned operation, the student then determines the most favorable location on the applied rubber dam for the stabilization of the tubing. When this determination has been made, it is beneficial if the tubing is passed between the metal of the rubber dam frame and the rubber dam material (Figure 2). The frictional contact helps to stabilize the tubing. Then the terminal end of the tubing can be anchored by inserting its tip between the bow of the rubber dam retainer and the posterior curtain of the rubber dam (Figure 3). If a winged retainer has been

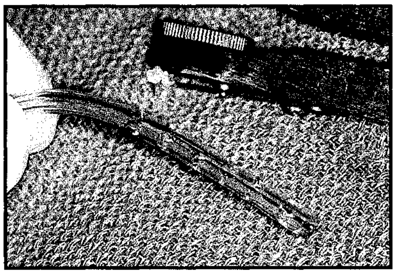
Figure 1. *Aspiration holes randomly located*

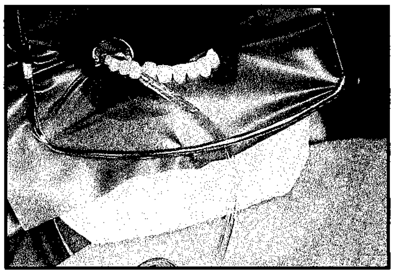
Figure 2. *Tubing stabilized between frame and dam*

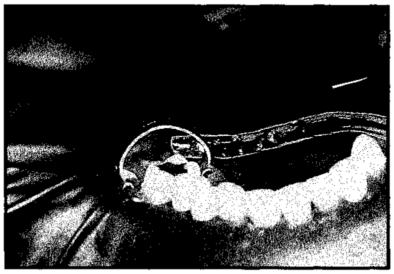
Figure 3. *Tubing anchored between bow of retainer and dam*

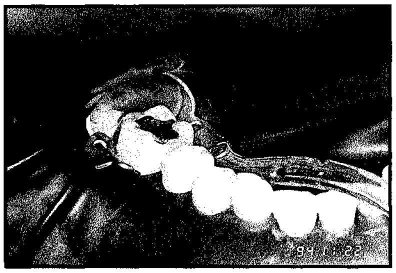

Figure 4. *Tubing anchored under wing of retainer*

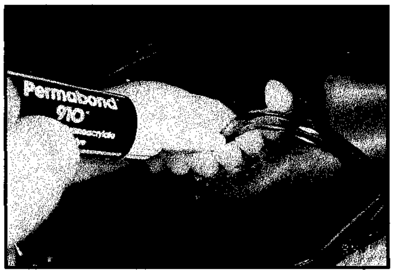

Figure 5. *MINIMAL application of cyanoacrylate glue*

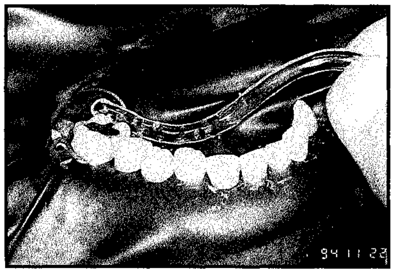

Figure 6. *Tubing bonded to rubber dam*

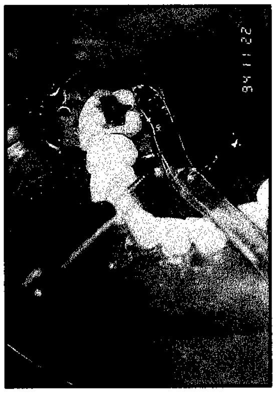

Figure 7. *Water stream directed to check aspiration*

used, the tubing can be stabilized by passing the tubing under the wing (Figure 4). A preferred mode of location and stabilization for the tubing is to place a drop or two of cyanoacrylate glue on the rubber dam, and then hold the tubing in contact with the glue momentarily (Figure 5). The bonding is almost immediate (Figure 6). CAUTION: Use a very minimal amount of the glue, and avoid contact of the glue with the aspiration holes to the degree possible. Careless use of the glue can greatly affect aspiration of the coolant.

Once the tubing is located and stabilized, the distal end of the larger tubing is inserted into the saliva ejector receptacle. The receptacle can be stabilized on the patient's napkin with masking tape. The saliva ejector system is then activated, and a good stream of water from the water syringe is directed at the aspiration holes to check for adequate evacuation (Figure 7).

At completion of treatment, the system is disposed of along with other expendable materials.

CONCLUSION

An evacuation system that allows a dental student, working without assistance, to develop an appreciation for the washed-field technique has been presented. The system as described can be made available for pennies per unit and is disposable. Such a system can increase the operating efficiency of any large clinic.

(Received 6 July 1994)

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ORIGINAL ARTICLES

The Effect of Air Thinning on Dentin Adhesive Bond Strength

T J HILTON • R S SCHWARTZ

Clinical Relevance
Air thinning of three dentin adhesives prior to light polymerization significantly reduced their bond strength to dentin.

SUMMARY

The purpose of this study was to determine if air thinning three dentin adhesives would affect bond strength to dentin. Ninety human molars were mounted in acrylic and the occlusal surfaces ground to expose a flat dentin surface. Thirty teeth were randomly assigned to one of the following dentin bonding agent/composite combinations: A) Universal Bond 3/TPH (Caulk), B) All-Bond 2/Bis-Fil-P (Bisco), and C) Scotchbond Multi-Purpose/Z-100 (3M). The primers were applied following the manufacturers' instructions. The adhesives were applied by two methods. A thin layer of adhesive was applied with a brush to 15 specimens in each group and light cured. Adhesive was brushed on to the remaining 15 teeth in the group, air thinned for 3 seconds, and then polymerized. The appropriate composite was applied in 2 mm increments and light cured utilizing a 5 mm-in-diameter split Teflon mold. Following 3 months of water storage, all groups were shear tested to failure on an Instron Universal Testing Machine. Bond strength was significantly higher in all groups when the dentin bonding agent was painted on without being air thinned. Scotchbond Multi-Purpose had significantly higher bond strength than All-Bond 2, which had significantly higher bond strength than Universal Bond 3.

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INTRODUCTION

Dentin adhesives are used to attain adhesion of composite resin restorative materials to tooth structure. They provide retention, reduce microleakage (Duke, 1993), and improve marginal adaptation (van Dijken & Horstedt, 1987). The adhesion of the dentin bonding agent to dentin is thought to be via the formation of a "hybrid zone," described by Wang and Nakabayashi (1991). The hybrid zone, sometimes called the hybrid layer or interdiffusion zone, has been characterized by scanning electron microscope (SEM) and transmission electron microscope (TEM) analysis and consists of a layer of closely packed collagen fibrils infiltrated with resin (van Meerbeek & others, 1993).

A number of factors can adversely affect the bond to dentin, including the presence of pulpal fluid (Andreaus & others, 1989); chemical, mechanical, and thermal stress (Krejci, Kuster & Lutz, 1993); and polymerization shrinkage of the composite (Feilzer, De Gee & Davidson, 1990). Differences in the coefficient of thermal expansion between resin-based

Table 1. Dentin Bonding Agent/Composite Test Groups

Test Group	Dentin Bonding Agent	Restorative Composite
A	Prisma Universal Bond 3 (L D Caulk, Milford, DE 19963)	TPH
B	All-Bond 2 (Bisco, Inc, Itasca, IL 60143)	Bis-Fil
C	Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144)	Z-100

materials and tooth also stress the adhesive interface (Duke, 1993). It is important to cure the adhesive portion of a dentin bonding agent prior to placement of the overlying composite restoration. Failure to do so can have a significant adverse effect on the restoration seal as measured by microleakage (Crim, 1990) or bond strength (Erickson, 1989).

There are a number of reasons to reduce the thickness of a dentin adhesive. In restorative dentistry, adhesion is aimed at minimizing the interface between restorative materials and remaining tooth structure (Duke, 1993). The application technique utilized for dentin adhesives can have a profound effect on the subsequent bond to tooth. Retief, Wendt, and Bradley (1989) reported that when Scotchbond 2 was placed over 500 µm thick, shear bond strength was significantly reduced. Langdon, Moon, and Barnes (1994) reported that a 200 µm thickness of the same agent significantly reduced tensile bond strength. As the mismatch in the coefficient of thermal expansion between restorative materials and tooth increases, so too does microleakage at the restoration interface. Unfilled acrylic resin such as that found in dentin adhesives has a much greater mismatch with tooth structure than does the more heavily filled restorative composite resins (Bullard, Leinfelder & Russell, 1988). In addition, it is desirable to minimize the amount of unfilled resin utilized due to inferior physical properties in comparison to composite resins (Craig, 1989).

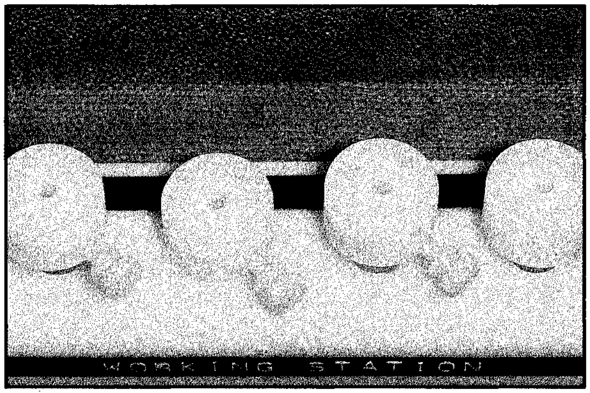

Figure 1. *Specimens with split Teflon mold*

Air thinning of dentin adhesives prior to polymerization has become a common practice and one recommended by most manufacturers (Causton & Sefton, 1989). However, overly aggressive thinning has been implicated as causing a decreased cure of the adhesive (Erickson, 1989). The purpose of this study was to determine the effect of 3-second air thinning on the bond strength of three different dentin bonding systems: Universal Bond 3, All-Bond 2, and Scotchbond Multi-Purpose.

METHODS AND MATERIALS

Tooth Selection and Preparation

Ninety recently extracted human molars free of caries, restorations, cracks or obvious defects were stored in chloramine T (J T Baker, Inc, Phillipsburg, NJ 08865). The roots were notched and the teeth were mounted in orthodontic acrylic resin (L D Caulk, Milford, DE 19963). The occlusal surfaces were ground to expose a flat dentin surface and smoothed with 600-grit silica carbide. Thirty teeth were randomly assigned to each of three dentin bonding agent/restorative composite test groups. Teeth were stored in room-temperature tap water between all procedures.

Test Groups

Table 1 lists the dentin bonding agent/composite test groups (n=30) used. All prepared dentin surfaces were cleaned with flour of pumice using a rubber cup in a slow-speed handpiece (Midwest

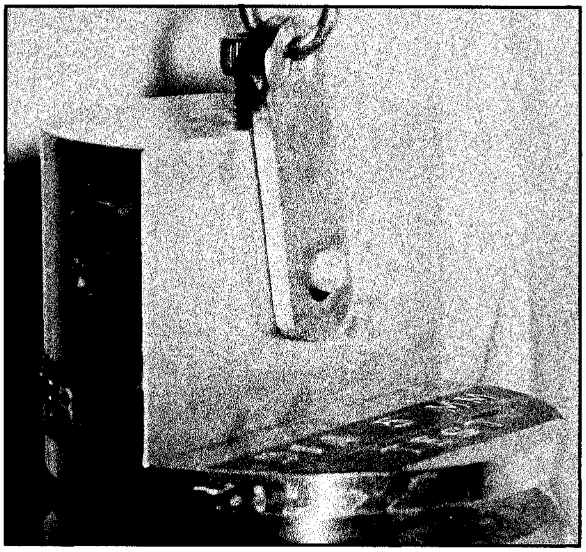

Figure 2. *Test apparatus for shear bond strength determination*

Table 2. Mean Shear Bond Strength in MPa [SD]

	Prisma Universal Bond 3	All-Bond 2	Scotchbond Multi-Purpose
Painted on	9.3 [4.8]	12.9 [5.1]	19.9 [7.1]
Air thinned	5.7 [4.6]	11.4 [5.6]	14.1 [8.9]

Dental Products, Des Plains, IL 60018), rinsed with an air-water spray, and wiped dry with a cotton pellet. Manufacturer's instructions for primer and adhesive application to the dentin surface utilizing brushes supplied in the respective kits were followed. Half of the specimens in each group had the adhesive thinned with a dry brush prior to curing, while the other half had the adhesive air thinned for 3 seconds with oil-free air from a dental unit air syringe prior to curing. The adhesive was cured for 20 seconds using an Optilux 400 visible light cure unit (Demetron Research Corp, Danbury, CT 06810). The specimens were placed in a holding device to facilitate composite application (Sabri Enterprises, Lombard, IL 60148). A 5 mm-in-diameter split Teflon mold (Figure 1) was attached to the dentin surface, and the appropriate composite was added in two 2 mm increments and light cured for 40 seconds per increment. After final cure, the Teflon mold was removed and the specimen placed in water. Following 3 months of storage in water, all specimens were tested to failure with a shear testing device (Figure 2) (Sabri Enterprises) utilizing a Universal Testing Machine (Instron Corp, Canton, MA 02021) at a crosshead speed of 5 mm/minute.

Scanning Electron Microscope Analysis

Two additional unmounted specimens were fabricated for each test group as described above with the exception that the split Teflon mold was not utilized for composite application. Following water storage, the tooth/composite samples were sectioned longitudinally with an Isomet saw (Buehler, Lake Bluff, IL 60044) under water/glycerin lubrication and smoothed successively to a 600-grit silica carbide finish followed by final finishing with flour of pumice. Specimens were desiccated under vacuum prior to sputter coating (Anatech Ltd, Alexandria, VA 22310) and examined with a Phillips model 515 scanning electron microscope (Phillips Electronic Instruments, Makwak, NJ 07430) for differing characteristics of the adhesive layer between the two application techniques and three adhesive systems.

RESULTS

Results of the shear test data are given in Table 2 and Figure 3.

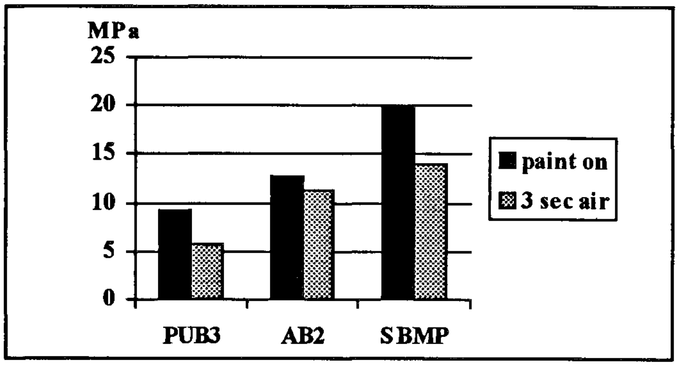

Figure 3. *Mean shear bond strengths*

Two-way ANOVA revealed significant differences between groups for method of application ($P < 0.001$) and dentin bonding agent type ($P < 0.01$), but with no significant interaction ($P > 0.45$). Scheffé's post hoc analysis revealed the following statistically distinct groups: the paint-on method produced significantly higher shear bond strength than 3-second air thinning regardless of which dentin bonding agent was used; Scotchbond Multi-Purpose produced the highest bond strength, followed by All-Bond 2, followed by Universal Bond 3. Visual inspection of the fractured specimens in all experimental groups revealed the failures to be adhesive in nature.

Figure 4 is a scanning electron micrograph of an All-Bond 2 paint-on sample showing a definite adhesive layer of consistent dimension. Figure 5 shows the same adhesive following 3-second air thinning. This SEM demonstrates an overall thinner adhesive layer of variable thickness.

DISCUSSION

The results of this study show that air thinning the adhesive portion of three dentin bonding systems for 3 seconds prior to curing significantly reduces shear bond strength. These results are consistent with the

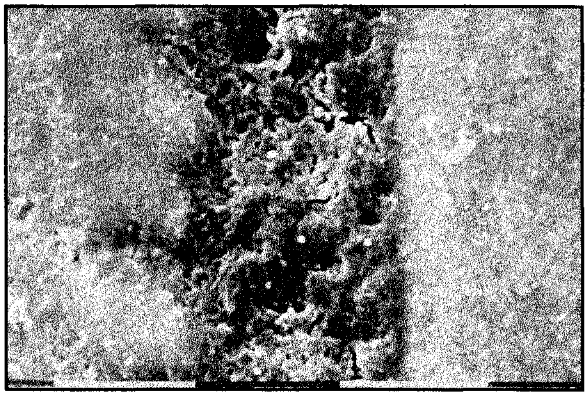

Figure 4. *SEM of All-Bond 2 paint-on sample (dentin on left, All-Bond 2 in center, composite on right, bar = 10 µm, magnification X1425)*

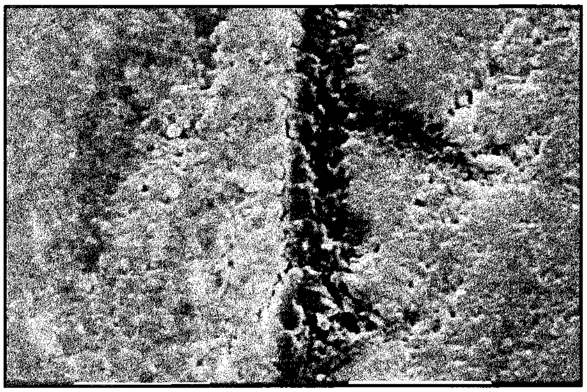

Figure 5. *SEM of 3-second air-thinned All-Bond 2 sample (dentin on right, All-Bond 2 in center, composite on left, bar = 10 µm, magnification X1425)*

findings of Causton and Sefton (1989), who reported that air thinning of Scotchbond 2 significantly reduced the shear bond strength of P-50 to dentin. More recently, air thinning was found to significantly reduce the shear bond strength of the following dentin bonding agent/composite combinations: Denthesive II/Charisma, Optibond/Herculite, and Scotchbond Multi-Purpose/Z-100 (Alian & Powers, 1994). The most likely reason for this result can be found in the chemistry of the polymerization reaction, where free radicals are needed for the formation of the resin polymer (Causton & Sefton, 1989). By virtue of its greater reactivity, oxygen effectively interferes with polymer formation by binding up the reaction sites on the growing radical formation (Ruyter, 1981). Oxygen diffuses through the resin, inhibiting its set until the rate of radical formation matches or exceeds the oxygen diffusion rate (Causton & Sefton, 1989). This results in the formation of an uncured "air-inhibited" layer on the surface of the polymerized resin (Ruyter, 1981). Air thinning reduces the thickness of the adhesive in some areas to the point that the air-inhibited layer extends beneath the dentin, preventing polymerization of resin in the critical resin-dentin interdiffusion (hybrid) zone, adversely affecting bond strength (Causton & Sefton, 1989). In addition, the air stream directed over the adhesive may enhance the rate of diffusion of oxygen through the resin, causing the inhibition zone to extend deeper than in the paint-on groups.

Ruyter (1981) noted that two effects account for the depth of oxygen inhibition: the initiator system and viscosity of the resin. The more viscous a resin, the slower the rate of oxygen diffusion. Although not a factor evaluated in this study, it may be that viscosity variances influenced the bond strengths of the different dentin bonding agent brands and is an area for further research.

The scanning electron micrographs appear to corroborate the rationale presented for the study findings. The paint-on groups demonstrated thicker layers of adhesive that were consistent in depth (Figure 4). The air-thinned groups had narrow layers that varied in thickness, resembling the "waves" or "ripples" of resin observed on SEM (Figure 5).

There appear to be two opposing philosophies in the dental literature regarding the thickness of dentin bonding agents. On the one hand, minimal thickness of the adhesive between composite resin and tooth structure has been recommended (Duke, 1993). A thick adhesive layer can adversely affect bond strength (Retief & others, 1989; Langdon & others, 1994); increase crack propagation, leading to loss of fracture toughness (Tam & Pilliar, 1993); increase the coefficient of thermal expansion mismatch with tooth structure (Bullard & others, 1988); and increase the component with lesser physical properties (Craig, 1989). In addition, a minimal thickness of polymerized bonding agent is required to allow seating of indirect porcelain or composite restorations (Qualtrough & others, 1991). Competing against this is the need to have an adhesive resin layer that is thick enough to allow polymerization in the deeper portion, especially in the resin-dentin zone needed for adhesion to dentin (van Meerbeek & others, 1993) while still allowing for the formation of an uncured layer on the surface that is required to bond subsequent increments of composite (Podshadley, Gullett, & Binkley, 1985). The ideal thickness of a dentin adhesive remains to be determined by further research. However, the results of this study demonstrate that air thinning of dentin adhesives may be contraindicated.

CONCLUSION

1. Three-second air thinning of the adhesive portion of all three dentin bonding agents tested significantly reduced the shear bond strength to dentin.

2. The shear bond strengths of the three dentin bonding agents were statistically different regardless of application technique: Scotchbond Multi-Purpose > All-Bond 2 > Universal Bond 3.

(Received 26 May 1994)

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Shear Bond Strengths of Resin-modified Glass-Ionomer Restorative Materials

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Clinical Relevance
Resin-modified glass-ionomer restorative materials have higher dentin bond strengths than a conventional glass-ionomer restorative.

SUMMARY

The purpose of this study was to evaluate the shear bond strength of resin-modified glass-ionomer restorative materials to dentin. The materials tested were Fuji II LC, Geristore, Photac-Fil, VariGlass VLC, and Vitremer. Ketac-Fil, a conventional glass ionomer, was used as the control. The occlusal surfaces of 60 extracted molars were ground flat in dentin using 600-grit silicon carbide abrasive paper. Dentin surfaces were treated according to manufacturers' instructions, and restorative materials were applied using gelatin capsule matrices. Shear bond strengths were determined after the specimens were thermocycled 500 times. Mean bond strengths of the resin-modified glass ionomers ranged from 1.4 MPa (Photac-Fil) to 12.3 MPa (Fuji II LC). Except for Photac-Fil, all values were significantly higher than the control. Pairwise comparisons between the means for Fuji II LC and Vitremer, Vitremer and Geristore, and Geristore and VariGlass were not significantly different.

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INTRODUCTION

Glass-ionomer cements possess several beneficial properties, including physicochemical adhesion to tooth structure and release of fluoride ions (Walls, 1986). Glass ionomers have gained acceptance in the United States as liners, luting agents, and core build-up materials, but their use as restorative materials has been less common (Reinhardt, Swift & Bolden, 1993). Compared with composite resins, the glass ionomers are relatively unesthetic and have poor physical properties, including low flexural strength and fracture toughness (Walls, 1986; Wilson, 1989). Furthermore, they undergo a long and complex setting reaction and are easily damaged by excessive moisture or desiccation (Mount & Makinson, 1982; Walls, 1986; Wilson, 1989).

In order to overcome these disadvantages, several manufacturers have recently developed resin-modified glass-ionomer restorative materials that are hybrids of conventional glass-ionomer cements and visible-light-activated composite resins. They are more esthetic and less water-sensitive than conventional glass ionomers, but are also harder to use and less esthetic than composite resins (Clinical Research Associates, 1992).

Resin-modified glass ionomers undergo a dual setting reaction. Mixing of their two components (typically a powder and a liquid) initiates the classic acid/base setting reaction of the conventional glass-ionomer cements. In addition, exposure to visible light initiates polymerization of methacrylate groups (Albers, 1990; Watson, 1990; Mitra, 1991). It should be noted that some products touted as resin-modified glass ionomers may have almost no true glass-ionomer properties such as the acid/base reaction, fluoride release, and chemical adhesion to enamel and dentin (Clinical Research Associates, 1993).

Because the resin-modified glass ionomers are such new materials, very few studies of their physical properties or clinical performance have been published. However, several studies presented at a recent research meeting indicated that resin-modified glass ionomers have higher dentin bond strengths than conventional glass-ionomer restorative materials (Burgess & Burkett, 1993; Moon, Covey & Hass, 1993; Pierik, Gartner & Mitra, 1993). As a result, the resin-modified glass ionomers may also have less microleakage than conventional glass ionomers (Chandwani, L'Herault & Nathanson, 1993; Crim, 1993a,b; Fitchie & others, 1993; Sidhu, 1993).

The purpose of this study was to evaluate the shear dentin bond strengths of five resin-modified glass-ionomer restorative systems. The materials tested were Fuji II LC (GC America, Chicago, IL 60658), Geristore (Den-Mat Corp, Santa Maria, CA 93456), Photac-Fil Aplicap (ESPE-Premier Sales Corp, Norristown, PA 19404), VariGlass VLC (L D Caulk/Dentsply, Milford, DE 19963), and Vitremer (3M Dental Products, St Paul, MN 55144). Ketac-Fil Aplicap (ESPE-Premier), a conventional Type II glass-ionomer restorative material, was used as a control. The dentin conditioners and/or primers recommended by the respective manufacturers were used before the restorative materials were applied (Charlton & Haveman, 1993).

METHODS AND MATERIALS

Sixty recently extracted and caries-free human molars were obtained. The teeth were thoroughly cleaned and stored in distilled water containing thymol crystals as a disinfectant. The teeth were removed from the thymol solution and stored in distilled water for at least 24 hours before beginning the experiment.

The teeth were mounted in 1-inch-in-diameter phenolic rings (Buehler, Ltd, Lake Bluff, IL 60044) with cold-cure acrylic resin. The occlusal surfaces were ground flat on an Ecomet V polisher (Buehler) to expose dentin. The dentin was inspected with a dissecting microscope to ensure that no enamel remained. Dentin was polished on the grinder using wet 240-, 400-, and 600-grit silicon carbide abrasive paper.

The specimens were randomly assigned to six treatment groups (n = 10) for bonding with the various resin-modified glass-ionomer restorative materials:

Group 1. GC Dentin Conditioner (10% polyacrylic acid) was applied for 20 seconds using a cotton pellet. The dentin was rinsed with water for 30 seconds and blotted dry (not desiccated) with tissue paper. Encapsulated Fuji II LC, shade C2, was triturated according to the manufacturer's instructions. The material was injected directly into a gelatin capsule (internal diameter = 4.6 mm, length = 5.8 mm; Eli Lilly & Company, Indianapolis, IN 46285) and gently condensed as needed. The capsule was applied to the dentin. After removal of excess, the material was cured from four sides for a total of 80 seconds using an Optilux 401 visible-light-activation unit with an 11 mm curing tip (Demetron Research, Danbury, CT 06810).

Group 2. Tenure Conditioner (Den-Mat) was applied to the dentin surface for 45 seconds. After rinsing with water and blotting the surface with tissue paper, Tenure Primers A and B were mixed and applied to dentin. The primers were applied in multiple coats, until the dentin surface appeared glossy. Geristore pastes A and B (shade 62) were mixed together and loaded into a Centrix (Shelton, CT 06484) syringe and injected into a gelatin capsule. The gelatin capsule was applied to dentin, excess was removed, and the material was light cured for a total of 80 seconds.

Group 3. Ketac-Conditioner (ESPE-Premier), a 25% polyacrylic acid solution, was dispensed onto the dentin surface for 10 seconds. The surface was rinsed with water for 30 seconds and was blotted with tissue paper. Photac-Fil Aplicap shade B3 was triturated according to the manufacturer's instructions. The material was injected and condensed into a gelatin capsule. The gelatin capsule was applied, excess was removed, and the material was light cured for a total of 80 seconds.

Group 4. ProBOND Primer (L D Caulk/Dentsply) was applied to dentin for 30 seconds and dried with compressed air. VariGlass VLC shade A2 was mixed by hand according to the manufacturer's directions. The material was loaded into a Centrix syringe, injected and condensed into a gelatin capsule, applied to dentin, and cured with visible light for a total of 80 seconds.

Group 5. Vitremer primer was applied to dentin for 30 seconds, replenishing as needed to ensure that the surface remained wet. The surface was dried for 15 seconds with compressed air, and the primer was light cured for 20 seconds. Vitremer shade A3 was mixed according to the manufacturer's directions and loaded into a Centrix syringe. The material was injected and condensed into a gelatin capsule. The capsule was applied to dentin, and the material was cured for a total of 80 seconds after excess was removed.

Group 6. Ketac-Conditioner was applied to dentin for 10 seconds. The surface was rinsed with water for 30 seconds and was blotted with tissue paper. Ketac-Fil Aplicap (LY shade) was triturated according to manufacturer's instructions, injected into a gelatin capsule, and applied to the dentin surface. Excess glass ionomer was gently removed as the material set.

For all light-cured specimens, the light guide was positioned as closely as possible to the glass ionomer/dentin interface. Intensity of the curing light was monitored periodically throughout the experiment using a Curing Radiometer (Demetron Research).

The lack of shade uniformity among materials was not a deliberate choice, but rather the result of limited product availability (the various manufacturers did not have the same shades in stock). Specimens were set aside for approximately 20 minutes, then were stored in distilled water for 48 hours. They were thermocycled for 500 cycles in water baths maintained at 5 and 55 °C, with a dwell time of 30 seconds in each bath. Shear bond strengths were tested using a materials testing machine (model 1445, Zwick of America, Inc, East Windsor, CT 06088). A knife-edge shearing device was applied to failure using a crosshead speed of 0.5 cm/min. The fracture loads (kg) were converted to shear bond strengths (MPa) using the cross-sectional area of the bonded posts of restorative material. Data were analyzed using a statistical software program (SAS Institute, Cary, NC 27513).

RESULTS

The results are summarized in the table. Fuji II LC had the highest mean shear bond strength, 12.3 MPa, and the control (Ketac-Fil) had the lowest bond strength, 1.1 MPa. Seven specimens of Photac-Fil and three specimens of Ketac-Fil were debonded either during water storage or thermocycling. Their bond strengths were recorded as zero for the statistical analysis. One-way analysis of variance (ANOVA) revealed a significant difference in mean bond strengths at $P < 0.0001$. Duncan's multiple range test showed that the bond strengths of Fuji II LC and Vitremer were not significantly different from each other at the 95% confidence level. However, Fuji II LC had a significantly higher mean bond strength than any of the remaining materials. The bond strengths of Vitremer and Geristore and Geristore and VariGlass VLC were not significantly different from each other. Photac-Fil and Ketac-Fil had significantly lower bond strengths than any of the other materials tested.

DISCUSSION

Glass-ionomer cements undergo a complex acid/base setting reaction in which polyacrylic acid attacks aluminosilicate glass particles (Smith, 1990). Calcium and aluminum ions released from the glass initiate gelation and hardening of the cement. Recent evidence suggests that subsequent formation of a silica network within the cement improves its strength after initial hardening (Wasson & Nicholson, 1993).

When a glass ionomer is applied to enamel or dentin, polyacrylic acid forms complexes with calcium ions on the tooth surface, resulting in a chemical interaction between substrate and cement (Smith, 1992). In addition, polyacrylate chains displace phosphate ions from the tooth surface (Wilson, Prosser & Powis, 1983). Calcium ions accompany the phosphate ions, forming an ion-enriched layer within the cement adjacent to the tooth surface. Other ion exchanges, particularly of cations, may occur at this interface. Mount (1991) has proposed that this ion-rich layer is the primary mechanism by which glass-ionomer cements bond to dentin and enamel.

Shear and tensile bond strengths reported for conventional glass-ionomer cements are uniformly low, typically in the range of 3-5 MPa (Hotz & others, 1977; Powis & others, 1982; Aboush & Jenkins, 1986). Certain pretreatments of the dentin surface, particularly partial removal of the smear layer with polyacrylic acid, can improve bond strengths somewhat (Powis & others, 1982). Glass-ionomer failures

Shear Bond Strengths (MPa) of Resin-modified Glass-Ionomer Restorative Materials to Dentin

Material	Shear Bond Strength Mean	SD	Duncan Group			
Fuji II LC	12.3	4.9	A			
Vitremer	11.8	5.9	A	B		
Geristore	8.6	4.6		B	C	
VariGlass VLC	5.4	2.5			C	
Photac-Fil	1.4	0.6				D
Ketac-Fil (control)	1.1	0.7				D

Groups with same letter are not significantly different at alpha = 0.05.

appear to be largely cohesive within the cement, so that bond strengths are limited by the tensile strength of the material (Mount, 1991).

Resin components can be added to glass ionomers to improve their physical properties and clinical working characteristics (Mitra, 1991). Many studies of light-activated (i e, resin-modified) glass-ionomer liners have shown that their bond strengths are superior to those of conventional glass ionomers, generally in the range of 6-12 MPa (McCaghren & others, 1990; Strickland, Retief & Russell, 1990; Mitra, 1991; Prati, Pashley & Montanari, 1991; Hinoura, Miyazaki & Onose, 1991; García-Godoy, 1992; Lin, McIntyre & Davidson, 1992; Burgess & Burkett, 1993). Resin-modified restoratives have been introduced only recently, but early studies of these materials have reported similar findings (Burgess & Burkett, 1993; Moon & others, 1993; Pierik & others, 1993). Some of the improved bond strength can almost certainly be attributed to the improved cohesive strength of the resin-modified materials (Mount, 1991).

One recent study (Lin & others, 1992) used scanning electron microscopy and related analytical techniques to identify three factors that are involved in the adhesion of a light-activated glass-ionomer liner to dentin. First, penetration of the glass ionomer through the smear layer and into dentinal tubules is greater than that observed with chemical-cure glass ionomer, so there is more mechanical interlocking with the substrate. Also, the adsorption of a thin, strong polymer layer on dentin may be more rapid with the light-cured material. Finally, the study demonstrated that ion exchanges occur between glass ionomer and dentin at their interface.

Some evidence suggests that dentin adhesives can improve the adaptation (Watson, 1990) and bond strength of light-activated glass-ionomer liners (Hinoura & others, 1991). Similar findings might be expected with resin-modified restorative materials. Two of the materials tested in this study, VariGlass VLC and Geristore, include components of the dentin adhesives ProBOND and Tenure as steps in their bonding protocol. The primer used with Vitremer is similar to that in the Scotchbond Multi-Purpose adhesive system (3M). Also, testing in our laboratory indicates that the use of a dentin adhesive substantially improves the bond strength of Photac-Fil (unpublished data).

The bond strengths of the resin-modified glass ionomers determined in this study are lower than those typically reported for composite resin bonded to dentin with current-generation adhesive systems (Cooley, Tseng & Barkmeier, 1991; Kanca, 1992; Swift & Triolo, 1992). However, composites require relatively high bond strengths for adequate retention and marginal adaptation because substantial shrinkage forces occur within the composite as it polymerizes (Davidson, de Gee & Feilzer, 1984). Setting of conventional glass ionomers involves salt formation, with cross-linking and entanglement of polyacrylate chains rather than polymerization, so shrinkage is less. Therefore, glass ionomers have proved quite effective in clinical studies despite their lower bond strengths (Powell, Gordon & Johnson, 1992). Little is known about shrinkage of resin-modified glass ionomers (Smith, 1992), but microscopic evaluations of liner adaptation indicate that some shrinkage does occur (Watson, 1990; Cooley & Barkmeier, 1991; Burgess & others, 1993). Shrinkage can be reduced by increasing the powder/liquid ratio, which is analogous to reducing shrinkage by increasing the volume fraction of filler in a composite resin (Watson, 1990).

Polymerization shrinkage is likely to be a more significant problem in materials such as Geristore and VariGlass (Clinical Research Associates, 1993) that have resin-like characteristics. These materials may require higher bond strengths than materials that are more like conventional glass-ionomer cements.

Degree of cure might have affected the bond strengths determined in this study. The columns of restorative material applied to dentin substrates were relatively thick (over 4 mm in diameter). Despite light activation from different angles for a total of 80 seconds, light penetration to the glass ionomer/dentin interface may have been less than ideal. Clearly, inadequate curing of material at this interface would result in lower bond strengths. This is one reason that most manufacturers of resin-modified glass-ionomer restorative materials recommend placement and light curing of small increments (2 mm). It should be noted that the two materials with the highest bond strengths in this study also achieve a measurable hardness in approximately 7 minutes even if not light activated, which indicates that they have effective self-cure mechanisms (Clinical Research Associates, 1993).

Glass-ionomer cements, including the resin-modified restoratives, are water-based materials. Presumably, therefore, they will bond better to dentin surfaces that are not completely dehydrated, as is the case with the newer hydrophilic dentin bonding systems (Kanca, 1992). In this study, dentin was blotted dry, not desiccated with air after dentin conditioning. Early clinical studies indicate that visibly moist dentin surfaces are the preferred substrate for bonding with these materials (Wilder & others, 1994).

CONCLUSIONS

Under the conditions of this study:

(1) Fuji II LC had the highest, and Photac-Fil had the lowest, mean bond strength of the resin-modified

glass ionomers tested.

(2) Except for Photac-Fil, all of the resin-modified glass-ionomer restorative materials had significantly higher shear bond strengths to dentin than the control, a conventional Type II glass ionomer.

(3) The bond strengths of Fuji II LC and Vitremer, Vitremer and Geristore, and Geristore and VariGlass VLC were not significantly different from each other.

(Received 27 January 1994)

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Fracture Toughness of Conventional or Photopolymerized Glass Ionomer/ Dentin Interfaces

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Clinical Relevance
The fracture-toughness test could be a useful measure of the integrity of the glass ionomer/dentin interface.

SUMMARY

Several new light-cured glass-ionomer materials have been developed for restorative use. It is not yet clear, however, whether the ability of the conventional glass ionomers to bond chemically to dentin has been preserved in the new light-cured glass ionomers whose chemical compositions have been modified. The fracture toughness test was recently introduced as an appropriate method of measuring the fracture resistance of an interface. We have applied this test to the glass ionomer/dentin interface for the first time.

Ten mini short-rod fracture-toughness specimens were fabricated for each group. Each specimen contained a chevron-shaped glass ionomer/dentin interface along its midplane. After 24 hours in 37 °C water, the specimens were tested by loading at 0.5 mm/min. The interfacial K_{IC} results (MPa·m$^{1/2}$) (SD), analyzed by ANOVA and Fisher's LSD test ($P < 0.05$), were: Chem-fil II, 0.17 (0.04); Vitremer, 0.18 (0.15); Fuji II LC, 0.33 (016). There were no significant differences in interfacial K_{IC} between the conventional and light-cured glass ionomers. Interfacial K_{IC}'s for a light-cured glass ionomer were, however, significantly higher when an intermediary dentin bonding agent was used. SEM examination of the fractured surfaces indicated that crack propagation generally occurred along the bond interface, and indicated the formation of a resin-infiltrated layer when the dentin bonding agents were used. It was concluded that the fracture-toughness test could be a useful measure of the integrity of the glass ionomer/dentin interface. The clinical effect of an intermediary layer between the glass ionomer and the tooth structure is, however, unknown and requires further investigation.

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INTRODUCTION

Glass-ionomer cements are often the restorative material of choice for selected lesions because of their ability to bond by physicochemical mechanisms to enamel and dentin and because of their ability to inhibit secondary decay (McLean & Wilson, 1977; Smith, 1990). However, conventional glass-ionomer cements have poor tensile strength properties, are extremely technique-sensitive, have a long maturation time, and have poor handling properties.

Recently, new glass-ionomer materials have been introduced that are photopolymerizable. The promise of improved physical, bonding, and handling properties for photopolymerizable glass ionomers, in addition to sustained fluoride releases, make the use of photopolymerizable glass ionomers appear almost ideal for class 5, root, and abrasion lesions. The clinical history of the new photopolymerizable glass-ionomer materials has, however, been relatively short thus far. The compositional nature of the photopolymerizable glass ionomers varies between that of a resin composite and a glass ionomer. Such materials incorporate light-activated resin components such as pendant methacryloxy groups, HEMA, and photosensitizers. The setting reaction of these materials therefore includes the initial free radical photopolymerization of the resin components in addition to the slower acid-base reaction of the parent conventional glass ionomers (Mitra, 1991). A recently introduced restorative glass-ionomer material has now claimed to have incorporated a third curing mechanism based on the autocure reaction of resins. It has been suggested that some of the new light-cured materials may behave more like a resin composite than that of a glass ionomer (Tam, McComb & Pulver, 1991). It was, therefore, hypothesized that the bond of the photopolymerizable glass ionomers to enamel and dentin could benefit further by the use of dentin bonding agents.

The bond strength test is one of the most commonly used tests for dentin-bond characterization. Several studies have measured the shear and/or tensile bond strength of conventional and photopolymerizable glass ionomers to dentin (Aboush & Jenkins, 1986; Joynt & others, 1990; McCaghren & others, 1990; Mitra, 1991; Hewlett, Caputo & Wrobel, 1991; Lin, McIntyre & Davidson, 1992; Prati & others, 1992; Rusz & others, 1992; Chadwick & Woolford, 1993; Cortes, García-Godoy & Boj, 1993). The reliability and validity of conventional bond strength tests, however, have been questioned. A closer examination of the failed bond strength specimen surfaces revealed that the failure occurred either cohesively within the glass ionomer or the smear layer. A resultant cohesive fracture of the glass-ionomer substrate could be attributed either to a strong adherence of the glass ionomer to the dentin or to poor strength properties of the glass ionomer itself. It is likely that the nonuniform stress distribution generated during conventional bond strength testing (Van Noort & others, 1989, 1991) contributes to the glass-ionomer material fractures. When substrate fractures occur, bond strength test results become more a measurement of the material's strength properties (and cross-sectional area of fracture) than of the actual integrity of the bonded interface.

Table 1. Glass-Ionomer Materials and Dentin Bonding Agents Used for Bonding to Dentin for Each Test Group

Group 1	Chem-Fil Express (De Trey/Dentsply, Weybridge, Surrey, England)
Group 2	Vitremer Tri-Cure Glass Ionomer System (3M)
Group 3	Fuji II LC Light-Cured Glass-Ionomer Cement for Restorative Filling (GC America, Inc, Chicago, IL 60658)
Group 4	Fuji II LC Light-Cured Glass-Ionomer Cement for Restorative Filling plus All-Bond 2 (Bisco) (conditioner and adhesive)
Group 5	Fuji II LC Light-Cured Glass-Ionomer Cement for Restorative Filling plus All-Bond 2 (conditioner, primer, and adhesive)
Group 6	Fuji II LC Light-Cured Glass-Ionomer Cement for Restorative Filling plus Multi-Purpose (3M) (conditioner and primer)
Group 7	Fuji II LC Light-Cured Glass-Ionomer Cement for Restorative Filling plus Multi-Purpose (conditioner, primer, and adhesive)

Fracture mechanics parameters offer a means of assessing bonding integrity, since they describe the intrinsic fracture resistance of the interface (Rice, 1988). Interfacial fracture toughness (K_{IC}) results should, therefore, account for both intrinsic bond strength and inherent defects across the interface. The plane-strain fracture-toughness test was recently introduced as an appropriate method of measuring the fracture resistance of a resin composite-dentin interface (Tam & Pilliar, 1993). The miniature short rod specimen geometry contained a chevron-shaped bonding area specifically designed to develop a significant stress concentration at the interface. Bond failures occurred along the bond plane during interfacial fracture toughness testing.

The objectives of this study were:

1. to assess the use of the novel interfacial fracture-toughness test for measuring the bond integrity of a dentin/glass ionomer interface, an interface which is frequently subject to nonbond plane failures during conventional bond strength testing,
2. to compare the interfacial fracture resistance of dentin/photopolymerizable glass ionomer interfaces versus a dentin/conventional glass ionomer interface, and
3. to examine the effects of using the components of an intermediary dentin bonding agent on the fracture resistance of a dentin/photopolymerizable glass ionomer interface.

METHODS AND MATERIALS

The photopolymerizable glass-ionomer materials (Groups 2 and 3) are listed in Table 1. A conventional glass ionomer (Group 1) was also included in the study for comparison. All-Bond 2 Universal Dental

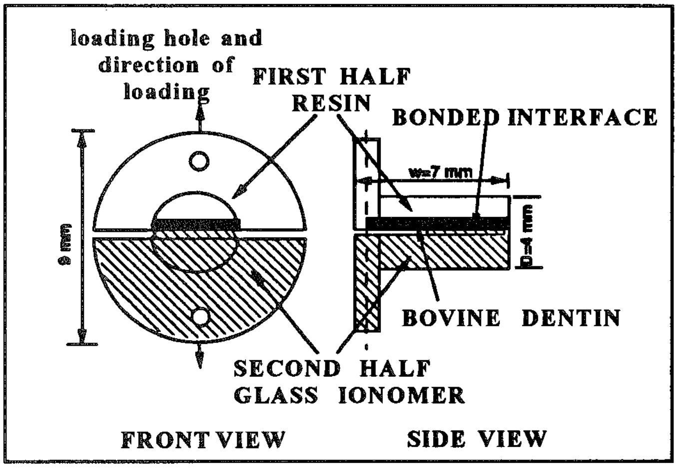


Figure 1. *Miniature short-rod fracture-toughness specimen for testing the glass ionomer/dentin interface*

Adhesive System (Bisco, Itasca, IL 60143) and Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144) were used as the intermediary dentin bonding agents (Groups 4-7).

Ten miniature short-rod fracture-toughness specimens were made for each test group. Each specimen contained a chevron-shaped glass ionomer/dentin-bonded interface along its midplane (Figure 1). The method for specimen fabrication and interfacial fracture toughness calculation is detailed in Tam and Pilliar (1993). Generally, a slice of bovine dentin was initially bonded to resin composite (Bis-Fil Light Cure Small Particle Composite for All-Purpose Bond, Bisco) using the acid-etched enamel technique to form a half specimen with an exposed dentin surface for bonding. This dentin surface was subsequently polished on wet 600-grit SiC paper, rinsed copiously with distilled water, and carefully treated according to the manufacturer's instructions for the glass-ionomer or dentin bonding material (Table 2). The powder and liquid components of the glass-ionomer materials, which had been dispensed by weight, were then immediately mixed, loaded into a syringe (Centrix, 3M), and placed against the dentin surface and into the mold to form the completed specimen. A highly polished stainless steel spacer was used between the dentin and glass ionomer to form the chevron-shaped bonding area. The photopolymerizable materials were light cured for 2 minutes within the mold and for 2 minutes out of the mold to ensure complete polymerization (Triad light-curing unit, model TCU-1, Dentsply International Inc, York, PA 17405). The conventional glass-ionomer specimens were kept within the mold and protected from dehydration and water contamination for 1 hour prior to demolding. Attempts to demold the conventional glass-ionomer specimens at earlier time intervals led to crazing and premature specimen failure by fracture of the conventional glass-ionomer bulk material. All fracture-toughness specimens were placed into distilled water immediately after fabrication.

Table 2. Steps Used for Bonding the Glass-Ionomer Material to Dentin for Each Test Group

Group	Dentin Treatment	Priming Step	Adhesive Step
Group 1	—	—	—
Group 2	—	Primer 30 seconds and light cure*	—
Group 3	10% polyacrylic acid 20 seconds	—	—
Group 4	10% phosphoric acid 15 seconds	6 coats Primer A,B	—
Group 5	10% phosphoric acid 15 seconds	6 coats Primer A,B	Bonding resin*
Group 6	10% maleic acid 15 seconds	Primer	—
Group 7	10% maleic acid 15 seconds	Primer	Adhesive

*Polymerized using Translux II (Kulzer, Wehrheim, Germany)

After 24 hours' storage in water at 37 °C, the specimens were mounted on specially designed jigs to the Instron Universal Testing Machine (model TTCM, Instron, Canton, MA 02021). A tensile load was applied to each specimen at an extension rate of 0.5 mm/min. The peak load measured at the time of specimen failure was obtained for each specimen and the plane-strain interfacial fracture toughness (K_{IC}) was calculated. The interfacial K_{IC} results were analyzed by ANOVA and Fisher's LSD test ($P < 0.05$). All fractured specimens were viewed under X2.5 light magnification to determine the general type of specimen failure (adhesive versus cohesive). In addition, representative fracture surfaces from each test group were examined under the SEM to confirm the location of failure.

RESULTS

The interfacial K_{IC} results are summarized in Table 3. There were no significant differences in interfacial K_{IC} results between the photopolymerizable and the conventional glass ionomers when manufacturer's recommendations were followed for bonding to dentin. The addition of intermediary dentin bonding agent components significantly increased the fracture resistance of a photopolymerizable glass ionomer/dentin interface.

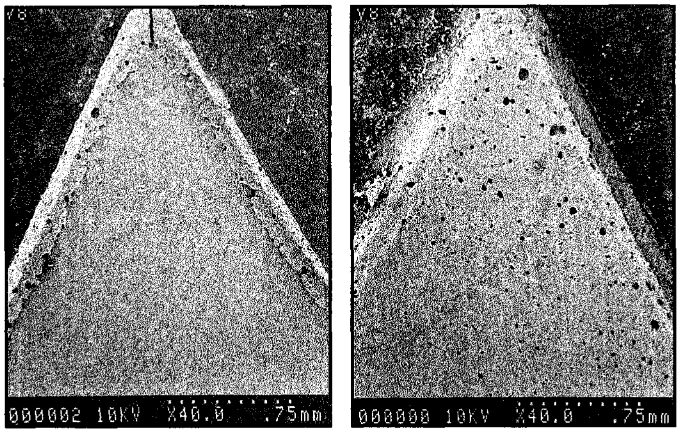
Under X2.5 magnification, the fracture surfaces appeared flat. This indicated that bond failure generally occurred along the interface (adhesive-type

*Table 3. 24-Hour Interfacial Toughness Results**

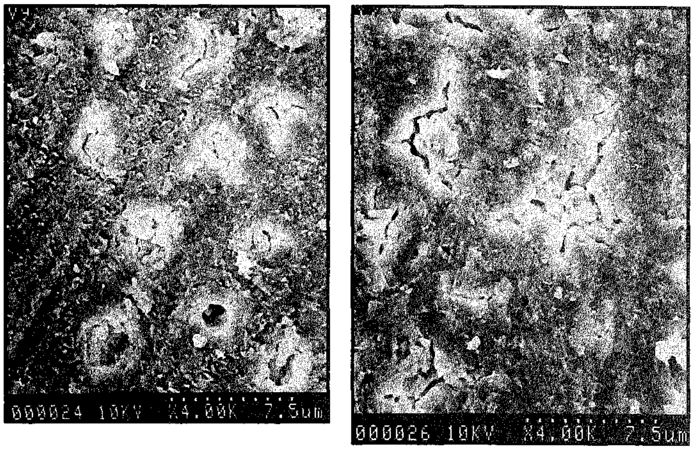
GROUP	K_{IC} (MPa·m$^{1/2}$) n	x	SD
Group 1	8	0.17	0.04
Group 2	10	0.18	0.15
Group 3	10	0.33	0.16
Group 4	10	0.63	0.14
Group 5	10	0.52	0.18
Group 6	10	0.54	0.21
Group 7	10	0.53	0.24

*Vertical bar denotes no significant difference ($P < 0.05$).

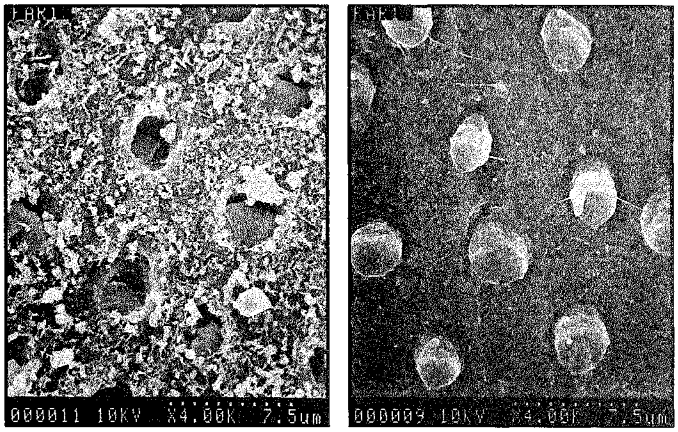
failure). SEM examination of the fractured surfaces confirmed that the crack propagation generally occurred along the bond plane (Figures 2A and 2B). Under higher magnification, irregular groove markings and occluded tubules, generally associated with the presence of a smear layer, were visible on the dentin fracture surfaces of Groups 1-3, the glass ionomer/dentin interfaces where no dentin bonding agent components were used (Figure 3A). The Group 3 dentin fracture surfaces, whose surfaces were treated with polyacrylic acids, did show a few open tubules, however. The opposing glass-ionomer fracture surfaces of Groups 1-3 did not show evidence of penetration of the glass-ionomer material into the tubules (Figure 3B). The voids and defects seen on the glass-ionomer fracture surface represent a poor adaptation of the glass-ionomer material to the dentin surface in the region of the tubule orifices. For the conventional and photopolymerizable glass-ionomer interfaces in which no dentin bonding agent components were used, bond failure appeared to occur within the smear layer between the dentin and glass-ionomer material.



Figures 2A & 2B. *Vitremer dentin (left) and glass-ionomer (right) fracture surfaces (X20). The original chevron shape of the bonded interface is apparent. SEM examination of the fractured surfaces indicated that bond failure generally occurred along the interface (adhesive-type failure). The voids on the glass-ionomer fracture surfaces were likely a result of air incorporation during material mixing.*

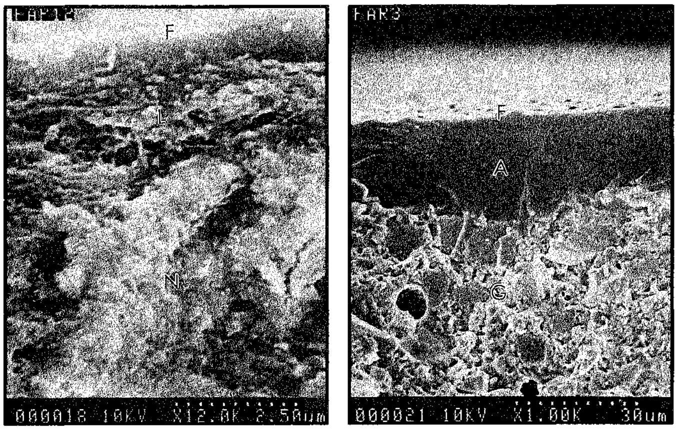


Figures 3A & 3B. *Fuji (Group 3) dentin (left) and glass ionomer (right) fracture surfaces (X2000). The dentin fracture surface showed a smear layer and generally occluded dentinal tubules. The glass-ionomer surface contained voids, and there was generally no penetration of the glass-ionomer material into the dentinal tubules.*



Figures 4A & 4B. *Fuji (Group 5) dentin (left) and glass-ionomer (right) fracture surfaces (X2000). The smear layer has been removed and the opened dentinal tubules contain fractured resin tags on the dentin fracture surface. Fractured resin tags can also be seen to project from the glass-ionomer fracture surface.*

In contrast, for Groups 4-7, when the dentin bonding agent components were used, there was evidence of smear layer removal, dentin demineralization, and resin penetration into the tubules. When the adhesive resin component of the dentin bonding agent was used, the dentin fracture surfaces showed opened tubules containing fractured resin tags (Figure 4A). The opposing glass-ionomer fracture surfaces showed resin tags projecting from the bond plane (Figure 4B). Transverse sections of the Groups 4-7 dentin fracture surfaces showed the formation of an interfacial dentin interdiffusion zone 1-4 μm wide in the intertubular dentin regions (Figure 5A). Below this interdiffusion zone, the dentin appeared normal and unaffected by the bonding procedures. Transverse sections of the opposing glass-ionomer fracture surface showed the adhesive resin layer attached to the underlying glass-ionomer material when the adhesive resin component was used (Figure 5B). Bond failure thus appeared to occur at the interdiffusion zone/adhesive resin interface when the adhesive resin component was used. When the adhesive resin component of the dentin bonding agent was not used, bond failure appeared to occur at the interdiffusion zone/glass-ionomer material interface.



Figures 5A & 5B. *Fuji (Group 5) dentin (left, X6000) and glass-ionomer (right, X500) fracture surfaces (cross-section). A resin-infiltrated layer was formed when an intermediary dentin bonding agent was used. Bond failure occurred at the resin-infiltrated layer/adhesive resin interface. L = resin-infiltrated layer; N = normal dentin; F = fracture surface; A = adhesive resin; G = glass-ionomer material.*

DISCUSSION

Plane-strain fracture toughness is a fundamental parameter used to characterize a material's resistance to crack propagation and is material intrinsic. By establishing K_{IC} results for glass ionomer/dentin interfaces, the fracture toughness of this material interface could be compared with other reported K_{IC} results. The K_{IC} for dentin has been recorded as 3.08 ± 0.33 MPa · $m^{1/2}$ (El Mowafy & Watts, 1986). The K_{IC} results for conventional glass ionomers have ranged between 0.42 - 0.55 MPa · $m^{1/2}$ (Goldman, 1985; Lloyd & Adamson, 1987). The fracture toughness of the glass ionomer/dentin interface (if used according to manufacturer's instructions: without an intermediary dentin bonding agent) was far below that of dentin and slightly below that of the conventional glass ionomers. The glass ionomer/dentin interface would, therefore, likely be the weak link in a glass-ionomer-bonded-to-dentin restoration. SEM examination of the fracture surfaces indicated that crack propagation did generally occur along the bond plane. In this regard, it is concluded that the fracture-toughness test could be a useful measure of the integrity of the glass ionomer/dentin interface. There are a number of difficulties with this interfacial fracture toughness test when applied to the glass ionomer/dentin interface, however. These include the complexity of the fracture-toughness specimen, the fragility of some of the glass-ionomer-to-dentin bonds in the presence of the deliberately placed stress concentrator, and the assumption of equal compliance for the two specimen halves. Although the latter could be compensated for by adjusting the specimen geometry for the two halves, it makes the process of specimen fabrication for a wider range of materials with different elastic moduli much more difficult. A preliminary investigation determined the mean modulus of elasticity for each of the dental materials used in the fabrication of the fracture-toughness specimens (Table 4). The results suggested that the difference in compliance between the glass ionomer and resin-composite specimen halves would have been greatest in the Vitremer and Fuji II LC fracture toughness specimens and least in the Chem-fil fracture toughness specimens. The effect of a nonuniform modulus of elasticity throughout the total specimen requires further investigation.

Reported values for fracture toughness of resin composite/dentin interfaces have ranged between 0.20-0.69 MPa · $m^{1/2}$ (Tam & Pilliar, 1993). The fracture toughness of the glass ionomer/dentin interface is, therefore, comparable to that of weaker resin composite/dentin interfaces. Although the interfacial K_{IC} results were generally higher for the photopolymerizable glass ionomers than for the conventional glass ionomers, no significant differences

*Table 4. 24-Hour Modulus of Elasticity Results**

GROUP	n	Modulus of Elasticity (GPa) x	SD
Chem-Fil	6	7.36	1.68
Vitremer	9	5.76	1.16
Fuji II LC	10	5.76	0.84
Bis-Fil	8	10.63	1.35

*Determined by flexure of 2 mm x 2 mm x 20 mm rectangular bar specimens (X-head speed at 0.5 cm/min). Vertical bar denotes no significant difference ($P < 0.05$).

were found. This could be explained by the observation that in all these cases, bond failure generally appeared to occur within the smear layer. Alternatively, some investigators have reported the presence or formation of a thin intermediate layer at the glass ionomer/dentin interface (Watson, 1990; Geiger & Weiner, 1993; Sidhu & Watson, 1994). It is possible that bond failure could occur at this altered glass-ionomer material interface.

The fracture-toughness results suggested that the components of a new-generation dentin bonding agent, at least its conditioner and primer components, could be used to improve the bonds of a photopolymerizable glass ionomer to dentin. The SEM examination showed that the etching procedure removed the smear layer, opened the dentinal tubules, and demineralized the surface dentin to a depth of 1-4 µm. This would permit the formation of a primer- and resin-infiltrated layer and resin tags. Primers are generally bifunctional monomers that have an affinity for both dentin and resin. The recent improvements in the bonding of resin composites to dentin using the newer dentin bonding agents have primarily been attributed to a micromechanical mechanism, largely in the form of the resin-infiltrated layer (Van Meerbeek & others, 1992; Pashley & others, 1993). The removal of the smear layer and infiltration of the intertubular demineralized dentin by primer alone or by the primer and the resin adhesive increased the fracture toughness of a photopolymerizable glass ionomer/dentin interface significantly to a level similar to that of a resin composite/dentin interface using the same new-generation dentin bonding agent. When the etching and priming components of the dentin bonding agents were used, bond failure occurred at the junction between the primer-infiltrated demineralized dentin layer and the glass ionomer. When all the components of the dentin bonding agents were used at the glass ionomer/dentin interface, the resin adhesive layer appeared to bond intimately to the resin in the photopolymerizable glass ionomer. Bond failure generally occurred at the junction between the resin-infiltrated layer and the overlying resin adhesive layer. This corresponded to the fracture site for the resin composite-dentin interface (Tam & Pilliar, 1994). The increase in the fracture toughness results for these glass ionomer/dentin interfaces containing the components of a dentin bonding agent could, therefore, also be attributable to micromechanical mechanisms.

The ability of a material to inhibit recurrent caries formation is an important clinical property. Conventional glass-ionomer materials have been shown to inhibit secondary caries formation on the tooth surface (by a topical effect of the fluoride released into the saliva) and along the tooth/restoration interface (Hattab, Mok & Agnew, 1989; Hicks, Flaitz & Silverstone, 1986; Retief & others, 1984; Serra & Cury, 1992). A sustained fluoride release and an intimate contact of the restoration to the tooth margins is needed to facilitate the exchange of fluoride into the hydroxyapatite of the surrounding tooth material. The addition of an intermediary layer, particularly a resin adhesive layer, between the glass iomomer and the dentin could, therefore, prevent or reduce the amount of fluoride incorporation into the adjacent dentin. Yet a well-sealed margin should prevent microleakage and wall lesion formation, thereby reducing the need for fluoride along the tooth/restoration interface. Thus, the disadvantage of reduced fluoride incorporation along the tooth/restoration interface must be weighed against the advantage of improved bonding at the interface. The surface of the tooth structure adjacent to a well-sealed glass-ionomer restoration should still benefit from the topical release of fluoride. The clinical effect of an intermediary layer between the glass ionomer and the tooth structure is unknown. The manufacturer's instructions for Vitremer do suggest that a primer layer be placed between the tooth and the glass ionomer. However, the smear layer was not removed and the resultant interfacial fracture toughness results for this system were relatively low. The use of the etching and priming components—without the resin adhesive—from a new-generation dentin bonding agent could both increase the integrity of a photopolymerizable glass ionomer/dentin bond and still allow fluoride release into adjacent tooth material. Further investigations are being planned by the authors.

CONCLUSIONS

1. SEM examination of the fracture surfaces indicated that crack propagation generally occurred along the bond interface. It is concluded that the fracture toughness test could be a useful measure of the integrity of the glass ionomer/dentin interface.
2. There were no significant differences in interfacial K_{IC} results between the photopolymerizable and the conventional glass ionomers when manufacturers' recommendations were followed for bonding to dentin.
3. The addition of an intermediary dentin bonding agent significantly increased the fracture resistance of a dentin/photopolymerizable glass-ionomer-bonded interface. This corresponded with the formation of a dentin interdiffusion zone and resin tags between the dentin and glass-ionomer substrates, and suggested that dentin bonding agents could be used to improve the bonds of a photopolymerizable glass ionomer to dentin. The clinical effect of an intermediary layer between the glass ionomer and the tooth structure is, however, unknown and requires further investigation.

(Received 26 May 1994)

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Reduction of Marginal Gaps in Composite Restorations by Use of Glass-Ceramic Inserts

L A GEORGE • N D RICHARDS • F C EICHMILLER

Clinical Relevance
The use of a glass-ceramic insert decreased the marginal gaps resulting from polymerization shrinkage.

SUMMARY

The objective of this study was to evaluate the effects of glass-ceramic inserts on reducing the marginal gaps caused by polymerization shrinkage in composite restorations. A light microscope was used to measure the largest gap at margins around restorations made in glass cylinders and tooth cavities with and without adhesion promoters. Where the cylinder was not silanated, the average gap was less in samples containing an insert than in those without. Two preparations were made in the dentin of 20 human molars. In each molar one cavity was restored with a dentin bonding agent and composite and the other with a dentin bonding agent and an insert seated in the composite. The average maximum gap width of restorations containing inserts was statistically less than for those with only composite (paired *t*-test, $P < 0.0001$). When considering the volume of composite displaced by the insert, these results indicate that the use of a glass-ceramic insert decreased the marginal gaps resulting from polymerization shrinkage.

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INTRODUCTION

Since the introduction of composite resin restorative materials in the 1960s (Bowen, 1962, 1963), these widely used materials have been the subject of numerous studies to improve their properties. Much attention has been focused on the polymerization shrinkage of these materials. If the polymerization shrinkage is great enough, the resulting stresses can compromise the union (chemical bonding and/or micromechanical interlocking) of the composite with the cavity surfaces of the tooth. If the polymerization stresses exceed the strength of the composite-tooth bond, then bond breaking occurs and causes a gap to form between the tooth and the restoration (Asmussen & Jorgensen, 1972). Measurement of this gap has been interpreted to represent an evaluation of efficacy of the attachment of the restorative material to the tooth structure (Asmussen & Jorgensen, 1972). Hansen (1982) examined four light-cured composite resins and found that they shrank linearly from 0.24% to 0.63% (average gap width calculated as percent of the diameter of the cavity).

If the amount of polymerizing material in composite restorations could be reduced, the detrimental problem of polymerization shrinkage would decrease. Studies have shown a decrease in microleakage around composite restorations in which silane-treated glass-ceramic inserts were incorporated (Bowen, 1987; Donly & others, 1989). Results of those studies suggest that marginal gaps between the composite and the cavity wall would decrease with the incorporation of glass-ceramic inserts. Previous researchers have utilized light microscopes with measuring oculars to study the marginal gap associated with polymerization shrinkage in composite restorations (Hansen & Asmussen, 1989; Fujimitsu & others, 1989). The purpose of this investigation was to evaluate the effects of glass-ceramic inserts on the marginal gap that results from polymerization shrinkage of composite restorations in model and in vitro dentinal cavities.

METHODS AND MATERIALS

The effects of glass-ceramic inserts on the marginal gap around composite restorations were evaluated by use of light microscopy. Two experiments were carried out, one with restorations placed in glass cylinders (model cavities) and the other with restorations placed in cavities in the dentin of extracted human molars.

Experiment 1 (Model Cavities)

A 3x2 complete factorial experiment was carried out. The two factors involved were as follows: (1) insert at three levels: no insert, nonsilanated insert, and silanated insert; and (2) glass cylinder at two levels: cylinder walls silanated and cylinder walls not silanated, for a total of six treatments. The experiment was replicated six times and blocked by day for a total of 64 specimens prepared in 2 days. The open glass cylinders were 4 mm long with an inner diameter of 3.9 mm and an outer diameter of 5.95 mm. Sixteen pairs of specimens were prepared each day; one of the cylinders in each pair was filled with a BIS-GMA-based composite (Silux Plus, 3M Dental Products, St Paul, MN 55144) and the other with the composite and either a silanated or nonsilanated tapered-cylinder glass-ceramic insert with a diameter ranging from 1.4 mm to 1.8 mm and a length of 3.6 mm (ß-Quartz Inserts, Lee Pharmaceuticals, South El Monte, CA 91733). The inner walls of half the cylinders were painted with 3-methacryloxypropyltrimethoxysilane (Enamalite 500, Lee Pharmaceuticals). Following the application of the silane, the inner wall of each of the cylinders was painted with a thin layer of BIS-GMA-based unfilled resin (Mirage, Chameleon Dental Products, Kansas City, KS 66101), and the cylinder was filled with a composite (Silux Plus, 3M). The individual products chosen were based upon chemical compatibility and not upon particular clinical considerations. The same procedure was followed for the other half of the cylinders with the exception of the silane. A glass-ceramic insert, either silanated or nonsilanated, was painted with unfilled resin and embedded in the composite in one of the cylinders of each pair. The composite was cured from the top side of the cylinder for 2 minutes with a visible curing light with a 9 mm tip (The Max, L D Caulk, Milford, DE 19963). The cured specimens (Figure 1) were stored at 37 °C in a 100% humidity chamber for 96 hours. The specimen cylinder ends (Figure 2) were then finished to a flat surface with 240-grit SiC paper (Mager Scientific, Dexter, MI 48130) under water. The marginal gap between the wall of the cylinder and the composite was measured with a light microscope (Olympus B03, Olympus, Tokyo, Japan) equipped with a measuring ocular. The margin was surveyed, and two observers measured the largest gap at a magnification of X100. Each observer took three measurements for a total of six readings for each specimen.

Experiment 2 (Dentinal Cavities)

The mesial or distal root surface dentin of 20 human molars that had been stored in distilled water and 0.2% sodium azide since extraction was cut with a slow-speed dental lathe to provide a flat plane large enough for two preparations. Two cylindrical preparations approximately 3 mm in diameter and 1.5 mm deep were made side by side in the flat surface of each tooth. Aqueous nitric acid (2.5%wt/

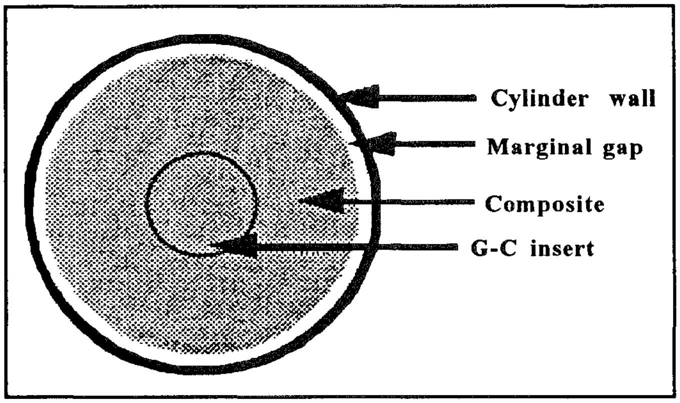

Figure 1. *Sample configuration of specimens in glass cylinders used in Experiment 1*

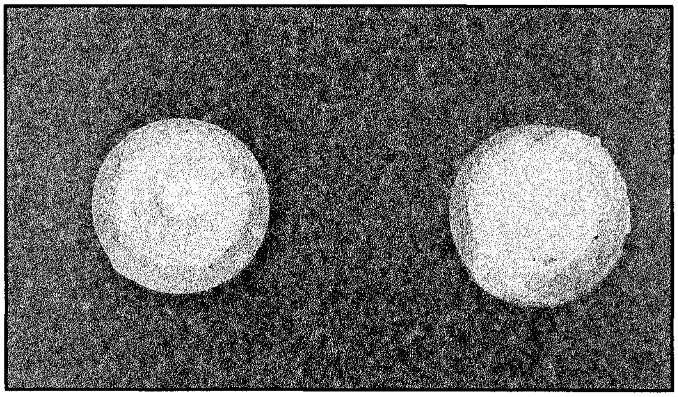

Figure 2. *Cylindrical specimens with and without insert used in Experiment 1*

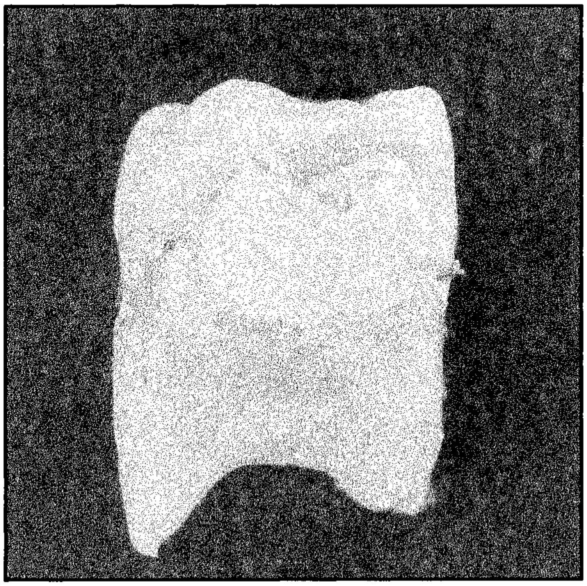

Figure 3. *Restoration specimen used in Experiment 2*

wt) was agitated on the surface for 60 seconds, then rinsed with distilled water for 10 seconds, and dried with a gentle air stream for 10 seconds. Five sequential coats of a mixture of PMGDM (the reaction product of pyromellitic dianhydride), PMDA, GDM (glycerol dimethacrylate), and the Mg salt of NTG-GMA (the reaction product of N(p-tolyl) glycine and glycidyl methacrylate) (Mirage ABC, Chameleon Dental) were painted on the surface and air dried after all coats had been placed. The tooth preparations were filled with a composite (Mirage FLC, Chameleon Dental) in one increment. A silanated tapered-cylinder glass-ceramic insert was embedded in the composite of one of the two restorations prior to curing. The restorations comprised of composite alone were cured for 1 minute, and the restorations comprised of composite and insert were cured for 2 minutes. The additional 1-minute curing time was to ensure a maximum cure around and under the insert, thereby maximizing the resulting shrinkage. The teeth were stored at 37 °C in a 100% humidity chamber for 5 days. The restorations (Figure 3) were then finished with fine-grit diamond burs and Sof-Lex disks (3M). Measurements of the marginal gap were made with the same procedures used in Experiment 1.

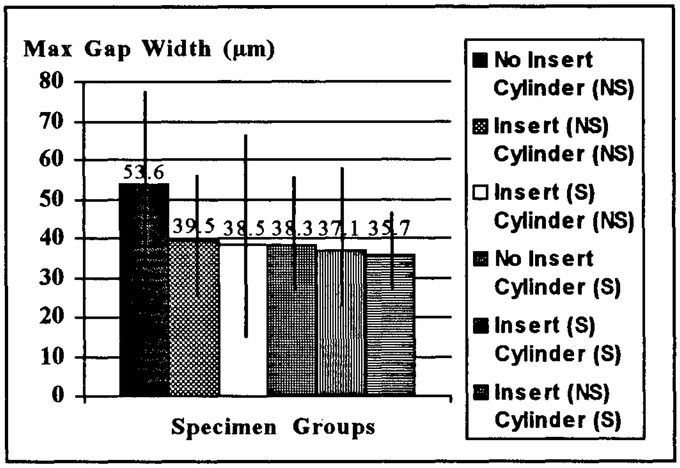

Figure 4. *Average maximum gap width at the margin of the glass cylinder with and without silane adhesion promoters for the specimen groups in Experiment 1 (S = silanated; NS = not silanated)*

Statistical analysis of the data in both experiments was carried out with SAS (Statistical Analysis System) computer software package (SAS Institute, Inc, 1988).

RESULTS

The average maximum gap width at the margin for the specimen groups in Experiment 1 is given in Figure 4.

The effects of the two primary factors, type of insert (no insert, nonsilanated insert, and silanated insert) or silanation of the glass cylinder (with or without silane), were not statistically significant. A significant interaction, however, was found between these two factors ($P = 0.0014$). Duncan's Multiple Comparisons Test (Duncan, 1955; Wall, 1986) when performed on nonsilanated cylinder samples indicated a smaller average gap in the samples containing an insert than in those without an insert ($P = 0.05$). Duncan's Multiple Comparisons Test performed on silanated cylinder samples indicated no significant difference in the average gap in the samples in which an insert was present and in the samples in which an insert was not present.

In Experiment 2 the average maximum gap width of the restorations in the human molars containing only composite was 11.5 µm (n=120, s=2.3), and that of the composite plus insert was 6.7 µm (n=120, s=1.6). A paired *t*-test revealed that the average maximum gap width of the restorations in the molars containing inserts was statistically less than that of restorations comprised of composite alone ($P < 0.0001$).

DISCUSSION

The current limit of 70-75 vol % filler loading in composite materials leaves them with enough polymerizable monomers present to result in significant volumetric shrinkage following polymerization. The incorporation of glass-ceramic inserts into composite restorations provides for increased overall filler loading by permitting the insert to serve as a large "megafiller" particle within the restoration. These inserts are capable of displacing 50%-75% of the composite material in some restorations. The decrease in composite material causes the restoration to exhibit less overall shrinkage and smaller marginal gaps.

The coupling force of the composite to the wall of the glass cylinder mediated by the silane in Experiment 1 was greater than the effect of the insert in these samples. The inability of the insert to overcome the shrinkage forces was due in part to the fact that the insert comprised only about 8 vol % of the cavity in the cylinder, an amount which was insufficient to exceed the coupling effect of the silane.

The effect of the volume displacement by the insert was apparent in the samples in which the glass cylinder wall was not silanated. The relatively small volume fraction of the insert was still great enough to decrease the contraction gap in these samples when the coupling forces of the cylinder wall silane were not present. This condition would be analogous to a "clinical" restoration where adhesion to the cavity wall would be poor or not present.

The effectiveness of the insert in clinical conditions was demonstrated in Experiment 2 involving human molars. The volume fraction of the filling occupied by the insert in this experiment was approximately 37%, which more typically reflects the situation in clinical applications. The marginal gaps in the fillings that incorporated an insert averaged 42% smaller than those in fillings comprised of composite alone. The size of the gap in the filling containing an insert was 5.7 times greater in Experiment 1 than that in Experiment 2. The volume fraction of the filling occupied by the insert in Experiment 1 was 4.6 times smaller than that in Experiment 2. These results show a clear relationship between the size of the marginal gap and the percent insert by volume in composite restorations.

CONCLUSION

The results of this study indicate that the addition of glass-ceramic inserts to composite restorations decreases the marginal gap between the cavity wall and the composite material. These results lead to the conclusion that the incorporation of glass-ceramic inserts into composite restorations decreases the overall dimensional change due to polymerization shrinkage in these restorations.

Acknowledgments

This investigation was supported, in part, by a USPHS research grant to the American Dental Association Health Foundation from the National Institutes of Health—National Institute of Dental Research and is part of the dental research program conducted by the National Institute of Standards and Technology in cooperation with the American Dental Association Health Foundation.

Disclaimer

Certain commercial materials and equipment are identified in this paper to specify the experimental procedure. In no instance does such identification imply recommendation or endorsement by the National Institute of Standards and Technology or the ADA Health Foundation or that the material or equipment identified is necessarily the best available for the purpose.

(Received 7 July 1994)

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OPERATIVE DENTISTRY, 1995, **20**, *155-159*

Shear Bond Strength of Resin to Acid/Pumice-microabraded Enamel

M A ROYER • J C MEIERS

Clinical Relevance
Enamel with intrinsic stains not removed by microabrasion treatment using an HCl/pumice mixture can have composite bonded directly to it without further acid etching.

SUMMARY

The effect of enamel microabrasion techniques consisting of either 18% hydrochloric acid in pumice or a commercially available abrasive/10% hydrochloric acid mixture, PREMA, on composite/enamel shear bond strengths was investigated. Sixty extracted third molars had the bonding surface flattened and were divided into six treatment groups (n=10) with the enamel treated prior to bonding as follows: Group 1—untreated; Group 2—37% phosphoric acid etched for 30 seconds; Group 3—18% hydrochloric acid/pumice mixture applied for five 20-second treatments; Group 4—similar to Group 3 with additional 37% phosphoric acid etch; Group 5—treated with PREMA compound applied for five 20-second treatments; Group 6—similar to Group 5 treatment with additional 37% phosphoric acid. Herculite XR composite resin was then bonded to all samples using a VLC unit. Samples were tested in shear, and fractured enamel surfaces were evaluated using light microscopy to determine the enamel-to-resin failures. Resin bond strengths to microabraded and H_3PO_4-etched enamel were similar to bond strengths of untreated H_3PO_4-etched enamel and were significantly better than bond strengths to PREMA-treated or unetched enamel.

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INTRODUCTION

Acid/pumice microabrasion is a technique used to remove superficial intrinsic stain from enamel (McCloskey, 1984; Croll & Cavanaugh, 1986). The technique involves removal of the surface enamel by stripping to produce its effect. If the stain is contained within the surface-stripped enamel, it is removed.

Presently there are two methods of microabrasion. The first method uses a mixture of 18% hydrochloric acid and pumice, which is applied to the surface with a tongue blade. The second method uses a commercially produced 10% hydrochloric acid/abrasive mixture, PREMA (Premier Dental Product, Norristown, PA 19401), applied with an applicator stick or cup mounted on a gear reduction handpiece.

The success rate of stain removal with acid pumice microabrasion is not totally predictable. If the technique is unsuccessful, a composite covering may be required. Croll (1989) recommends that a bonded photopolymerized polishable composite resin restoration be placed if stain proves too deep for elimination. He suggests it is necessary to prepare the treated enamel surface with a diamond so that a freshly cut enamel surface is exposed for proper phosphoric acid etching. The possible effect of prior hydrochloric acid/pumice on enamel bonding of composite without additional rotary removal of enamel first has never been reported.

The closest correlation to microabrasion's possible effect on resin-to-enamel bonding is vital bleaching. Studies examining the effect of vital bleaching on enamel bonding have been conflicting. The mean in vitro bond strength of composite resin to phosphoric acid-etched enamel has been reported to exceed 22 MPa (Berry & others, 1990). Machida, Anderson, and Bales (1992) investigated the effect of carbamide peroxide bleaching treatment on acid-etched enamel to resin bond strengths. They concluded that there was no significant difference in adhesive enamel-resin bond strengths between the teeth treated with carbamide peroxide versus untreated teeth prior to phosphoric acid etching. Titley and his associates performed a similar study using bovine teeth immersed in 35% hydrogen peroxide for 60 minutes, simulating chairside vital bleaching procedure (Titley & others, 1988). Their results indicate that bleaching enamel prior to acid-etch veneering or orthodontic resin placement had a potential for reducing adherence to the treated surface. Treatment affected the shear bond strength, reducing it from greater than 22 MPa on untreated enamel to less than 4 MPa on peroxide-treated teeth. Titley, Torneck, and Rose (1992) later evaluated the shear bond strength of resin to 10% carbamide peroxide-bleached teeth and found that the bond strength was significantly lower when Silux (3M Dental Products, St Paul, MN 55144) was immediately bonded to bleached enamel. However, the Silux bond strength reached greater than 22 MPa when the samples were stored in water after bleaching for a day before bonding.

The purpose of this investigation was to test the effect of acid pumice microabrasion on composite to enamel shear bond strength.

METHODS AND MATERIALS

Sixty molar teeth stored in 0.2% sodium azide were used. A buccal or lingual enamel surface was sanded to a flat plane with 600-grit aluminum-grit paper using an Exakt (Exakt Medical Instruments, Oklahoma City, OK 73112) grinding/polishing machine under a constant flow of water. All teeth were stored in 37 °C deionized water after sanding and between treatments.

The 60 teeth were randomly placed into six treatment groups (n=10) with the following surface treatments performed prior to resin bonding. Group 1: no treatment (negative control); Group 2: 37% phosphoric acid (L D Caulk/Dentsply, Milford, DE 19963) etch applied to the enamel using a cannula for 30 seconds and rinsed with a stream of water for 30 seconds (positive control); Group 3: A thick solution of coarse pumice (Moyco, Philadelphia, PA 19132) mixed with 18% hydrochloric acid (Aldrich Chem Co, Milwaukee, WI 53201) was applied with a PREMA rubber cup mounted on a gear reduction handpiece to the flattened enamel for 5-20-second treatments with a 40-second rinse after each treatment; Group 4: Microabraded as Group 3, acid etched for 30 seconds with 37% phosphoric acid, and rinsed for 30 seconds; Group 5: Treated with the PREMA-system paste applied with the PREMA cup mounted on a gear reduction handpiece for 5-20-second treatments with a 40-second rinse after each treatment; and Group 6: PREMA treatment as in Group 5 followed by a 30-second H_3PO_4 etch and a 30-second rinse.

Immediately after abrading and etching, each treated surface was coated with XR Primer and XR Bond (Kerr Mfg Co, Romulus, MI 48174) following the manufacturer's directions. A 3 mm-long piece of 3 mm-in-diameter clear plastic pipette was luted to the treated enamel surface with sticky wax, and Herculite XR (Kerr) shade L was syringed into the matrix in two increments. Each increment of resin was hand condensed and light cured for 60 seconds using the MAX light (L D Caulk). Specimens were stored in deionized water after bonding for 48 hours at 37 °C, then thermocycled between 5 and 55 °C for 1000 cycles with a dwell time of 30 seconds. After thermocycling, the specimens were again stored in deionized water at 37 °C for 24 hours. With the bonded surface exposed, the specimens were embedded in Caulk clear orthodontic resin (L D Caulk) in a Teflon split mold 22 mm in diameter and 22 mm deep. Specimens were mounted in a specimen holder and tested in shear on a Universal Testing Machine (United Calibration Corp, Garden Grove, CA 92145) until bond failure at a crosshead speed of 0.5 mm/minute. Shear bond strength was calculated and expressed in MPa.

Fracture sites were examined for each sample using a binocular light microscope (Olympus SZ 3060-F Zoom Stereo Microscope, Olympus Optical, LTD, Tokyo, Japan) at a magnification of X60. Fracture modes were classified as adhesive, cohesive, or mixed and were defined as follows: adhesive failures showed no signs of enamel fracture or remnants of resin on the tooth, cohesive fractures showed complete fracture of either enamel or resin, and mixed samples showed both adhesive and cohesive failure. Representative samples from each treatment group were prepared for viewing in the SEM. Specimens were sputter coated and viewed using an Amray 1200 B SEM (Amray Corp, Bedford, MA

01730) with an acceleration voltage of 30 KV.

Statistical significance between shear bond strengths at the $P < 0.05$ level was determined using ANOVA, Student-Newman-Keuls, and Dunnett tests.

RESULTS

Figure 1 shows the composite-to-enamel shear bond strengths. Values were (mean ± SD): Group 1—12.01 ± 4.99; Group 2—19.29 ± 4.22; Group 3—21.21 ± 4.50; Group 4—22.30 ± 4.81; Group 5—13.80 ± 4.81, and Group 6—22.11 ± 6.01. Groups 2, 3, 4, and 6 had significantly higher bond strengths than Groups 1 and 5. There was no significant difference between the acid-etched group (Group 2), the PREMA and acid-etch group (Group 6), and the pumice/18% hydrochloric acid and acid-etch group (Group 4). Additionally, between the microabrasion treatments, the HCl/pumice microabraded surface-resin shear bond strength (Group 3) was significantly stronger than PREMA-microabraded surface-resin bond strength (Group 5).

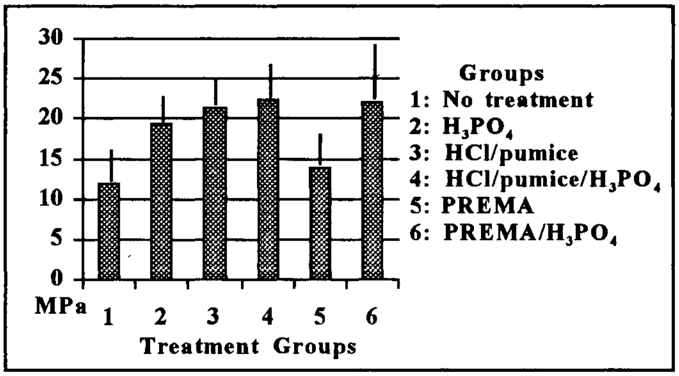

Figure 1. *Composite to enamel shear bond strengths*

Scanning electron micrographs of the enamel surfaces from the six treatment groups prior to bonding are shown in Figures 2-7. Figure 2 shows a Group 1 sample with striations created by the sandpaper with enamel smear layer overlying the surface. The Group 2 sample (Figure 3) shows a typical etch pattern of enamel with striations still evident from the sanding. The Group 3 sample (Figure 4) shows less apparent sanding striations and a hint of an etched, herringbone appearance. The etched surfaces shown in Group 4 (Figure 5) and Group 6 (Figure 7) show no sign of sanding striations or smear layer. Striations from the Exakt grinder and a prominent smear debris layer are visible in the Group 5 sample (Figure 6).

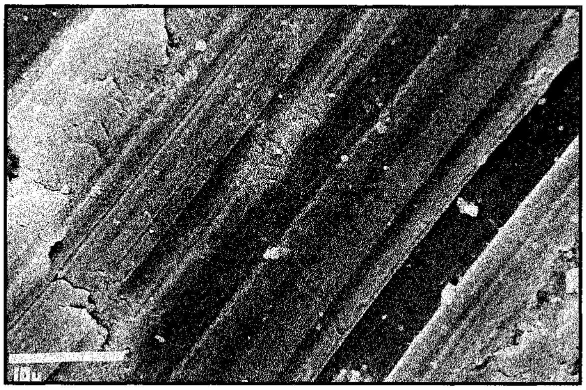

Figure 2. *SEM of Group 1 sample showing the enamel smear layer created with sandpaper (original magnification X1000)*

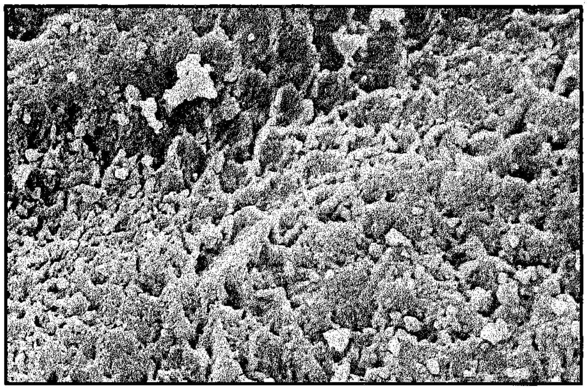

Figure 3. *SEM of Group 2 sample showing enamel surface created with 37% H_3PO_4 treatment of surface created in Group 1 (original magnification X1000)*

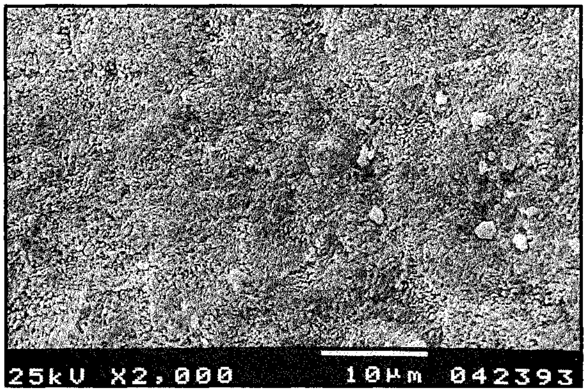

Figure 4. *SEM of Group 3 sample showing enamel surface created with the microabrasion technique using an 18% HCl/pumice mixture and rinsing (original magnification X1000)*

The table shows the breakdown of the binocular light microscope classifications of fractures by treatment groups ranked from the highest bond strength to the lowest. Group 6 showed the only consistent correlation between bond strength and expected type of bond failure with just two adhesive failures and the remainder mixed or cohesive.

DISCUSSION

The samples that were microabraded with either the HCl/pumice mixture or the commercial PREMA

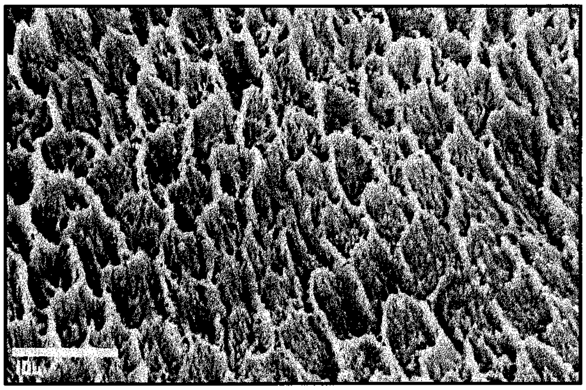

Figure 5. *SEM of Group 4 showing enamel surface created with 37%* H_3PO_4 *etching of the surface shown in Figure 4 (original magnification X1000)*

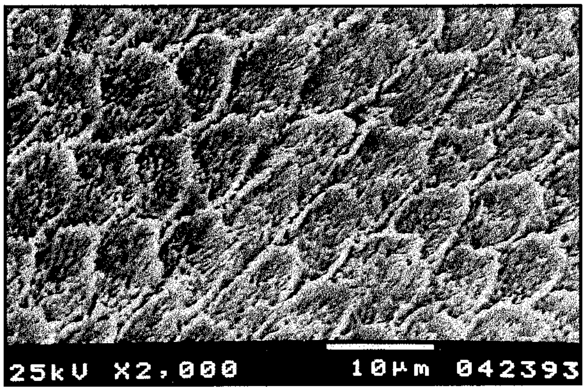

Figure 7. *SEM of Group 6 showing the enamel surface created from etching the surface in Group 5 with 37%* H_3PO_4 *acid (original magnification X1000)*

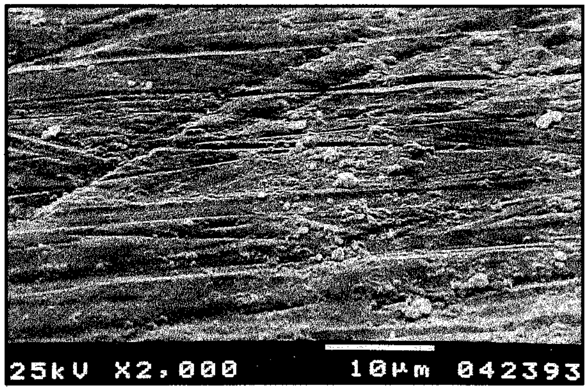

Figure 6. *SEM of Group 5 showing enamel surface created with the PREMA compound. Note polished appearance when compared to those of Figures 3-5 and the striations still apparent from the original sanding. (original magnification X1000)*

compound and then etched had similar composite-to-enamel bond strengths as the positive control. Only the PREMA compound when used by itself decreased resin bond strength. Clinically, the significance of this means that if intrinsic stains cannot be totally removed from teeth by chairside HCl/pumice microabrasion treatment, a resin can be applied during the same appointment without further stripping or roughening of the surface with a diamond to remove the treated surface layer to improve retention of the resin. Subsequent etching of both types of microabraded surface with 37% phosphoric acid produced bond strengths equal to the traditionally treated H_3PO_4-etched surface. These data are corroborated by the SEM appearance of the treated enamel surfaces of these samples. One of the benefits from enamel etching is a cleansing effect that removes enamel smear layer created by the microabrasion process (Figure 6). Donly, O'Neill, and Croll (1992) evaluated the surface effect created by 10 applications of PREMA compound, 20 seconds each application, and noted the "abrasion" effect created. They described the resultant layer as "a highly polished, densely compacted, mineralized structure, possibly mixed with silicon carbide abrasive and silica debris." Group 5 in our study, which was bonded immediately after PREMA treatment, showed extensive smear embedded in the surface layer and no apparent etch pattern or three-dimensional relief for retention (Figure 6). This group had the lowest mean shear bond strength. The SEM of Group 5 (Figure 6) closely resembled the surface of a similarly treated enamel surface in Donly's study (Donly & others, 1992). However, an SEM of a sample from Group 6, which was PREMA treated, etched, and washed, showed an etched retentive surface, which corroborated with the high mean shear bond strengths displayed within that group (Figure 7). Group 3 samples that were microabraded but not etched showed some debris and some honeycombing (Figure 4). The mean bond strength of Group 3 was significantly higher than the bond strength of Group 5, suggesting that the higher acid content of the HCl/pumice produced some etching, and the pumice/acid mixture was more easily

Type of Bond Failures (Ranked from High to Low Bond Values)

Group	Adhesive	Cohesive	Mixed
6	2	4	4
4	6	3	1
3	5	1	4
2	4	1	5
5	5	0	5
1	7	2	1

washed off than the PREMA mixture. The SEM's of Groups 4 and 6 resembled the SEM's of microabraded enamel from Tong and others (1993).

Teeth not microabraded had significant striations from the sanding process used to create a flat surface for placement of the matrix and resin (Figure 2). These striations and the use of XR Primer and XR Bond explain the higher-than-expected shear bond strengths found in Group 1 (negative control). The SEM's of the microabraded teeth show decreased striations from the sanding. Waggoner and others (1989) studied the amount of tooth structure removed by microabrasion using an 18% HCl/pumice mixture and reported that 12 microns of enamel were lost after the initial application, and 26 microns were lost after each successive 5-second application. The solution was hand rubbed onto the enamel surface for 5 seconds using a stick and rinsed with water for 10 seconds. A series of 10 applications could remove 25% of the labial enamel of an incisor. Tong and others (1993) also studied the amount of tooth structure removed by microabrasion by applying a slurry of 18% HCl and pumice with a prophy cup in a slow-speed handpiece with light hand pressure. When 20 applications of 5 seconds' duration each were applied, an enamel loss of 360 microns was reported. Because a significant amount of enamel can be removed by microabrasion, dentin could have been exposed. The combination of enamel loss by initial grinding followed by the microabrasion compounds and the possibility of dentin exposure led to the use of dentin bonding agents as part of the bonding protocol.

CONCLUSION

The bond strengths of microabraded enamel with the HCl/pumice mixture with and without H_3PO_4 etching and the PREMA compound with H_3PO_4 etching was as high as to enamel etched with the traditional 37% H_3PO_4 treatment. Clinically, the significance of this result may be extrapolated to mean that if intrinsic stain cannot be totally removed from teeth with HCl/pumice microabrasion treatment, a resin can be applied to this surface without further rotary preparation of the enamel to remove the microabraded surface layer.

Disclaimer

The opinions or assertions contained in this article are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Navy, Department of Defense, or the US government.

This project was supported under the Naval Medicine Research Development Command Work Unit M0095-3014.

(Received 11 July 1994)

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Comparative SEM and TEM Observations of Nanoleakage within the Hybrid Layer

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Clinical Relevance
TEM is required to determine the exact distribution of the silver within the hybrid layer.

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SUMMARY

Most adhesive interface studies have involved SEM demonstration of the penetration of adhesive resins into demineralized dentin surfaces with subsequent creation of hybrid layers. Nanoleakage is a term that describes the diffusion of small ions or molecules within the hybrid layer in the absence of gap formation. The present microscopic study examined the nanoleakage of the hybrid layer using a silver nitrate staining technique. Adhesive dentin sandwiches, which were immersed in a silver nitrate solution, were prepared for both SEM and TEM examination using both the Clearfil Liner Bond and All-Bond 2 adhesive systems. Both systems demonstrated silver accumulation within the hybrid layers. Clearfil Liner Bond System showed scattered silver particles at the bottom two-thirds of the hybrid layer by both SEM and TEM observation, whereas All-Bond 2 revealed stained fiber-like structures within the full thickness of the hybrid layer. To evaluate the quality of the hybrid layer, the utilization of tracer molecules such as silver nitrate that are detectable by both SEM and TEM is proposed. It is important to determine the location and morphology of these nanometer-sized porosities that may permit the hydrolysis of collagen fibers and degradation of adhesive monomers.

INTRODUCTION

The advent of adhesive dentistry has caused a dramatic change in restorative procedures. Current adhesive systems have become more and more acceptable in their clinical performance by enhancing the adhesion of resins to dentin (Van Meerbeek & others, 1994). In order to obtain proper adhesion, it is essential to create a hybrid layer at the resin-dentin interface (Nakabayashi, 1985; Sugizaki, 1991; Wang & Nakabayashi, 1991; Gwinnett & Kanca, 1992; Eick & others, 1991, 1992, 1993a,b; Van Meerbeek & others, 1992, 1993a,b). The hybrid layer is created by the penetration and polymerization of adhesive monomers after removal and/or modification of the smear layer and superficial demineralization of the dentin. However, it is not clear to what extent the adhesive resins have penetrated and polymerized within the hybrid layer, because techniques that involve polishing the hybrid layer may inadvertently occlude its porosities with resin-polishing debris. The quality of the resin-infiltrated zone is one of the important topics of current research, but little information is available about its detail. It is therefore of crucial importance to evaluate the quality of hybrid layers formed by current dentin adhesive systems.

Wieczkowski and others (1992) reported that silver nitrate provided a clear tracer of both the location and extent of marginal leakage. Recently, Sano and others (1994a,b) extended that work by demonstrating lateral diffusion of silver nitrate through the hybrid layer using an SEM technique. The silver nitrate penetration patterns, termed *nanoleakage*, varied with regard to the adhesive systems, but diffusion channels of nanometer dimensions were observed to exist in most of the hybrid layers. However, the actual location of such nano-spaces within the hybrid layer was not clear, because the electron beam interacted with so much silver that the exact location of the silver particles was partially obscured. In addition, the limited resolution of backscattered and secondary electron images of the SEM failed to identify the interaction between the components of the hybrid layer and silver nitrate.

Another approach to evaluating the quality of the hybrid layer is by observing ultrathin sections by TEM (Sugizaki, 1991; Van Meerbeek, 1993a; Eick & others, 1991, 1992, 1993b). In such TEM studies, specimens are generally embedded in epoxy resin prior to cutting ultrathin sections. However, if there were any porous structures within the resin-infiltrated demineralized dentin (i e, hybrid layer), the embedding resin might penetrate into these porosities to create an artificially perfect epoxy-filled hybrid layer. To avoid this problem, Nakabayashi's group observed bonded interfaces using ultrathin TEM sections without embedding in epoxy resin (Nakabayashi, 1985; Watanabe, Nakabayashi & Pashley, 1994), but they did not use electron-dense tracers to detect existing porosities. Silver nitrate is an excellent tracer as the silver ions are very small, and it has a high solubility, permitting preparation of highly concentrated solutions. However, after reduction of the silver ions to metallic silver, the hardness of the silver makes it difficult to prepare ultrathin sections of mineralized, nonembedded sections. This can be overcome by making thicker, semi-ultrathin sections for TEM observations.

The purpose of this study was to identify the actual location of the submicron-to-nanometer-sized porosities within the hybrid layer of two different bonding systems using SEM and TEM techniques and to compare the results obtained with each technique.

METHODS AND MATERIALS

Extracted human third molars stored at 4 °C in isotonic saline containing 0.2% sodium azide were used in this study. A pair of dentin disks approximately 1-1.5 mm thick were prepared from each tooth by using a low-speed diamond saw (Leitz 1600 Microtome, Wetzler, Germany) under copious water lavage. One surface of each disk without any enamel remnants or exposure of the pulp chamber was finished with #600 silicone-carbide paper under running water to create a standardized smear layer. The smear layer of each disk was conditioned, and the two disks were bonded together according to the manufacturer's instructions with either All-Bond 2 (Bisco, Itasca, IL 60143) or Clearfil Liner Bond System (Kuraray, Osaka, Japan).

All-Bond 2 utilizes an All-Etch technique where the entire cavity is acid etched with 10% phosphoric acid for 15 seconds followed by water rinsing. Rather than air-drying completely, the dentin surface was left very moist (the so-called wet bonding technique) prior to the application of the mixture of equal volumes of Primers A and B. Primer A contained 2% N-tolylglycineglycidyl methacrylate, while primer B contained 16% bisphenyl-dimethacrylate. Both primers were dissolved in acetone. Multiple layers (five to seven) of the mixture were painted on the etched dentin surface until it became glossy. The surface was then air dried and covered with a layer of resin adhesive that was light cured for 20 seconds.

Clearfil Liner Bond System utilizes an acid conditioner made of 10% citric acid and 20% calcium chloride with sufficient silica to produce a gel. The dentin surface was acid etched with this gel for 60 seconds followed by water rinsing and air drying. The etched surface was then treated with 3% N-

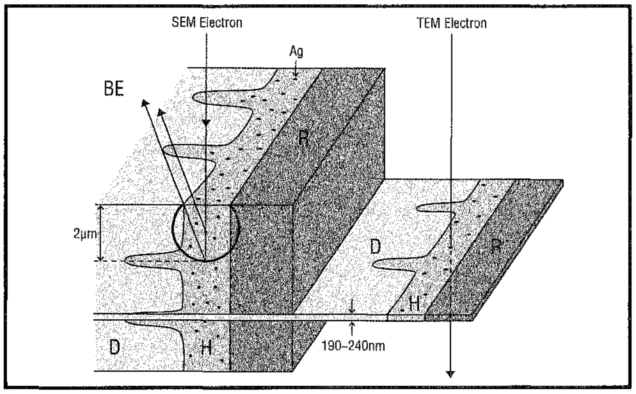

Figure 1. *Cross sections of the volume of dentin examined by both SEM and TEM techniques. R = resin; H = hybrid layer; D = mineralized dentin; Ag = silver particles; BE = backscattered electrons.*

methacryloyl-5-aminosalicylic acid in alcohol for 60 seconds followed by evaporation of the alcohol with air. Then the adhesive resin was applied, gently thinned with air and light cured for 20 seconds. The bonded disks were then stored in water at 37 °C for 24 hours (Inokoshi & others, 1990).

The specimens were sectioned perpendicular to the bonded surface through the center of the dentin disks with a diamond disk under running water. One-half of each specimen was used for SEM and the other half for TEM. There were five specimens in each bonding group, yielding 10 specimen halves. Five of the 10 halves were used for SEM and the other five halves were used for TEM studies. Three of the pairs of specimens were placed in silver nitrate, and two pairs were not stained with silver nitrate to serve as negative controls. Each specimen was coated with nail varnish except for the cut surface, which exposed the resin-dentin interface. The experimental specimens were immersed in a 50% (w/v) silver nitrate solution at room temperature for 24 hours in the dark. The control specimens were immersed in water for 24 hours. Next, the nail varnish was removed and the specimens soaked in photo-developing solution under fluorescent light for 8 hours to facilitate reduction of silver ions to metallic silver, as previously described (Wu & others, 1983; Wieczkowski & others, 1992; Xin & others, 1992; Sano & others, 1994a,b).

For completion of SEM sample preparation, the silver-stained resin-bonded specimens were embedded in Epoxy resin (Quetol-812, Nisshin EM, Tokyo, Japan), then ground and polished using wet silicone-carbide paper and diamond pastes down to a size of 1 µm (Inokoshi & others, 1990). Each specimen was etched with a 10% aqueous solution of phosphoric acid for 3-5 seconds to facilitate observation of the hybrid layer at the resin-dentin interface (Gwinnett & Kanca, 1992). Specimens were then coated with a thin layer of gold and observed under an SEM (model JXA 840, JEOL Ltd, Tokyo, Japan) by means of both secondary and backscattered electron images (Sano & others, 1994a,b).

For TEM examination, the silver-stained specimens were fixed in 1% glutaraldehyde in cacodylate buffer (0.1M, pH 7.4) for 1 hour. Then four to six small rectangular sticks with the smallest portion of less than 1 x 1 mm were sectioned from the silver-stained

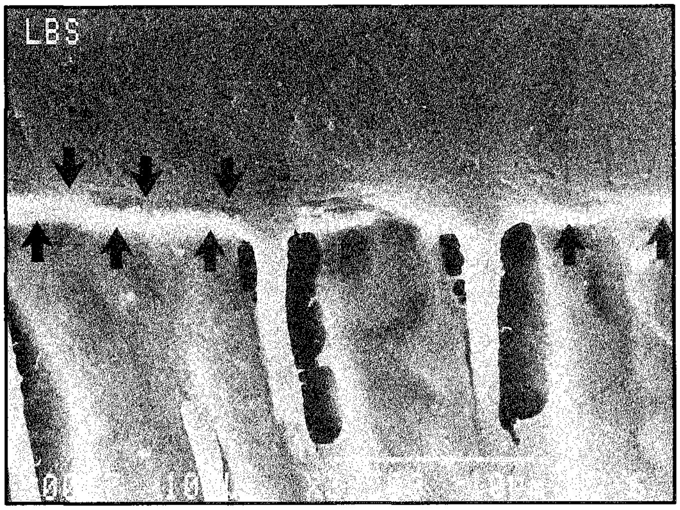

Figure 2A. *Secondary electron image of human dentin bonded with the LBS after exposure to silver nitrate, followed by polishing and then etching with 10% phosphoric acid for 5 seconds to reveal the extent of the acid-resistant resin-infiltrated dentin. Upper black arrows indicate the approximate position of the resin-dentin interface, and lower black arrows indicate the position of the bottom of the hybrid layer. The resin tags appear loose due to loss of peritubular dentin during the brief acid etch. (original magnification X2135)*

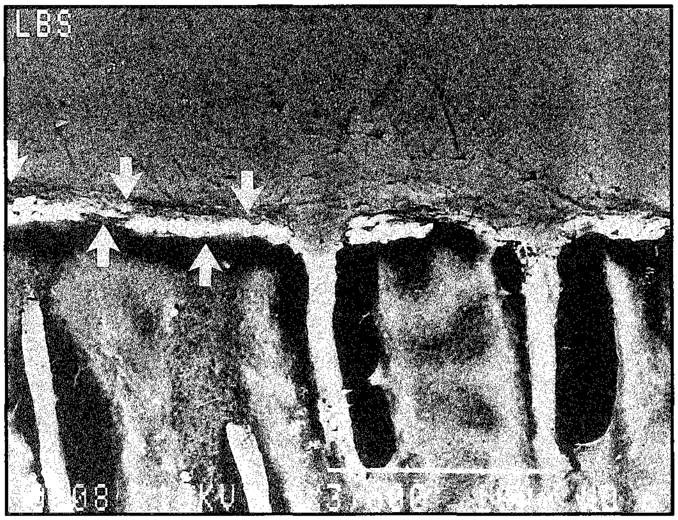

Figure 2B. *The same specimen as shown in Figure 1A but viewed with backscattered electrons. The bright (white) material represents silver that permeated through the base of the hybrid layer. The top and the bottom of the hybrid layer are indicated by white arrows. Note the silver was retained at the bottom of the hybrid layer even after acid etching. (original magnification X2345)*

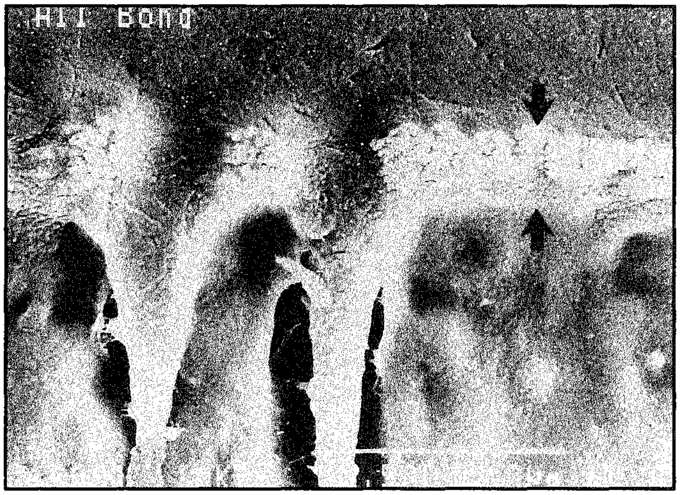

Figure 3A. *Secondary electron image of human dentin bonded with All-Bond 2 after being placed in silver nitrate. The specimens were then sectioned, polished, and briefly acid etched. The hybrid layer thickness is indicated by the black arrows. The bright areas indicate the presence of silver throughout most of the hybrid layer. (original magnification X2345)*

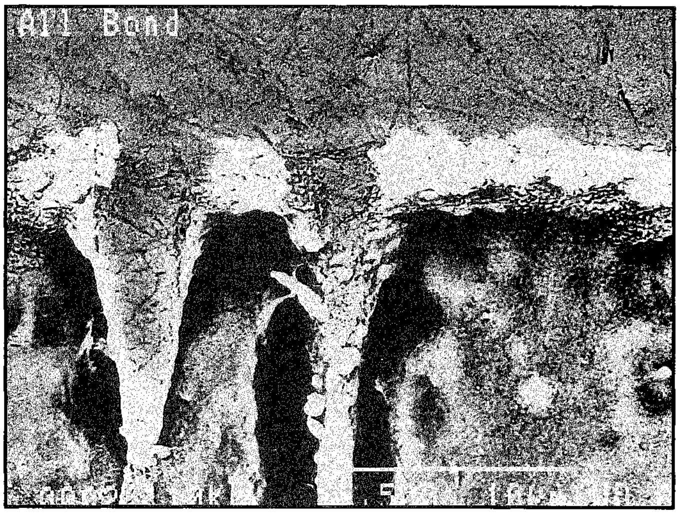

Figure 3B. *Same specimen as was shown in Figure 2A but viewed by backscattered electrons to enhance the contrast between silver and resin or dentin. Most of the hybrid layer appears to have been penetrated by silver. (original magnification X2240)*

surface in a direction perpendicular (Figure 1) to the stained surface, with a low-speed diamond disk (Isomer, Buehler Ltd, Lake Bluff, IL 60044). Control specimens that were not exposed to silver nitrate were also processed in parallel with the experimental specimens. Mineralized semi-ultrathin sections of approximately 190~240 nm in thickness, as judged by their interference colors, were obtained from the rectangular sticks using an ultramicrotome (LKB Ultratome, Washington, DC) and a sapphire knife (Sapphatome, SS-45, Sakura Fine Chemical Co Ltd, Tokyo, Japan). The sections were examined with a TEM (JEM-100, JEOL) operating at 80 KV.

RESULTS

SEM Observations

Figures 2A and 2B show the resin-dentin interface of Clearfil Liner Bond System (LBS)-treated dentin when viewed by SEM. A hybrid layer approximately 2~3 µm in thickness was observed at the interface. Silver penetration of the Clearfil Liner Bond System by both secondary and backscattered electron images was observed in the bottom half of the hybrid layer created within intertubular dentin. The granular nature of the silver accumulation within the hybrid layer was obscured by the high intensity of both backscattered and secondary electron images. Resin tags were only occasionally stained by silver nitrate. SEM micrographs in Figures 3A and 3B show the interface between the resin and dentin bonded with All-Bond 2. A hybrid layer with a thickness of approximately 4-5µm was observed between the polymerized adhesive and underlining mineralized dentin. Silver accumulation was found throughout the full thickness of the hybrid layer of intertubular dentin. A strong backscattered electron image obscured the detail of the location of silver particles compared to the secondary electron image. Silver stained both the outer part of funnel-shaped resin tags and the deeper portions of the resin tags.

TEM Observations

TEM micrographs in Figures 4A and 4B show the interface between the adhesive resin and dentin after treatment with the Clearfil Liner Bond System. A TEM micrograph of low magnification (Figure 4A) demonstrated a hybrid layer between the adhesive resin and underlining mineralized dentin. Silver within the hybrid layer appeared as fine granular particles. These particles were distributed mainly in the bottom two-thirds of the hybrid layer towards the mineralized dentin. Higher magnification of the interface (Figure 4B) revealed silver deposition both at the base of the hybrid and at the top of mineralized dentin. Slight penetration of silver was found at the interface between the resin tags and mineralized dentin. Very fine silver particles less than 50 nm were noted in the adhesive layer.

TEM micrographs (Figures 5A and 5B) of the interface of All-Bond 2-treated dentin and resin showed a different pattern of silver penetration. The silver nitrate formed a highly branched, reticular, fiber-like structure within the hybrid layer and tubule walls. These delicate structures were not continuous. This intermittent network of silver precipitate in the hybrid layer showed occasional connections to the

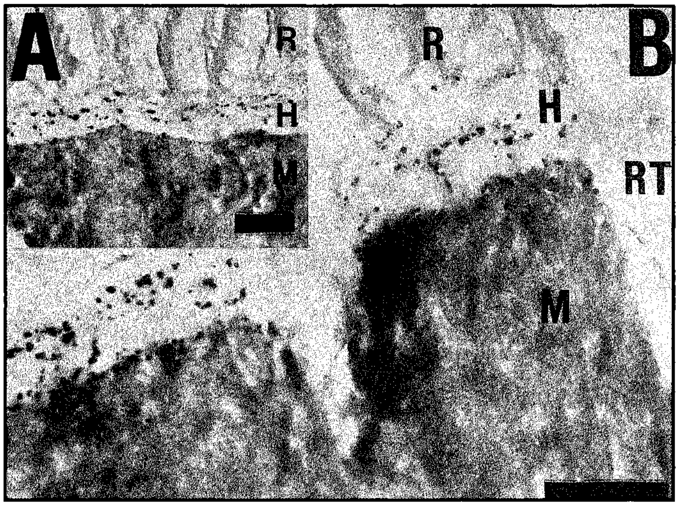

Figure 4. **A**. *TEM of dentin bonded with LBS and then exposed to silver nitrate. This is a mineralized section through the adhesive (R), hybrid layer (H), and mineralized dentin (M). The black particles distributed within the hybrid layer are silver and were not seen in the control sections. (Bar = 2 μm).* **B**. *Higher magnification TEM of Figure 3A showing the distribution of silver in the hybrid layer. RT = resin tag. (Bar = 2 μm.)*

mineralized intertubular dentin and peritubular dentin. An amorphous, thin, silver-stained layer was also noted at the top of the hybrid layer.

In some relatively thinner sections of the resin-dentin interface of the All-Bond 2 specimens (Figures 6A and 6B), there were two types of fine structures formed by silver nitrate staining. One was a delicate fiber-like structure, and the other was large, granular, silver grains.

The negative controls consisted of specimens that were not exposed to silver nitrate but were otherwise processed exactly like those specimens exposed to silver nitrate. Scanning electron microscopy of these control specimens did not show any indications of electron-dense deposits in the bottom of the hybrid layers of specimens bonded with either All-Bond 2 or Clearfil Liner Bond System (not shown). Similarly, transmission electron micrographs of the negative controls did not reveal any electron-dense material in the hybrid layers of specimens bonded with either of the bonding systems (not shown).

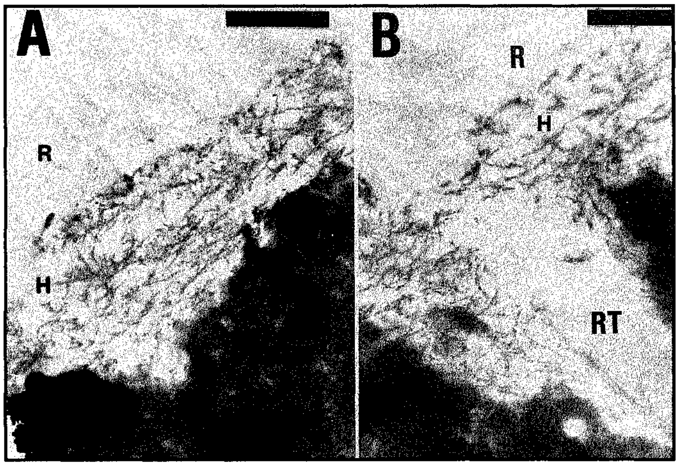

Figure 5. **A**. *TEM of dentin bonded with All-Bond 2 after immersion in silver nitrate. Note the accumulation of silver at the top of the hybrid layer as well as throughout the hybrid layer (H) arranged in a delicate reticular pattern. R = adhesive resin; bar = 3 μm.* **B**. *TEM of another dentin specimen bonded with All-Bond 2, which exhibited a resin tag surrounded by resin-infiltrated demineralized dentin with some traces of silver. (Bar = 3 μm.)*

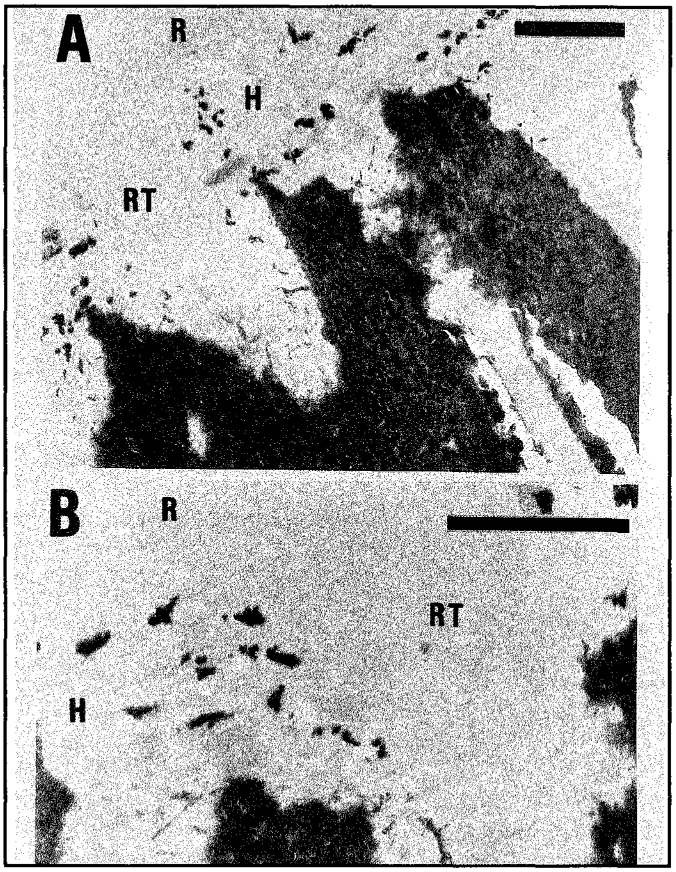

Figure 6. **A**. *TEM of All-Bond 2-treated dentin following exposure to silver nitrate. In this specimen, the silver was distributed in scattered granular deposits that were less extensive than that seen in Figure 4. R = adhesive resin; H = hybrid layer; RT = resin tag. (Bar = 2 μm.)* **B**. *Higher magnification TEM of Figure 5A showing a transition between granular versus fiber-like deposits of silver nitrate. (Bar = 2μm.)*

DISCUSSION

The quality of the hybrid layer is of considerable interest. Ideally, adhesive monomers should penetrate the full extent of the demineralized zone so that all collagen fibers are enveloped by resin. This penetration should protect the collagen from hydrolysis and provide an excellent seal of dentin. Eick and others (1993b) demonstrated the complete penetration of the hybrid layer by HEPMA, a sulfur-analog of HEMA, using EDS/STEM techniques with some but not all bonding systems. However, it is not clear if subsequently applied adhesive monomers will show the same distribution. A number of authors have used the Inokoshi technique of polishing cross sections of bonded specimens, followed by argon ion beam etching of the polished surfaces to enhance the relief and contrast between the bonding zones (Sugizaki, 1991; Van Meerbeek & others, 1992). Using this technique, most hybrid layers look very well infiltrated by resin. Unfortunately, the technique may inadvertently fill porosities within the hybrid layer with resin smeared from the adhesive layer, thereby exaggerating the degree of filling of the hybrid layer by resin. Fractured specimens that have not been polished show far more porosities in the bottom half of the resin-infiltrated demineralized zone (Titley & others, 1994; Carvalho, unpublished observations). By exposing the bonded dentin to silver nitrate before the specimens are subsequently sectioned and polished, the silver is deposited within whatever porosities are available in the hybrid layer. Once in place, they remain even after sectioning, polishing, and etching. If there were no porosities or unfilled zones within the hybrid layer, then no silver should be able to infiltrate that layer. Using this technique, all bonding systems that have been examined show some silver penetration into these submicron-sized, nanometer spaces. The penetration of silver into such spaces within the hybrid layer in the absence of a gap between the composite resin and the dentin is called nanoleakage (Sano & others, 1994b).

A recent Micro-Raman spectroscopy report (Van Meerbeek & others, 1993b) demonstrated the gradual transition of resin concentration in the demineralized superficial dentin. Thus, the concentration of resin was highest at the top of the hybrid layer and lowest near the bottom. According to our SEM pictures of LBS-treated dentin, silver accumulation at the bottom half of the hybrid layer was in agreement with this distribution of resin that showed a progressively diminishing impregnation of resin. The pattern of silver accumulation seen in TEM micrographs of LBS-treated dentin confirmed that these defects were also scattered randomly within the hybrid layer. These defects or porosities may be created during the infiltration and polymerization of the adhesive monomers. It is not clear whether these porosities were due to incomplete resin infiltration, to polymerization shrinkage, or to the extraction of incompletely polymerized hydrophilic monomers during the 24-hour immersion in water.

If the adhesive shrinkage was great enough to contract the hybrid layer, liquid might be drawn into the adhesive interface and may then appear as void-like structures. The LBS adhesive contains ethanol and hydrophilic monomethacrylates such as HEMA, NMSA, and MDP. Although the manufacturer recommends the evaporation of ethanol solvent prior to light curing, it might be difficult to remove ethanol completely within the adhesive. Thus, remnants of ethanol might have restricted the conversion of soluble adhesive monomers to insoluble polymers, or the ethanol may have become entrapped as a separate phase during polymerization. The hydrophilic monomethacrylates may create single-chain polymers that could allow larger intermolecular spaces than that of cross-linking polymers like BIS-GMA. Moreover, the hydrophilic nature of these monomers may permit absorption of water after polymerization. Presumably, the slight staining of the adhesive resin by very fine silver particles implies the presence of nanometer-sized diffusion channels (less than 50 nm) within the polymerized adhesive resin. The TEM micrographs of LBS-bonded specimens failed to show the same reticular pattern of silver distribution within the hybrid layer that was seen with All-Bond 2. This may mean there is a better affinity of the LBS adhesive system for collagen fibers than that of All-Bond 2, which showed more silver-stained fiber-like structures within the hybrid layer.

The TEM micrographs of the All-Bond 2 resin-dentin interface showed an interesting silver penetration pattern. The outlines of the delicate reticular structures within the hybrid layer may correspond to collagen fibers that were incompletely enveloped by the adhesive resin. Recent adhesive systems such as All-Bond 2 have shown enhanced shear bond strengths when bonded to moist dentin (Gwinnett & Kanca, 1992). In that study, bond strength values to wet dentin approached those recorded for enamel. The mechanism of the wet bonding technique is believed to be due to the maintenance or re-expansion of the three-dimensional network of collagen fibers after acid conditioning, leaving sufficient spaces between the collagen fibers for the infiltration of adhesive monomers. Since it is important to restrict the collapse of collagen fibers to maintain the size of interfiber spaces for the penetration of adhesive monomers, it might be difficult to completely replace the water around the collagen fibers with the combination of acetone and adhesive monomers. According to the results of this study, silver nitrate revealed the outline of fiber-like structures within the All-Bond 2-infiltrated hybrid layer that was bonded using moist dentin. We speculate that the priming procedure of All-Bond 2 failed to completely replace all of the water with adhesive monomers. It was difficult to detect the exact interaction between the collagen fibers and silver because of the limited resolution of TEM image using semi-ultrathin sections (i e, 190 ~ 240 nm). However, it is interesting to raise the question of whether silver had penetrated around or within the collagen fibers. Silver stains have been used to stain proteins (Hayet, 1975). Presumably, if each collagen fiber was completely enveloped by resins, there would be no opportunity for silver ions to react directly with collagen. That seemed to be the case in the upper part of the hybrid layer with either bonding system, but was not the case in the lower half of the hybrid layer.

When viewing specimens infiltrated with silver by SEM techniques, the electron beam penetrates several microns into the specimen, depending on the nature of the specimen and the accelerating voltage. This produces both secondary electrons and backscattered electrons from both the surface and the subsurface (Figure 1). Thus the volume of dentin containing silver is relatively large and gives an SEM image that exaggerates the amount of silver that is at the surface. When semi-ultrathin sections (190~240 nm) are prepared from the same specimens and then viewed by transmission electron microscopy, the volume of dentin and silver that is examined is approximately 10% that of the SEM observations. This provides better resolution of the distribution of silver within semi-ultrathin sections of mineralized specimens in TEM.

Clearly, higher-resolution SEM and TEM studies are needed to obtain further insight into the interactions between the resin and collagen fibers and hydroxyapatite, and to evaluate the real sealing potential and adhesion of bonding resins to dentin. Further research is needed to evaluate the long-term clinical consequences of nanoleakage. If the collagen fibers are destroyed by water hydrolysis, then the resin side of the failed bonds should contain the top half of the hybrid layer. Identification of the site of bond failures requires careful high-resolution SEM study.

CONCLUSIONS

1. Silver nitrate solutions can be used to evaluate the quality of hybrid layers in bonded restorations.
2. Silver nitrate penetrates most hybrid layers to varying degrees.
3. SEM examination of bonded specimens can easily detect silver nitrate penetration into hybrid layers.
4. However, transmission electron microscopy is required to determine the exact distribution of the silver within the hybrid layer.

Acknowledgments

This work was supported, in part, by grant DE06427 from the National Institute of Dental Research and by the Medical College of Georgia Dental Research Center. The authors thank Shirley Johnston for excellent secretarial support.

(Received 19 July 1994)

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DEPARTMENTS

ABSTRACTS

The editor wishes to thank the second-year Comprehensive Dentistry Residents at National Naval Dental Center, Naval Dental School, Bethesda, MD 20889-5602, for their assistance in the preparation of these abstracts.

Dentin bond strength after air drying and rewetting. *Gwinnett AJ (1994) *American Journal of Dentistry* 7(3) 144-148.

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Primers of current-generation dentin bonding systems are primarily hydrophilic monomers. The use of these hydrophilic agents has led to the concept of "wet bonding," in which the dentin is not dried to dessication prior to primer placement or is remoistened after rinsing and drying to ensure that the enamel has been properly etched. This study investigated the effect of air drying and remoistening of dentin on resin composite bond strength and determined the extent to which the outermost collagenous network and surface area of dentin contributed to interfacial strength. The dentin bonding system tested was All-Bond 2, which recommends an all-etch technique and bonding to moist dentin. Groups 1-6 (n=10) were conditioned with 10% phosphoric acid for 20 seconds and Groups 7-12 (n=10) were not. Groups differed on how they were treated prior to primer placement: wet controls, drying for different times, and drying for different times then remoistening. Shear bond strengths were determined and reported in MPa units. Results revealed that in Groups 1-6 (acid conditioned), the values for dried, remoistened samples were not statistically significantly different from the wet controls, but the mean values to dry dentin were significantly less compared to the wet groups. Values of Groups 7-12 showed a statistically significant reduction upon drying that did not recover in value upon rehydration. The morphological integrity and moist state of dentin plays a significant role in allowing resin to diffuse through it to interact with the partially demineralized dentin below, though it may not contribute to interfacial strength. Moisture prevents the collapse of dentin, which would reduce resin diffusion and optimal bond strength. Moisture appears to play a significant role in achieving optimal bond strength with some fourth-generation dentin bonding systems.

A clinical evaluation of posterior composite resin restorations. *Bryant RW & Hodge KL (1994) *Australian Dental Journal* 39(2) 77-81.

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One operator placed 330 class 1 or 2 restorations in 72 patients. At least one amalgam (Dispersalloy) and three composite resin restorations of three different resin materials (Heliomolar, Herculite X-R, P-30) were placed in each subject. Amalgam and composite resin restorations were prepared, restored, and polished in standard accepted techniques. At 3 years, Herculite X-R had significantly more restorations with evidence of wear than the other materials tested. Of the composite resins, P-30 showed significantly less marginal crevice formation and tended to show less marginal discoloration than the Heliomolar and Herculite X-R restorations. Heliomolar and Herculite X-R exhibited a relatively smooth surface while P-30 had a coarse texture. Also, significantly larger proportions of Heliomolar and Herculite X-R were rated as smooth and free of scratches at 3 years than at 1 year. Modern composite resins exhibit increasingly small quantities of wear, and therefore composite wear rates have declined in their significance. Marginal and bulk fractures have since increased in clinical importance for posterior composite resin restorations. The Heliomolar and Herculite X-R composite resin restorations exhibited increasing evidence of marginal fracture with time. Heliomolar also showed evidence of failure by wear in the central fossa and bulk fracture. Although P-30 exhibited frequent evidence of wear, marginal fracture was infrequent.

Dentine bonding—the effect of pre-curing the bonding resin. *McCabe JF & Rusby S (1994) *British Dental Journal* 176(9) 333-336.

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Several variables are known to influence the bond strength between a resin-based restorative material and dentin using dentin bonding agents. Some variables such as the smear layer and location of the dentin have been examined extensively. One variable apparently not investigated is the need to establish a strong bond between the dentin and the bonding resin prior to composite placement. Some manufacturers (Syntac) claim equal acceptability whether the bonding resin is precured or cured together with the composite. This study examined the effects of precuring of two bonding agents as compared to curing with composite placement by measurement of 24-hour shear bond strengths. Cavity preparations 5 mm wide x 2 mm deep were made in 40 extracted, caries-free teeth at three levels of dentin: superficial, middle, and deep dentin. Syntac (Heliobond) and ART Bond DBA were used in this study followed with hybrid composites of P-50 and Brilliant Dentine respectively. Both modify the smear layer with maleic acid solutions. The results clearly showed that precuring of the adhesive resin causes a signficant increase in the shear bond strength for both ART Bond and Syntac. Additionally ART Bond showed adhesive, cohesive, and mixed failures at the dentin/resin interface especially significant with the precuring samples. Syntac showed all adhesive failures. These findings obviously have clinical significance, since they demonstrate the need to establish a bond between adhesive resin and dentin before composite placement. The researchers speculated that the explanation for the results probably involve both polymerization shrinkage stresses and depth of cure factors.

The effect of margin design on the marginal adaptation of temporary crowns. *Keyf F & Anil N (1994) *Journal of Oral Rehabilitation* 21(4) 367-371.

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The purpose of this study was to evaluate the marginal adaptation of two different temporary crown finish line types. Forty-eight specimens were prepared, 24 with chamfer finish lines and 24 with shoulder finish lines. Temporary crown fabrication was accomplished using a silicone template and the temporary material Protemp, a Bis-acryl composite resin. Samples were then divided into three different groups that were 1) evaluated immediately after polymerization, 2) evaluated after 1-day storage in a water bath at 37 °C, and 3) evaluated after 76 days' storage in a water bath at 37 °C. All specimens were embedded in cold resin, divided into four pieces, and polished. All measurements of the temporary crowns were made by using a statistically significant difference between the adaptation of the temporary crowns of the chamfer and the shoulder type. The marginal gap of the chamfer increased from day 1 to day 7, but was not statistically significant. The marginal gap of the shoulder increased from day 1 to day 7 and was statistically significant.

Accurate marginal fit and proper contour and surface finish of a temporary crown are needed to maintain healthy contiguous gingiva before the placement of the final restoration. Three factors seem to influence the marginal adaptation of temporary crowns: polymerization shrinkage, water adsorption, and type of finish line.

The influence of restorative material on the survival rate of restorations in primary molars. *Papathanasiou AG, Curzon MEJ & Fairpo CG (1994) *Pediatric Dentistry* 16(4) 282-288.

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The survival rate of different restorative materials in primary molar restorations was measured. Four types of restorative materials were evaluated: preformed crowns cemented with zinc phosphate cement, amalgam, composite resin, and glass ionomer. Restorations were graded as failed, withdrawn, or censored (restoration intact at end of study). Previous studies suggested that preformed crowns have the best success rate, while amalgams and composites have similar success rates. Insufficient data exist on glass-ionomer restorations. In this study, preformed crowns had the best survival rate followed by amalgam, composite, and glass ionomer. The differences were highly significant ($P = 0.0001$) for all materials. Median survival times for restorations were: 5 years for preformed crowns and amalgam, 32 months for composite, and 12 months for glass ionomer. The 5-year survival estimate was 68% for preformed crowns and 60% for amalgam, and the 4-year survival estimate was 40% for composite and 5% for glass ionomer. These results are consistent with results from previous studies.

A recent study suggests the possible reason for the high failure rate of the glass ionomer is that hand-mixed glass-ionomer cements (like the one used in this study) often do not have the proper powder/liquid ratio, resulting in an inferior material. The researchers also speculated that failure of composite restorations may be due to the difficulty involved in the isolation of primary teeth and due to the decreased resin bonding to primary enamel. Finally they indicated that failure of preformed crowns may be due to failure of the cement.

Properties related to strength and resistance to abrasion of VariGlass VLC, Fuji II LC, Ketac-Silver, and Z-100 composite resin. *Dhummarungrong S, Moore BK & Avery DR (1994) *Journal of Dentistry for Children* 61(1) 17-20.

(*Khon Kaen University, Faculty of Dentistry, Department of Pediatric Dentistry, Khon Kaen, Thailand)

The purpose of this study was to evaluate some of the physical properties of VariGlass VLC and Fuji II LC and to compare the results with Ketac-Silver and Z-100 composite resin. Forty-two specimens of each material were prepared. Specimens were tested for compressive strength, diametral tensile strength, transverse strength, and toothbrush abrasion. The compressive, diametral tensile, and transverse strengths of Z-100 were the highest. Ketac-Silver achieved a significantly higher compressive strength than the others, and Fuji II LC was significantly higher than VariGlass VLC. Fuji II LC had a significantly higher diametral tensile and transverse strength than VariGlass VLC or Ketac-Silver. The greatest abrasion resistance was exhibited by VariGlass VLC, possibly due to its smaller, harder filler particles. VariGlass VLC will not harden unless exposed to a curing light, indicating that the conventional acid-base curing reaction of a glass ionomer plays a limited role in its properties. This study supports the use of VariGlass VLC and Fuji II LC in class 3 and 5 restorations. Due to their lower compressive strengths they are probably not indicated for stress-bearing restorations. Clinically both materials provide more working time and set faster than conventional glass ionomers.

BOOK REVIEWS

A CONSUMER'S GUIDE TO DENTISTRY

Gordon J Christensen

Published by C V Mosby, St Louis, 1994. 247 pages, 411 illustrations. $49.95.

The author is extremely well qualified to prepare this book: He is one of the best known dentists and speakers in the world and is very active in investigating and reporting on dental products. His purpose in this book is to help consumers find answers to questions about their oral health problems, allowing them to discuss questions intelligently with dental professionals. Designed to inform the consumer, the book uses common dental terms and a minimum of professional terminology. It should provide easy reading for consumers.

The book reviews a broad area of clinical dental subjects. Readers are told in chapters 1-3 about types of dentists (specialists) and how to locate the right dentist for their needs. A discussion of major topics and concerns is held in the next 12 chapters. Operative dentistry subjects appear in various places. For those interested in pursuing subjects in depth, outstanding professional textbooks are referenced. Also, readers are provided extensive information on dental schools, professional dental organizations, and constituent dental societies. The book is well indexed and contains numerous excellent color photographs, although a few of the photos are reproduced from textbooks and did not reproduce clearly.

A survey of eight nondental/laypeople who briefly reviewed this book at this reviewer's request was unanimously negative. To my surprise, all of these responded with such comments as "gross," "graphic," and "pretty bloody." I was personally disappointed with this feedback, because I did not find the photos to be offensive at all. It seems that laypeople may prefer the pamphlets, bland by dentists' standards, found in many waiting rooms. Drawings might be more acceptable to them than photos of the real thing.

The author has missed an excellent opportunity to educate readers about the value of the rubber dam in routine restorative procedures. A rubber dam is shown in only two of the more than 400 illustrations and does not appear in the index. In chapter 3, no indication is made of the routine use of rubber dam in restorative procedures as a possible way of identifying conscientious general dentists. The harmful effects of tobacco use are clearly noted but might have been made stronger and shown more prominently. Likewise, the issue of the safety of dental x-rays is succinctly stated, but since it is a current area of concern among patients, it could have received more attention.

I envision the attraction of this book to be in libraries where aspiring dentists can review it for information about what our profession does. It may be that a dentist's waiting room should contain a copy so as to stimulate interest. Because of potential reactions from some patients, perhaps dentists should be selective in determining which patients scan the book. It is certainly unique and, to this reviewer's knowledge, the first and only one of its kind.

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ATTACHMENTS FOR PROSTHETIC DENTISTRY

Michael Sherring-Lucas and Paul Martin

Published by Quintessence Publishing Co, Inc, Chicago, 1994. 84 pages, 163 illustrations. $38.00.

This short text of 84 pages is intended as a primer on attachments for the technician without previous experience in this phase of dentistry. It is designed to be used with the Cendres & Métaux SA catalogue, a European laboratory precision attachment manufacturer. The attachments presented are primarily of European origin and are often not those used in North America.

The use of the tooth numbering system based upon the four quadrants may be confusing to those who are not familiar with this method. Illustrations are a combination of line drawings and photographs. The line drawings are generally well done, but unfortunately many of the photographs have inadequate enlargement, making them of little value in identifying specific technique requirements. A variety of procedures and materials are outlined, covering the basic classifications of attachments, but they are not of sufficient depth to allow the technician to actually complete a precision attachment partial denture.

No rationale for the selection of any attachment is presented, although the technician's role in the planning of the treatment is emphasized, the implication being that the technician selects the appropriate attachment based upon the manufacturer's recommendations.

While this text may well serve its intended purpose of providing a brief introduction to the technician, it is of little value to the clinician or to the technician not using Cendres & Métaux products and materials.

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THE ART AND SCIENCE OF OPERATIVE DENTISTRY
Third Edition

Clifford M Sturdevant, Theodore M Roberson, Harold O Heymann, and John R Sturdevant, Editors

Published by C V Mosby, St Louis, 1994. 824 pages, 2497 illustrations. $69.95.

This new edition is a remarkable textbook that covers the topic of operative dentistry in a manner not achieved before. The editors are well-known authorities in the field, as are the contributors: Drs Bayne, Crawford, Haywood, Heymann, Lundeen, May Jr, Roberson, Daniel Shugars, Diane Shugars, Sluder Jr, Smith, C Sturdevant, J Sturdevant, Taylor, and Wilder. The editors are to be commended for putting together such a formidable group of experts as contributors for the text.

The chapter headings are indicative of the broad scope of topics addressed. Chapter 1: "Introduction to Operative Dentistry"; Chapter 2: "Clinical Significance of Dental Anatomy, Histology, Physiology, and Occlusion"; Chapter 3: "Cariology: the Lesion, Etiology, Prevention and Control"; Chapter 4: "Infection Control"; Chapter 5: "Patient Assessment, Examination and Diagnosis, and Treatment Planning"; Chapter 6: "Dental Materials"; Chapter 7: "Fundamentals of Cavity Preparation"; Chapter 8: "Instruments and Equipment for Tooth Preparation"; Chapter 9: "Preliminary Considerations for Operative Dentistry"; Chapter 10: "Pain Control"; Chapter 11: "Isolation of the Operating Field"; Chapter 12: "Amalgam Restorations for Class 1 Cavity Preparations"; Chapter 13: "Amalgam Restorations for Class 2 Cavity Preparations"; Chapter 14: "Amalgam Restorations for Classes 3, 5, and 6 Preparations"; Chapter 15: "Complex Amalgam Restorations"; Chapter 16: "Direct Tooth-colored Restorations for Classes 3, 4, and 5 Cavity Preparations"; Chapter 17: "Tooth-colored Restorations for Classes 1, 2, and 6 Cavity Preparations"; Chapter 18: "Additional Conservative Esthetic Procedures"; Chapter 19: "Cast Metal Restorations for Class 2 Cavities"; Chapter 20: "Direct Gold Restorations."

It is important to note that this text is truly the state of the art as exemplified by its conservative philosophy and its excellent chapter on caries as a disease and methods to control or eliminate this disease.

The book is the most comprehensive text on operative dentistry ever published. It is well written, organized, easy to read, and has in excess of 2400 illustrations and color plates. Illustrations include excellent photographs and line drawings. This book would be most valuable for all practicing general dentists and all students. It can be obtained for the bargain price of $69.95. Quite remarkable in this day and age!

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SEDATION: A GUIDE TO PATIENT MANAGEMENT
Third Edition

Stanley Malamed and Christine Quinn

Published by C V Mosby, St Louis, MO, 1995. 641 pages, 266 illustrations. $46.95, softbound.

Having used earlier additions of *Sedation: A Guide to Patient Management* as the textbook for my sedation courses, I was pleased to find that in this third edition, Dr Stanley Malamed has succeeded in composing an up-to-date, basic text that can be used by practicing dentists to supplement their skills with techniques and theories of various forms of sedation. The book is philosophically oriented to the clinical application of pediatric and adult sedative technique from many different avenues: oral, inhalation, intravenous, transmucosal, intramuscular, and a smaller discussion of hypnosis and iatrogenic sedation. Theory, physiology, pharmacology, armamentarium, complications, and techniques are discussed in varying degrees for each of the above. Different levels of sedation are covered, ranging from minimal sedation to general anesthesia with a quality discussion on how to differentiate them. Patient evaluation preoperatively and patient monitoring intra- and postoperatively are covered comprehensively in chapters devoted to those subjects. Complications and management of emergencies receive several chapters of review, all nicely composed. Finally, with the help of co-author Christine Quinn, the application of sedation to the pediatric, medically compromised, physically compromised, and geriatric patient populations is discussed along with appropriate modifications. In all of the above topics much new information (current to 1994 knowledge) has been added in comparison with the second edition, resulting in a generally, nicely balanced and useful textbook.

The most difficult criticism of the book is that in trying to be so thorough, Dr Malamed includes but does not always do justice to several topics. As a result, it has the unintentional effect of lulling the reader into a false sense of confidence. Three examples follow: First, most of the pharmacology of the medications discussed is geared toward clinical relevance rather than an exhaustive treatise on the mechanisms of action, etc. Some medications are covered very thoroughly, while others receive barely enough to warrant inclusion. Instead, the reader is referred to many source articles and texts. This makes it seem like the pharmacokinetics of the medications are less important than other aspects of sedation, when this reader believes the sedationist needs to have a firm background in the medications being administered. Second, the author discusses advanced sedation techniques utilizing medications such as propofol and ketamine in such a way as to suggest that these drugs may be appropriate for use by doctors with extensive experience in the basic techniques of IV sedation. In many circles these medications are considered general anesthetic agents, requiring significantly more training to competently utilize them in one's practice. In a text such as this, where the overall focus is on basic armamentarium, basic sedative principles, basic techniques, etc, it seems potentially dangerous to superficially cover medications like these with such complex pharmacology. It is as if the focus of the book has been lost. These medications and techniques really should be placed in an advanced text, not in the same one that covers beginner techniques like intravenous cannulation. Finally, the entire section on general anesthesia is, again, too superficial to serve much purpose except to introduce the reader to the topic. Its inclusion conveys the message that the text is covering the topic with the same depth and user-friendliness of the basic technique chapters, when in reality it does not.

A minor criticism of the book is that most of the photographs in the third edition are poorly reproduced and can be difficult to interpret for the novice. The more experienced sedationist will find this to be only a nuisance.

With these cautions in mind, it must be stressed that this is still an excellent and useful textbook to be used in conjunction with a course in sedative theory and technique. This reader requires it for his courses on the subject. It reads well, is nicely indexed and referenced, and covers the topic in sufficient depth to be quite useful in the educational arena. It is also highly recommended as a quality reference/refreshing review for those practitioners who are already trained in the techniques. Of course, the nature of the subject causes the text to have a much more limited appeal for the practicing dentist who is not trained or being trained in sedative technique.

In conclusion, so long as one recognizes the adjunctive nature of this textbook to formal didactic and clinical teaching, this is an excellent text by a recognized author in the field and is recommended for all who utilize sedation in their practices or are conducting/attending a sedation course.

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INSTRUCTIONS TO CONTRIBUTORS

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JULY-AUGUST • VOLUME 20 • NUMBER 4 • 129-172

EDITORIAL

CLINICAL ARTICLE

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