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# OPERATIVE DENTISTRY

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# EDITORIAL

# Is There a Future for Gold Foil?

The answer to this question is emphatically yes. Gold foil restorations have been with us for many years and will remain so. There are still a great many instances where preserving tooth structure can best be accomplished with the use of gold foil. Gold foil has long been known to seal the walls of a cavity remarkably well while being accepted by oral tissue much better than other materials. These facts continue to justify its use even with today's quest for more "whiteness."

It often requires more of an effort on the part of the dentist to reassure patients of its value as an excellent restoring agent. Once convinced, however, the patient will enjoy years of service, possibly more than other materials might offer.

Today's curriculum in dental schools does not train dental students in the use and placement of gold foils; thus it has become more difficult for newly graduated dentists to incorporate its use into their dental practices. Our organization seeks to remedy that situation.

The American Academy of Gold Foil Operators is an organization that dates from 1952. The founding president was Dr Bruce Smith, who shepherded it for the next two years. Other great members of operative dentistry have followed to give the academy the credentials that stand for excellence.

The AAFGO has always prided itself on helping other dentists to become more proficient in the use of direct gold techniques. It has further encouraged those interested in becoming members of working operative or gold foil study clubs. These clubs are hands-on groups of dentists who work together to promote a better understanding of the use and placement of the material. Along with such efforts, the academy sponsors well-designed courses at university dental schools where the participants are given an intense and thorough instruction in the gold foil technique.

Much has been accomplished over the years to lessen the feeling that direct gold is difficult to manipulate. Dr Lloyd Baum and others have been instrumental in developing first Goldent and more recently Easy Gold. In both instances the gold has been prepared in such a manner to make it easier to condense and less time consuming to use.

Patients still rely upon the sound judgment of the dentist to formulate a beneficial treatment plan for them. The consideration of the dentist to use gold foil in selected areas will provide years of service.

There is an adage that says, "You should look behind yourself to see where you have been in order to get a better idea of the direction in which you are going." Gold foil has been with us in the past, it is being used in the present, and it will be with us in the future. Surely gold foil commands a better fate than that of the Richmond crown.

GLENN H BIRKETT, DDS
President
American Academy of Gold Foil Operators

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# CLINICAL ARTICLE

# Direct Esthetic Restoration of Anterior Root Canal-treated Teeth

H A ST GERMAIN, Jr • J C MEIERS


## SUMMARY

**The esthetic restoration of anterior root canal-treated teeth with significant loss of tooth structure is a challenging clinical situation. For younger patients or for patients requiring interim treatment plans, restoring badly broken-down anterior teeth with composite resin provides an expedient and esthetic solution. Current visible-light-activated composite resin materials require an incremental build-up to ensure adequate depth of cure. With the use of custom-contoured, stabilized, thin crown forms and strategically placed vent holes, the clinician can efficiently provide cost-effective direct composite resin restorations that meet the patients' esthetic needs.**



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## INTRODUCTION

Anterior root canal-treated teeth with less than one-half of the coronal tooth structure remaining are typically treatment planned to receive a porcelain crown. However, for younger patients or patients requiring an interim treatment plan, a direct esthetic restoration may be more appropriate. In these cases, if greater than one-half of the coronal tooth structure remains, a direct composite restoration utilizing the existing tooth structure is a viable treatment option. With greater tooth loss, the need for additional retention for the coronal build-up becomes more critical. In cases where less than one-half of the coronal tooth remains, the use of prefabricated cemented posts and anti-rotational features such as self-threading pins, slots, or grooves can be an expeditious way to provide additional retention in retaining direct core build-ups. Composite resin is presently the material of choice for anterior teeth when a direct core build-up is planned, especially when an all-ceramic restoration is the final restoration.

This article will present a restorative technique for the direct restoration of an anterior root canal-treated tooth with significant loss of tooth structure using a perforated crown form. The goal of this procedure is to provide an esthetic, interim restoration in an expedient and predictable manner utilizing current state-of-the-art materials in

composite resin technology.

## TECHNIQUE

As a clinical example, the case to be described is a root canal-treated mandibular lateral incisor with less than one-half the clinical crown remaining. The tooth has been prepared with a prefabricated cemented post (Parapost, Whaledent, New York, NY 10001) and a self-threaded 0.017-inch pin (Max, Whaledent) for a direct composite resin core build-up (Figure 1). A small-particle visible-light-activated hybrid composite resin (Tetric, Vivadent USA, Amherst, NY 14228) is the selected composite resin class because of the combination of strength and polishability. Prior to rubber dam application, the appropriate body and incisal shades are determined for the light-activated composite resin. Placing a small increment of composite on an adjacent tooth and light activating is an excellent way to confirm the match of the selected shade. Depending on the shade blends of the adjacent teeth, the choice of an incisal shade to duplicate incisal translucency needs to be carefully considered.

Rubber dam isolation is achieved and peripheral remaining enamel is etched with 35-40% phosphoric acid for 15 seconds and rinsed. If a considerable amount of dentin is present, any of the current dentin bond systems that have an acidic primer can also be used for this step. The respective unfilled bond agent or adhesive primer is applied and light-activated (Figures 2 & 3).

A variety of crown forms are available as a matrix in direct composite resin build-up procedures. Strip-Crowns (ESPE/Premier, Norristown, PA 19404) are particularly useful in these situations because they are easily adapted to the treatment tooth without interference from adjacent teeth due to their thin and flexible construction (Figure 4). This will permit the attainment of approximal contacts on the adjacent teeth with the initial crown build-up, eliminating the need of having to place additional composite resin to achieve approximal contact and also saving time.

Although crown forms are useful adjuncts in composite resin core build-ups, they do have several disadvantages. The crown form itself can split during seating due to the high-viscosity of composite resin materials. The crown form may

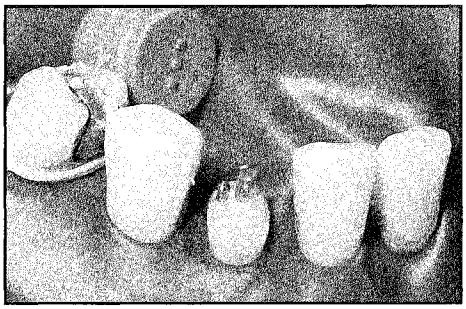


Figure 1. *Root canal-treated mandibular lateral incisor with a prefabricated cemented post and self-threaded pin*

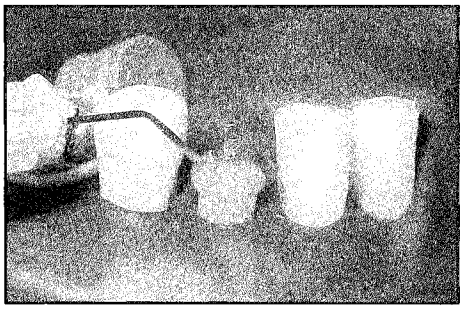


Figure 2. *Acid etchant conditioner placed on dentin and/or enamel*

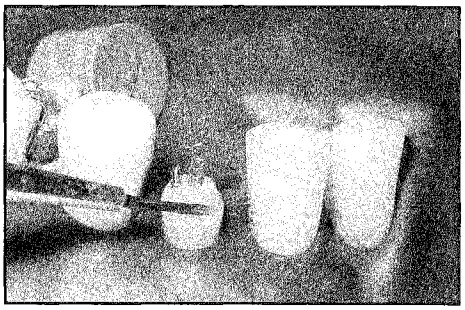


Figure 3. *Respective dentin bond system and/or unfilled resin bond agent placed*

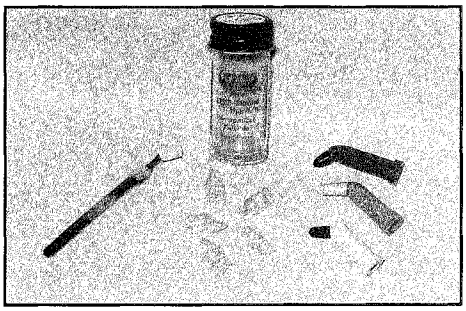


Figure 4. *Strip-Crowns and various syringeable, light-activated composite resin materials with Vita shade tab*

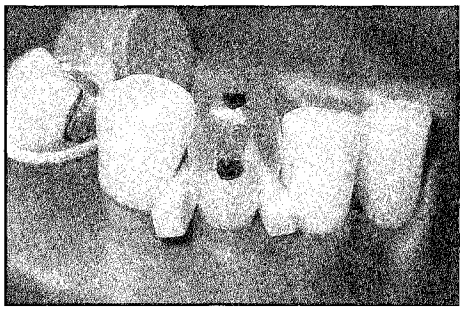


Figure 5. *Crown form matrix adapted with facial and incisal vent hole position indicated*

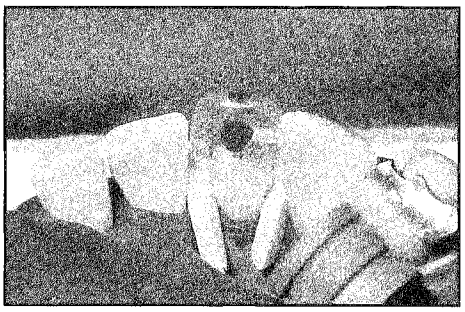


Figure 6. *Crown form matrix adapted with the position of the lingual vent hole position indicated*

be incompletely seated prior to polymerization. Also, insufficient polymerization can result within the total body of visible-light-cured composite resin if using a bulk placement technique.

The following technique will describe how to avoid these problems. A Strip-Crown Matrix is custom-trimmed to fit the anatomical requirements of the tooth to be restored with crown and bridge scissors. It is then tightly wedged in position. Vent holes are strategically placed to allow for incremental build-up of the light-activated composite resin through the matrix without having to remove it. The vent holes are placed in three separate locations (facial, incisal edge, and lingual) with a #6 round bur (Figures 5 & 6). The facial vent hole must be located about 2 mm gingival to the lingual vent hole, because the first increment of composite resin will be placed from the facial, and access for condensing this initial increment of composite will be attained from the lingual vent hole. The diameter of the vent hole will vary depending on the size of the tip orifice of the syringeable composite resin system you are using (Figure 7). A small round burnisher (Birtles Spatula applicator, Thompson Dental Mfg, Co, Missoula, MT 59801) is used from the lingual access vent hole to condense the first increment of composite resin. This avoids the potential problem of the lingual-gingival margin not being completely covered when the composite resin is expressed from the facial vent (Figures 8A & 8B). This first increment is light activated for 40 seconds from the facial aspect and then 40 seconds from the lingual aspect.

The second increment of composite resin is delivered through the lingual vent. To ensure proper adaptation onto the first increment, the incisal vent is occluded with a finger until the composite resin has been seen to overlap and completely cover the first increment. If incisal translucency is an important factor, the selected incisal shade of composite resin should be added at this time (Figures 9-11). Taking the finger from the incisal vent will allow a slight amount to extrude and prevent an air pocket from forming. This increment is light-activated for 40 seconds from the facial aspect and 40 seconds from the lingual aspect.

The excess composite resin extruding from the vent holes should be contoured smooth and the crown form peeled from the restored tooth. Occlusion is

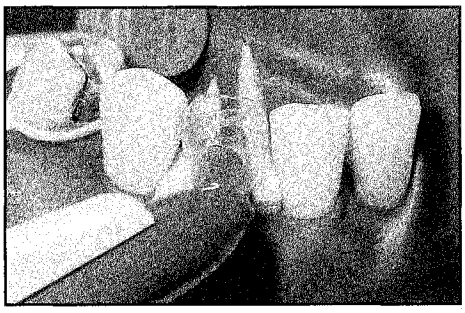
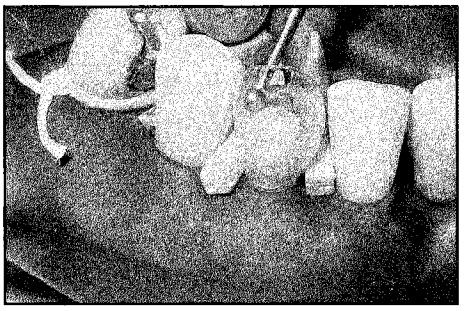
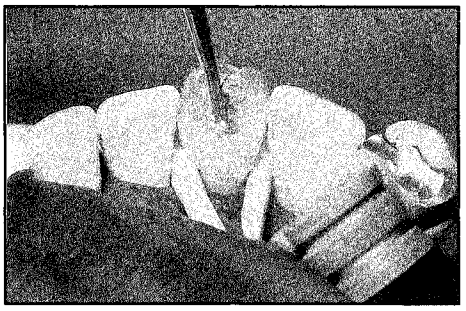


Figure 7. *Syringeable, light-activated composite resin with tip placed inside facial vent hole*





Figures 8A & B. *Access gained from the lingual vent to condense the lingual-gingival margin with a small round burnisher*

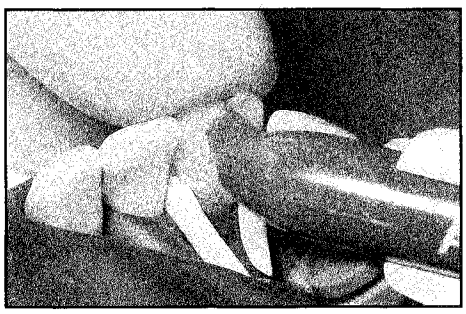


Figure 9. *Covering the incisal vent with a finger to facilitate adaptation of second increment of composite resin*

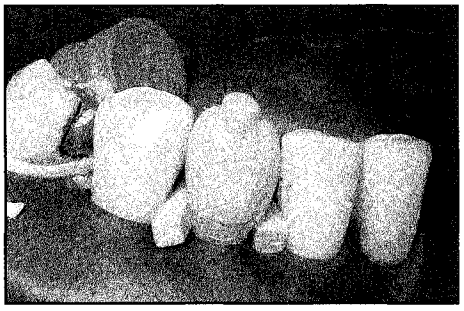


Figure 10. *Excess composite resin extruding through the incisal vent after finger pressure is released*

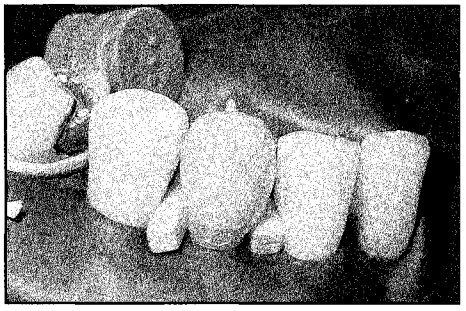


Figure 11. *Contouring extruded composite resin prior to removal of the Strip-Crown*

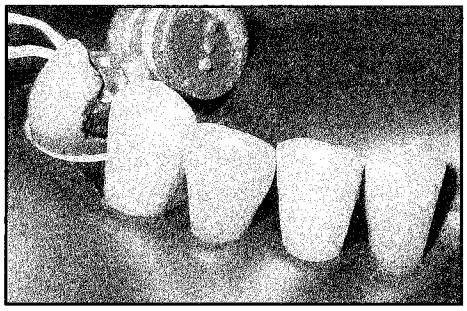


Figure 12. *Finished and polished direct composite resin restoration of anterior root canal-treated tooth*

checked and care is especially taken to minimize potentially destructive excursive contact areas. Subsequent finishing procedures are carried out with micron finishing diamonds, carbide finishing burs, abrasive disks, and rubber abrasive points followed by polishing pastes as recommended for the specific brand of composite resin being used. (Figure 12). Following all finishing procedures, a 40-second light activation is performed both facially and lingually to maximize the polymerization and subsequent mechanical and physical properties of the freshly exposed composite surface.

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# ORIGINAL ARTICLES

# Shear Bond Strengths of Composite to Dentin Using Six Dental Adhesive Systems

P T TRIOLO, Jr • E J SWIFT, Jr • W W BARKMEIER

**Clinical Relevance**
High bond strengths of composite to dentin can be achieved using current-generation resin adhesive systems.


## SUMMARY

**The development of adhesive agents for bonding composite to dentin has rapidly evolved in recent years. It is postulated that dentin bond strengths in the range of 17 MPa are sufficient to resist the polymerization shrinkage of composite resins. The purpose of this study was to evaluate the shear bond strengths of the following dentin adhesive systems: All-Bond 2 (Bisco), Imperva Bond (Shofu), Optibond (Kerr), Permagen (Ultradent), ProBond (Caulk/Dentsply), and Scotchbond Multi-Purpose (3M). Sixty human molars (10 per group) were mounted in phenolic rings, and the occlusal surfaces were flat ground in dentin to 600 grit. The prepared dentin bonding sites were treated according to the directions for each of the systems evaluated. A gelatin capsule technique was used to bond Bis-Fil composite cylinders to the teeth. The specimens were stored in water at 37 °C for 24 hours. Mean shear bond strengths were as follows: Scotchbond Multi-Purpose: 23.1 ± 2.6 MPa, All-Bond 2: 21.4 ± 7.8 MPa, Imperva Bond: 19.8 ± 6.1 MPa, Optibond: 19.7 ± 3.6 MPa, ProBond: 16.3 ± 4.5 MPa, and Permagen: 16.2 ± 3.0 MPa. There was not a significant difference ($P > 0.05$) in the bond strengths of Scotchbond Multi-Purpose, All-Bond 2, Imperva Bond, and Optibond. The bond strengths of Scotchbond Multi-Purpose and All-Bond 2 were significantly greater ($P < 0.05$) than ProBond and Permagen. Current-generation dentin adhesive systems have approached or exceeded the theoretical threshold value to resist contraction stresses during polymerization of resin materials.**



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## INTRODUCTION

Acid etching of enamel creates an irregular surface that is ideal for resin bonding. Shear bond strengths of composite resin to etched enamel are typically in the range of 20 MPa (Barkmeier, Shaffer & Gwinnett, 1986; Nordenvall, Brännström & Malmgren, 1980). Such bond strengths provide clinically successful retention and marginal seal of direct and indirect

restorations, orthodontic brackets, and pit and fissure sealants.

Bonding of resins to dentin has proved to be a more difficult challenge than bonding to enamel. The earlier dentin adhesives had low bond strengths and performed rather poorly in clinical studies (Chan, Reinhardt & Boyer, 1985; Eliades, Caputo & Vougiouklakis, 1985; Heymann & others, 1988). However, recent developments of hydrophilic systems have made dentin bonding a more reliable and predictably consistent clinical procedure. Bond strengths approaching or exceeding 20 MPa have been reported for various current-generation dentin adhesives (Barkmeier & others, 1990; Barkmeier, Suh & Cooley, 1991; Cooley, Tseng & Barkmeier, 1991; Gwinett, Dickerson & Yu, 1992; Triolo & Swift, 1992). These studies have established repeatable shear bond strengths with several bonding systems, but the bond strengths of the newest dentin bonding agents have not been confirmed.

The purpose of this study was to evaluate the shear bond strengths of six dentin adhesive systems to dentin. The systems tested were All-Bond 2 (Bisco Inc, Itasca, IL 60143), Imperva Bond (Shofu Dental, Menlo Park, CA 94025), Optibond (Kerr Manufacturing Company, Romulus, MI 48174), Permagen (Ultradent Products, South Jordan, UT 84065), ProBond (Caulk/Dentsply, Milford, DE 19963), and Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144).

## METHODS AND MATERIALS

Sixty extracted intact human molars were stored in distilled water with thymol crystals for approximately 1 month before they were used in this study. The teeth were mounted in 1-inch-in-diameter phenolic ring forms (Leco Corporation, St Joseph, MI 49085) with cold-cure acrylic resin. The occlusal surface of each tooth was ground flat on a water-cooled Ecomet III (Buehler, Ltd, Lake Bluff, IL 60044) grinder/polisher using 120-grit silicon carbide abrasive paper to expose dentin. The dentin was polished with 320- and 600-grit silicon carbide paper on the same device. The teeth were randomly assigned to six groups (n = 10) for bonding with the various adhesives.

Manufacturers' instructions were strictly observed for all bonding systems. The batch numbers of each system are listed in Table 1. The dentin was conditioned for all materials except ProBond. Although an etchant is not supplied with Optibond, dentin conditioning is recommended. Tooth Conditioner Gel (Caulk/Dentsply), 37% phosphoric acid, was used for conditioning the dentin with the Optibond system. The instructions for All-Bond 2, Permagen, and ProBond state explicitly that dentin should be kept moist for primer application. For these materials, excess moisture was blotted with tissue paper (Kimwipes EX-L, Kimberly-Clark Corporation, Roswell, GA 30076) after the etchant was rinsed off. For Optibond and Imperva Bond, the dentin was dried with compressed air but was not aggressively air dried or desiccated.

*Table 1. Batch Numbers of Bonding System Components Used in This Study*

| Bonding System | Component | Batch Number |
|---|---|---|
| All-Bond 2 | All-Etch | 79023 |
| | Primer A | 69243 |
| | Primer B | 69233 |
| | D/E Bonding Resin | 69293 |
| Imperva Bond | Etchant | 49275 |
| | Primer | 19228 |
| | Bond Agent | 49222 |
| Optibond | Prime | 752142 |
| | DC Activator (3A) | 752312 |
| | DC Paste (3B) | 752316 |
| Permagen | Ultra-Etch 35% | 0208%17Q9 |
| | Primers A & B | 0208%17Q9 |
| | Bonding Resin | 0208%17Q9 |
| ProBond | Primer | 930312 |
| | Adhesive | 930628 |
| Scotchbond Multi-Purpose | Etchant | 3DA |
| | Primer | 3CK |
| | Adhesive | 3BT |

Number 5 gelatin capsules (Eli Lilly and Company, Indianapolis, IN 46285) were filled approximately two-thirds full with composite resin (Triad Inlay/Onlay Composite), and the composite was polymerized for 1 minute in a Triad 2000 unit (Equipment Division/Dentsply, York, PA 17405). A final increment of small particle size composite (Bis-Fil) was placed in the gelatin capsules, and the capsules were seated securely against the treated bonding sites. Excess material was removed, and the composite was light-cured for a total of 120 seconds (four 30-second curing sequences equally divided around the circumference of the composite cylinders) with a

Translux EC (Heraeus Kulzer, Inc USA, Irvine, CA 92718) light-activation unit. The curing light output was monitored with a dental radiometer (Demetron Research Corporation, Danbury, CT 06810). The specimens were stored in distilled water at 37 °C for 24 hours.

The specimens were then mounted in a custom fixture (Figure 1) for determination of shear bond strengths using a Universal Testing Machine (Model 1123, Instron Corporation, Canton, MA 02021). A knife-edged chisel was used to deliver the shearing force. The bonded composite cylinders were placed under continuous loading at 5 mm/minute until fracture occurred. Shear bond strengths were calculated and recorded in MPa units. The fracture sites were examined visually to determine the type of failure that occurred during the debonding procedure. Data were analyzed using a one-way ANOVA and post hoc Fisher Protected Least Significant Difference.

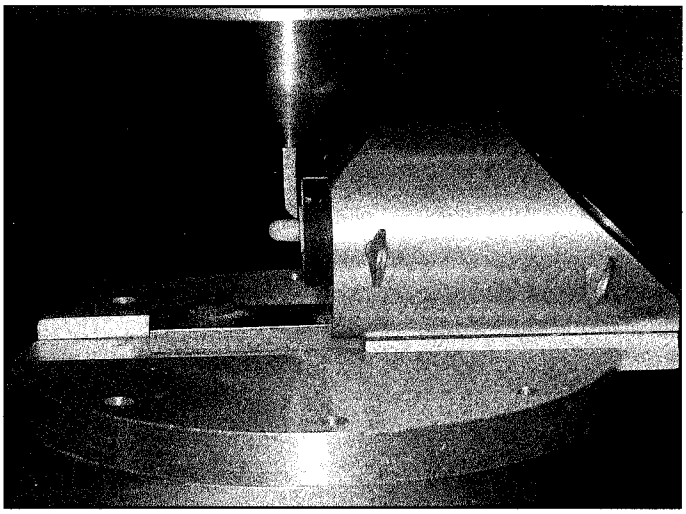

Figure 1. *Test assembly for shear bond strength testing*

## RESULTS

Mean shear bond strengths ranged from 16.2 ± 3.0 MPa for Permagen to 23.1 ± 2.6 MPa for Scotchbond Multi-Purpose. The data are summarized in Table 2. The bond strengths of Scotchbond Multi-Purpose and All-Bond 2 were significantly greater ($P < 0.05$) than those of Permagen and ProBond. The bond strengths of Imperva Bond and Optibond were statistically equivalent to Scotchbond Multi-Purpose and All-Bond 2.

Cohesive failures of dentin (Figure 2) occurred in all 10 specimens treated with Scotchbond Multi-Purpose. Six cohesive failures in dentin occurred with All-Bond 2 and Imperva Bond and with three of 10 specimens with Optibond and ProBond. There were no cohesive fractures in dentin with the Permagen group.

*Table 2. Shear Dentin Bond Strengths (MPa) of the Adhesive Systems Evaluated in This Study*

| Bonding System | Mean | SD | High | Low | CV%* |
|---|---|---|---|---|---|
| Scotchbond Multi-Purpose | 23.1 | 2.6 | 27.1 | 20 | 11.3 |
| All-Bond 2 | 21.4 | 7.8 | 29.1 | 8.4 | 36.4 |
| Imperva Bond | 19.8 | 6.1 | 30 | 8.7 | 30.8 |
| Optibond | 19.7 | 3.6 | 25.6 | 14.3 | 18.3 |
| ProBond | 16.3 | 4.5 | 25.6 | 8.6 | 27.6 |
| Permagen | 16.2 | 3.0 | 21.5 | 12 | 18.5 |

*Coefficient of variation

Groups connected by line are not different at the 5% significance level.

## DISCUSSION

The shear bond strengths of composite to dentin for the six adhesive systems evaluated in this study were remarkably similar. This may seem unlikely because, except for All-Bond 2 and Permagen, their chemical compositions are quite different. However, they probably all achieve dentinal bonding by a similar mechanism, i e, penetration of resin monomers into a conditioned dentin surface (Eick & others, 1991; Van Meerbeck & others, 1992).

All-Bond 2 uses 10% phosphoric acid to condition the dentin. Hydrophilic primers containing N-tolyglycine-glycidyl methacrylate (NTG-GMA) and biphenyl dimethacrylate (BPDM) in acetone are applied to infiltrate the decalcified superficial dentin

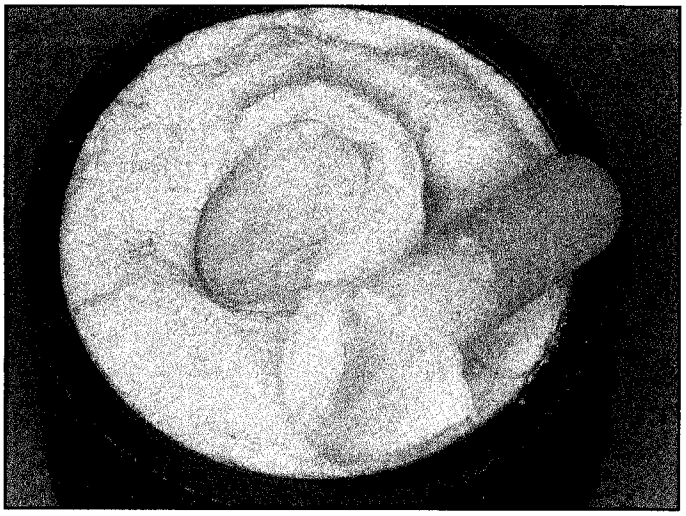

Figure 2. *Cohesive failure in dentin*

surface. An unfilled resin containing BIS-GMA and 2-hydroxyethyl methacrylate (HEMA) is applied before the restorative material is placed.

Permagen can be used with either a 10% or a 35% phosphoric acid etchant. A shorter etching time is required for the 35% acid, as was done in this study. The Permagen primers are similar to the All-Bond primers, containing NTG-GMA and a proprietary hydrophilic resin in acetone.

Imperva Bond utilizes a 37% phosphoric acid as a conditioner. In this study, a 15-second application time was used to condition dentin. The primer contains HEMA and 4-acryloxyethyltrimeric acid with a silane coupling agent in water. The adhesive is triethylene glycol dimethacrylate (TEGDMA), camphoroquinone, dimethyamino ethylmethacrylate, and butylated hydroxytoluene (BHT).

Optibond is not supplied with a conditioner, but the manufacturer states that any phosphoric acid gel can be used. Optibond Prime is a light-activated hydrophilic primer that contains HEMA, glycerol phosphate dimethacrylate (GPDM), a phthalate, ethanol, and water. The Dual-Cure adhesive used in this study contains BIS-GMA, HEMA, glycerol dimethacrylate, barium glass, and fumed silica fillers, and disodium hexafluorosilicate.

The chemistry of ProBond is based on that of Prisma Universal Bond 3 (Caulk/Dentsply). It is a two-component system that does not require dentin conditioning. The primer contains acetone, ethanol, and a phosphate adhesion promoter, dipentaerythritol penta acrylate phosphoric acid ester (PENTA). The adhesive resin is the same as the Prisma Universal Bond 3 Adhesive, and contains urethane dimethacrylate (UDMA), PENTA, glutaraldehyde, and photoinitiators. While the adhesive resin is identical to that previously used with the Prisma Universal Bond 3 system, the primer has been modified by the deletion of HEMA and the addition of acetone. Studies have shown that acetone-based primers are very effective in bonding to wet or moist dentin. (Gwinnett, 1992; Gwinnett & Kanca, 1992; Kanca, 1992).

The Scotchbond Multi-Purpose Etchant is a 10% maleic acid that is used to condition both enamel and dentin. The primer in this system is an aqueous solution of HEMA and Vitrebond copolymer. The adhesive resin is a combination of BIS-GMA resin, HEMA, and a photoinitiator.

Most of the latest-generation dentin adhesives involve the penetration of resin monomer into the smear layer on dentin or into a dentin surface that has been decalcified with an acid, forming an "interdiffusion layer" (Van Meerbeck & others, 1992). This area, also referred to as the "resin-reinforced zone" (Suh, 1991) or "hybrid layer" (Nakabayashi, Nakamura & Yasuda, 1991), is believed to be the primary bonding mechanism for current-generation dentin adhesive systems (Eick & others, 1991). Diffusion of resin monomers into the dentin surface, with subsequent formation of a "resin-reinforced zone," appears to be essential for a durable bond to dentin. The inability of previous-generation dentin adhesives to provide consistently high bond strengths may be directly related to their failure to fully wet and penetrate into the dentin surface. The results of this study certainly indicate that strong bonds can be achieved with current systems. The failure of dentin during the debonding procedure, versus adhesive failure between the resin and dentin, demonstrates the excellent adhesive characteristics of the newer systems.

## CONCLUSION

Munksgaard, Irie, and Asmussen (1985) postulated that a composite to dentin bond strength in the range of 17 MPa, or greater, was required to resist the contraction shrinkage of composite materials. The bond strengths of composite to dentin with earlier-generation resin adhesive systems did not approach this threshold value (Triolo & Swift, 1992; Van Meerbeck & others, 1992). These current-generation adhesive systems are now capable of exceeding the bond strength threshold level required to resist the polymerization shrinkage of resin restorative materials.

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# In Vitro and Clinical Evaluations of a Dentin Bonding System with a Dentin Primer

A SENDA • K KAMIYA
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**Clinical Relevance**
Bond strength of Light Bond to dentin is improved by priming the dentin with Light Bond Primer.

## SUMMARY

**The purpose of this study was to investigate the effect of a dentin primer in improving dentin-to-composite bond strengths mediated by a dentin adhesive. The investigation consisted of both an in vitro tensile bond test, in which fresh bovine dentin was used, and clinical evaluation. In the in vitro bond test, bovine dentin surfaces were treated with the primer (an aqueous solution of HEMA) for different durations (10, 20, 30, and 60 seconds) prior to bonding of the light-cured adhesive and placement of a light-cured composite material. For the clinical evaluation, a total of 33 cervical erosion lesions were restored with the combination of the primer, the adhesive, and the composite. To comply with ADA requirements for the acceptance program of dentin bonding agents, no enamel etching nor any mechanical retentive locks were performed in those restorations.**

**Significant increases in bond strength were obtained in specimens treated with the primer. Regarding the clinical evaluation in which 30 restorations were available for the 6-month recall and 15 restorations were also available for the 1-year recall, all samples demonstrated a retentive rate of 100%.**

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## INTRODUCTION

Development of new resin bonding materials and techniques has enhanced the popularity of current esthetic and conservative restorative dentistry. However, clinical studies have shown that resin-dentin bonding has not yet achieved clinically satisfactory results. Insufficient resin-dentin bonding may be one of the reasons that resin restorations are not reliable (Albers, 1985; Jordan, 1993). In the early 1980s, several dentin bonding agents were introduced. However, clinical studies have revealed that retention of restoratives depends mainly on mechanical retentive locks and/or the phosphoric acid etching of enamel, because sufficient adhesive strength could not be expected from the bonding agent itself (Council on Dental Materials, Instruments and Equipment, 1987; Jordan, Suzuki & Boksman, 1988).

Recently, new or third-generation dentin bonding systems have become commercially available. In each system, pretreatment of the dentin is required prior to bonding. Jordan, Suzuki, and MacLean (1989a), Jordan and others (1989b), Senda and others (1990a, 1990b), and Bastos and others (1990) carried out clinical research in accordance with the ADA requirements for the acceptance program of dentin bonding agents, and showed the clinical effectiveness of these new-generation bonding agents.

Tokuso Light Bond (Tokuyama Soda Co, Ltd, Tokyo, Japan), evaluated in the present study, is a one-component light-cure-type bonding agent containing a carboxylic acid monomer (MAC-10) and was designed to adhere to untreated dentin (Kawaguchi & others, 1988a, 1988b; Sasama, 1989). Kawaguchi and others (1988a, 1988b) and Sasama (1989) reported that this particular bonding agent had the same bond strength to untreated dentin as the new-generation dentin bonding systems. However, our preliminary clinical studies of the bonding agent (not published) did not show satisfactory results without enamel etching and mechanical retentive locks. These results suggest that the pretreatment of dentin is also necessary for Light Bond in clinical applications. Recently, therefore, Tokuso Light Bond Primer (Tokuyama Soda) has been developed as a dentin primer for Light Bond.

The purpose of this study was to investigate the effect of Light Bond Primer in improving bond strength of Light Bond to dentin. The investigation consisted of both an in vitro test and clinical evaluation in accordance with ADA requirements.

## METHODS AND MATERIALS

Table 1 shows the primer, bonding agent, and composite materials used in the present study.

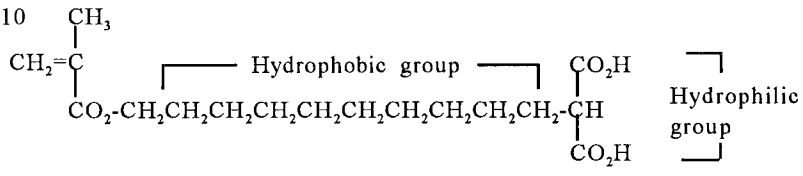
Since we felt that bond strengths depended on storage periods of extracted teeth and the presence of pulp, we used bovine teeth, extracted 6 hours previously, to determine bond strengths and contact angles. We also used them for scanning electron micrography (SEM) observations.

A total of 33 cervical erosion lesions were restored with the combination of Light Bond Primer, Light Bond, and Palfique Estelite (Tokuyama Soda) or Palfique Light (Tokuyama Soda). (Note: Palfique Light was changed to Palfique Estelite due to a change in the composition and the distribution of filler particles. After the present study was started, Palfique Light was taken off the market.) Patients visiting the Aichi Gakuin University Dental Clinic for the treatment of cervical erosion lesions were chosen for this study. After being notified of the purpose, the methodology, and of the anticipated results of the study, they consented to participate. Table 2 shows age and sex distribution of patients and the kind of restored teeth. Although teeth with severe symptoms, such as hypersensitive dentin and pulpitis, were excluded from the present study, all teeth restored were vital and some had slight cold-water sensitivity. As a matter of routine, the patients were given active oral hygiene instructions.

*Table 1. Materials Used*

| Materials | Batch | Composition |
|---|---|---|
| Tokuso Light Bond Primer | 101, 201<br>301 | HEMA (35%)<br>$H_2O$ (65%) |
| Tokuso Light Bond | 018 | MAC-10* (20%)<br>BIS-GMA (24%)<br>HEMA (18%), 3G (38%)<br>photoinitiators |
| Palfique Estelite | EU209 | $SiO_2$-$ZrO_2$ filler**<br>diluting monomers<br>photoinitiators |
| Palfique Light*** | LU299 | $SiO_2$-$TiO_2$ filler**<br>diluting monomers<br>photoinitiators |

*MAC-10




**spherical fillers (average particle size: 0.2 x $10^{-3}$ mm)

***Palfique Light is no longer on the market, since it was superseded by Palfique Estelite.

### In Vitro Test

Labial enamel of bovine teeth was removed using #120 grit sandpaper and running water, exposing the dentin. These flat dentin surfaces were then prepared by smoothing with #800 sandpaper and running water. Then Light Bond Primer, an aqueous solution of HEMA, was applied on the dentin surfaces with a small

*Table 2. Distribution of Subjects in Clinical Evaluation*

**Age and Sex of Patients**

| Age | Male | Female |
|---|---|---|
| 21-30 | 0 | 0 |
| 31-40 | 0 | 2 |
| 41-50 | 0 | 3 |
| 51-60 | 3 | 5 |
| 61- | 1 | 1 |
| Total | 4 | 11 |
| | 15 | |

**Teeth Restored**

| Teeth | Maxillary | Mandibular |
|---|---|---|
| I | 4 | 1 |
| C | 5 | 1 |
| P | 16 | 4 |
| M | 2 | 0 |
| Total | 27 | 6 |
| | 33 | |

disposable brush for different durations (10, 20, 30, and 60 seconds) prior to applications of Light Bond. Specimens not treated were used as controls. Light Bond Primer was dried with a gentle air stream, and then Light Bond was applied, followed by a 10-second light cure. Palfique Estelite was placed in a circular window (4 mm in diameter and 1.5 mm in thickness), which was prepared on the surface of the specimens by means of adhesive tape and paraffin wax, and light cured for 30 seconds. Specimens were prepared using a standard randomized, blind experimental design. Six specimens were prepared for each experimental group and the control group.

The specimens were immersed in 37 °C water and were stored for 24 hours. Then each specimen of composite resin was stuck to the stainless steel attachment of a Universal Testing Machine (Autograph, AG-5000D; Shimadzu Co, Tokyo, Japan) with a cyanoacrylate glue. The tensile bond strength was measured with a crosshead speed of 10 mm per minute in air at 23 ± 1 °C and 50 ± 10% relative humidity (Figures 1A & 1B). Specimens were tested at random, and bond strengths were measured as the load at failure divided by the interfacial area at bonding.

As a statistical analysis for each Light Bond Primer treatment, differences between means of tensile bond strengths were tested by a one-way analysis of variance in order to test the null hypothesis that Light Bond Primer treatment has no effect on tensile bond strength. Differences between means of each experimental group were subjected to Student's *t*-test to determine the level of significance.

The interfaces between composite and dentin surfaces of specimens that were broken by the bonding test were observed using the wet SEM (ABT-55, Topcon Co, Tokyo, Japan) without any particular preparations, such as coating, deposition, or drying. After the tensile bond test, specimens were directly placed on the mount of the SEM device, and SEM pictures were taken. SEM pictures of the dentin surfaces of specimens treated with Light Bond Primer for 30 seconds and specimens not treated were

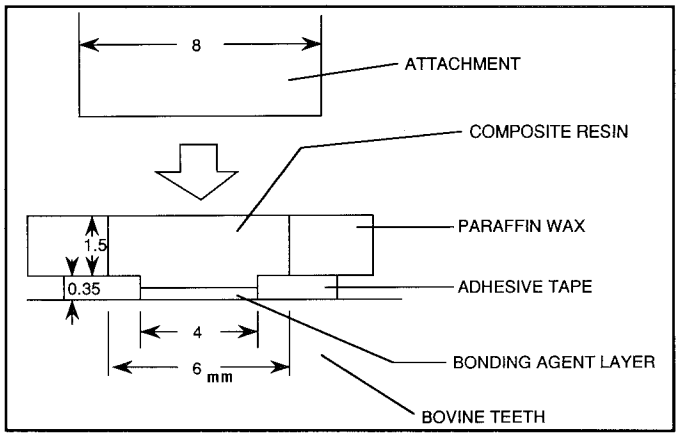



Figure 1A. *Preparation of specimen for the tensile bond test*

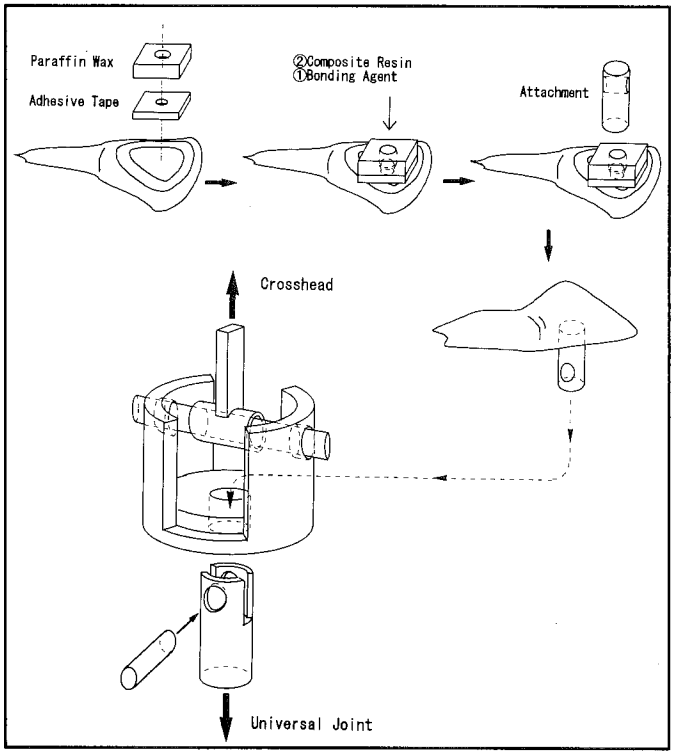



Figure 1B. *Diagrammatic representation of the assembly used*

*Table 3. Criteria for Clinical Evaluation (Cvar and Ryge, Modified)*

**Retention**
Alpha (A): Restoration is present.
Bravo (B): Restoration is partially lost.
Charlie (C): Restoration is absent.

**Color Stability**
Alpha (A): No mismatch, color of restoration and adjacent tooth are same.
Bravo (B): Slight discoloration
Charlie (C): Discoloration required replacement.

**Marginal Integrity**
Alpha (A): Excellent continuity at the resin-enamel interface, no ledge, no discoloration
Bravo (B): Ledge or ditch at resin-enamel interface without discoloration
Charlie (C): Marginal ditch or ledge with discoloration
Delta (D): Recurrent decay at margins

**Abrasion Resistance**
Alpha (A): Completely intact with no perceptible loss of contour
Bravo (B): Slight loss of contour not requiring replacement
Charlie (C): Extensive loss of contour requiring replacement

**Surface Texture**
Alpha (A): Smooth and shiny
Bravo (B): Smooth and dull
Charlie (C): Grainy and rough

**Surface Staining**
Alpha (A): Absent
Bravo (B): Present

**Postoperative Sensitivity**
Alpha (A): Absent
Bravo (B): Present

also taken in the same manner.

The contact angle between the bovine dentin surface treated with Light Bond Primer and water was also determined by means of the Contact Angle Meter, a contact angle measuring device (CA-DTA; Kyowa Interface Science Co, Ltd, Tokyo, Japan). Flat dentin surfaces were prepared in the same manner as described for the tensile bond test. Six specimens were used for both an experimental group in which dentin surfaces were treated for 30 seconds and a control group in which specimens were not treated. The data were statistically analyzed with Student's *t*-test and evaluated for significance.

## Clinical Evaluation

A total of 33 cervical erosion lesions were restored with the combination of Light Bond Primer, Light Bond, and Palfique Estelite (or Palfique Light), as described above. In these restorations, phosphoric acid etching of enamel and mechanical retentive locks were not performed in accordance with ADA requirements for the acceptance program of dentin bonding agents. A total of 30 restorations were available at the 6-month recall, and a total of 15 restorations were also available at the 1-year recall. Restorations were evaluated on the basis of retention, color stability, marginal integrity, abrasion resistance, surface texture, surface staining, and postoperative sensitivity in accordance with the modified criteria established by Cvar and Ryge (1971) (Table 3).

For each restoration, two examiners reached an agreement by forced consensus. The other procedures of the clinical test were in accord with clinical evaluations done by Jordan and others (1989a, 1989b) and Senda and others (1990a, 1990b).

# RESULTS

## In Vitro Test

The means of the tensile bond strengths of specimens that were treated with Light Bond Primer prior to bonding of Light Bond for different durations (0 seconds: not treated, 10, 20, 30, and 60 seconds) are shown in Figure 2. Significant ($P < 0.01$) increases in bond strength were obtained

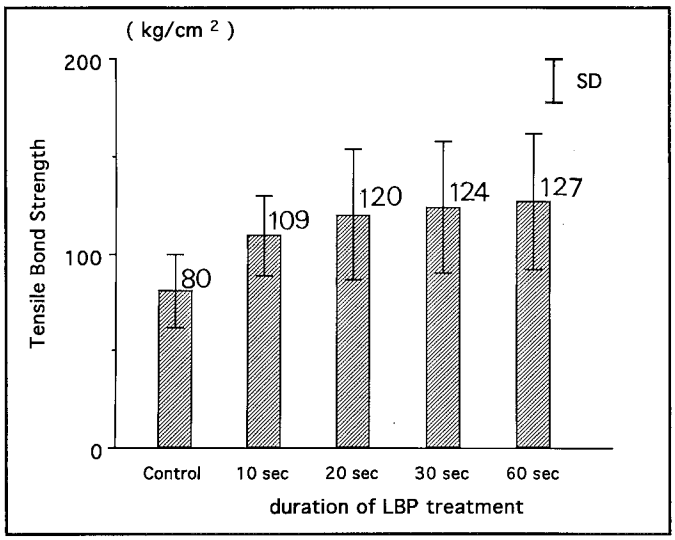



Figure 2. *Tensile bond strengths of specimens treated with Light Bond Primer for different durations (n = 6)*

in specimens treated with Light Bond Primer. In Table 4, the results of the analysis of variance and *t*-test are shown.

Table 5 shows differences in bovine dentin surface contact angles in specimens treated and not treated with Light Bond Primer. It seems that Light Bond

*Table 4. Results of Statistical Analysis of Tensile Bond Strengths*

**ANOVA**

| Source | df | SS | V | $F_o$ |
|---|---|---|---|---|
| A: Light Bond Primer Treatment (time duration) | 4 | 27106.03 | 6776.51 | 128.02** |
| Error | 31 | 1640.97 | 52.93 | |
| Total | 35 | 28747.00 | | |

**Multiple Comparison of *t*-Test**

| Light Bond Primer Treatment | 60 seconds | 30 seconds | 20 seconds | 10 seconds |
|---|---|---|---|---|
| 0 seconds | ** | ** | ** | ** |
| 10 seconds | ** | ** | | |
| 20 seconds | NS | | | |
| 30 seconds | NS | | | |

**$P < 0.01$; NS = not significant

Primer treatment makes dentin surfaces hydrophilic, since a significant ($P < 0.01$) decrease of contact angle was observed on specimens treated with Light Bond Primer.

*Table 5. Effect of Light Bond Primer Treatment on the Contact Angle of Dentin*

| Treatment | Mean of Contact Angle (°) |
|---|---|
| untreated | 57 (1) |
| Light Bond Primer-treated | 35 (2) |

**

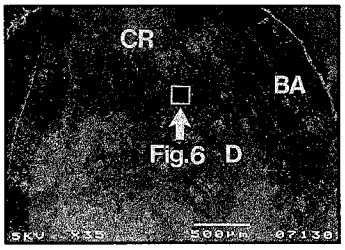
n = 6 (SD)

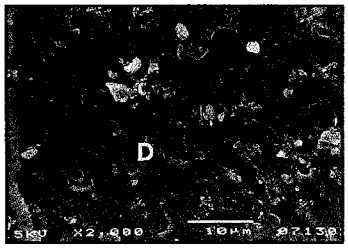
**Statistical difference between means of untreated and treated specimens were highly significant. ($P < 0.01$; Student's *t*-test).

Typical SEM pictures, Figure 3 (untreated) and Figure 4 (treated for 30 seconds with Light Bond Primer), show only slight differences between untreated and Light Bond Primer-treated dentin surfaces. These show that almost the same amount of smear layer remained on dentin surfaces after Light Bond Primer treatment.

SEM pictures of dentin-resin interface (Figures 5 and 6), which were taken after the tensile bond test, show that there was not only cohesive bonding failure in dentin but also combined bonding failure with 30-second Light Bond Primer treatment. On the other hand,

Figure 3. *SEM picture of bovine dentin surface without Light Bond Primer treatment (original magnification X1000)*




Figures 5 & 6. *SEM pictures of dentin-resin interface of specimen with Light Bond Primer 30-second treatment taken after tensile bond test (original magnification X17.5 and X1000 respectively). Cohesive and combined bonding failures were observed. CR = composite resin (Palfique Estelite); BA = bonding agent (Light Bond); D = dentin.*

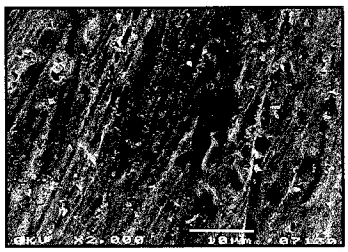
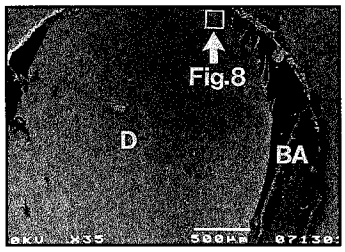
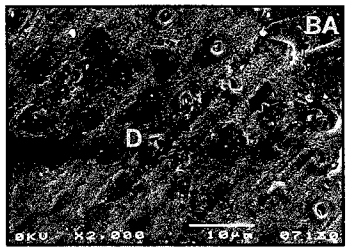


Figure 4. *SEM picture of bovine dentin surface treated with Light Bond Primer (original magnification X1000). In spite of the treatment, a smear layer remained, as with the untreated specimen.*




Figures 7 & 8. *SEM pictures of dentin-resin interface of specimen without Light Bond Primer treatment taken after tensile bond test (original magnification X17.5 and X1000 respectively). Resin-to-dentin bonding was fractured at the resin-dentin interface. BA = bonding agent (Light Bond); D = dentin.*

resin-dentin bonding was mostly fractured at the resin-dentin interface in untreated specimens. These are shown in Figures 7 and 8.

### Clinical Evaluation

As shown in Tables 6 and 7, both at the 6-month and 1-year recalls, samples demonstrated a retention rate of 100%. All samples achieved excellent ratings for all criteria with the exception of marginal integrity, in which 83% of samples demonstrated an excellent (Alpha) rating and 17% a Bravo rating at the 6-month recall. All samples also demonstrated excellent ratings in all paramemeters except for marginal integrity and surface staining.

*Table 6. Results at 6-Month Recall [%]*

| | Retention | Color Stability | Marginal Integrity | Abrasion Resistance | Surface Texture | Surface Staining | Postoperative Sensitivity |
|---|---|---|---|---|---|---|---|
| A | 30 [100.0] | 30 [100.0] | 25 [83.3] | 30 [100.0] | 30 [100.0] | 30 [100.0] | 30 [100.0] |
| B | 0 [0.0] | 0 [0.0] | 5 [16.7] | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] |
| C | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] | | |
| Total | 30 [100.0] | 30 [100.0] | 30 [100.0] | 30 [100.0] | 30 [100.0] | 30 [100.0] | 30 [100.0] |

## DISCUSSION

Light Bond is a one-component light-cure-type dentin-enamel bonding agent and contains a carboxylic acid monomer (MAC-10). Kawaguchi and others (1988a, 1988b) reported that this particular bonding agent adheres to bovine dentin as well as other new-generation dentin bonding agents without any prebonding dentin treatment. Sasama (1989) suggested that MAC-10 monomer showed smaller contraction gaps between resin and dentin than other bonding agents. This may be attributed to the carboxylic group contained in MAC-10 adhering to dentin by chelation or ionic bonding with the mineral of dentin.

However, our preliminary clinical study (not published), in which Light Bond was also used in combination with Palfique Light for restorations of cervical erosion lesions, showed a very low retention rate when both enamel etching and mechanical retentive locks were not performed. The result of this study indicated that there was no clinically satisfactory bond strength obtained at the resin-dentin interface. A dentin pretreatment prior to Light Bond application might be necessary for clinical situations, because of the discrepancy between results of in vitro and clinical investigations.

Thus, Light Bond Primer was introduced as the dentin primer for Light Bond. Light Bond Primer is composed of only HEMA and water. It does not contain any acids, such as carboxylic acids, and consequently, the SEM pictures showed only a slight change in the morphology of the dentin surface after a 30-second Light Bond Primer treatment. Light Bond Primer treatment neither removes nor dissolves the dentin smear layer, but Light Bond Primer treatment decreased significantly the contact angle at the bovine dentin surface; therefore, Light Bond Primer treatment improves the wettability or permeability of Light Bond to dentin.

Since tensile bond strengths were significantly increased when specimens were treated with Light Bond Primer, it seems that changes of dentin wettability or permeability affect bond strength of Light Bond to dentin. However, differences in Light Bond Primer treatment duration, especially between 20, 30, and 60 seconds, did not affect bond strength. These results suggest that 30-second Light Bond Primer treatment is enough for its clinical

*Table 7. Results at 1-Year Recall [%]*

| | Retention | Color Stability | Marginal Integrity | Abrasion Resistance | Surface Texture | Surface Staining | Postoperative Sensitivity |
|---|---|---|---|---|---|---|---|
| A | 15 [100.0] | 15 [100.0] | 10 [66.7] | 15 [100.0] | 15 [100.0] | 15 [100.0] | 15 [100.0] |
| B | 0 [0.0] | 0 [0.0] | 5 [33.3] | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] |
| C | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] | 0 [0.0] | | |
| Total | 15 [100.0] | 15 [100.0] | 15 [100.0] | 15 [100.0] | 15 [100.0] | 15 [100.0] | 15 [100.0] |

applications.

With regard to bond strengths of dentin bonding agents to vital dentin, clinical evaluations are strictly required, since there were many discrepancies suggested between in vitro and clinical investigations (Council on Dental Materials, Instruments and Equipment, 1987). There were also discrepancies found between the results of our preliminary clinical investigation and in vitro tests done by Kawaguchi and others (1988a, 1988b) in terms of Light Bond's bond strength. Those tests showed high bond strengths in vitro without any dentin pretreatment. However, almost 100% of the restorations that were restored in cervical erosion lesions without enamel etching and mechanical retentive locks using Light Bond in our preliminary clinical test were dislodged in 2 to 3 weeks. Since enamel etching is always performed during routine treatment and mechanical locks are sometimes placed in composite restorations, restorations employing recent bonding agents are seldom dislodged. Therefore, it may be difficult to analyze these discrepancies in clinical situations.

However, due to the use of dentin priming with Light Bond Primer (a pretreatment of dentin prior to Light Bond bonding), there was no discrepancy found in the present study. Significantly higher bond strength with Light Bond Primer treatment was observed in in vitro tests, and the retention rate was enormously improved in clinical evaluations when compared with the preliminary clinical test based on no Light Bond Primer treatment, because only dentin wettability and permeability were improved by Light Bond Primer treatment. This discrepancy between in vitro and clinical testing was not evident.

In the results of both the 6-month and 1-year recalls, all samples were excellent in almost all parameters. The exception was the criterion of marginal integrity: 17% and 33% of the samples were rated in the Bravo category at the 6-month and 1-year recalls respectively. In the marginal integrity criterion, any sample that had ledges or ditches at the resin-enamel interface without discoloration was rated Bravo. Therefore, 17% and 33% of the samples revealed ledges or ditches at only the enamel margins. This may be due to the fact that no phosphoric acid enamel etching was performed in the present study. These results have also been reported by Jordan and others (1989a, 1989b) and Senda and others (1990a, 1990b).

## CONCLUSION

Light Bond Primer, an aqueous solution of HEMA, improves the wettability and permeability of dentin. Both in vitro and clinical studies have shown that bond strength of Light Bond to dentin is improved by priming the dentin with Light Bond Primer. It seems that this particular dentin bonding restorative system, Light Bond Primer, Light Bond, and Palfique Estelite, can be used successfully in clinical situations.

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# Shear Bond Strength of Composite Resin to Microetched Metal with Five Newer-Generation Bonding Agents

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J W ROBBINS • M S FULKERSON

**Clinical Relevance**
All tested bonding agents developed a significant bond of composite resin to Rexillium III.

## SUMMARY

**The purpose of this study was to determine the shear bond strength of a hybrid composite resin to a nickel-chrome-beryllium (Ni-Cr-Be) alloy, using five of the newer-generation bonding agents: Optibond, All-Bond 2, Prisma Universal Bond 3, Restobond 4, and Amalgambond Plus with HPA. For each bonding system 10 samples of metal were microetched with 50-micron aluminum oxide prior to the placement of the bonding agent and resin. The shear bond strength was tested, and the results showed that Amalgambond Plus with HPA developed the strongest bond at 18.81 ± 3.924 MPa, followed by All-Bond 2 at 14.33 ± 3.408, Optibond at 13.97 ± 1.508, Prisma Universal Bond 3 at 12.51 ± 1.845, and Restobond 4 at 10.29 ± 1.407.**

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## INTRODUCTION

Porcelain-fused-to-metal (PFM) restorations have been used since the mid-1960s by dentists in order to provide their patients esthetic restorations while replacing lost tooth structure or preserving that which remains. A PFM crown or fixed partial denture combines the strength and accuracy of cast metal with the esthetics of porcelain. Dental porcelain has many desirable properties that include high compressive strength, biocompatibility, and esthetics. It does, however, exhibit brittleness and low tensile strength, which can cause a fracture in the porcelain as a result of trauma, metal flexure, or porcelain fatigue. When the fracture occurs cohesively within the porcelain, the repair bond strength of porcelain with intermediate bonding agent and composite has been shown to have bond strengths up to 30 MPa (Appeldoorn, Wilwerding & Barkmeier, 1993; Suliman, Swift & Perdigao, 1993; Kanca, 1991). However, when the fracture occurs at the metal interface, the repair is more problematic. Bond strengths of composite resin to porcelain have been found to be greater than that of composite to metal (Beck, Janus

& Douglas, 1990). Various methods, including macromechanical and micromechanical retention as well as chemical adhesion, of adequately bonding composite resin to metal have been designed (Tanaka & others, 1981; Livaditis & Thompson, 1982; Hudgins, Moon & Knap, 1985; Shen & others, 1983).

Restorations that have excellent marginal integrity but have porcelain fractured from the metal framework can be salvaged without replacing the whole prosthesis. One easy method of enhancing bond strength is roughening the surface by air abrasion with aluminum oxide, thereby increasing the surface area for bonding and decreasing surface tension. When this treatment is performed on the alloy, it provides a microscopically cleaned and roughened surface that allows efficient wetting by resin cements (Swift, 1989). The purpose of this study was to compare the ability of five newer-generation bonding systems to bond a composite material to a microetched metal surface without the use of conditioning acids.

## METHODS AND MATERIALS

A total of 50 Rexillium III (Jeneric Gold Co, Wallingford, CT 06492) samples were prepared to a flat surface by incremental polishing with 300-, 400-, and 600-grit silicon carbide paper. Using a Danville Microetcher (Danville Engineering, San Ramon, CA 94583), the samples were air abraded at 80 psi for 10 seconds with 50-micron aluminum oxide at a distance of 4-5 mm. The specimens were divided into five groups of 10 each. Five resin bonding agents, Optibond, All-Bond 2, Prisma Universal Bond 3, Restobond 4, and Amalgambond Plus with HPA, were evaluated for their shear bond strength to a Ni-Cr-Be alloy (Rexillium III). Table 1 lists the manufacturer and batch number of each resin bonding agent. The manufacturer's directions were followed for each system, except that no acids were used on the metal after the air abrasion process was completed. A summary of the procedure for each system is presented in Table 2.

*Table 1. Adhesive Systems*

| Adhesive System | Batch Number | Manufacturer |
|---|---|---|
| Optibond | Prime 1 750684<br>Adhesive 2 750663 | Kerr Mfg Co, Romulus, MI 48174 |
| All-Bond 2 | Primer A 039243<br>Primer B 029173 | Bisco, Inc, Itasca, IL 60143 |
| Prisma Universal Bond 3 | Primer 920924<br>Adhesive 921109 | L D Caulk, Milford, DE 19963 |
| Restobond 4 | Adhesive Part 2 2287<br>Metal activator Part 2b 2329<br>Resin N/A | Lee Pharmaceutical, South El Monte, CA 91733 |
| Amalgambond Plus with HPA | AA Adhesive 021793<br>B Base 30101<br>C Catalyst 211032<br>HPA Additive 21101 | Parkell, Farmingdale, NY 11735 |

The bonding agents were placed on the metal within the confines of a circular metal washer with an inside diameter of 7 mm. The washer was held in place with finger pressure while the bonding procedures were accomplished. After the bonding systems were light cured for the recommended times, the washers were removed. The composite resin used for all samples was Herculite XRV, Enamel shade A1 (Kerr Mfg Co, Romulus, MI 48174). The resin was placed in the smaller end of a Number 4 gelatin capsule (Eli Lilly and Co, Indianapolis, IN 46285) so that it was slightly underfilled. Three 40-second polymerization sequences, divided equally around the circumference of the cylinder, were completed using the Optilux 400 (Demetron Research Co, Danbury CT 06810) light-curing unit. The light intensity throughout the testing period was kept above a minimum of 400 mw/cm2 as determined by a Demetron Radiometer. The capsule was then slightly overfilled with more composite resin and positioned firmly onto the center of the metal bonding sites. Excess composite resin was removed from around the capsule with an explorer. The composite resin cylinders were once again polymerized with visible light directed at a 45° angle from the intersection of the metal bonding sites and composite resin cylinders. Four 30-second polymerization sequences, divided equally around the circumference of the composite resin cylinder, were completed. The average diameter of all the specimens was 5.1 ± 0.03 mm.

The specimens of each group were labeled and stored in 37 °C distilled water for 120 hours. All samples were then thermocycled for 500 cycles between water baths of 6 - 60 °C with a dwell time of 30 seconds before determination of bond strength. The specimens were mounted in a custom jig that held the specimen at 90° to the shear blade (Figure 1). The shear bond strength of resin to alloy was determined by loading the samples to failure in an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021) using a crosshead speed of 0.5 mm/min. The Instron was equipped with a chisel-shaped blade that engaged the composite cylinder

adjacent to the composite-metal interface (Figure 2). The force required to shear the composite from the metal was recorded for each specimen. Using the diameter of each specimen, this value was converted to force per unit area, megapascal units (MPa). A one-factor analysis of variance (ANOVA) was used to test for group differences. A Scheffé F-test was used for all post hoc pairwise comparisons.

## RESULTS

The mean shear bond strengths and the standard deviations for the five bonding systems are listed in Table 3. The ANOVA showed a statistical difference between the groups at the 0.0001 level. The post hoc analysis showed a significant difference ($P > 0.05$) between Amalgambond Plus with HPA and all other groups. In addition, there was a statisical difference ($P > 0.05$) between All-Bond 2 and Restobond 4. Amalgambond Plus with HPA developed the strongest bond at 18.81 ± 3.924 MPa, followed by All-Bond 2 at 14.33 ± 3.408, Optibond at 13.97 ± 1.508, Prisma Universal Bond 3 at 12.51 ± 1.845, and Restobond 4 at 10.29 ± 1.407.

## DISCUSSION

Various methods have been advocated to increase bond strengths between resins and metals, including silicoating (Imbery & others, 1992), the use of acidic agents on the surface of the metal (Love & Breitman, 1985), and the use of specific electrolytic solutions (Thompson, Del Castillo & Livaditis, 1982). Chemical bonding may be accomplished by using an intermediate interface between the resin and the metal surface. For example, it has been suggested that bonding in the All-Bond system takes place between the carboxyl groups in Primer B (BPDM) and the positively charged metal ions on the alloy surface (Albers, 1991). Others dispute the fact that any chemical bonds even exist, and if they do, suggest that they may even be detrimental to the long-term resin-to-metal bond strengths, since it is known that the shear bond strength of adhesives decreases with

*Table 2. Metal Surface Treatment and Procedures Followed for the Adhesive Systems*

| System | Agent Applied | Procedure |
|---|---|---|
| Optibond | (1) 50-micron $Al_2O_3$ abrasion | Air clean |
| | (2) Optibond Prime | Air dry 10 seconds |
| | | Light cure 20 seconds |
| | (3) Optibond adhesive | Light cure 30 seconds |
| | (4) Apply composite cylinder | Light cure 120 seconds |
| All-Bond 2 | (1) 50-micron $Al_2O_3$ abrasion | Air clean |
| | (2) Apply Primer A & B, 2 coats | Air dry 6 seconds |
| | (3) Apply dentin/enamel bonding agent | Light cure 20 seconds |
| | (4) Apply composite cylinder | Light cure 120 seconds |
| Prisma Universal Bond 3 | (1) 50-micron $Al_2O_3$ abrasion | Air clean |
| | (2) Apply primer, 30 seconds | Air dry 6 seconds |
| | (3) Apply adhesive | Thin with air |
| | | Light cure 10 seconds |
| | (4) Apply composite cylinder | Light cure 120 seconds |
| Restobond 4 | (1) 50-micron $Al_2O_3$ abrasion | Air clean |
| | (2) Adhesive Part 2 & metal activator Part 2b, apply 2 layers | Air dry 5 seconds |
| | (3) Apply unfilled resin | Thin with air |
| | (4) Apply composite cylinder | Light cure 120 seconds |
| Amalgambond Plus with HPA | (1) 50-micron $Al_2O_3$ abrasion | Air clean |
| | (2) AA adhesive agent | Thin with air |
| | | Let stand 30 seconds |
| | (3) Apply mix of: 3 drops base 1 drop catalyst 1 scoop powder | Let stand 60 seconds |
| | (4) Apply composite cylinder | Light cure 120 seconds |

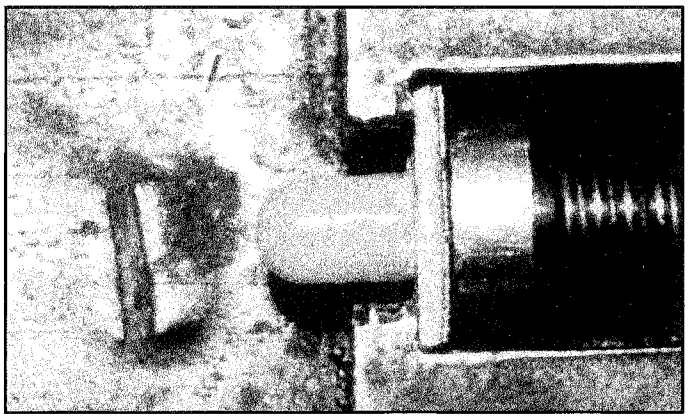

Figure 1. *Custom jig holding resin-metal specimen*

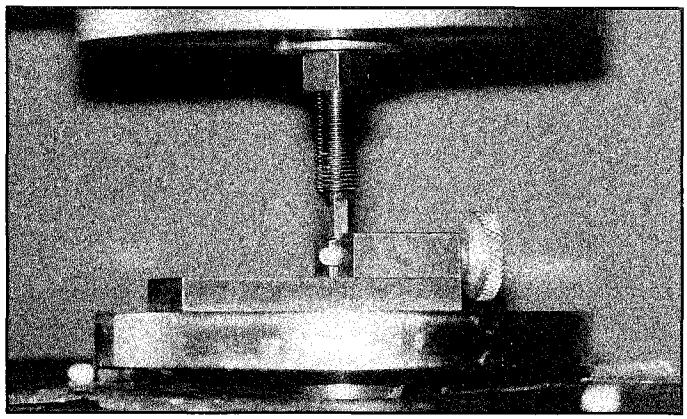

Figure 2. *Chisel-shaped blade engaging the composite cylinder on the Instron machine*

thermocycling (Eakle, 1986) and functional loading (Fissore, Nicholls & Youdelis, 1991).

Many of the adhesive agents on the market today make use of coupling agents to form bonds between commonly used composite resin systems and specific alloys; this type of bond is based on the chemistry of the resin system. Sero (1992) defines four categories of adhesive systems: 4-META/MMA-TBB, organic phosphates, organic acid and aldehydes, and surface active comonomers. The mechanism of how these adhesive agents function, whether by chemical means, micromechanical, or a combination of the two, is not completely understood. However, it is accepted that the combination of creating a high-energy, clean metal surface, and the subsequent coating of that surface with a liquid to enhance surface "wetting," facilitates micromechanical retention (Cincione, Stojkovich & Suh, 1993).

In this study, five bonding agents were tested to determine their bond strength to Rexillium III after treating the alloy with air abrasion only. The results showed Amalgambond Plus with HPA developed a mean bond strength of 18.81 MPa ± 3.924 MPa. All-Bond 2 and Prisma Universal Bond 3 had shear bond strengths of 14.3 ± 3.4 and 12.5 ± 1.8 respectively. Burgess, Nourian, and Summitt (1994) have shown comparable bond strengths of 13.2 ± 3 and 9.5 ± 2 MPa, All-Bond 2 and Prisma Universal Bond 3 respectively. The bond strength of Amalgambond Plus with HPA, when compared to that of acid-etched enamel, which has been reported in the range of 16-20 MPa (Barkmeier, Shaffer & Gwinnett, 1986) is excellent. If such a bond strength can be achieved in vivo, the use of caustic and potentially harmful acids and extraneous equipment can be eliminated for intraoral repair of porcelain/metal fractures.

*Table 3. Mean Shear Bond Strengths and Standard Deviations*

| Group | Number | Mean | Std Dev | Std Error |
|---|---|---|---|---|
| Amalgambond Plus with HPA | 10 | 18.8 | 3.9 | 1.2 |
| All-Bond 2 | 10 | 14.3 | 3.4 | 1.1 |
| Optibond | 10 | 14 | 1.5 | 0.5 |
| Prisma Universal Bond 3 | 10 | 12.5 | 1.8 | 0.6 |
| Restobond 4 | 10 | 10.3 | 1.4 | 0.4 |

Vertical lines designate groups that are not statistically different ($P > 0.05$).

## CONCLUSION

In this in vitro study, all resin bonding agents developed a composite resin bond to Rexillium III. However, the effect of other factors on the resin-metal interface, such as increased time between preparation and fracture, increased thermocycling, and functional loading, are unknown. Although the results of this preliminary laboratory study are promising, long-term clinical studies are necessary to confirm the clinical efficacy of the resin-metal bond using the newer-generation bonding agents.

The views expressed in this article are those of the authors and do not reflect the official policy of the US Army Dental Corps, the Department of Defense, or other departments of the US government.

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# Microleakage of Class 2 Superbond-lined Composite Restorations with and without a Cervical Amalgam Base

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**Clinical Relevance**
Although marginal leakage could not be eliminated, considerably less leakage at the cervical margin occurred with the Superbond D liner than with Scotchbond or amalgam.

## SUMMARY

**The purposes of the present study were: 1) to assess the microleakage at the cervical margin of Superbond-lined composite restorations with and without a cervical amalgam base and compare the results to cervical margins of composite restorations lined with Scotchbond 2, and 2) to compare the quality of the occlusal margins of Superbond-lined P-50 restorations with those bonded with Scotchbond 2. Forty-eight class 2 cavities were prepared in extracted or exfoliated primary molars. The teeth were randomly divided into three groups and restored as follows: Group A, amalgam + Superbond + P-50 (sandwich); Group B, Superbond + P-50; Group C, Scotchbond 2 + P-50 (control). Marginal leakage was assessed by the degree of dye penetration on sections of the restored teeth. The occlusal margins presented no or minimal leakage (degrees 0 and 1) in 53% of Group A restorations, 60% of Group B, and 44% of Group C. These differences were not statistically significant ($P > 0.05$). The cervical margins showed moderate to severe dye penetration (degrees 2 and 3) in 94% of Group A, 47% of Group B, and 87% of Group C. These differences were statistically significant ($P < 0.05$). The amalgam/Superbond/composite interface exhibited no leakage in 70% of the restorations. Although marginal leakage was not completely eliminated, Superbond exhibited significantly less leakage ($P < 0.05$) at the cervical margins than Scotchbond 2 or amalgam with Superbond.**

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## INTRODUCTION

Composite materials have been regarded for several years as an esthetic substitute for amalgam for restoration of affected teeth. However, contraction gaps at the cervical margin of class 2 restorations are created by polymerization shrinkage, and they are a major drawback for the use of composite material in this type of restoration (Jensen & Chan, 1985). The use of horizontal and vertical increments (Donly & Jensen, 1986) and reapplication of an unfilled resin (Torstenson, Brännström &

Mattsson, 1985; García-Godoy & Malone, 1985) have been suggested as methods to prevent microleakage and development of secondary caries in class 2 composite resin restorations. Since composites were shown to contract toward the light source (Lui & others, 1987), the conventional metal matrix band and wooden wedge were replaced by a transparent celluloid matrix and a clear wedge, directing the light through light-reflecting surfaces. A "sandwich" technique was also advocated, exploiting the already-known sealing quality of the amalgam at the cervical margins and the esthetic appearance of composite materials (Kossa, 1987; Cardash, 1988). In addition, new adhesive materials were introduced to the market that promised adhesion of composites to dentin and amalgam (Pashley, 1992). Superbond D liner, an autocuring bonding liner for composite resin, employing the 4-META monomer (4-methacryloxyethyl trimellitate) and catalyzed by TBB (tri-n-butylborane), has been shown to have strong dentin bonds and good biocompatability (Sun Medical Co, Ltd, 1993).

The purpose of this in vitro study was twofold: 1) to assess the microleakage at the cervical margin of class 2 Superbond-lined composite (P-50) restorations with and without a cervical amalgam base and compare the results to P-50 restorations lined with Scotchbond 2, and 2) to compare microleakage at the occlusal margins of Superbond-lined restorations with those using Scotchbond 2.

## METHODS AND MATERIALS

### Cavity Preparation

Forty-eight conventional class 2 cavities were prepared in extracted or naturally exfoliated primary molars. The collected teeth were stored in water and were either intact, had a small carious lesion, or had an old amalgam restoration removed during cavity preparation. Cavities were prepared using a #330 tungsten high-speed bur with water spray coolant, ensuring that the cervical margins of the box remained in enamel.

### Restorative Procedure

The teeth were randomly assigned to one of three groups, as presented in Table 1:

**Group A**, amalgam + Superbond D liner + P-50. Following adaptation of a transparent celluloid matrix band, a layer approximately 1 mm thick of non-gamma-2 amalgam (Silmet, Givatayim, Israel) was condensed on the gingival floor of the approximal box as shown in Figure 1. The cavity walls and surrounding enamel were then etched with 37% phosphoric acid for 20 seconds, washed, and dried. Superbond D liner (Sun Medical Co, Ltd, Kyoto, Japan) was applied over the etched area according to the manufacturer's instructions. Three vertical increments (buccal, lingual, and middle) were used to fill the box with P-50 (3M Dental Products, St Paul, MN 55144), and a fourth increment filled the occlusal part of the cavity. The composite was trimmed and each increment was cured separately for 20 seconds from the direction closest to its location.

*Table 1. Experimental Design, Distribution of Restored Teeth*

| Group | Number of Teeth | Type of Restoration |
|---|---|---|
| A | 17 | *amalgam + D Liner (Superbond) + P-50 |
| B | 15 | D Liner (Superbond) + P-50 |
| C | 16 | Scotchbond 2 + P-50 (control) |

*sandwich restoration

**Group B (control)**, Superbond D liner + P-50. The restorative procedure followed the same steps as in Group A, except that amalgam was not used.

**Group C**, Scotchbond 2 + P-50. The restorations were placed using similar steps as in Group B, but Scotchbond 2 (3M) was used instead of Superbond D liner.

All restorations were polished with a set of Sof-Lex aluminum oxide disks (3M) to decrease roughness. The restored teeth were kept at room temperature and at 100% humidity for 2 weeks to prevent dehydration. They were then thermocycled for 500 cycles between 4° ± 2° and 60 ° ± 2°, with a dwell time of 1 minute in each bath, and 1-minute intervals between the baths in ambient atmosphere. Remnants of roots were removed and the pulp chambers were sealed with IRM (Bayer, Leverkussen, Germany). All the teeth were coated with utility wax

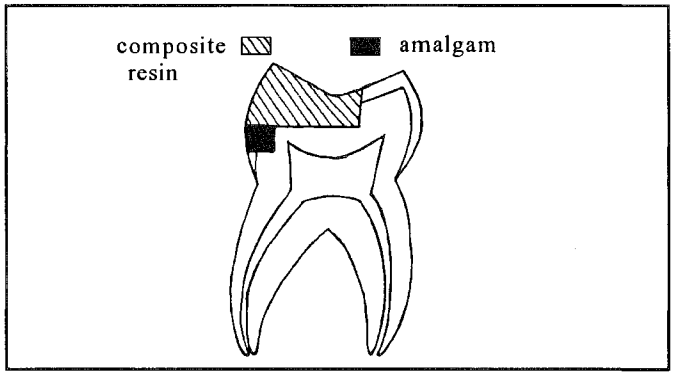


Figure 1. *Diagram of a sandwich restoration showing the cervical amalgam layer*

*Table 2. Assessment of Marginal Leakage by Depth of Dye Penetration*

| Depth of Dye Penetration | Group A: Amalgam + D Liner (Superbond) + P-50 | | Group B: D Liner (Superbond) + P-50 | | Group C: Scotchbond 2 + P-50 | |
|---|---|---|---|---|---|---|
| **Occlusal margin** | # | % | # | % | # | % |
| 0 | 2 | 11.8 | 1 | 6.7 | 3 | 18.7 |
| 1 | 7 | 41.2 | 8 | 53.3 | 4 | 25 |
| 2 | 6 | 35.3 | 2 | 13.3 | 6 | 37.6 |
| 3 | 2 | 11.7 | 4 | 26.7 | 3 | 18.7 |
| **Cervical margin** | | | | | | |
| 0 | 1 | 5.9 | 0 | 0 | 1 | 6.3 |
| 1 | 0 | 0 | 8 | 53.3 | 1 | 6.3 |
| 2 | 0 | 0 | 2 | 13.4 | 5 | 31.2 |
| 3 | 16 | 94.1 | 5 | 33.3 | 9 | 56.2 |
| **Amalgam-composite interface** | | | | | | |
| 0 | 12 | 70.6 | | | | |
| 1 | 1 | 5.9 | | | | |
| 2 | 0 | 0 | | | | |
| 3 | 4 | 23.5 | | | | |

The differences were statistically significant ($P < 0.05$) only on the cervical margins between Groups A and B and Groups B and C.

and nail polish, immersed in a 2% solution of basic fuchsin for 24 hours, washed in running water, and embedded in acrylic resin, as described in previous studies (Holan & others, 1986; Fisbein & others, 1988). Mesiodistal sections were obtained by grinding off the embedded teeth from buccal to lingual parallel to their mesiodistal axes, on a rotating disk under running water. Following evaluation of the exposed surface, the teeth were further ground to expose a deeper section of the restoration in another level (Guelmann & others, 1989) and examined under a binocular microscope (Model XT, Olympus, Tokyo, Japan) at X6 and X40 magnifications. Each restoration was evaluated for dye penetration in three sections that were obtained by sequential grinding. The depth of dye penetration was evaluated at the occlusal, cervical, and the amalgam-composite interfaces.

Leakage results at the occlusal and gingival margins were classified into four categories, as described by Fuks and others (1992):

Degree 0: no dye penetration;

Degree 1: penetration of dye along the occlusal or gingival wall of the filling, adjacent to the enamel only;

Degree 2: penetration of dye along the entire length of the occlusal or cervical wall of the filling, but not along the pulpal wall;

Degree 3: penetration of dye along the entire length of the occlusal or cervical wall of the filling, including the pulpal wall.

Microleakage results at the interface between the composite and the amalgam were similarly segregated into four modified categories of penetration:

Degree 0: no dye penetration;

Degree 1: penetration of dye up to the middle of the mesiodistal depth of the box;

Degree 2: penetration of dye beyond the level of the axiopulpal line angle, but less than half of the mesiodistal length of the restoration;

Degree 3: penetration of dye to half or more of the mesiodistal length of the restoration.

The most severe degree of dye penetration observed on any section of each tooth was recorded. Since small values were present in the categories, NO and MINIMAL (degrees 0 and 1) degrees of dye penetration were joined, as were the MODERATE and SEVERE (degrees 2 and 3) categories. Statistical differences between the groups were evaluated utilizing the chi-square test.

## RESULTS

The degrees of dye penetration at the occlusal and cervical margins are presented in Table 2.

No or minimal leakage (degrees 0 and 1) was observed in 53% of the occlusal margins in Group A, in 60% of Group B, and in 44% of Group C. These differences were not statistically significant ($P > 0.05$). Conversely, on the cervical margins, moderate to severe penetration of the dye (degrees 2 and 3) was present in 94% of Group A, in 47% of Group B, and in 88% of Group C. The differences were statistically significant ($P < 0.05$) only between Groups A and B and Groups B and C. In addition, there was no leakage (degree 0) at the amalgam-composite interface in 70% of the restorations.

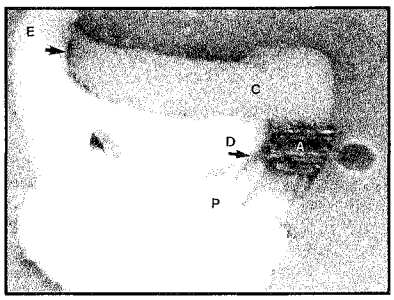


Figure 2. *Longitudinal section of a restoration of Group A prepared with amalgam, D Liner, and P-50. Notice the moderate dye penetration limited to the occlusal wall (Degree 2 = arrow), and a severe dye penetration at the cervical margin (Degree 3 = arrow). No leakage is evident at the amalgam-composite interface. E = enamel; D = dentin; C = composite; A = amalgam; P = pulp chamber filled with IRM.*

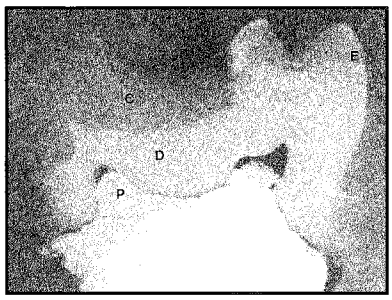


Figure 3. *Longitudinal section of a restoration of Group B prepared with D Liner and P-50. Minimal leakage (Degree 1) can be observed at the occlusal and cervical margins. E = enamel; D = dentin; C = composite; P = pulp chamber filled with IRM.*

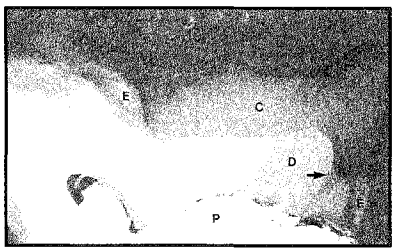


Figure 4. *Section of a restoration of Group C (control: Scotchbond 2 and P-50). Minimal leakage is evident at the occlusal wall (Degree 1), whereas severe dye penetration (Degree 3 = arrow) is seen at the cervical margin. E = enamel; D = dentin; C = composite; P = pulp chamber filled with IRM.*

Representative samples of the different groups are shown in Figures 2-4.

## DISCUSSION

The present study was designed to determine microleakage of amalgam-composite restorations in primary molars, based on the good results of a previous study (Eidelman & others, 1990) utilizing a similar technique in permanent teeth. The results of this study were poor. In Group A severe leakage at the cervical margin was evident in 94% of the restorations. The application of a copal varnish, or storing the specimens longer to encourage development of corrosion products, might improve the marginal seal. However, varnish could interfere with the acid-etching process if it was not totally removed from the enamel before acid etching was accomplished. We felt that good adaptation could be achieved with a properly condensed non-gamma-2 amalgam, for almost no leakage was evident in retrieved primary molars utilizing this technique without a copal resin in a previous study (Fuks, Grajower & Eidelman, 1986).

The use of a celluloid matrix mounted in a Tofflemire matrix holder held in a special device to imitate the function of a wedge by Eidelman and others (1990) was not employed in the present study, because the buccal enamel bulge and the cervical constriction of the primary molars impeded the utilization of this device. Thus, the matrix was tightened to the maximum, and finger pressure was exerted to close the cervical margin. More leakage was observed in primary teeth when composite and glass-ionomer restorations were compared to those in permanent teeth, utilizing identical filling techniques (Fuks & others, 1992; Koenigsberg, Fuks & Grajower, 1989). These differences were attributed to a reduced bond strength of the materials to primary dentin (Walls, McCabe & Murray, 1988).

The restorations of Group B (Superbond D liner + P-50) were significantly better than those of the other groups ($P < 0.05$); however, leakage could not be completely eliminated, as dye penetration occurred in 47% of cervical margins evaluated.

The most important characteristic of a dentin bonding agent is its ability to penetrate into the dentin area on a molecular level. When a monomer infiltrates the dentin and polymerizes in situ, it creates a resin-impregnated layer (hybrid layer). The formation of the hybrid layer, where the resin combines with collagen (not the mechanical bonding created by the tags in the tubules), is the key to strong dentin bonds. There is a risk that acid etching might demineralize the dentin to a depth of 5 microns, for instance, while the resin infiltration may only extend 4 microns, leaving a 1-micron demineralized zone at the base of the hybrid layer that is unprotected by mineral or resin, thereby being structurally weak (Pashley, 1992). If the pulpodentin complex can remineralize this unprotected basal 1 micron of demineralized dentin (Tatsumi & others, 1992), then the layer may become as strong as normal dentin, and not be a zone of debonding that has been seen in vitro by Nakabayashi, Nakamura, and Yasuda (1991). This could also be responsible for the leakage observed in the present in vitro study.

## CONCLUSIONS

Although marginal leakage could not be eliminated, considerably less leakage at the cervical margin occurred with the Superbond D liner than with Scotchbond or amalgam. However, there was no

difference in leakage at the occlusal margins for all three systems. Additionally, no significant difference in microleakage was observed at the cervical margin between the amalgam liner and the Scotchbond 2 + P-50 groups.

**Acknowledgment**

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# Shear Bond Strength of Composite Resin to Fresh Amalgam

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M BERKOVICH • M HELFT

**Clinical Relevance**
Macro- and micromechanical retention is recommended for composite-veneered amalgam restorations even though dentin bonding agents are used.

## SUMMARY

**The shear bond strength between fresh amalgam and composite resin using three adhesive systems was assessed. Amalgambond (5.19 MPa), All-Bond (3.45 MPa), and Clearfil New-Bond (4.37 MPa) had comparable shear bond strengths higher than Enamel Bond (1.27 MPa) after 48 hours of water immersion. This bond was hydrolytically degraded during 100 days of immersion in water. The greatest deterioration was observed for Clearfil New-Bond (0.81 MPa). Amalgambond provided the best results, whereas All-Bond and Clearfil New-Bond had comparable bond strength to Enamel Bond at the end of the experiment.**

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## INTRODUCTION

A properly designed and skillfully manipulated amalgam restoration that replaces one or two cusps or restores an entire occlusal surface may serve for many years. However, in some visible areas in the mouth, such as the buccal aspect of maxillary premolars, an amalgam restoration can present an esthetic problem. An alternative method of treatment incorporating both the desired mechanical properties of amalgam and the esthetic qualities of composite resins is the composite-veneered amalgam restoration (Gordon, Laufer & Metzger, 1985; Quiroz & Swift, 1986; Cardash & others, 1990). This procedure can be accomplished in one or two sessions. In the one-session procedure, retention is obtained from fresh amalgam, immediately postcondensation, implying that bonding is taking place prior to setting. In the two-session procedure, retention is obtained by mechanical or chemical means. Mechanical means include roughening the amalgam, preparing undercuts, direct bonding of composite resin to etched enamel around the amalgam, or inserting self-threading pins into the set amalgam during the second appointment (Gordon & others, 1985). Chemical means use multipurpose adhesive materials that bond to amalgam, composite resin, and tooth structure.

Several bonding systems have been investigated as chemical agents that adhere composite resins to

set amalgam. Cooley, McCourt, and Train (1989) used a 4-methacryloxyethyl-trimellitate anhydride (4-META)-based bonding agent (Cover-Up II, Parkell Products Inc, Farmingdale, NY 11735) and reported a shear bond strength between 4.40 and 7.47 MPa. They also tested a modified phosphonate ester of BIS-GMA (Panavia, J Morita USA, Inc, Tustin, CA 92680) for which a bond strength between 3.19 and 3.84 MPa was reported. In a study conducted by Hadavi, Hey, and Ambrose (1991), a 4-META-based bonding agent (Cover-Up) showed a bond strength of 4.34 MPa to amalgam.

The purpose of this study was to determine the shear bond strength of composite resin to fresh amalgam and the stability of this bond during a long period of immersion in water using three recently developed bonding systems: (1) Clearfil New-Bond (Kuraray Co, Osaka, Japan), a phosphonated ester, using 10-methacryloxydecyldihydrogen-phosphate (10-MDP) as the active monomer; (2) Amalgambond (Parkell), a modification of the 4-META-based bonding systems; and (3) All-Bond (Bisco Inc, Itasca, IL 60143), a multipurpose adhesive based on the unique active monomer biphenyldimethacrylate (BPDM). As a control, an unfilled BIS-GMA bonding agent originally intended for bonding composite resins to etched enamel that does not form a known chemical bond with dental alloys or amalgam was used (Enamel Bond, Ultradent Inc, South Jordan, UT 84095).

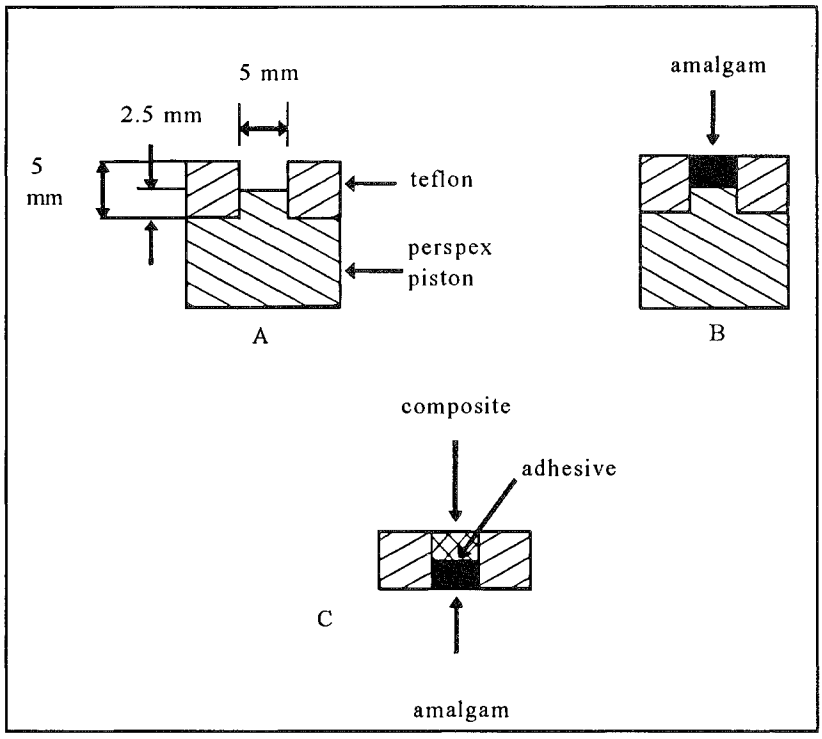


Figure 1. *Stages of sample preparation: A) Teflon mold and perspex piston, B) Postcondensation stage, C) Final specimen within the mold*

## METHODS AND MATERIALS

Twenty-four cylindrical specimens, 5 mm in diameter x 5 mm in height, composed of equal parts of amalgam and composite resin with a layer of bonding material in between, were prepared for each adhesive: Clearfil New-Bond, Amalgambond, All-Bond, and Enamel Bond.

### Specimen Preparation

Cylindrical Teflon molds with an inner diameter of 5 mm and a height of 5 mm were fabricated. A close-fitting perspex piston, 5 mm in diameter and 2.5 mm in height, was matched to each hole in the Teflon mold, creating a cavity with dimensions of 5 mm x 2.5 mm (Figure 1A). A high-copper amalgam enriched with palladium (Valiant-PHD, L D Caulk/Dentsply, Milford, DE 19963) was condensed against the perspex piston using an automatic condensor (Kavo, Biberach-Ris, Germany). Excess amalgam was removed, leaving the amalgam surface continuous with the Teflon cylinder surface (Figure 1B). The mold was reversed and the piston gently released. Each adhesive system was carefully prepared according to the manufacturer's instructions and applied to the freshly unset condensed amalgam surface. A composite resin (P-50, 3M Dental Products, St Paul, MN 55144) was packed against the layer of the bonding agent in two increments. Each increment was cured for 60 seconds at a 90° angle to the surface of the composite resin using an Elipar II light-curing unit (ESPE-Premier, Norristown, PA 19404). Excess resin was removed before final curing to ensure a continuous surface with the Teflon mold (Figure 1C).

Specimens were gently released from the mold and stored at 37 °C and 100% humidity in a light-proof container for 1 week to ensure final setting of the amalgam and postirradiation polymerization of the composite. The samples were then divided into two subgroups. Twelve samples were immersed in distilled water at 37 °C for 48 hours, and 12 samples were immersed in similar conditions for 100 days, with the water being changed every week.

Following the immersion period, samples were thermocycled for 300 cycles at 5 °C and 55 °C, with a dwelling time of 20 seconds using a Constant Temperature Bath (Techne Inc, Princeton, NJ 08540).

### The Loading Device

A device constructed from two identical stainless steel plates, 2.5 mm thick, with a penetrating cylindrical hole, 5 mm in diameter, was fabricated. By combining the plates, a testing

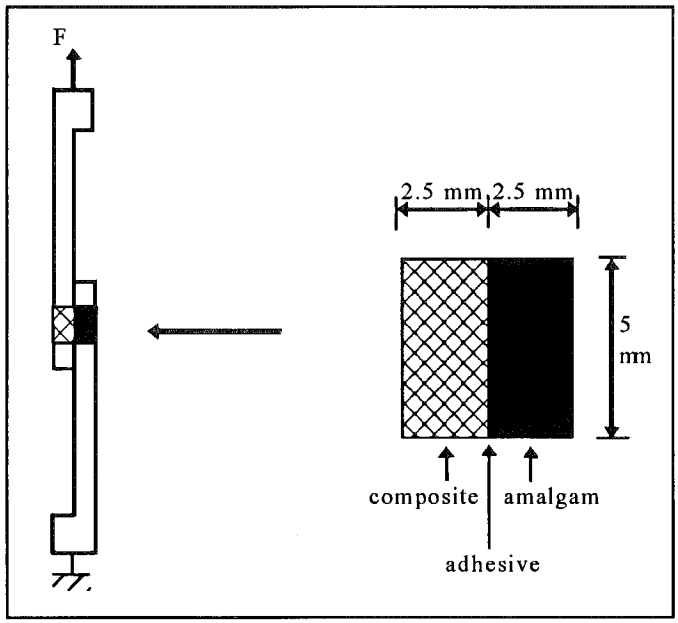


Figure 2. *Schematic presentation of the shear strength experimental technique*

chamber was created in which the samples fit exactly (Figure 2). The device was attached to an Instron Universal Testing Machine (Instron Co, Canton, MA 02021) and subjected to a continuous increasing force, with a crosshead speed of 0.5 mm/min, until debonding resulted.

The mean shear strength required to cause debonding of the sample was calculated by dividing the maximum force (F max) registered at the time of debonding by the cross-sectional area of the sample (A):

$$\text{Shear Strength [MPa]} = \frac{\text{F max [N]}}{\text{A [mm}^2\text{]}}$$

Statistical analysis was carried out using a two-way analysis of variance with a Bonferroni test. Statistical significance was defined as $P < 0.01$.

## RESULTS

The mean shear strength values required to debond the composite resin from the amalgam are presented in Figure 3 for the various bonding agents and different immersion times. As the Levine test for variance showed a normal distribution of variance only when a logarithmic scale was used, the results were further analyzed using ln (shear strength).

A statistically significant ($P < 0.001$) difference was found between the various adhesive materials and different immersion times. The data were then subjected to a Bonferroni test to determine which comparisons were statistically significant (table). There was no significant difference in the bond strength provided by the three bonding agents, New-Bond, Amalgambond, and All-Bond, after 48 hours of immersion. However, all three provided higher shear strength compared with the control bonding group, Enamel Bond ($P < 0.001$). Bond strengths measured after 48 hours were not significantly different from those measured after 100 days of immersion for bonding agents Amalgambond, All-Bond, and the control agent Enamel Bond, but were significantly decreased ($P < 0.001$) for New-Bond. Bond strength values after 100 days of immersion were significantly higher for Amalgambond compared with All-Bond, New-Bond, and Enamel Bond. No statistically significant difference was found for bond strengths provided by All-Bond, New-Bond, and Enamel Bond after immersion for 100 days.

## DISCUSSION

This study showed comparable shear bond strength between fresh amalgam and composite resin after 48 hours for New-Bond, Amalgambond, and All-Bond. However, these values (3.45-5.19 MPa) were 2.5 to 4 times higher ($P < 0.001$) than that obtained for the

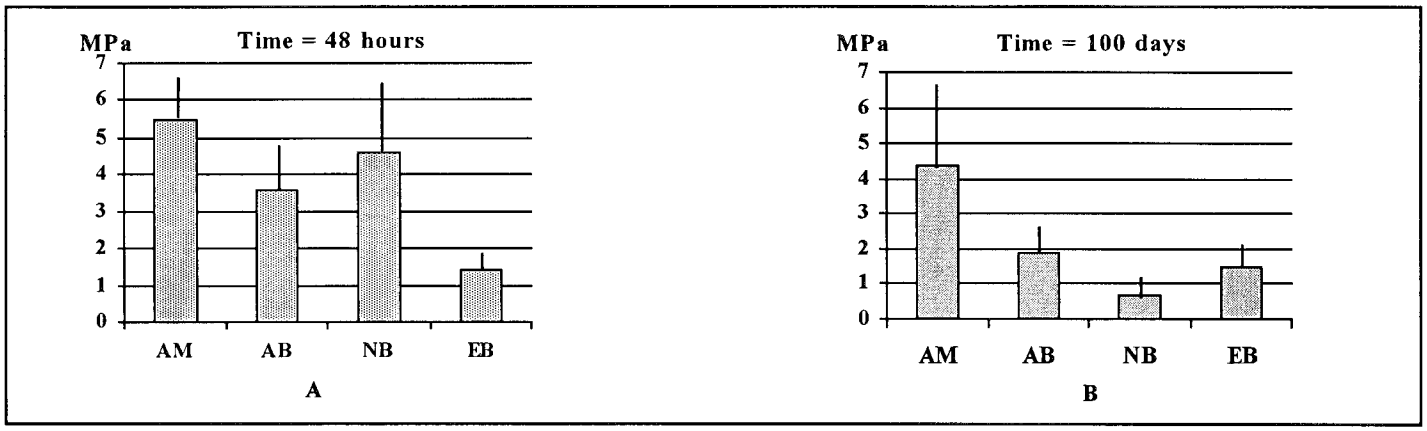


Figure 3. *Mean shear strength and standard deviation as affected by adhesive agent and immersion time. A) Immersion after 48 hours, B) Immersion after 100 days*

Enamel Bond control group (1.27 MPa). The difference observed reflects the characteristics of Enamel Bond, an unfilled BIS-GMA resin, used to achieve a micromechanical bond between composite resins and etched enamel. Since Enamel Bond does not contain components that are known to form a chemical bond with amalgam, the bond formed through Enamel Bond in an amalgam-composite resin system is purely micromechanical. In contrast, Amalgambond, All-Bond, and New-Bond contain active monomers, which might induce better wetting or adherence to dental alloys and amalgam through chemical bonding. In either mechanism, improved micromechanical or chemical bonding, a significantly greater bond strength was provided compared to Enamel Bond.

*Comparison of All Subgroups of Adhesive Material and Immersion Times Using the Bonferroni Test*

| | EB100d | EB48h | NB100d | NB48h | AB100d | AB48h | AM100d | AM48h |
|---|---|---|---|---|---|---|---|---|
| AM48h | S** | S** | S** | NS | S** | NS | NS | |
| AM100d | S** | S** | S** | NS | S** | NS | | |
| AB48h | S** | S** | S** | NS | S** | | | |
| AB100d | NS | NS | S** | S* | | | | |
| NB48h | S** | S** | S** | | | | | |
| NB100d | NS | NS | | | | | | |
| EB48h | NS | | | | | | | |
| EB100d | | | | | | | | |

AM=Amalgambond; AB=All-Bond; EB=Enamel Bond; NB=New-Bond; d=days; h=hours; NS=nonsignificant; S=significant.

*$P < 0.01$; **$P < 0.001$.

Previous studies in which the shear bond strength between set amalgam and composite resin was assessed after short durations of storage in distilled water reported results of similar magnitude to those obtained with fresh amalgam in the present study. The shear bond strength obtained by Cover-Up II and Panavia on diamond-treated amalgam surfaces was 6.87 and 3.23 MPa respectively (Cooley & others, 1989). A bond strength of 4.34 MPa using the Cover-Up II system was observed by Hadavi and others (1991). A 4-META-based bonding agent, Superbond (Sun Medical Co, Japan), and Panavia yielded a bond strength of 4.45 and 4.28 MPa respectively (Barzilay & others, 1990). A shear bond strength of 4.5 MPa by the Amalgambond adhesive system was reported by Navratil, Galan, and Williams (1993). Ruse and others (1993) found a shear bond strength of 2.0 MPa between Valiant PhD (Caulk/Dentsply) and Herculite X-R (Kerr Mfg Co, Romulus, MI 48174) mediated by All-Bond.

The bond strength between fresh or set amalgam and composite resins are identical to those reported for freshly mixed amalgam and dentin. A shear bond strength between Tytin (Sybron/Kerr) and dentin of 5.10 MPa (Hasegawa & others, 1992) and between admixed alloy and dentin of 3.84 MPa (Cooley, Tseng & Barkmeier, 1991) using Amalgambond was reported. These values were much lower compared with those obtained between composite resins and dentin (17.09-29.34 MPa) by the current investigation of adhesive materials (Cooley & others, 1991; Kanca, 1991; Hasegawa & others, 1992).

The common denominator to amalgam-composite systems or amalgam-dentin systems that impairs the bond strength is the bond between the adhesive material and the amalgam. The existence of a "true" chemical bond between amalgam and adhesive resins is controversial. Miller and others (1992) demonstrated that an adhesive type of failure occurred at the Amalgambond-amalgam/gallium alloy junction as opposed to cohesive failure occurring within the composite resin at the Amalgambond-composite resin interface. Stereomicroscope observation on debonded surfaces in the present investigation also detected adhesive failures in most samples, and a combination of adhesive-cohesive fractures only in a few samples. A change in surface roughness of high-copper amalgams over time, due to the formation of $Cu_6Sn_5$ crystals, provides microroughness essential for mechanical bonding to occur (Okabe & others, 1978).

Some bonding agents used to bond composite resin to dentin have been found to be sensitive to hydrolytic degradation in in vitro studies (Phillips, 1988). SEM observations by Smith and Ruse (1986) showed that systems using acid etching for dentin preconditioning developed mechanical interlocking that was lost after prolonged immersion periods. Bond strength and marginal leakage achieved after short immersions of up to 7 days by Gluma (Columbus Dental, St Louis, MO 63188), Tenure (Den-Mat Corp, Santa Maria, CA 93456), and XR-Bond (Kerr) were substantially better than those measured after 6 months of storage in a 37 °C water bath (Crim, 1991). We therefore examined the effect of prolonged immersion on the bond strength between composite resin and amalgam. After 100 days of water immersion, bonding strength decreased in all study groups, although this reached statistical significance only for New-Bond ($P < 0.001$) (Figure 3). A relatively moderate decline

in bond strength after the 100 days was also noted for All-Bond, so that the bond strength when using New-Bond and All-Bond was significantly lower at this point in time compared to Amalgambond ($P < 0.01$). Furthermore, the bond strength after 100 days' immersion achieved with New-Bond and All-Bond was not superior to the values measured for the control Enamel Bond group ($P > 0.05$).

The observation of a significant decline in bond strength after prolonged water immersion is probably due to either hydrolytic degradation of the chemical bond between the active monomers in the bonding agents studied and the amalgam or destruction of the micromechanical interlocking initially induced by them. The greatest deterioration in bond strength was observed for New-Bond (five times lower after 100 days versus 48 hours). This may be attributed to the rapid release of phosphate molecules from phosphonated ester bonding agents, including Clearfil New-Bond, reflecting the hydrolytic breakdown of the resin-bonded phosphorus that occurs in an aqueous medium, measured by P-NMR spectroscopy (Eliades & Vougiouklakis, 1989). In the present investigation the remaining amalgam-composite resin bond strength after 100 days of immersion was similar to that achieved using the control agent, Enamel Bond, which did not contain an active monomer.

The highest bond strength was provided by the 4-META-based Amalgambond in all stages of our study. Tanaka and others (1986, 1988) have shown that the bond between 4-META monomers and nonprecious or gold-treated alloys is performed through an oxide film formed over the metal alloy surface after active oxidation or heat treatment. Barzilay and others (1990) reported that the bond strength of 4-META monomer to amalgam was half that of its bond to a nickel-chromium alloy. The exact mechanism of adhesion to amalgam is unclear. Obviously the oxide layer over the amalgam surface was not sufficiently formed by the time the adhesive material was applied. Further study is therefore needed. This may lead to improvements in the bond strength achieved, equivalent to that obtained with gold alloys—20 MPa (Tanaka & others, 1988) and nickel-chromium alloy—22 MPa (Tanaka & others, 1986).

In this study when amalgam and composite resin were joined by an adhesive system, the bond strength was low and underwent active hydrolysis, so one cannot rely on chemical means. Added macro- or micromechanical retentive features obtained from amalgam and from the tooth structures surrounding the restoration must not be abandoned when composite-veneered amalgam restorations are being carried out.

## CONCLUSIONS

(1) Amalgambond, All-Bond, and Clearfil New-Bond initially provided similar shear bond strength between fresh amalgam and composite resin. However, this bond was hydrolytically degraded during long-term immersion in water.

(2) Even the highest bond strength provided by Amalgambond is still very low compared to the values reported when used to bond composite to dentin and dental alloys. Added macro- or micromechanical retention is still mandatory in composite-veneered amalgam restorations.

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# Influence of Different Factors on Bond Strength of Hybrid Ionomers

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**Clinical Relevance**
Bond strength is not only dependent on the pretreatment of dentin, but also on the glass ionomer/resin composition of the material.


## SUMMARY

**A new generation of filling materials, the hybrid-ionomer cements, has been introduced recently. In many clinical situations these hybrid ionomers may be an alternative to conventional glass-ionomer cements and resins bonded with dentin bonding agents. During the past years research has focused on factors influencing bond strength of dentin bonding systems, but there is not much knowledge about the bond strength of hybrid- and glass-ionomer filling materials under different conditions. Bond strengths of four hybrid ionomers, one conventional glass-ionomer cement, and one cermet cement were determined in superficial and deep, dry and moist dentin using a simplified pulp chamber model. All materials showed significantly higher bond strength to superficial compared to deep dentin. Moisture showed no significant influence on any material neither in deep nor in superficial dentin. Bond strengths of Fuji II LC, Variglass, and Vitremer were distinctly higher than those of the conventional glass-ionomer cement (Ketac-Fil) and the cermet cement (Ketac-Silver), while that of Photac-Fil was not significantly different. Ionomer samples failed cohesively in superficial dentin in over 60% of the samples. The bonding interfaces between Fuji II LC and Variglass and the treated dentin surface showed tags but no distinct hybrid layer. Bond strength is not only dependent on the pretreatment of the dentin, but also on the glass-ionomer resin composition of the material.**



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## INTRODUCTION

A new generation of glass-ionomer restorative cements has been introduced recently. These hybrid-ionomer cements possess the advantages of a conventional glass-ionomer restorative material with a chemical bond to tooth structure and fluoride release (Mount, 1993; Cao & others, 1994). Furthermore, they are claimed to be immediately resistant against water uptake and loss because of their light-activated resin component and, therefore, not as technique sensitive as conventional glass-ionomer cements. Hybrid ionomers form an interpenetrating network in which the glass-ionomer matrix and the resin matrix link. This polymerization provides stronger mechanical properties than in conventional glass-ionomer filling materials (Rusz & others, 1992). Additional strength over time is gained as a result of the glass-ionomer setting reaction (Croll, 1993; Mount, 1993).

Glass-ionomer cements have a wide range of applications, but especially for core build-ups, class 5 lesions, and root caries lesions, it is necessary that they bond well to dentin. There are numerous publications on the question of pretreatment of dentin for improvement of bond strength of glass-ionomer cements (Hewlett, Caputo & Wrobel, 1991; Prati & others, 1992).

At present there are four different hybrid-ionomer restorative materials available on the market, and each material requires a different pretreatment of the dentin: Fuji II LC (GC America, Chicago, IL 60658) and Photac-Fil (ESPE-Premier, Norristown, PA 19494) require dentin conditioning with polyacrylic acid, Vitremer (3M Dental Products, St Paul, MN 55144) uses a special light-curing, self-etching primer, and Variglass VLC (L D Caulk/Dentsply, Milford, DE 19963) requires the Probond Primer.

Dentin moisture showed no influence on the bond strength of conventional and light-cured glass-ionomer liners and bases (Mitchem & Gronas, 1991; Prati & Pashley, 1992). Vitrebond, a light-curing glass-ionomer liner, showed no significant difference in bond strength in deep and superficial dentin with and without pulpal pressure (Prati, Pashley & Montanari, 1991), but there is not much knowledge on the effect of different dentin depths and moisture on bonding abilities of glass-ionomer filling materials.

The aims of this study were (1) to evaluate the influence of dentin depth and moisture on bond strength to dentin of four new hybrid-ionomer restorative materials in comparison to one conventional glass-ionomer restorative cement and one cermet cement using a simplified pulp chamber model and (2) to study the interface between the hybrid ionomer and the pretreated dentin surface to clarify the bonding mechanism.

## METHODS AND MATERIALS

### Specimen Preparation

Human molars without caries were stored in a solution of 0.9% saline and 0.25% sodium azide at room temperature for less than 2 weeks after extraction. Two-thirds of the roots were cut off and teeth were sectioned (Isomet Low Speed Saw, Buehler, Ltd, Lake Bluff, IL 60044) longitudinally in a mesiodistal direction. Pulp tissue was removed with a stainless steel instrument, taking care not to touch the walls of the pulp chamber. Then the pulp chamber was filled with a moist cotton pellet. Tooth sections were embedded in a self-curing resin (Sampl Kwick, Buehler) without covering the cotton-filled pulp chamber. The cotton pellet was removed and teeth were abraded using silicon carbide paper (Automet, Buehler) from 240- to 600-grit until the remaining dentin thickness above the pulp chamber was 2.0-2.5 mm (superficial dentin) or 0.5-1 mm (deep dentin). The remaining dentin thickness was measured with calipers accurate to 0.1 mm. The abraded teeth were stored another 24 hours in distilled water at room temperature in order to re-moisten the dentin.

The specimens were divided according to dentin depth and condition: superficial, dry dentin; deep, dry dentin; superficial, moist dentin; deep, moist dentin.

*Table 1. Types, Batch Numbers, Dentin Treatment, and Manufacturers of Products Tested*

| Product | Type | Batch Number | Dentin Treatment | Manufacturer |
|---|---|---|---|---|
| Ketac-Fil (KF) | glass ionomer | Capsules: 039/51<br>Conditioner: 0005 W209 | Ketac Conditioner 10 seconds, rinse and dry | ESPE<br>Seefeld, Germany |
| Ketac-Silver (KS) | cermet cement | Capsules: 412/02<br>Conditioner: 0005 W209 | Ketac Conditioner 10 seconds, rinse and dry | ESPE |
| Photac-Fil (PF) | hybrid ionomer | Capsules: II-47, II-48<br>Conditioner: 0005 W209 | Ketac Conditioner 10 seconds, rinse and dry | ESPE |
| Vitremer (VI) | hybrid ionomer | Powder: 19930728<br>Liquid: 19930728<br>Primer: 19930728 | Primer 30 seconds scrubbing, dry Primer, light cure for 20 seconds | 3M Dental Products<br>St Paul, MN 55144 |
| Fuji II LC (FU) | hybrid ionomer | Powder: 100321<br>Liquid: 250321<br>Conditioner: 300721 | Fuji Conditioner 20 seconds scrubbing, rinse and dry | GC America<br>Chicago, IL 60658 |
| Variglass (VA) | hybrid ionomer | Capsules: 931007<br>Primer: 930415 | Probond Primer 30 seconds, dry | L D Caulk/Dentsply<br>Milford, DE 19963 |

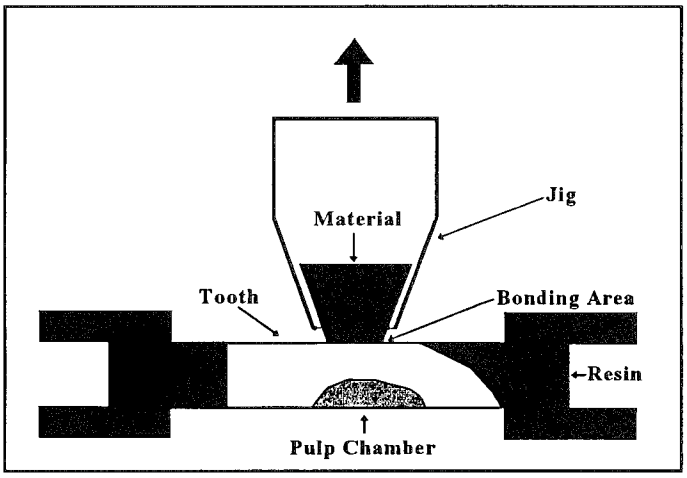


Figure 1. *Prepared tooth with bonded material showing the inverted, truncated cone*

Moist dentin was achieved by filling the pulp chamber with 0.9% saline using a micropipette before the pretreatment of the dentin. As a result of capillary forces, the dentinal tubules filled with saline. Dry dentin was obtained by leaving the pulp chamber empty.

*Table 2. Tensile Bond Strength and Mode of Failure of Four Hybrid Ionomers and Two Conventional Glass-Ionomer Cements in Superficial and Deep, Dry, and Moist Dentin*

| Material | Dentin Depth | Condition | Failure | Bond Strength MPa |
|---|---|---|---|---|
| FU | superficial | dry | aaaaa* | 13.8 (2.3)** |
| FU | superficial | moist | aaaaa | 15.6 (1.7) |
| FU | deep | dry | bbbbb | 8.2 (1.9) |
| FU | deep | moist | abbbb | 11.0 (3.7) |
| PF | superficial | dry | bbbbc | 4.8 (0.8) |
| PF | superficial | moist | abbbc | 4.9 (1.8) |
| PF | deep | dry | ccccc | 0.3 (0.3) |
| PF | deep | moist | ccccd | 0.4 (0.4) |
| VI | superficial | dry | abccc | 9.0 (2.2) |
| VI | superficial | moist | abbbb | 7.3 (2.2) |
| VI | deep | dry | ccccd | 3.8 (2.7) |
| VI | deep | moist | ccccd | 1.2 (0.2) |
| VA | superficial | dry | accccc | 13.1 (3.3) |
| VA | superficial | moist | ccddd | 9.8 (3.4) |
| VA | deep | dry | ccddd | 3.9 (2.2) |
| VA | deep | moist | ccddd | 2.4 (2.1) |
| KS | superficial | dry | ccccc | 3.4 (0.5) |
| KS | superficial | moist | bbccc | 4.7 (1.2) |
| KS | deep | dry | ccccc | 1.3 (1.3) |
| KS | deep | moist | ddddd | 0.4 (0.2) |
| KF | superficial | dry | bbbbb | 3.1 (0.8) |
| KF | superficial | moist | bbbbb | 2.8 (0.7) |
| KF | deep | dry | bbbbb | 1.5 (0.7) |
| KF | deep | moist | bbbcc | 1.2 (0.7) |

*Mode of bonding failure: a = cohesive bulk fracture; b = cohesive fracture with a firmly attached, thin, and homogeneous layer; c = mainly adhesive fracture with islands of firmly attached material; d = adhesive fracture.
**Mean of five replications with standard deviations in parentheses. Tukey intervals from ANOVA ($P < 0.05$) for comparisons among products, between two dentin depths, and between dry and moist dentin were 1.7, 0.7, and 0.7 MPa respectively.

## Bonding Procedures and Bond Strength Testing

One conventional glass-ionomer cement, one cermet cement, and four hybrid-ionomer filling materials (Table 1) were applied to the dentin surfaces according to the manufacturers' instructions in an inverted truncated cone polytetrafluoroethylene die (4 mm in height, 3 mm in bonding diameter). Light-curing materials were cured (Optilux 400, Demetron Research Corp, Danbury, CT 06810) in two layers. The curing light was monitored with a light meter (Curing Radiometer Model 100, Demetron). Chemically cured materials (Ketac-Fil and Ketac-Silver) were covered with a light-curing varnish (Ketac-Glaze, ESPE-Premier) after the setting reaction.

Samples were stored 24 hours in 100% RH at 37 °C. Figure 1 shows the prepared tooth and the bonded cement.

Tensile bond strength was tested in a Universal Testing Machine (Instron 8501, Instron Corp, Canton, MA 02021) at a crosshead speed of 0.05 cm/min.

## Statistical Analysis

Means and standard deviations for each product were determined from five replications of each dentin depth and condition. In a first step, data were analyzed by a three-factor analysis of variance (Super Anova, Abacus Concepts, Inc, Berkeley, CA 94704). Differences between two means that were larger than the calculated Tukey-Kramer interval were considered statistically significant ($P < 0.05$).

In a second step, pairwise comparisons of means were performed applying Student-Newman-Keuls test (SPSSPC+, SPSS Inc, Chicago, IL 60611) at the 0.05 level of significance.

## Microscopic Evaluation

Specimens for the scanning electron microscope (SEM) evaluation were prepared by dehydration in graded ethanol and drying in a Pel-Dry-II (Ted Pella, Inc, Reading, CA 96003). Then the specimens were sputter coated with gold (EMS-550, EMS, Fort Washington, PA 19034) for 60 seconds.

Dentin surface pretreatment was examined by scanning electron microscopy (JSM 820, JOEL, Peabody, MA 01960). Failure sites were classified as shown in Table 2 using magnifying glasses (X3) and SEM evaluation: a = cohesive bulk fracture; b = mainly cohesive fracture in the restorative material with a firmly attached, thin, and homogeneous layer;

c = mainly adhesive fracture with islands of firmly attached material; d = adhesive fracture. Failure site classification data were not analyzed statistically.

Cross sections showing bonding interfaces between the hybrid ionomers and the pretreated dentin were obtained by cutting the specimens (Isomet Low Speed Saw, Buehler). Sections were ground with 600-grit abrasive paper and wet polished with 0.05 µm alumina. Sections were immersed in 6 mol/L HCl for 30 seconds for dissolution of the mineral component of the dentin, and then they were immersed 10 minutes in 1% NaOCl in order to remove the collageneous material (Nakabayashi & Takarada, 1992). Sections were dried, gold coated, and examined in the SEM as described previously.

*Table 3. Results of the Three-Factor ANOVA for Comparison among Products*

| | Photac-Fil | Vitremer | Variglass | Ketac-Silver | Ketac-Fil |
|---|---|---|---|---|---|
| **Fuji II LC** | s | s | s | s | s |
| **Photac-Fil** | | s | s | ns | ns |
| **Vitremer** | | | s | s | s |
| **Variglass** | | | | s | s |
| **Ketac-Silver** | | | | | ns |

s = significantly different at $P < 0.05$; ns = not significantly different at $P < 0.05$.

## RESULTS

Table 2 and Figure 2 show the results of the tensile bond test for all products. Tukey-Kramer intervals calculated from three-factor ANOVA at the 95% level of confidence for comparisons among products, between two dentin depths, and between dry and moist dentin were 1.7, 0.7, and 0.7 MPa respectively. Results for the comparison among products are listed in Table 3.

Figures 3 and 4 show dentin surfaces after active dentin conditioning with 10% polyacrylic acid and dentin priming with the Vitremer Primer respectively. The Student-Newman-Keuls test showed that all four hybrid ionomers, the conventional glass-ionomer cement, and the cermet cement showed significant differences in bond strength between superficial and deep dentin. Only Fuji II LC showed no significant difference between superficial and deep dentin in the presence of moisture; it had significantly higher bonding values than any other material in superficial and deep, dry and moist dentin. Photac-Fil had the lowest bond strengths of the hybrid ionomers; its bond strength was not significantly different from the conventional glass-ionomer cement and the cermet cement (Table 3). No material showed significant differences in bond strength between dry and moist dentin. Results of the type of failure are shown in Table 2. Figure 5 shows a special type of mostly cohesive failure with a thin, homogeneous, and firmly attached layer, which is barely visible at X3 magnification.

Fuji II LC showed cohesive failure in the cement for all conditions, whereas Photac-Fil failed 80% cohesively in the material in superficial dentin and 90% mixed cohesively/adhesively in deep dentin. Vitremer failed 70% cohesively in the material in superficial dentin, whereas Variglass failed 10% cohesively in the material in superficial dentin. Ketac-Fil showed 100% cohesive fractures in the material in superficial dentin.

Figures 6 and 7 show the bonding interface between Fuji II LC and dentin, and between Variglass and dentin respectively. Interfaces of the other materials showed big gaps between material and dentin after the drying procedure for the SEM and were, therefore, not evaluated.

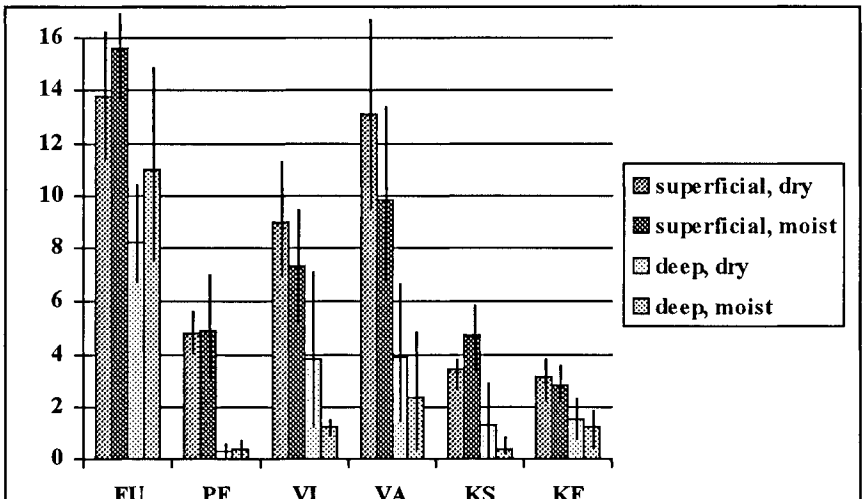


Figure 2. *Tensile bond strengths (means of five replications with standard deviations) of four hybrid ionomers, one conventional glass-ionomer cement, and one cermet cement in superficial and deep, dry and moist dentin*

## DISCUSSION

In the present experiment the dentin surface and the embedding resin were ground together because the embedding resin had to have a certain thickness to withstand the bending of the specimen in

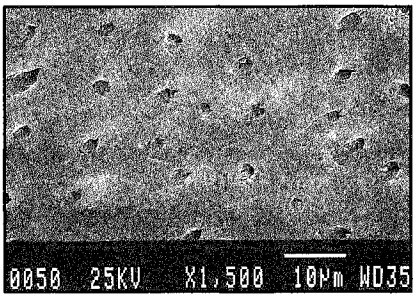


Figure 3. *Photomicrograph illustrating the dentinal surface after pretreatment with GC Conditioner (10% polyacrylic acid, 20 seconds scrubbing). Complete removal of the smear layer occurred, most of smear plugs in the dentinal tubules were removed (original magnification X750).*

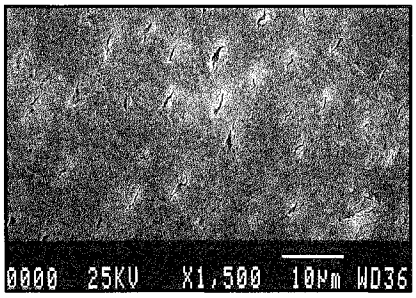


Figure 4. *Photomicrograph illustrating the dentinal surface after pretreatment with Vitremer Primer. Removal of the smear layer occurred, smear plugs were left in the tubules (original magnification X750).*

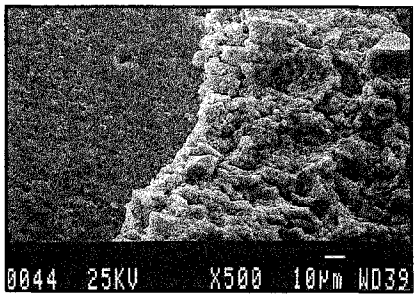


Figure 5. *Photomicrograph illustrating a mainly cohesive fracture with a thin homogeneous firmly attached layer of material on the dentin surface (failure type b) (original magnification X250)*

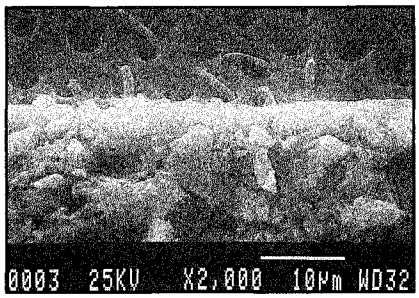


Figure 6. *Photomicrograph showing the bonding interface between Fuji II LC and pretreated dentin (original magnification X1000)*

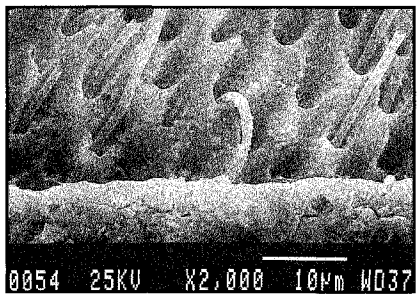


Figure 7. *Photomicrograph showing an area of tag formation at the bonding interface between Variglass and pretreated dentin (original magnification X1000)*

the tensile test. It has to be considered that this grinding procedure may have allowed the embedding resin to become impacted in the test dentin surface and might have favored the bond strength of hybrid ionomers with a higher resin component, and conversely could have reduced the bond strength of the more conventional glass-ionomer cements. However, our results showed that a conventional glass-ionomer cement (Ketac-Fil) and a hybrid ionomer (Photac-Fil) from the same manufacturer showed no significant difference in bond strength, and the bonding values of Ketac-Fil were similar to those of other investigations (Cooley & Train, 1991; Hewlett, Caputo & Wrobel, 1991).

All four hybrid ionomers, the conventional glass-ionomer cement, and the cermet cement showed significantly lower bond strengths in deep compared to superficial dentin. There are several publications (Pashley, 1989; Pashley, 1991; Olsson, Öilo & Adamczak, 1993) showing that the percentage of intertubular dentin is lower in deep dentin than in superficial dentin, because of the increasing diameter of the dentinal tubules. Our results confirm that the remaining dentin thickness has an important influence on bond strength (Tagami, Tao & Pashley, 1990).

The interface between Fuji II LC and dentin (Figure 6) showed small tags in the dentinal tubules but no distinct hybrid layer at the hybrid ionomer-dentin interface like most of the latest-generation dentin bonding agents (van Meerbeek & others, 1992). However, the present results showed that the bond strength of a hybrid ionomer like Fuji II LC was much higher than that of a conventional glass-ionomer cement like Ketac-Fil. Fuji II LC even bonds better to moist dentin than a latest-generation dentin bonding agent like Syntac (Vivadent, Schaan, Liechtenstein) (Friedl & Powers, 1994).

Conditioning with 25% polyacrylic acid did not only remove the smear layer from the surface and the intertubular plugs but also demineralized the surface of dentin (Eliades, 1993). The SEM picture (Figure 3) shows that active conditioning with 10% polyacrylic acid also provides a very smooth surface without smear layer and dentinal smear plugs. The exposed collagen network might be penetrated by hydroxyethylmethacrylate (HEMA) and other monomers and, therefore, a small layer for micromechanical retention might be provided at the interface. However, it cannot finally be decided from the

present SEM study if a micromechanical mechanism besides the resin tags might be involved or if the improved bonding compared to a conventional glass-ionomer cement is only the result of an optimal surface contact which is necessary for maximal bond strength (van Dijken, 1992) and an improved wetting capability provided by HEMA. The improved mechanical properties of hybrid ionomers may have also contributed to higher bond strengths and may have influenced the mode of failure.

Vitremer uses a primer containing maleic acid for conditioning the dentin surface that removes most of the smear layer but not dentinal smear plugs. SEM microphotographs (Figures 3 and 4) show that the active conditioning with polyacrylic acid exposed more dentinal structure than the Vitremer primer. The cleanliness of the surface (Davidson, Abdalla & de Gee, 1993) may be one factor for improved ionic bonds to the exposed dentinal matrix and better wettability even in the presence of moisture and might have contributed to the superior bond strength of Fuji II LC compared to Vitremer especially in deep dentin where not much intertubular dentin for bonding is available. Erickson (1989) and Pashley (1991) pointed out that dentin surfaces prepared with a HEMA-containing primer are susceptible to moisture. However, in our experiment the lower bond strengths of Vitremer and Variglass in the presence of moisture were not statistically significant.

The kind of failure of the hybrid ionomers supports the theory of a layer firmly attached to dentin at the ionomer-dentin interface. In more than 60% of the cases, failure in superficial dentin was either a cohesive bulk fracture or a type of a mainly cohesive fracture in the material leaving a thin layer of the material on the dentin surface (Figure 5) that seemed to be very well attached; only 3% were adhesive failures. This layer was also described in a study on resin-modified glass-ionomer cements (Rusz & others, 1992). In the present study there seemed to be no direct relationship between the mode of fracture and bond strength values, which means that high bond strength values are not necessarily correlated with a cohesive type of fracture. Fuji II LC and Variglass had almost the same bond strength values in superficial, dry dentin, but Fuji II LC showed a cohesive bulk fracture in all cases, whereas Variglass failed in 80% of the samples in a more adhesive type of fracture. Photac-Fil with a much lower bond strength failed mostly in a cohesive type of fracture.

Both Photac-Fil and Fuji II LC use pretreatment with polyacrylic acid. However, Photac-Fil showed no significant difference in bond strength compared to the conventional glass-ionomer cement and the cermet cement tested and was not sensitive to moisture. Insensitiveness of conventional glass-ionomer cements to moisture in dentinal tubules was described in an earlier study (Pashley, 1991) and bond strengths of Ketac-Fil in the present test system support these findings. Compared to the other hybrid ionomers, Photac-Fil showed high fluoride release rates (Cao & others, 1994). This seems to be an indication that Photac-Fil is chemically more related to glass-ionomer cements. Therefore, the higher bond strength of Fuji II LC by similar dentin conditioning might be explained by a higher content of HEMA, which provides superior wetting ability. The bonding mechanism of Variglass is similar to that of a dentin bonding agent (Prisma Universal Bond 3, L D Caulk/Dentsply) (Crim, 1993). Prisma Universal Bond 3's primer is 6% PENTA (phosphonated pentaacrylate ester) and 30% HEMA in an ethanol solution and is chemically similar to the Variglass primer (Probond). PENTA is considered to be a weakly acidic, self-etching primer that promotes adhesion (Perdigao & others, 1994). It modifies the smear layer and may facilitate penetration of the smear layer with hydrophilic monomers that have an affinity for the organic and/or inorganic components of the underlying dentin (van Meerbeck & others, 1992). Because of its characteristic weak acid, PENTA may or may not remove the smear layer, depending on the thickness of the smear layer and plugs (Barkmeier & Cooley, 1992; Erickson, 1992). The microphotograph (Figure 7) shows that the resin part of the Variglass was able to penetrate into the dentinal tubules and form tags like the Fuji II LC (Figure 6), but the area of this tag formation was much smaller in Variglass compared to Fuji II LC. Although Davidson and others (1993) and Prati (1993) reported that the dentin smear layer cannot prevent a negative effect of water in the tubules, our results showed no significantly lower bond strength of Variglass in moist dentin, which may have been due to a decrease in dentin permeability caused by the Prisma Universal Bond 3 primer (Haller & others, 1992).

## CONCLUSIONS

The hybrid ionomers, the conventional glass-ionomer cement, and the cermet cement tested have significantly higher bond strength to superficial compared to deep dentin. Bond strengths of all materials are not significantly influenced by the presence of moisture. Bond strengths of Photac-Fil are not significantly different from a conventional glass-ionomer cement.

Bond strength is not only dependent on the pretreatment of the dentin, but also on the glass ionomer/resin composition of the material.

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# Award of Excellence

The Academy of Operative Dentistry is to be commended for its selection of Clifford M Sturdevant as the 1995 recipient of the Award of Excellence. In my estimation, such recognition for this giant of operative dentistry is long overdue.

Dr Clifford Sturdevant, or "Dr Cliff," as he is affectionately known to his many friends, received his DDS degree in 1943, graduating with honors from Atlanta-Southern Dental College, later known as Emory University. Dr Cliff came to Chapel Hill in 1950 with his father, Dr Roger E Sturdevant, who was the first chair of operative dentistry at UNC. In fact, Dr Cliff taught the first freshman class admitted to the School of Dentistry at UNC, which graduated in 1954. In 1959 Dr Cliff was appointed chair of operative dentistry and served in that capacity for 20 years. In 1980 he was the first member of the Dental School faculty to retire with 30 years of dedicated service.

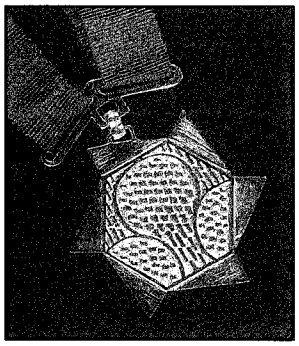
Dr Cliff has been known world-wide as a leader in dental education and as an authority on operative dentistry. Throughout his long career, he has been actively involved in numerous dental organizations, and in fact was a charter member of the Academy of Operative Dentistry. Among his most noteworthy accomplishments was the textbook, *The Art and Science of Operative Dentistry*, first published in 1968. Written jointly by past and current department members, this textbook is still recognized as a leading textbook in operative dentistry. In fact, Dr Cliff, as senior editor, recently completed the onerous task of ensuring the completion and publication of the third edition. He spent untold hours on this new edition, which undoubtedly will become one of his legacies to operative dentistry.

*Clifford M Sturdevant*

In the 1970s Dr Sturdevant was instrumental in the development and implementation of Project ACORDE, one of the first formal attempts by operative dentistry educators to consolidate philosophies and generate teaching materials regarding conservative cavity preparations and restorations of teeth. Dr Cliff also has been an innovator in the realm of operative dentistry for years. Not only did he invent or codesign many devices such as the light body injection syringe for impression materials, "Jiffy tubes" for cement application, and various instrument and bur designs, but he also introduced numerous progressive concepts in operative dentistry that are

still used today.

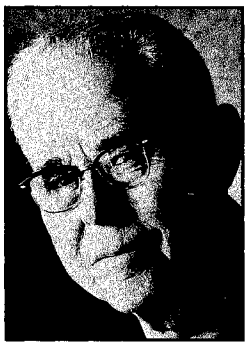
In fact, Dr Cliff has always been a bit of a maverick, with the foresight and vision to continually seek to improve clinical operative dentistry through new and improved materials and techniques. This progressive attitude has not always been popular or consistent with the mainstream opinion among those in operative dentistry circles who have often been resistant to change. Nonetheless Dr Cliff has always striven to keep operative dentistry abreast of the numerous and exciting developments and advancements that have occurred in dentistry. This desire for continual improvement in operative dentistry materials and techniques led to Dr Cliff's establishment at UNC of one of the first clinical research programs in operative dentistry and biomaterials in the country in the late 1960s. Consistent with his constant pursuit of clinical excellence, the goal of the UNC Clinical Research Program in Operative Dentistry has always been to strive to improve the practice of operative dentistry through clinical investigations. Under the able leadership of Dr Karl Leinfelder and later Dr Stephen Bayne, this clinical research program has had a dramatic impact on the teaching and practice of operative dentistry and is a source of continued pride for the School of Dentistry at UNC. In fact to recognize Dr Cliff's efforts in establishing this Clinical Research Program 25 years ago at UNC, the Clifford M Sturdevant Endowment Fund for Clinical Research in Operative Dentistry was recently established at the University of Carolina at Chapel Hill. Most importantly, the clinical research program envisioned by Dr Cliff some 25 years ago truly has developed into one of the most respected and reputed programs of its kind in the world, clearly a lasting and fitting tribute to Dr Clifford M Sturdevant.



No one individual has embodied the spirit of clinical excellence in operative dentistry more than Clifford M Sturdevant. In fact, I will always remember the words engraved on a bronze plaque that rested on his desk during his years as department chair. They read, "If it's almost right, it's wrong!" His unyielding pursuit of excellence and love for dentistry has had a profound impact on the dental profession and on all who have known him. Through a lifetime of dedicated service and unswerving commitment to clinical dentistry, he has established a legacy of clinical excellence to which we all continue to aspire. I can think of no one more deserving of this award than Dr Cliff. It is with great pleasure and personal pride that I present this year's Academy of Operative Dentistry Award of Excellence to Dr Clifford M Sturdevant.

HARALD O HEYMANN

# Hollenback Prize for 1995



*George Hollenback*

*Karl F Leinfelder*

It seems very fitting that in 1995 the Operative Academy acknowledge two great leaders in dentistry who fortuitously crossed paths during their academic careers. Dr Karl F Leinfelder, this year's Hollenback awardee, worked together with Dr Clifford M Sturdevant, recipient of this year's Award of Excellence, teaching dental materials and together developing one of the first clinical research programs in operative dentistry at the University of North Carolina. Their pioneering work in bringing clinical research into the discipline of operative dentistry has been a model for many other programs throughout the country. Dr Leinfelder began his academic career in 1962 as a clinical instructor at Marquette University, where he ultimately became the coordinator of postgraduate instruction before leaving in 1970 for North Carolina. At the University of North Carolina, he became part of the graduate faculty as a professor and associate director of the Dental Research Center. In 1983 Dr Leinfelder moved to the University of Alabama where he now has the position of chairman of the Department of Biomaterials.

Dr Leinfelder is acknowledged internationally as an expert and leader in dental materials and clinical research. He has written over 150 publications including research articles, abstracts, and textbooks. He has lectured internationally on operative materials and techniques, including several times before this academy. By sharing his knowledge, time, and expertise, he has assisted many organizations, including the American Dental Association and its Council on Dental Materials, Instruments and Equipment; the American and International Associations of Dental Research; the National Institute of Dental Research; and our own Academy of Operative Dentistry.

Without doubt, Dr Leinfelder's greatest contribution to the members of this academy has been his long and successful involvement in clinical research. His efforts have helped to evaluate the clinical performance of many of the materials and techniques used in practice today.

Dr Leinfelder has earned a reputation for his frank and objective opinions, which he is always more than willing to share. He has the ability to communicate in an effective and entertaining fashion to both research audiences and practitioners. His seemingly unending enthusiasm and incredible travel schedule will likely mean we will benefit from his lectures for years to come. Some day, medical science may learn the secret of what fuels this man. Dr Leinfelder has been given numerous awards recognizing his leadership and involvement in dental research and education. The membership of the academy has benefitted greatly from his work and takes pleasure in presenting Dr Karl F Leinfelder with one more award, the 1995 Hollenback Memorial Prize.


FRED EICHMILLER

# DEPARTMENTS

## BOOK REVIEW

### *AESTHETIC DESIGN FOR CERAMIC RESTORATIONS*

David Korson, Editor

Published by Quintessence Publishing Co, Inc, Chicago, 1994. 159 pages, 294 illustrations. $78.00.

David Korson has produced a well-written, easy-to-read, and beautifully documented book on aesthetic design for ceramic restorations. A renowned dental ceramist, Mr Korson has lectured and presented courses worldwide. His purpose for writing this volume, his second Quintessence publication, is to advance the communication between dentist and dental technician and to give advice on working practices to achieve this. This book meets his stated purpose and target audience.

The chapters are well introduced and concisely laid out in outline style. Other Quintessence books on dental ceramics have also documented his first chapter on ground sections of natural teeth and his review of these sections and anatomic characteristics of natural teeth. The chapter on dentist-technician-patient communication has many excellent ideas on this topic, including the responsibility between dentist and technician, patient education by the dentist and technician, and the patient's involvement. The direct involvement of the patient in the laboratory, specifically the trying in of the wax-up and bisque bake presented by the author in this section, may not be carried out in the United States due to current laws placing limitations on any treatment by the dental technician. However, these techniques could be quite useful for the technician and dentist who share the same office.

For the technician and dentist alike, there is a brief but excellent review of tooth preparation, care of soft tissues, impression procedures, fabrication of provisionals, and appropriate crown contours at the margins. Another chapter that provides an extremely beneficial review for dentist and technician outlines laboratory procedures carried out by the technician involving impressions, die trimming, and the use of occlusal records. The book imparts ideas on custom-shade tab fabrications along with staining procedures to enhance the natural appearance of ceramic restorations. This is done through the use of beautifully documented case studies and in-depth explanations. The author reviews communication techniques through dental photography and the equipment needed to achieve this. In addition, the author has devoted an entire chapter to advanced laboratory techniques, which include esthetic ceramic margins, opalescence in dental ceramics, development of dentin mamelons, the aged dentition, and anterior tooth position and form.

David Korson has written a comprehensive book on aesthetic design for ceramic restorations. Although all proposed ideas in this book may not necessarily be integrated into every laboratory and dental practice, this book is highly recommended for the operative/restorative dentist and technician team that is dedicated to esthetic excellence in the field of ceramic restorations.

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## CORRECTION

Two errors were noticed in *Operative Dentistry* **19(6)**. In the headings of Table 1 on Page 218 and Table 6 on Page 220, the Flexural Strengths should be labelled as Megapascals rather than Gigapascals. Thanks to Fred Eichmiller for the heads-up on this error!

## ANNOUNCEMENT

Schools, Study Clubs, Individual Members: A teaching video on the Ferrier class 5 direct gold procedure is available. It is a step-by-step procedure from preparation to the finish of the restoration. Approximate length is 28 minutes with narration and music. The video can be purchased through :

Department of Restorative Dentistry
Loma Linda University
Loma Linda, CA 92350.
Cost: $50.00.

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## Manuscripts

Submit the original manuscript and one copy; authors should keep another copy for reference. Type double spaced, including references, and leave margins of at least 3 cm (1 inch). Supply a short title for running headlines and a FAX number for the corresponding author. Spelling should conform to *American Heritage Dictionary of the English Language,* 3rd ed, 1992. Nomenclature used in descriptive human anatomy should conform to *Nomina Anatomica,* 6th ed, 1989; the terms *canine* and *premolar* are preferred. The terms *vestibular*, *buccal*, *facial*, and *lingual* are all acceptable. SI (Système International) units are preferred for scientific measurement, but traditional units are acceptable. Proprietary names of equipment, instruments, and materials should be followed in parentheses by the name and address of the source or manufacturer. The editor reserves the right to make literary corrections.

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