OPERATIVE DENTISTRY

july-august 1998 • volume 23 • number 4 • 161-216

(ISSN 0361-7734)

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JULY-AUGUST 1998 • VOLUME 23 • NUMBER 4 • 161-216

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

OPERATIVE DENTISTRY (ISSN 0361-7734) is published bimonthly for $55.00 per year in the US and Canada (other countries $70.00 per year) by University of Washington, Operative Dentistry, Health Sciences Bldg, Rm D-775, Seattle, WA 98195-7457. Periodicals postage paid at Seattle, WA, and additional mailing offices. **POSTMASTER:** Send address changes to: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

Subscriptions
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Subscription Manager: Judy Valela

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GUEST EDITORIAL

Has Competence Replaced Excellence?

The science of dentistry continues to evolve with the ever-increasing number of preventive, diagnostic, and treatment technologies being introduced to us every day. It is no wonder that dental education continues to lag and curriculums drop more and more clinical requirements in favor of didactic studies. Programs that were once completed in three to four years, with breaks between terms, now require a full four years with no breaks at all. Clinical requirements no longer count surfaces of a particular type of restoration completed, but rather determine when "competence" in that particular technique has been achieved. When did we make this move from an expectation of excellence to one of competence? Is this change unique to dentistry, or are cardiology students also only required to demonstrate competence?

The town crier has declared that caries is dead and restorative dentistry is near extinction. However, we all know better. It is true that we are seeing fewer lesions than ever before, and that the lesions are smaller and in different locations than those we experienced decades ago. However, the reality is that we all see and treat caries every day. Fortunately, the treatment of the disease has changed considerably. That incipient shadow we may have once immediately filled we can now watch for several months while topical fluoride treatments enhance its potential for remineralization and repair. A rampant-caries patient is placed on an antibacterial regimen until salivary cultures indicate that the disease is under control and restoration can begin. Once caries has resulted in irreversible damage, however, the skills necessary to repair that damage are no less and no different from those taught nearly a century ago. The same level of skill and excellence is necessary to produce a conservative slot inlay as it was to make its predecessor, that may have had extensions into every occlusal groove for prevention. The patient that just completed radiation and chemotherapy for throat cancer will challenge every preventive and restorative skill we have learned, and may give extension for prevention a whole new meaning.

The fact that we are generally filling fewer and smaller lesions gives even more cause to continue our drive towards excellence. We now have the opportunity to restore a tooth and confidently assume that it may never need treatment again. What better reason for producing a product that has the potential for a lifetime of service. That invisible, lingual-approach class 3 foil makes more sense than ever when you consider that the twenty-year-old patient in your chair may never have another lesion or need another restoration. The one buccal or occlusal pit on that twelve-year-old may be the only treatment ever needed. Shouldn't we also make it the only filling ever needed?

As science continues to improve our methods and choices, let us make sure we still continue to recognize and teach what is truly excellence in dentistry. Competence is for typodonts and plaster teeth; excellence is what is required to meet today's restorative challenges.

FREDERICK EICHMILLER
President
American Academy of Gold Foil Operators

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BUONOCORE MEMORIAL LECTURE

Michael Buonocore

Materials of the Future: Preservative or Restorative?

KENNETH J ANUSAVICE

INTRODUCTION

It is not possible to predict the future of dental materials with great certainty. However, by analyzing trends in dental material product development and supported research over the past several decades, one might be able to predict future developments with reasonably good probabilities, at least in the near term. The virtual explosion of dental materials products in the past decade provides evidence that this trend will likely continue well into the distant future.

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The title of this paper implies that there may be a shift in the emphasis of dental practice from the traditional surgical model, which is based on the assumption that caries lesions are correctable by surgical removal of demineralized tooth structure and replacement with an inert material, to a medical model that is based on diagnosis of caries status (active or arrested), remineralization therapy for noncavitated lesions, and monitoring these lesions for evidence of remineralization. Cavitated teeth are restored as has been done through the traditional surgical model, but noncavitated lesions are not treated surgically except when esthetic and functional requirements must be met. The former philosophy is called *restorative dentistry* and the latter is termed *preservative dentistry* (Dawson & Makinson, 1992; Anusavice, 1995). The sections that follow will describe the limitations of the materials currently used for restorative dentistry and the future directions that dentistry is likely to follow through research in the fields of biomaterials, biomimetics, and tissue engineering.

THE FUTURE OF DENTAL AMALGAM

Dental amalgam has been in use in the United States since about 1832. Since that time the concerns about the safety of amalgam have divided dentists into two or more groups. This controversy has peaked and ebbed like an unending sine wave over the past 166 years. Now other biocompatibility issues have arisen throughout the world relative to other materials and products, including the estrogenic potential of monomeric components leached from sealants and composites, the allergenicity of nickel,

gold, palladium, hydroxyethyl methacrylate, eugenol, polyether impression materials, latex gloves, and methyl methacrylate, and the potential adverse effects of fluoride. A significant percentage of dentists have resorted to using more costly inlays, onlays, and crowns to avoid some of their concerns about mercury released from dental amalgam. However, these treatments generally require two or more appointments, and they are considerably more costly than direct filling materials.

Because of the large influx of new materials into the dental marketplace, clinicians have become confused on whether the esthetic benefits of tooth-colored materials outweigh the durability of dental amalgam. Dental amalgams have represented for the past 166 years one of the most durable and technique-insensitive direct filling materials. The relative performance and technique sensitivity of amalgam and alternatives to amalgam are summarized in Table 1. The bold type in Table 1 indicates the most significant deficiencies of these materials. Note that amalgam has only two significant deficiencies, while each of the other materials has three or more deficiencies. Furthermore, the cost per year is significantly lower for amalgam restorations. Although a few countries (Sweden, Denmark, Germany, and Japan) have either proposed the elimination of dental amalgam or have greatly curtailed its use, these decisions are made in part to reduce the risk of environmental pollution from dental offices. There is little evidence that supports the elimination of amalgam because of its toxicity. The Finland Department of Health (Widstrom, 1997) summed up the current consensus of health agencies best with the following statement: "When evaluating scientific articles, reports and other articles, the expert group could find no scientific proof for the statement that amalgam restorations are hazardous to health or that they could cause chronic mercury poisoning."

Although composites have improved greatly because of improved formulations and incremental curing techniques, their relatively high two-body wear rates in approximal areas may represent one of its main limitations. Wendt, Ziemiecki, and Leinfelder (1996) reported wear rates over 24 months of 243 μm for P-30 (3M Dental Products, St Paul, MN 55144), 211 μm for P-50 (3M Dental Products), 184 μm for Heliomolar (Vivadent, Schaan, Liechtenstein), and 198 μm for Clearfil Photoposterior (Kuraray, Osaka, Japan) composites compared with only 19 μm for enamel-to-enamel wear during this period. Fifty direct resin composites and 20 indirect

Table 1. Properties and Handling Characteristics of Restorative Materials for Posterior Restorations

PROPERTY	AMALGAM	COMPOSITE	COMPOMER	RESIN-MODIFIED GLASS IONOMER	GOLD FOIL	CERAMIC
Biocompatability	**Good**	**Good**	**Good**	**Good**	**Fair to good**	Excellent
Technique Sensitivity	Very low	**Moderate to High**	**Moderate to High**	**Very high**	**Very high**	**Moderate**
Median Survival Time	10 years	7 years	Unknown--5 years (estimate)	Unknown--3 years (estimate)	15 years	Variable--5 years (estimate)
Wear Resistance	Excellent	Occlusal: Very good **Approximal: Fair to Poor**	**Fair**	**Fair to poor**	Excellent	Excellent
Fracture Resistance	Good	Good	Fair to good	**Fair to poor**	Very good	Fair to excellent
Self-sealing	Good	**None**	**None**	**None**	**None**	**None**
Esthetics	**Very poor**	Excellent	Good to excellent	Fair to very good	**Poor**	Excellent
Relative Cost (Two-Surface)	$100	$150	$150	$150	**$400**	**$500**

composites were placed in premolar and molar teeth and evaluated for approximal wear rates. Ten enamel-to-enamel approximal surfaces were chosen as controls. The two indirectly processed composites, Coltène Brilliant DI (Coltène, Altstätten, Switzerland) and P-50 (3M Dental Products) were heat-treated to ensure a greater degree of conversion. The wear rates of these materials were 179 μm and 114 μm respectively during the 24-month period. The mean approximal wear rates for the directly placed composites were not significantly different in first bicuspid sites (206 μm) and second bicuspid sites (204 μm) compared with first molar (200 μm) and second molar (256 μm) locations.

Other studies have shown that while the wear rates in occlusal areas are reasonably low, the wear rates are patient-dependent, with some patients exhibiting relatively high wear levels. Other limitations of posterior composites include their potential for incomplete curing in some areas such as gingivoproximal margins, which may not be cured adequately because of light absorption in adjacent tooth structure and light scattering. Relative to their biocompatibility, there are some concerns over the monomers that may be leached from these incompletely cured areas.

In spite of these limitations, posterior composites, whether directly or indirectly cured, represent the most attractive alternative to dental amalgam. Compomers, resin-modified glass ionomers, and glass ionomers lack the fracture resistance and overall durability of amalgam and composites and cannot be used for all of the applications that are currently indicated for amalgam. The so-called ceromers or polyglass composites, some of which contain fiber-reinforced cores, are indirectly processed composites that may offer some advantages over direct composites including higher strength, reduced wear, and better marginal adaptation. However, the extra cost and inconvenience to patients because of the laboratory fee and a second appointment offset these advantages to a certain extent.

NOVEL MATERIALS FOR THE NEAR FUTURE

Because of the unprecedented recent interest in preservative dentistry and esthetic dentistry, manufacturers are taking advantage of technological and materials science advances to facilitate the practice of dentistry. Air abrasion, intraoral video cameras, CAD-CAM technology, vital tooth bleaching, simplified bonding systems, and advanced implantology techniques and materials have "raised the bar" relative to the concepts and techniques that the dental office staff must learn to be considered competent practitioners of the art and science of dentistry. However, let's take a look into the more-distant future to envision several potential scenarios that may offer further challenges and opportunities.

Consider a future practice in which we have passively smart materials, actively smart materials, specialized preventive/esthetic coatings, wear-resistant coatings, nonshrinking composites, technique-insensitive adhesives, memory polymers, laser-welded hydroxyapatite, health-monitoring materials, biomimetic materials, and the potential to produce genetically engineered tissues. Advances in these areas will change our perception of the currently available inert materials (amalgams, cast metals, composites, ceramics, metal-ceramics) from materials of excellence to remnants of an antiquated surgical-intervention era. Passively smart materials of the current era, such as glass ionomers, tend to release fluoride ions as the pH of oral fluids decreases, but the release continues above a pH of 5.5 when fluoride release is not needed to inhibit demineralization of enamel and dentin. An actively smart material will terminate the release of diagnostic or preventive agents when the pH rises above 5.5 and releases predetermined levels of these agents as the pH decreases.

BIOMIMETICS AND TISSUE ENGINEERING

Biomimetic materials are those that mimic nature. Materials of this type can be developed in one of at least two ways: synthetically through materials science or through molecular biology. Synthetically derived materials can consist of controlled biomineralization of a substrate that enhances the deposition of mineral phases such as hydroxyapatite. Another example is the design of hierarchical laminated, interwoven composite structures of organic and inorganic phases that mimic the structure of the extremely tough surface regions of stone crab claws. Biomimetic products can mimic natural tissues and organs. Within the next 50 years we will also be able to produce hormones, growth factors, and specialized proteins and polymers by biomimetic approaches.

Tissue engineering is the theory and process through which selected cell populations are transplanted to create new tissue substitutes for the repair or replacement of damaged or missing tissue. This process will allow the reconstruction of bone, cartilage, muscle, cementum, dentin, enamel, periodontal ligament, pulp tissue, and salivary glands. The elemental stages of tissue engineering include isolation of parenchymal cells (osteoblasts, chondrocytes, hepatocytes, enterocytes, and urothelial cells), production of a cell-polymer construct (cell-infiltrated polymer scaffolds), implantation of the cell-polymer construct, and assessment of the histological and functional characteristics of the engrafted tissue. The polymer scaffold may be permeable or impermeable and may be designed to be nonbiodegradable

(artificial heart, liver, and kidney) or exhibit a specific rate of biodegradation (artificial skin, cartilage, and nerve repair).

The biomaterials used for tissue engineering must: 1) produce a desired cellular response; 2) exhibit a desired state of degradability; 3) be economically feasible; 4) exhibit low or negligible toxicity; and 5) possibly demonstrate drug-delivery capability. For stress-bearing areas, the scaffold would be required to demonstrate sufficient strength and stiffness for tissue regeneration to occur. A femur that needs to be lengthened would require external fixation in addition to the rigid scaffold material. For this application mesenchymal stem cells would be harvested and isolated from marrow, expanded through cell culture, incorporated into a porous ceramic, and implanted for bone augmentation. To generate new dentin, a mixture of bovine collagen matrix and human osteogenic protein (OP) can be placed either in contact with exposed pulp tissue or applied to the surface of a thin area of dentin.

PREDICTIONS FOR THE YEARS 2025 AND 2050

Between the years 2000 and 2010, it is likely that the use of amalgam will decline and be replaced by improved resin-based composites. However, we have nearly reached the performance limits of these composites and future developments will focus primarily on decreasing the technique sensitivity of the bonding agents and the composites themselves. We will no longer experience the wide variability in quality that is associated both with varying skill levels and also with the subjective aspects of the manufacturer's instructions for use. For example, what is meant by rinsing the etching medium for 15 seconds? Does this mean a vigorous air-water rinse or a passive low-pressure water flow? What is meant by the recommendation that conditioned dentin should be neither too wet not too dry? How does one know for certain that the resin at the proximogingival margin of a class 2 composite is adequately cured? How much fluoride should be released from fluoride-releasing liners, cements, and restorative materials to be effective in preventing caries progression in a medium-risk or high-risk patient? Because of the subjectivity involved in following imprecise instructions or indications for use, the long-term outcomes of restorations produced with technique-sensitive materials cannot be predicted with a high level of confidence.

Technique-insensitive composites will become available before 2010, assuming that polymerization shrinkage can be reduced to a negligible level. Zero-shrinkage composites can be formulated: 1) by increasing the filler content; 2) by incorporating hydrophilic, hygroscopic monomers; 3) through ring opening of cyclic anhydrides; 4) by using expanding fillers or reinforcing phases; and 5) through the use of orthospirocarbonates. One group requires the absorption of water to offset the polymerization shrinkage. Another group also requires time for offsetting expansion to occur, and significant stresses may develop before sufficient water is absorbed. Once these limitations are overcome, composites of the 21st century will become nearly as technique-insensitive as dental amalgam.

However, amalgam will retain its status as the most technique-insensitive material well into the 21st century. Although research will continue into the methods of reducing the release of mercury into the environment, amalgam use will virtually be eliminated by the year 2020 because of the demand by society for esthetics over durability. BIS-GMA and urethane dimethacrylate resins have reached their full potential, and additional performance will be derived from control of shrinkage and improved occlusal and approximal wear resistance. Metal-ceramic crowns and bridges will represent the material system of choice for high-stress and long-span reconstructions. The excellence of ceramic veneers will remain and CAD-CAM units will accelerate the delivery time to the patient of composite and all-ceramic inlays, onlays, and crowns. Overall, a slight increase in indirect resins, all-ceramic crown products, and in the use of machinable polymers will occur by 2010.

By the year 2005, smart materials will start to replace fluoride-releasing products; remineralization therapy will increase; tougher, kinder ceramics will be introduced; sealing margins of defective restorations will be preferred to re-restoration; and OP will be introduced to regenerate dentin. By the year 2010, I predict that amalgam use will have declined further; that shell crowns will be made of a biomimetic composite; stereolithography will be used to create three-dimensional polymer scaffolds for tissue engineering; remineralization products will be widely used; sealing in caries lesions with "smart" controlled-release resins will be adopted over glass-ionomer products for underserved populations; and engineered tissues will have become more commonly used. In 2010, biomimetics will start to replace amalgam; remineralization will become more completely adopted; smart materials will replace resin-modified glass ionomers; and engineered periodontium will be successful. By 2050, surface-analysis devices will exhibit caries-diagnosis sensitivity of 95% or more; remineralization will be routine; cavitation of enamel will be rare; tooth regeneration will be demonstrated; and dental labs will be used for producing engineered tissue constructs. Enhanced diagnosis of early caries lesions will improve the percentage of positive outcomes derived from remineralization therapy. The introduction of novel products will continue to

occur while preservative dentistry practices will represent the standard of care. As predicted by G V Black in 1896, "The day is surely coming when we will be practicing preventive rather than reparative dentistry." This prediction appears to be on target.

Making predictions for the future entails considerable uncertainty, since the profession may resolve many of these challenges through other unanticipated approaches. However, one prediction is certain to be realized, and dentists should be prepared for it. Dentists will be inundated by the avalanche of new products, technologies, and information on optimum oral health care, and they must be able to differentiate hope from hype, i e, their expectations of performance from manufacturers' claims for the products. The information explosion must be managed in an efficient manner for clinicians to be considered competent as practitioners of oral health care. It is surprising to realize that if you have read the *New York Times* once in 1998, you have scanned more information than a person in 1773 saw in his or her entire lifetime! Dental education in the future must prepare graduates with the ability to access and analyze this information in an organized and efficient manner.

MANAGEMENT OF CARIES AS A SLOWLY PROGRESSING INFECTIOUS DISEASE

Management of caries as an infectious disease will minimize the risk of restorative overtreatment and will allocate more resources to underserved populations and those who are at a moderate-to-high risk for this disease. Since caries progression through enamel is slower than generally believed (Shwartz & others, 1984; Berkey & others, 1988) and may be slower in patients who have received regular fluoride treatment, or who consume fluoridated water (Shwartz & others, 1984; Pitts, 1983), new strategies will be adopted in the near future. Because a large percentage of enamel lesions remain unchanged over periods of 3 to 4 years, and because progression rates through dentin are comparably slow (Emslie, 1959; Kolehmainen & Rytömaa, 1977; Craig, Powell & Cooper, 1981) preservative dentistry will apply the principles of infection control and lesion-monitoring procedures to assess caries-risk status, lesion-activity status, evidence of lesion arrest, and evidence of lesion remineralization over extended periods of time. For certain populations, progression times of 6 to 8 years through enamel can be expected (Berkey & others, 1988; Zamir & others, 1976; Gröndahl & others, 1977; Hugoson, Koch & Hallonsten, 1988). Furthermore, the percentages of approximal lesions that are seen radiographically in the outer half of dentin that are cavitated has declined over the past several decades to approximately 41% (Pitts & Rimmer, 1992). Because of these factors, monitoring the balance between demineralization and remineralization will exemplify the standard of care for the practice of preservative dentistry.

PRESERVATIVE DENTISTRY VERSUS TRADITIONAL SURGICAL INTERVENTION

The principles of preservative dentistry are to delay placement and replacement of restorations until absolutely necessary and to use the most appropriate durable materials for each clinical condition consistent with the patient's chief complaint and the patient's desires based on a discussion of all relevant treatment choices during the informed-consent session. When restorative treatment is indicated, the most minimally invasive method and associated materials are indicated, e g, a preventive resin restoration versus a traditional class 1 amalgam or composite. Remineralization protocols are preferred to invasive surgical methods when no evidence of cavitation is present. However, not all patients are

Table 2. Comparison of the Surgical and Preservative Models of Caries Management

20th Century Surgical Model	21st Century Preservative Model
Develop treatment plan at first visit	Provisional diagnosis and risk assessment
Assume that all lesions are active	Determine caries activity over time
Restore lesions in inner half of enamel	Remineralize noncavitated enamel lesions
Restore all lesions in dentin	Restore only cavitated lesions
Assume that fillings control disease	Reduce infection risk; restore if necessary
When in doubt, intervene surgically	When in doubt, seal, repair, or remineralize

good candidates for remineralization therapy. For example, patients who are not compliant with home-care instructions, dietary recommendations, or recall appointments are not suitable candidates for preservative dentistry regimens.

Remineralization therapy, which requires strict compliance by the patient and rigorous monitoring of sites at risk by the dentist and hygienist, is the most conservative method currently available to treat noncavitated primary or secondary lesions. As our diagnostic tools increase in sensitivity such that accurate diagnosis of disease status and the relative balance of demineralization and remineralization are known at any point in time, remineralization approaches will dominate our future treatment-planning choices as patients will overwhelmingly prefer this option compared with surgical-intervention options. In addition to this treatment philosophy, the future will offer new minimally invasive surgical methods that will decrease patient discomfort and reduce their anxiety over dental treatment. These advances will surely increase our access to a significant percentage of infrequent users of professional dental care. Summarized in Table 2 is a comparison of the differences between the 20th century surgical model and the 21st century preservative model. Which one would you choose as a patient in the 21st century?

CONCLUSION

There are many challenges that must be overcome for the profession to shift the management of caries from a surgical approach with early intervention to a preservative approach with long-term monitoring of remineralization success. These research challenges include the need to enhance the sensitivity of diagnostic methods for incipient caries, to develop site-specific indicators of future caries risk, and to establish clear evidence-based guidelines for optimum management of caries as an infectious disease. When these challenges are overcome, the benefits of modern "smart" biomaterials and engineered tissues will be fully realized.

(Delivered 19 February 1998)

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ORIGINAL ARTICLES

Repairability of Three Resin-modified Glass-Ionomer Restorative Materials

R A SHAFFER • D G CHARLTON • C B HERMESCH

Clinical Relevance
Time of repair of resin-modified glass-ionomer materials significantly affects bond strength.

SUMMARY

The purpose of this study was to evaluate the repair shear bond strengths of three resin-modified glass-ionomer restorative materials repaired at two different times. Thirty specimens of Fuji II LC, Vitremer, and Photac-Fil were prepared in cavities (2 mm X 7 mm) cut into acrylic resin cylinders. After the initial fill, half of the specimens were repaired 5 minutes later and half 1 week later. The specimens were stored in 37 °C distilled water when not being repaired or tested. Repairs were made without any surface preparation of the initial fill. Each specimen was mixed according to the manufacturer's directions, placed in the preparation in 1-mm increments and photocured for 40 seconds. The last increment was covered with a plastic strip and a glass slide before curing to create a smooth surface. Repairs were accomplished by drying the specimen for 10 seconds, then adding the new material to the unprepared surface using a 3-mm-thick polytetrafluoroethylene mold. The specimens were thermocycled 500 times, stored in 37 °C distilled water for 1 week, then loaded to failure in shear at a rate of 0.5 mm/min. Data were analyzed using a one-way ANOVA and Z-value multiple comparison test to determine significant differences at the 0.05 significance level. Vitremer showed no significant difference in shear bond strength for 5-minute and 1-week repair periods, while Fuji II LC and Photac-Fil did. Repair bond strength of Vitremer was significantly greater than Fuji II LC and Photac-Fil at both repair times. This study showed that time of repair significantly affected the bond strength of two of the materials tested.

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INTRODUCTION

Recently, resin-modified glass-ionomer products have become popular as restorative materials, especially for class 3 and 5 lesions. They have several advantages compared to traditional glass-ionomer cements such as command set, high early strength, and reduced sensitivity to moisture contamination (Sidhu & Watson, 1995). As with other directly placed restoratives, the resin-modified glass ionomers may occasionally require repair because of color changes within the material and at the margins (Maneenut, 1995). Other reasons for repairing these

materials include voids, marginal chipping, and lack of contour due to underfilling or overpolishing.

Although resin-modified glass-ionomer restorative materials occasionally need to be repaired, no research has been published on the repair shear bond strengths over time of the currently available resin-modified glass-ionomer restorative materials (Fuji II LC, Vitremer, and Photac-Fil). Clinical dentists would benefit from research that provides a comparison of the repairability of these materials. Two repair times were chosen that closely simulate the times that clinicians would most commonly need to repair restorations.

The purpose of this study was to evaluate the repair shear bond strengths of three resin-modified glass-ionomer restorative materials repaired at 5 minutes or 1 week after initial placement.

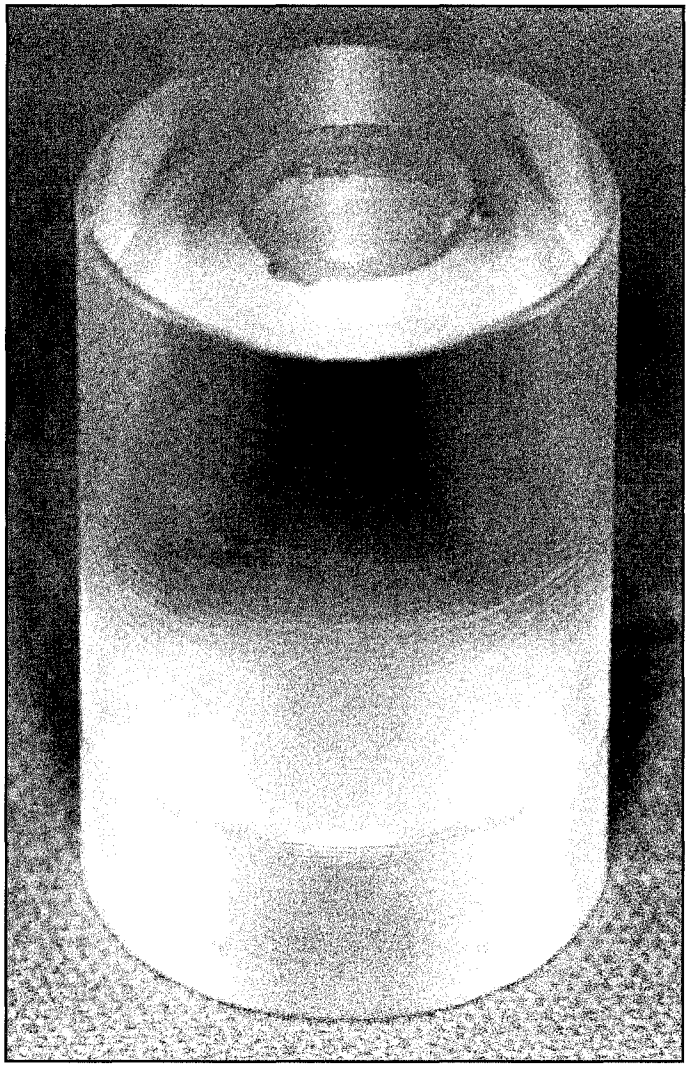

Figure 1. *Cavity preparation in acrylic chamber for original fill of resin-modified glass-ionomer restorative*

METHODS AND MATERIALS

Ninety 25-mm long sections were cut from prefabricated, solid, acrylic rods 15 mm in diameter (Townsend Plastics, Des Moines, IA 50315). A 2-mm deep by 7-mm-in-diameter cavity was cut into one end of each cylinder using a steel drill bit and a drill press (Maximat V10, Campbell Tools Co, Springfield, OH 45501) (Figure 1). Undercuts were made in the walls of the cavity using a dental high-speed handpiece and a #½-round bur. The resin-modified glass-ionomer materials used in this study were: Fuji II LC (Shade A2, GC America Inc, Chicago, IL 60658); Vitremer (Shade C2, 3M Dental Products, St Paul, MN 55144); and Photac-Fil (Shade A2/L, ESPE America, Norristown, PA 19404). Each material was prepared according to its manufacturer's instructions. The hand-mixed materials (Fuji II LC and Vitremer) were mixed on a pad and placed in the cavity in 1-mm increments using a dispensing gun (Mark IIIp Speed Slot, Centrix, Shelton, CT 06484) and light-protected tip. Photac-Fil was mixed using a triturator (Automix Computerized Mixing System, Kerr Corp, Orange, CA 92867) and dispensed in 1-mm increments using a dispenser device provided with the product. Each increment of material was polymerized for 40 seconds with a visible-light-curing unit (Optilux 400, Demetron Research Corp, Danbury, CT 06810). An 8-mm-in-diameter curing wand (Turbo Tip, Demetron Research Corp) was used for all photocuring. A radiometer (model 100, Demetron Research Corp) was used to verify the adequacy of the light's intensity immediately prior to each use. The last increment of material was covered with a plastic strip and a cover slide to create a smooth surface parallel to the end of the acrylic cylinder.

The specimens were randomly divided into two groups for each of the three materials. Repairs were made at 5 minutes and 1 week. The 1-week repair specimens were stored in 37 °C distilled water prior to repair. The experimental design is shown in Figure 2. As called for in the manufacturers' instructions, the exposed surfaces of the Fuji II LC and Vitremer samples to be repaired at 1 week were coated initially with an application of GC Fuji Coat LC and Finishing Gloss respectively. The resins were polymerized by light activation for 40 seconds. Repairs for both time groups were accomplished by drying the specimen for 10 seconds and then adding the new material to the unprepared surface using a 3-mm-thick polytetrafluoroethylene mold with an internal diameter of 4 mm. Each material was mixed, placed, and light activated as described above. Repairs were made with shades B3 for Fuji II LC, A3 for Vitremer, and B3/Y for Photac-Fil. These shades were distinctly different from the shades of

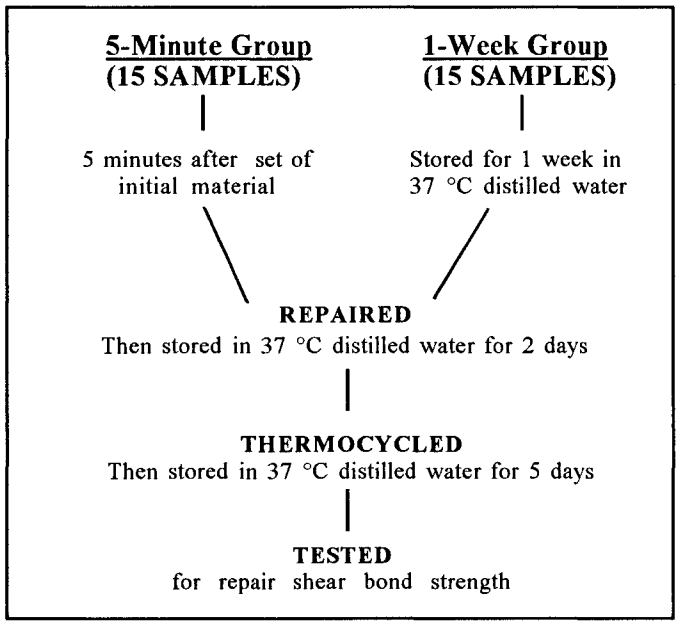

Figure 2. *Experimental design of study*

the original materials, to make it possible to determine the exact location of the failure after testing. Immediately following repair, all exposed surfaces of the Fuji II LC and Vitremer specimens were coated with their respective light-activated sealers. The resin was polymerized by light activating it for 40 seconds. The specimens were immediately placed in 37 °C distilled water, stored for 2 days, and then thermocycled 500 times between a 5 °C and a 55 °C water bath (dwell time of 40 seconds). After thermocycling, all specimens were stored in 37 °C distilled water. One week after repair, the specimens were tested in shear using a steel ring engaging the specimen cylinders and attached by a chain to a testing machine (model 1000, Tinius-Olsen, Willow Grove, PA 19090) (Figure 3). The specimens were loaded to failure at a crosshead speed of 0.5 mm/min.

The data were initially analyzed using a two-way ANOVA; however, a significant interaction was found between the main effects (time of repair, material). Therefore, a one-way ANOVA and Z-value multiple comparison tests were used to determine significant differences at the 0.05 level of significance.

A stereomicroscope (Ziess Stemi SR, Carl Zeiss Inc, Thornwood, NY 10594) at X8 magnification was used to evaluate the mode of failure. Failures were classified and recorded as cohesive (those occurring within either the original or the repair material), adhesive (those occurring at the repair interface), or mixed (a combination of cohesive and adhesive failures).

RESULTS

Mean shear bond strength values in MPa and standard deviations for the 5-minute and 1-week repairs are presented in Table 1. Vitremer showed no significant difference between the 5-minute and 1-week repair shear bond strengths. For both Fuji II LC and Photac-Fil, the 1-week repair shear bond strengths were significantly lower than the 5-minute strengths. The repair bond strengths of Vitremer were significantly greater than those of Fuji II LC and Photac-Fil. Modes of failure are presented in Tables 2 and 3. For the 5-minute repairs Vitremer exhibited predominantly mixed failures. All of the Fuji II LC failures were adhesive in nature, while the majority of the Photac-Fil failures were cohesive. For the 1-week repairs, Vitremer and Fuji II LC exhibited modes of failure similar to those of the 5-minute repairs. Interestingly, the 1-week Photac-Fil repairs were evenly distributed between adhesive and mixed failures. Unlike the 5-minute Photac-Fil failures, none of the 1-week repair failures were cohesive.

DISCUSSION

Glass-ionomer cements have been compositionally modified in recent years through the addition of resins (McLean, Nicholson & Wilson, 1994). Unfortunately, there is a great deal of confusion about glass-

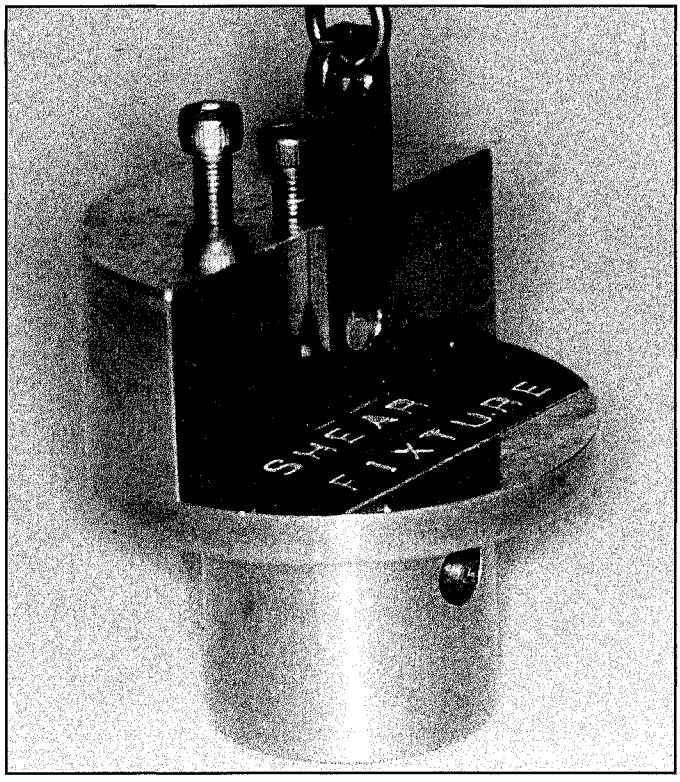

Figure 3. *Shear bond strength testing apparatus*

Table 1. Mean Shear Bond Strengths (MPa) of Repaired Resin-modified Glass-Ionomer Restorative Materials

Materials	5-Minute Repairs	1-Week Repairs
Vitremer	19.17 ± 4.55	16.32 ± 4.01
Fuji II LC	11.34 ± 2.23	9.31 ± 2.78
Photac-Fil	10.07 ± 1.78	3.38 ± 2.30

Lines connect nonsignificant differences at the 0.05 level. Mean ± standard deviation; N = 15.

Table 2. Modes of Failure for 5-Minute Repairs

Materials	Cohesive	Adhesive	Mixed
Vitremer	1	1	13
Fuji II LC	0	15	0
Photac-Fil	12	0	3

Adhesive: failures occurring at the repair interface; Cohesive: failures occurring within either the original or the repair material; Mixed: a combination of adhesive and cohesive failures. N = 15.

ionomer cements and related materials, because no standard terminology exists to distinguish between them. A standardized terminology has been suggested to identify these materials based on their composition (McLean & others, 1994). Three terms have been proposed for common and scientific use: glass-ionomer cement, resin-modified glass ionomer, and polyacid-modified composite resin. Glass-ionomer cements are defined as consisting of an acid-decomposable glass and a water-soluble acid that set by an acid-base reaction. Glass-polyalkenoates and glass-polyphosphonates are the two subgroups of glass-ionomer cements. Resin-modified glass ionomers consist of a glass-ionomer cement and a resin. The acid-base reaction of the glass-ionomer component must be present and contributes to its setting reaction. A light and/or chemically induced free radical resin polymerization reaction is also present. Polyacid-modified composite resins are resin materials that may contain glass-ionomer cement components but lack the acid-base reaction as a critical part of their setting reaction.

In this study, three commercially available resin-modified glass-ionomer restorative materials were used to evaluate the efficacy of repairing them by adding a new mix of the same material to the original restoration. Unfortunately, no studies have been published on this method of repairing these materials. Some interesting comparisons and contrasts, however, can be made by reviewing the literature on repairs of traditional glass-ionomer restorative materials (Parra & Kopel, 1992; Charlton, Murchison & Moore, 1991; Robbins & others, 1989) and those of polyacid-modified composite resins (Flores, Charlton & Evans, 1995). Many of the glass-ionomer studies found that the time of repair had a significant effect on the resulting repair bond strength. Parra and Kopel (1992) studied the repair bond strength of two glass-ionomer restorative materials at three repair times and found that the shear bond strength was adversely affected by time of repair: repairs made at 24 hours and 6 days were lower than those made at 15 minutes. Robbins and others (1989) found that the repair shear bond strength of three glass-ionomer materials decreased significantly as time of repair increased from 30 minutes to 3 months. Charlton and others (1991) measured the tensile repair bond strength of two restorative glass ionomers and found that bond strengths were greater for repairs made at 20 minutes than for those made at 24 hours, but the differences were not always statistically significant. One study on the shear bond strength of a repaired polyacid-modified composite resin has been published (Flores & others, 1995). It found that 5-minute repairs were stronger than 1-week repairs.

In the present study, time also had an effect in significantly reducing the repair bond strengths of Fuji II LC and Photac-Fil. Interestingly, Vitremer did not show a reduction in repair bond strength with time. This may be due to a possible difference in formulation of the materials. A study by Nicholson, Anstice, and McLean (1992) on the compressive

Table 3. Modes of Failure for 1-Week Repairs

Materials	Cohesive	Adhesive	Mixed
Vitremer	3	1	11
Fuji II LC	0	15	0
Photac-Fil	0	7	8

Adhesive: failures occurring at the repair interface; Cohesive: failures occurring within either the original or the repair material; Mixed: a combination of adhesive and cohesive failures. N = 15.

strength of resin-modified glass-ionomer liners/bases showed that these materials are adversely affected by water storage. The authors hypothesized that the reduction in strength was caused by water uptake into the hydrogel matrix, leading to an increased plasticity and a reduction in strength. Because Fuji II LC exhibited a significant reduction in bond strength and the mode of failure was the same for both time groups (adhesive), it would appear that the contributing factor was an adverse effect of water storage on the surface of the original material. Photac-Fil also exhibited a significant reduction in bond strength; however, the mode of failure for the two time groups was different. For the 5-minute repair specimens, the mode of failure was primarily cohesive, while the 1-week repair specimens exhibited mixed and purely adhesive failures. This difference was most likely due to an adverse effect of storage on both the surface and the overall strength of the material. Vitremer did not show a statistically significant reduction in repair bond strength with storage. Because the majority of failures for both time groups were mixed, neither the surface nor the overall strength of the original material appeared to be adversely affected by storage.

The theory that water exposure can adversely affect certain resin-modified glass-ionomer restorative materials appears supported by the data for Photac-Fil. It showed the largest reduction in bond strength when repaired at 1 week and, importantly, it was the only product that was not protected against moisture contamination by application of a light-activated bonding resin.

Several clinically relevant observations were made during laboratory manipulation of the three materials. Vitremer was the most difficult material to mix and dispense because of its extremely viscous nature and short working time. The mixed material was frequently too viscous to dispense, probably due to its chemical-cure reaction, which began within 3 minutes from the start of mixing. It was also observed that mixing a smaller quantity of powder and liquid (i e, one scoop of powder and one drop of liquid) produced a thinner, more easily dispensed product than mixing a larger quantity of powder and liquid (i e, two scoops of powder and two drops of liquid). Fuji II LC and Photac-Fil were easy to dispense and had an adequate amount of working time.

It was also noted that the repair material adhered well when the 5-minute repairs of all three materials were made. However, for the 1-week repairs of Vitremer and Photac-Fil, the newly added materials easily broke away from the bonding site if the mold was not carefully removed after the repairs were made. Clinically, this may cause problems in the immediate postrepair period, especially when no mechanical retention is available between the original and the newly added repair material.

CONCLUSIONS

The results of this study indicated that time of repair significantly affected the repair shear bond strength of two of the tested resin-modified glass-ionomer restorative materials. Based on the bond strength values, it appears that 5-minute repairs of Vitremer, Fuji II LC, and Photac-Fil and 1-week repairs of Vitremer and Fuji II LC are practical. When repaired at 1 week, Photac-Fil performed poorly. Future research should be done to clinically assess the efficacy of repairing these materials.

Disclaimer

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(Received 6 February 1997)

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Repair of New-Generation Tooth-colored Restoratives: Methods of Surface Conditioning to Achieve Bonding

A U J YAP • C E Y QUEK • C H KAU

Clinical Relevance
Surface conditioning of resin-modified glass-ionomer cements does not enhance repair bond strengths. For polyacid-modified composites, repair bond strengths were enhanced by the application of low-viscosity resin after surface conditioning.

SUMMARY

The shear bond strength of repaired resin-modified glass-ionomer cements and polyacid-modified composite resins after different methods of surface conditioning was studied. For the resin-modified glass-ionomer cement, none of the surface treatment methods had a significantly higher repair bond strength than the control. For the polyacid-modified composite, the application of low-viscosity resin after treatment with maleic acid, polyacrylic acid, and air abrasion appeared to be of paramount importance, for it enhanced bonding of the repaired specimens.

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INTRODUCTION

In recent years there has been a steady increase in the use of resin-modified glass-ionomer cements and polyacid-modified composite resin for restorative purposes. Both materials were developed to overcome the problems of conventional glass-ionomer cements, which include early low mechanical strengths and poor esthetics resulting from moisture sensitivity (Mount, 1990). A true resin-modified glass-ionomer cement hardens by two reactions: (1) the comparatively slow acid-base reaction between glass powder and organic acid, and (2) an immediate photochemically induced polymerization of the resin component (Wilson, 1990). Polyacid-modified composite resins, however, differ in their setting characteristics. They are a type of composite resin in which the filler and matrix resin undergo an acid-base reaction over a period of time after hydration and light activation. The acid-base reaction has been claimed to promote further crosslinking, thus hardening of the entire matrix (Dentsply, 1994).

These esthetic tooth-colored restoratives release fluoride, adhere to enamel and dentin, and are appropriate for the restoration of noncarious cervical tooth loss (Yap & Neo, 1995). There have, however,

been reports of loss of cervical restoration contours following continued erosion or abrasion, and replacement or repair may be necessary (Ngo, Earl & Mount, 1986). The advantages of repair of localized defects include saving of tooth structure and increased longevity of restorations at low cost (Mjör, 1993), and it may be preferable to totally remove and replace. While the repair of glass-ionomer cements and composite resins has been studied (Mitasaki-Matsou & others, 1991; Jamaluddin & Pearson, 1994), little research has been conducted on the method of surface conditioning for the repair of the newer hybrid materials.

This project examined the shear bond strength of repaired resin-modified glass-ionomer cements and polyacid-modified composite resins after different methods of surface conditioning and identified the best method of surface conditioning for the repair of these restoratives. The mode of bond failure of the repaired restoratives was also studied.

METHODS AND MATERIALS

The resin-modified glass-ionomer cement and polyacid-modified composite resin selected for investigation were encapsulated Fuji II LC (GC Corp, Tokyo, Japan) and Dyract (Dentsply, Weybridge, England, UK) respectively.

Specimen Preparation

The restorative materials were manipulated according to the manufacturers' instructions and placed or syringed into the central cylindrical recess (10 mm in diameter and 1.5 mm deep) of customized cylindrical acrylic molds. A glass slide was then placed on the mold and excess material was extruded out. The materials were then light polymerized for 40 seconds through the glass plate. A layer of low-viscosity resin was applied over the resin-modified glass-ionomer cement. All specimens were then stored in distilled water at 37 °C for 1 week. Forty-two specimens of each material were prepared. After the 1-week storage period, specimens were adjusted using a model trimmer (MT1, Renfert GmbH, Hilzingen, Germany) to ensure a flat bonding surface. This surface was subsequently treated with 320-grit sand paper and washed for 15 seconds with a water spray from an air-water syringe. At no point were the restoratives allowed to desiccate. Each set of materials was then divided into seven groups of six and treated as follows: **Group 1 (control)**: left untreated, gently air dried for 5 seconds; **Group 2**: etched for 20 seconds with 10% maleic acid (Scotchbond Multi-Purpose Dental Adhesive System, 3M Dental Products, St Paul, MN 55144), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied and light polymerized for 20 seconds; **Group 3**: etched for 20 seconds with 10% maleic acid (Scotchbond Multi-Purpose), washed for 30 seconds, gently air dried for 5 seconds; **Group 4**: conditioned for 20 seconds with 10% polyacrylic acid (GC Conditioner, GC Corp, Toyko, Japan), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied and light polymerized for 20 seconds; **Group 5**: conditioned for 20 seconds with 10% polyacrylic acid (GC Conditioner), washed for 30 seconds, gently air dried for 5 seconds; **Group 6**: air abraded (at 58 psi) for 2 seconds with 50 µm aluminous oxide (Keramo3, Renfert GmbH), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied and light polymerized for 20 seconds; **Group 7**: air abraded for 2 seconds with 50 µm aluminous oxide (Keramo3), washed for 30 seconds, gently air dried for 5 seconds.

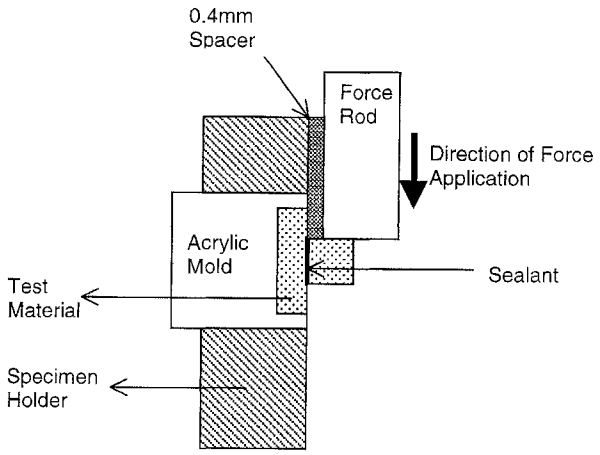

Figure 1. *Schematic drawing of the shear bond test set-up*

Shear Bond Strength

Hollow plastic cylinders (3.4 mm in internal diameter, 1.5 mm in height) were centered on the pretreated surfaces of the specimens. The cylinders were filled with the respective restoratives, light polymerized for 40 seconds, and removed. Both restoratives were condensed into the cylinders, and a thickness of material no greater than 1.5 mm was maintained to ensure total light polymerization. A circular bond area (9.0 mm^2), simulating the repair of the materials evaluated, was thus achieved.

The bonded specimens were then placed into a test jig, which ensured that the shear load could be applied parallel to the bonded interface. A 0.4 mm spacer was placed so that a constant distance was

Table 1. Mean Shear Bond Strength (MPa) and Standard Deviations

Materials	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Resin-modified glass-ionomer cement	5.67 (2.83)	8.80 (7.53)	9.70 (5.47)	11.41 (4.92)	9.43 (2.95)	6.11 (5.99)	5.70 (4.01)
Polyacid-modified composite resin	6.03 (3.67)	17.21 (5.64)	7.56 (5.37)	19.38 (6.64)	6.91 (2.00)	22.22 (3.21)	10.38 (3.37)

maintained between the pretreated restorative surface and the point of force application through the force rod (Figure 1). The specimens were tested at a cross head speed of 0.5 mm/minute with an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021). The maximum strength (MPa) was calculated based on the internal cross-sectional area of the hollow cylinders.

Mode of Bond Failure

The fractured surfaces were examined with a stereomicroscope (Olympus, Tokyo, Japan) at X20 magnification to determine the mode of failure. A few specimens showed multiple failure modes. These failure modes were, however, classified according to the dominant mode of failure for simplification of analysis. Three categories of failure mode were identified: **Type I**. adhesive failure at repaired interface; **Type II**. cohesive failure in the restorative; and **Type III**. cohesive failure in the low-viscosity resin when used.

Statistical Analysis

The mean and standard deviation were calculated for each specimen group. One-way analysis of variance and Scheffé's multiple-range tests were performed to determine significant differences in bond strength data. For failure modes, the data were subjected to Kruskal-Wallis one-way analysis of variance, and intergroup comparisons were performed using the Mann-Whitney U and Wilcoxon's Rank Sum tests. All statistical tests were conducted at a significance level of 0.05.

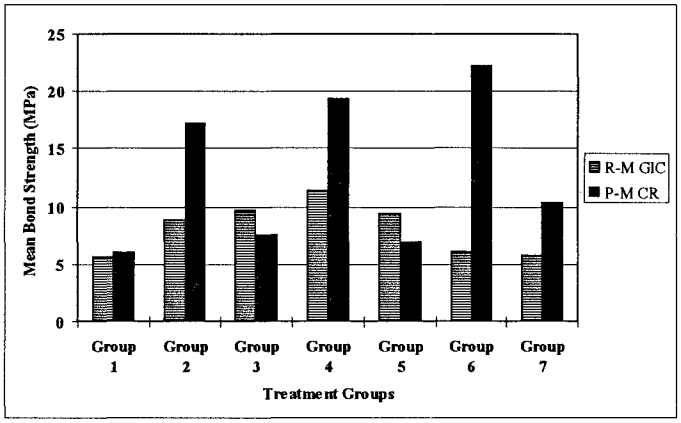

Figure 2. *Mean shear bond strength. R-M GIC = resin-modified glass-ionomer cement; P-M CR = polyacid-modified composite resin.*

RESULTS

The mean shear bond strengths and standard deviations are reflected in Table 1 and Figure 2. Ranking from highest to lowest bond strength for the resin-modified glass-ionomer cement was as follows: Group 4 > Group 3 > Group 5 > Group 2 > Group 6 > Group 7 > Group 1. No statistically significant differences in bond strengths were noted between the different treatment groups. For the polyacid-modified composite resin, ranking from highest to lowest bond strength was: Group 6 > Group 4 > Group 2 > Group 7 > Group 3 > Group 5 > Group 1. One-way analysis of variance revealed significant differences among treatment groups. Results of intergroup comparisons using Scheffé's test are shown in Table 2. The failure modes after repair by percentage are reflected in Table 3 and results of intergroup comparisons are shown in Table 4. For the resin-modified glass-ionomer cement, Groups 1, 5, and 7 had significantly more adhesive failure (Type I) than Group 2. For the

Table 2. Intergroup Comparisons of Shear Bond Strengths (Results of ANOVA and Scheffé's Test)

Material	Differences
Resin-modified glass-ionomer cement	No statistical significance
Polyacid-modified composite resin	Groups 2, 4, 6 > 1, 5 Also 4, 6 > 3 and 6 > 7

$P < 0.05$; > indicates statistical significance.

Table 3. Failure Modes after Repair by Percentage

MATERIAL	RESIN-MODIFIED GLASS-IONOMER CEMENT			POLYACID-MODIFIED COMPOSITE RESIN		
Failure Mode	**Type I**	**Type II**	**Type III**	**Type I**	**Type II**	**Type III**
Group 1	100%	0%	NA	100%	0%	NA
Group 2	33%	67%	0%	0%	100%	0%
Group 3	50%	50%	NA	17%	83%	NA
Group 4	83%	17%	0%	0%	100%	0%
Group 5	100%	0%	NA	33%	67%	NA
Group 6	67%	33%	0%	0%	100%	0%
Group 7	100%	0%	NA	67%	33%	NA

Categories of failure mode: I. adhesive failure at repaired interface; II. cohesive failure in the restorative; III. cohesive failure in the low-viscosity resin when used

polyacid-modified composite resin, the control group (Group 1) had significantly more adhesive failures than the other treatment groups with the exception of Group 7. In addition, Groups 2, 4, and 6 also had significantly more cohesive failures (Type II) than Group 7. No predominately cohesive failure in the low-viscosity resin was noted for either restorative.

DISCUSSION

Restoration replacement invariably leads to the enlargement of the cavity preparation, even for intact areas not directly related to the defect that caused the actual failure (Elderton, 1977). The loss of tooth structure may even be greater with tooth-colored restorations, as it is often difficult to demarcate between tooth and restorative. Repair may, therefore, be an important alternative to replacement of restoratives to save tooth structure. This is especially true in cases of recently placed restorations with localized defects that were identified after delayed finishing procedures.

The stresses at the interface of restorations are complex but can be identified as mainly a tensile or shear type of stress, created either by forces working perpendicular to or parallel to the tooth surface (Øilo, 1993). As the restoratives evaluated were usually used in class 5 cavities, where stresses are expected to be parallel to the tooth surface, a shear bond test was used. The purpose of such tests was to establish a value showing the strength of the bond. Bond strength is the force per unit area required to break a bonded assembly with failure occurring in or near the adhesive/adherent interface (International Organization for Standardization,1982a,b). Bond strength is related to size of the bonding area, which was kept controlled in this experiment. The possible effects of polymerization of the restoratives, which affects the bond area, could have contributed to the moderate standard deviation noted with some treatment groups.

For the resin-modified glass-ionomer cement, no significant differences in shear bond strength were noted among the treatment groups for the untreated (control) group. The repair bond strength was the lowest. The highest repair bond strength was obtained by conditioning with polyacrylic

Table 4. Intergroup Comparisons of Failure Mode (Results of ANOVA, Mann-Whitney U, and Wilcoxon's Rank Sum Tests)

Material	Differences	Remarks
Resin-modified glass-ionomer cement	1, 5, 7 > 2	Statistical differences applied to Type I failure (adhesive failure at repaired interface)
Polyacid-modified composite resin	1 > 2, 3, 4, 5, 6 Also 7 > 2, 4, 6	Statistical differences applied to Type I failure (adhesive failure at repaired interface)

$P < 0.05$; > indicates statistical significance.

acid followed by resin application. The lack of statistical significance between the two treatment groups may not, however, justify the increased investment of clinical time. Air-abrading resin-modified cements for repair purposes did not increase bond strength. Priming the bond surface with maleic and polyacrylic acid appeared to improve bond strength minimally. The presence of low-viscosity resin as an intermediary did not significantly enhance bond strength. Incorporation of resins did not appear to influence the cohesive bonding mechanism of glass-ionomer cements. In this respect, the resin-modified glass-ionomer cement behaved like conventional glass ionomers. It is possible that a chemical interaction between exposed glass particles and polyacrylic acid could produce a chemical union between the new and aged material, resulting in the minor increase in bond strength. Treatment with maleic acid, on the other hand, produced an etched surface, the depth of etch being determined by the length of exposure to acid and the time after mixing at which the acid was applied (Taggart & Pearson, 1991). Failure modes, with the exception of Group 2 (maleic acid and resin), were generally at the junction between the old and new material, with the low-viscosity resin intact on the primed surfaces when applied. No correlation between bond strength and failure mode was noted.

For the polyacid-modified composite resin, significant differences in shear bond strength were noted among the different treatment groups. The lowest bond strength was observed with the repaired control specimens and the highest with specimens treated with air abrasion and resin (Group 6). Surface treatment with maleic acid, polyacrylic acid, and air abrasion together with resin application (Groups 2, 4, and 6) resulted in significantly higher bond strengths than with no treatment (Group 1) and conditioning with polyacrylic acid alone (Group 5). In addition, significant differences in bond strengths were also noted between surfaces treated with polyacrylic acid and air abrasion together with resin application (Groups 4 and 6) and surfaces treated with maleic acid only (Group 3). For the specimens that were air abraded, the application of resin resulted in significantly better bonding. Treatment with maleic acid, polyacrylic acid, and air abrasion alone did not result in significantly greater bond strengths when compared to the control group. Results showed application of low-viscosity resin to be of paramount importance in the repair of polyacid-modified composite resins, for it enhanced bonding of the repaired specimens. In this aspect, polyacid-modified composite resins behave like conventional composite resins, where the application of a thin layer of low viscosity resin before repair also reinforced repair bond strengths (Boyer, Chan & Torney, 1978; Mitasaki-Matsou & others, 1991). The adhesive bond between the low-viscosity resin and polyacid-modified composite should be both chemical and micromechanical in nature. With the exception of Group 7, all other treatments showed significantly more cohesive failures compared to the control. All treatment groups with resin application (Groups 2, 4, and 6) also had significantly more cohesive failures than air abrasion alone (Group 7). Again, no apparent correlation was noted between bond strength and mode of failure.

Clinical applications of the results are as follows: For resin-modified glass-ionomer cements, repairs should be kept to a minimum, for high-repair bond strengths cannot be achieved. Since none of the surface treatment methods had a significantly higher repair bond strength than the control, surface roughening with burs followed by washing with water appeared to be the procedure of choice for the repair of resin-modified glass-ionomer cements in the interest of time and cost. For polyacid-modified composite resins treated with maleic acid, polyacrylic acid, and air abrasion, coating a thin layer of intermediate low-viscosity resin enhanced bonding of the repaired specimens. The highest repair bond strength was obtained with surface roughening, air abrasion for 2 seconds with 50 μm aluminous oxide, washing with water for 30 seconds, gently air drying for 5 seconds, coating with low-viscosity resin, and light polymerizing for 20 seconds before addition of new material.

CONCLUSIONS

The shear bond strength of repaired resin-modified glass-ionomer cements and polyacid-modified composite resins after different methods of surface conditioning was studied.

Resin-modified Glass-Ionomer Cement

Ranking from highest to lowest bond strength was: polyacrylic acid with resin (Group 4) > maleic acid (Group 3) > polyacrylic acid (Group 5) > maleic acid with resin (Group 2) > air abrade with resin (Group 6) > air abrade (Group 7) > no treatment (Group 1).

None of the surface conditioning methods had a significantly higher repair bond strength than the control.

Polyacid-modified Composite Resin

Ranking from highest to lowest bond strength was: air abrade with resin (Group 6) > polyacrylic acid with resin (Group 4) > maleic acid with resin (Group 2) > air abrade (Group 7) > maleic acid (Group 3) > polyacrylic acid (Group 5) > no treatment (Group 1).

Treatment with maleic acid, polyacrylic acid, and air abrasion alone did not result in significantly greater bond strengths when compared to the control group.

Application of low-viscosity resin is of paramount importance in the repair of polyacid-modified composite resins after treatment with maleic acid, polyacrylic, and air abrasion, as coating a thin layer of intermediate low-viscosity resin enhanced bonding of the repaired specimens.

(Received 11 February 1997)

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Factors Affecting Light Transmission of Single-Use, Plastic Light-curing Tips

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Clinical Relevance
Curing-light transmission through single-use, plastic light-curing tips was found to provide adequate light-intensity levels, provided the operator is knowledgeable of important differences in handling characteristics between these devices and conventional, glass fiber-optic light guides currently in use.

SUMMARY

Recently, manufacturers introduced presterilized, single-use, plastic light-curing tips to be used either routinely or on patients with known or questionable communicable health concerns. The purpose of this study was to examine the effect of these single-use tips on light transmission compared to conventional fiber-optic bundles in a variety of commercial light-curing units. Also, the effects of surface contact with the plastic tips (human tissues, reflective or opaque media, and barrier films) were evaluated. Where applicable, single-use tips from two sources (Caulk/Dentsply and Demetron) were placed in commercial curing units (Optilux 150 and 500, MAX 100, Spectrum Curing Light, and 3M XL-3000), and the intensity was compared to that of the conventional glass curing tip used with that specific curing unit. Intensity readings were also made for 6 continuous minutes using plastic tips in a high-intensity curing unit to simulate veneer bonding. If the sides of the plastic tip came in contact with the operator's fingers or the patient's tongue and/or cheek during a clinical procedure, a lowering of transmitted light intensity resulted. The glow emitted from the sides of the tip when in use may be annoying to the operator. To prevent this glare, the operator may be tempted to treat the sides of the tip by painting, applying a thin polymer barrier, abrasion, or wrapping in an opaque reflective material (aluminum foil). A significant decrease in light intensity can result if plastic curing tips contact oral tissues or bare hands. Application of thin polymer barriers was found to significantly reduce light transmission value. Also, surface modification (coating with paint or surface scratches) was found to greatly reduce light intensity levels, while wrapping the tip in aluminum foil produced a very small increase. Results indicated that transmitted light intensity with use of plastic tips was dependent

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upon both the brand of plastic tip tested and the different photocuring units. Either a slight increase or a slight decrease in intensity was noted. Plastic tips did not degrade in transmitted intensity when exposed to the heat produced during a simulated veneering scenario. In summary, use of plastic, single-use light-curing tips can provide adequate intensity for photoactivated restorative techniques; however, the clinician must be aware of specific, clinically relevant limitations with their use. Clinicians must also note that these tips are not designed for re-use.

INTRODUCTION

Light-curing is an integral component in contemporary clinical dental practice. Maintenance of adequate light energy for photoactivation of restorative materials is a central focus in clinical practice (Caughman, Rueggeberg & Curtis, 1995).

Because dental light-curing tips are placed intraorally in a field capable of causing blood and saliva contamination, and because these items require reuse, DHHS recommends sterilization of curing tips between patient use (US DHHS, 1993; ADA, 1988). Any method of sterilization resulting in decreased light transmission from the curing source to the photoactivated restorative material can significantly affect the cure and physical properties of the resulting restoration (Ferracane, 1985). Autoclaving deposits a tenacious, light-reducing scale on curing-tip ends (Rueggeberg, Caughman & Comer, 1996). After only three autoclave cycles, this adherent film can reduce light transmission by as much as 50%. This film can be removed, and reduced in its ability to reform, by performing periodic polishing with a commercial maintenance kit. However, expense of purchasing a large number of tips as well as paying for personnel to sterilize and maintain them may result in elevated operating costs.

Recently, manufacturers introduced single-use light-curing tips. These devices are made of clear plastics, and are designed to be discarded after one use, eliminating the time and expense of sterilization and maintenance. Two such tips are now commercially available. Both are packaged in presterilized blister packs. One of these devices is available with adapters to fit a variety of different commercial light-curing units.

The clinician is already familiar with manipulation of conventional fiber-optic glass-bundled light-curing tips. However, it remains to be proven that similar use can be transferred to plastic tips, or if special techniques must be applied to provide optimal clinical results.

The purpose of this research was to compare light transmission of conventional glass fiber-optic and plastic, single-use light-curing tips in a wide variety of commercial dental light-curing units. Also, the effect of plastic tip surface contact with human tissues, reflective or opaque media, and barrier films was evaluated.

METHODS AND MATERIALS

The plastic curing tips tested were the Demetron Disposable tip (#21014, 9 x 14 mm, Demetron Research Corp, Danbury, CT 06810-7377), and the SaniCure tip (#644728, 8 x 12 mm, L D Caulk/Dentsply, Milford, DE 19963-0359). Both tips are optically clear, and packaged in presterilized blister packs. Both are tapered, with a large end fitting the light-curing unit, and a small end directed toward the material to be light cured. The Demetron tip fits only Demetron units. However, the SaniCure tip comes with adapters so that the device may be used in light-curing units made by 3M, Demetron, and Caulk/Dentsply.

Comparing Intensity between Single-Use Plastic and Standard Glass Fiber-Optic Tips

The table indicates the comparisons of intensity values that were made for specific photocuring units and types of curing tips. For comparative purposes, the light intensity of a standard, glass-bundled light-curing tip (#20941, 8 mm tip, Demetron Research Corp) (the control group) and the Demetron plastic tip

Curing Units and Types of Curing Tips Compared for Transmitted Intensity Value

Curing Unit	Conventional Tip	Demetron Single-Use Tip	Caulk/Dentsply Single-Use Tip
XL-3000 (3M Dental Products)	X		X
Spectrum (Caulk/Dentsply)	X		X
Max 100 (Caulk/Dentsply)	X		X
Demetron 150 (Demetron Research Corp)	X	X	X
Optilux 500 (Demetron)	X	X	X

X = combined use of a specific curing unit and curing tip.

was obtained five times using a commercial photocuring unit (#10610, Optilux 500, Demetron Research Corp). The light unit provided 60-second exposures. No intensity reading was obtained on the initial exposure, allowing the bulb to heat to a stable level. The unit was then immediately re-activated, and the test values were recorded. Curing-light output was measured using a modified hand-held dental radiometer (#10503, model 100, Demetron Research Corp). This unit was modified such that the millivoltage output generated across an internal, fixed resistor was measured with a precision millivolt meter (model AN6503, Analogic Corporation, Danvers, MA 01923) (Rueggeberg & others, 1993). The authors previously correlated this voltage reading with various levels of measured light intensity, providing a regression formula from which a measured millivoltage reading could easily be transformed into a light-intensity value. The authors similarly calibrated the SaniCure with Demetron adapter and also the Demetron plastic tip. Another Demetron curing unit (Optilux 150, Demetron Research Corp) was tested in like manner. The same process was performed using the 7 mm 3M glass curing tip (#78-8060-9551-5, 3M Dental Products, St Paul, MN 55414-1000) and the SaniCure tip with 3M adapter in a 3M curing light (XL-3000). L D Caulk curing units (MAX 100 and Spectrum) were tested using their supplied 90° 8 mm glass curing tip (#644711) as well as with the SaniCure device.

Testing the Effect of Surface Contact

Several surface treatments were applied to the plastic curing tips to investigate the influence of objects touching the tip sides or ends. Intensity readings were taken using a commercial curing unit for which the SaniCure tip was designed (Spectrum). In the first test, baseline intensity readings were taken with the SaniCure tip without anything touching its outer surface while the unit was held over the detector window of the radiometer (no contact). The identical tip was wrapped with aluminum foil (Trinidad/Benham Corp, Denver, CO 80222) on its outer surface, and readings taken in a manner described above. The foil was removed, and a latex-gloved hand (#8856, Flexam latex gloves, Baxter Healthcare Corp, Valencia, CA 91355-8900) held the tip in a pencil-grasp at the tip curve during intensity measurement. Similar testing was performed with bare fingers. To test the influence of oral tissues touching the tip, the side of the plastic device was touched by a human tongue while intensity readings were being made. In addition, the same tip was encased in a light-curing barrier designed to protect conventional fiber-optic curing tips from intraoral contamination (model 4500, Pinnacle Products, Inc, St Paul, MN 55107). To identify if contact with the protective sleeve over the sides of the outer surface was an influencing factor, the same protective material was placed only over the radiometer detector as a single layer, and the bare SaniCure tip placed over it while taking the intensity reading. The same SaniCure tip was spray-painted black (Denplex spray paint #1202, X Laboratories, Inc, Wheeling, IL 60090), leaving the approximal and distal ends uncoated. The intensity reading of the tip was then tested as previously described. The last test consisted of abrading the outer surfaces of the plastic tip with 120-grit silicon carbide (Carbimet 120-grit, Buehler Ltd, Lake Bluff, IL 60044-1699), and then measuring the intensity. For each test, five replications of intensity values were recorded using the exposure protocol previously described.

A new SaniCure tip was placed into the curing unit that generated the greatest light intensity (825 mW/cm^2, Optilux 500, Demetron Research Corp). A simulated exposure of 6 continuous minutes was performed using both the conventional fiber-optic tip and the plastic SaniCure tip. This testing observed the effect of sustained elevated temperature levels from prolonged exposure times on the plastic tip's ability to provide continuous, high levels of light transmission. Five specimens were tested in this manner.

Statistical testing consisted of one-way ANOVAs for each of the above-described tests to observe for a significant effect of the independent variables on measured light intensity. Where applicable, Tukey-Kramer post hoc tests determined pair-wise differences. All statistical testing was performed at a preset alpha of 0.05.

RESULTS

Figure 1 presents mean intensity values obtained using the various types of curing tips in the different photocuring units. An ANOVA for intensity values tested in Demetron curing units (Optilux 150 and 500) indicated that all three values were significantly different from each other within each curing unit ($P = 0.0001$). Compared to the conventional tip, use of the SaniCure device in Demetron units increased intensity levels approximately 3%, while the Demetron plastic tip in the Demetron units decreased intensity values by 16%. An ANOVA of Caulk/Dentsply photocuring unit intensity values (MAX 100 and Spectrum) indicated that plastic tip use significantly reduced light intensity for both units below levels of the conventional tip ($P = 0.0001$). The intensity when using plastic tips in each type unit was reduced by approximately 8% of the conventional tip. The ANOVA for tip intensity values when using the

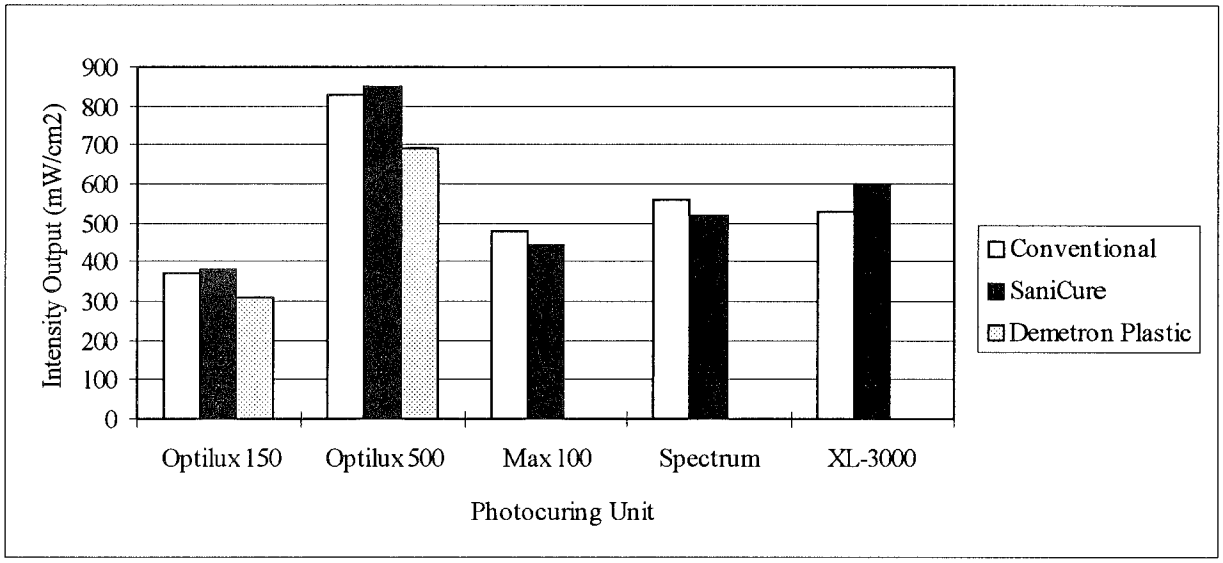

Figure 1. *Mean intensity levels measured using different photocuring units and tip types; n = five measurements per group. Standard deviation bars not included because of minimal values.*

XL-3000 curing unit indicated that use of the SaniCure tip increased intensity output 14% above that of the conventional fiber-optic tip values.

The effect of a simulated veneering exposure of 6 continuous minutes of high-intensity light through the SaniCure tip is seen in Figure 2. Compared to the intensity after the first 60 seconds of exposure, the mean intensity did not decrease with time ($P = 0.5604$).

Figure 3 shows the effect of materials contacting the SaniCure tip when used in the Spectrum curing unit. Only two treatments did not significantly lower the intensity output of the plastic as a result of contact with its surface: a latex-covered hand stabilizing the tip end during intensity measurement,

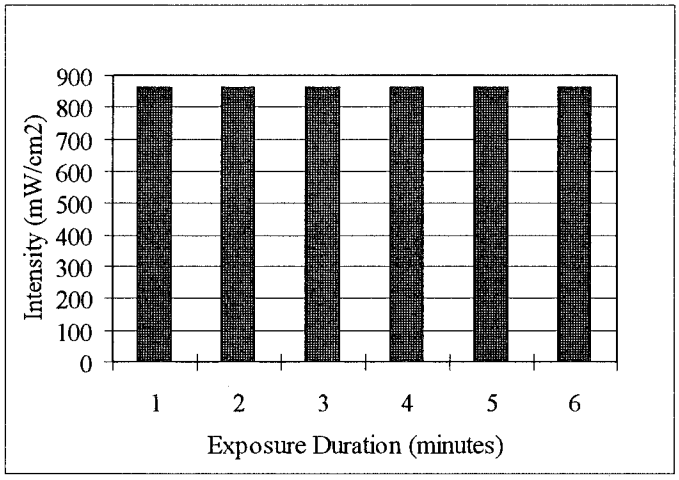

Figure 2. *Intensity levels measured using a continuous exposure from the Optilux 500 curing unit and the SaniCure plastic tip; n = 5. Standard deviation bars not included because of minimal values.*

and coverage of the tip with a layer of aluminum foil. All other treatments resulted in significant attenuation of light energy exiting the tip. Scratching the outer plastic tip surface or spraying the tip with an opaque paint resulted in extremely low to no light-intensity transmission values. Touching the tip with a bare hand or the tongue also resulted in a significant lowering of light-tip energy. Contact of a polymer barrier over the plastic tip sides resulted in lower intensity output than placing one thickness of barrier at the tip end.

DISCUSSION

These results indicated that use of the single-use, presterilized light-curing tip met clinically acceptable light-intensity values when used in different commercial light-curing units. Depending upon the curing unit and manufacturer of the plastic tip, either an enhancement or reduction in light intensity was noted with plastic tips compared to conventional fiber-optic glass bundles. The SaniCure tips showed a slight increase in the Demetron curing units (3%), while the Demetron plastic tips in their own units demonstrated a significant decrease in light intensity (17%). The SaniCure tips in Caulk/Dentsply units resulted in a slight (8%) decrease in light intensity, while this tip in the 3M unit yielded a significant increase in light levels (14%). In no case was the curing-unit output decreased below levels where adequate photocuring might not occur (300 mW/cm^2) (Rueggeberg & others, 1993).

Important clinical information for using these plastic tips should be emphasized. Because these tips are made from a thermoplastic polymer, exposure to

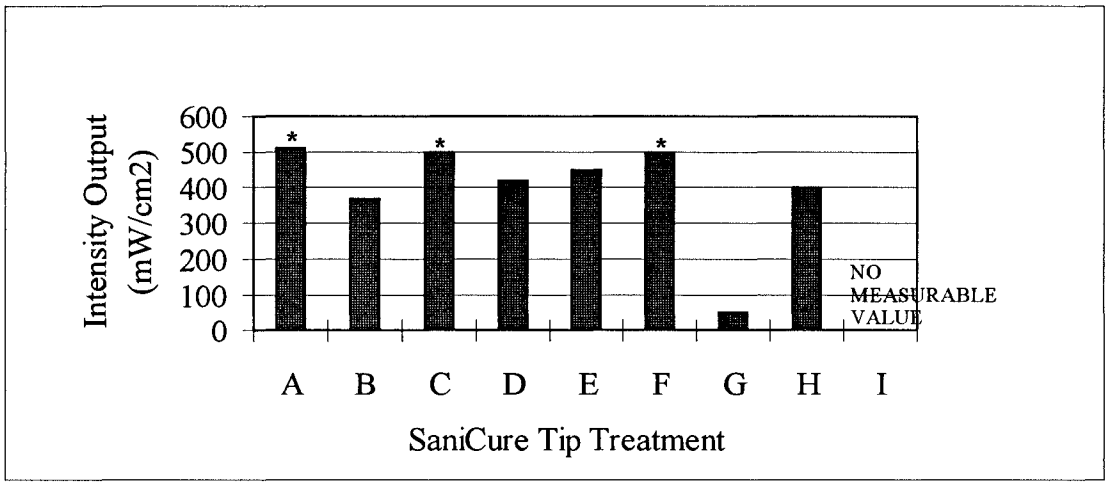

Figure 3. *Intensity levels measured using the Spectrum curing unit with the SaniCure tip and touching or modifying the tip in various manners. Treatments with an asterisk (*) are statistically equivalent. Standard deviation bars not included because of minimal values. Treatment coding: A = no contact; B = bare-hand grasp; C = latex-gloved grasp; D = with barrier sleeve encasing tip; E = through only end of barrier sleeve; F = aluminum foil surrounding tip sides; G = after roughening side with 120-grit abrasive; H = tongue touching tip side; I = side of tip spray-painted black.*

continuous, high levels of heat, as when bonding multiple veneers, might result in tip degradation and decrease in light transmission quality. The results of this study indicated that plastic tips can withstand a simulated veneer scenario up to 6 minutes in length at a very high light-intensity level without degradation in transmitted light levels.

Because there is no coating over the plastic tip, an extremely bright blue light surrounds the entire sheath of the plastic tips when in use. It is only natural to try to cover this tip to reduce glare. If "blue-blocker" filtering glasses are worn, the amount of glare is very tolerable. However, attempts to cover the tip sides with an opaque device (either roughening or application of black paint) resulted in almost total attenuation of the curing-light intensity. However, an alternative procedure may be to wrap the tip in aluminum foil, which resulted in no change in light transmission in our research results.

Current practice incorporates stabilization of the curing tip end while photocuring intraorally, so that radiation is maintained only at the site of interest. This research found that bare-handed stabilization results in significant intensity reduction (28%) compared to the use of a latex-gloved hand (no significant reduction in light output).

Even though these plastic tips are marketed as single-use devices, some practitioners may be tempted to reuse them and place a barrier shield to avoid cross-contamination. The results of this study indicated that touching plastic tip sides with a barrier sleeve significantly reduced light output by as much as 17%. When the intensity of the plastic tip was determined using only a single film thickness of this barrier material between the tip end and the radiometer detector, light was reduced only 12%. Thus, contact between the barrier sleeve and the tip side resulted in an additional 5% decrease in transmitted light intensity.

This study also indicated that touching the outer plastic tip surface to oral tissues should be avoided. Placing a tongue on the tip side during exposure resulted in a 23% decrease in transmitted light. This result implied that touching other moist oral structures (cheeks and lips) would also result in significant light-transmission decrease, but this assumption remains to be tested.

The reason that the outer surface of the plastic tips is so sensitive to contact may be related to the method of light transmission through the device. Light entering the plastic tip is refracted at an angle proportional to the ratio between the refractive index of air and the transmitting medium (in this case a clear thermoplastic polymer). This bent light travels within the plastic until it strikes the outer side surface, where it is internally reflected. Any medium that is in contact with the curing-tip side and that has an appropriate index of refraction can result in light energy being transmitted into that medium instead of being internally reflected within the tip. Thus, opaque coatings, moist surfaces (mucosa, tongue, cheek, hand), or external roughening will affect the manner in which light energy is reflected and thus transmitted at the plastic tip surface. Placement of an opaque medium on the tip surface would cause the light to be absorbed and not reflect back inside the tip. Application of a moist substance results in light reflecting into that material instead of reflecting internally toward the opposite tip side. Surface roughening would cause the reflected beam to be directed outside the tip as well as back toward the light source, thus reducing the amount sent forward toward the tip end.

CONCLUSIONS

Based upon the conditions imposed in this study, the following conclusions can be made:

1. The use of plastic, single-use, presterilized light-

curing tips resulted in either a slight decrease or increase in transmitted light energy with respect to the conventional fiber-optic glass-bundled curing tips.

2. The transmitted light intensity of a plastic tip was not affected by a long-duration exposure (6 minutes) when using a very intense curing light. Thus, these tips would be suitable for applications requiring long, continuous exposure times, such as veneer placement.

3. Intraoral stabilization of the light tip should be accomplished using latex gloves and not bare hands. These gloves did not significantly decrease light intensity output in plastic light tips.

4. Contact of the light tip with moist intraoral structures should be avoided, for this could result in significantly lower energy delivery to the restoration.

5. Application of aluminum foil did not significantly alter curing-light transmission, and proved an effective method to reduce tip glare.

6. Care should be taken not to scratch the outer surface of the plastic tip, as such surface modifications can greatly decrease transmitted light output.

7. Re-use of plastic tips is not recommended. Placement of thin polymer barriers significantly reduced plastic tip light output as a result of contact with the outer sides of the tip surface.

(Received 24 February 1997)

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Resin-infiltrated Dentin Layer Formation of New Bonding Systems

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Clinical Relevance
Self-etching systems, despite their limited RIDL thickness, produced the highest immediate bond strengths.

SUMMARY

The purpose of this study was to evaluate the resin-dentin interfacial morphology and shear bond strength of several new and experimental dentin bonding systems classified as single-bottle/total etch, multi-step/total etch, and self-etching. Class 1 and 5 cavities were prepared from freshly extracted permanent molars and restored with composite resin. Each bonded sample was cross sectioned and one-half was completely demineralized and deproteinized, while the other half was polished along the cut surface to permit measurement of the thickness of resin-infiltrated dentin layer (RIDL) within intertubular dentin (iRIDL) and around the peritubular walls (pRIDL) of resin tags by SEM. Shear bond strength was measured for all the systems 2 minutes after photocuring. SEM showed iRIDL and resin tags of different morphology depending on material and dentin location. The iRIDL was thinner in superficial dentin and thicker in deep dentin. Peritubular RIDL (pRIDL) was thinner than intertubular RIDL. Bond strength measurements varied from 12 to 21 MPa, depending on the materials used. Self-etching primer systems exhibited the highest bond strength, although one of the one-step/total etch systems also yielded very high values. The contribution of pRIDL to adhesion onto superficial dentin is limited by the small number of tubules.

Single-component bonding agents produced SEM morphology and bond strengths similar to those of multi-step systems. Self-etching systems, despite their limited RIDL thickness, produced the highest immediate bond strengths. Bond strength did not correlate well with the thickness and morphology of RIDL.

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INTRODUCTION

The morphology and thickness of the resin-infiltrated dentin layer (RIDL) of multi-step dentin bonding agents (DBAs) have been evaluated and measured by many investigators (Van Meerbeek & others, 1992, 1994, 1996; Tay & others, 1994; Pashley & others, 1995b). The bond strengths and sealing ability of dentin bonding systems seem to be unrelated to RIDL thickness but rather seem to correlate to dentin location and to the quality of dentin (Yoshiyama & others, 1995, 1996; Titley & others,

1994, 1995; Tay, Gwinnett & Wei, 1996). For this reason, resin tag morphology, lateral branches, and the quality of the RIDL are probably of more clinical and morphological importance than the thickness value of the RIDL. Recently, two groups of DBAs have been developed called single-component (or single-bottle) DBAs, and self-etching DBAs. The first group has been defined as single-component or one-bottle because the adhesive comonomer mixtures are stored in the same bottle (Tay & others, 1996). The functions previously accomplished by separate primers and bonding adhesives thus occur at the same time using the new single-bottle systems. However, there is a possibility that the lack of a separate primer may reduce the infiltration depth or the wetability of DBA, thereby reducing adhesion and sealing capacity.

The other group of DBAs, the self-etching agents, were developed to eliminate the conditioning, rinsing, and drying steps that may prove to be critical and difficult to standardize in operative conditions because of the instability of demineralized matrix (Pashley & others, 1995a,b; Tay & others, 1996). These self-etching/self-priming systems are applied directly onto the dentin and enamel smear layers (Barkmeier, Los & Triolo, 1995) for 30 seconds followed by air drying. Their adhesion mechanisms are different and should, at least in theory, eliminate certain problems related to the collapse of the collagen fibrils after conditioning. The question remains whether they are able to produce high bond strengths that are durable over time.

The main purposes of this study were to evaluate the morphology and thickness of RIDL of the newest DBAs and to observe if there are any differences in the SEM morphology between the single-bottle, the multi-step, and the self-etching bonding systems.

METHODS AND MATERIALS

Thirty-five class 1 and 15 class 5 cavity preparations were prepared in freshly extracted third molars from young patients to permit SEM examination of resin-dentin bonds made under clinically relevant conditions. In addition, class 5 cavity preparations were prepared in 15 of these molars. Twenty-four dentin disks obtained after the removal of root and occlusal enamel were prepared from 24 other freshly extracted teeth. Teeth were obtained from young patients (mean age 24.6 years) and stored at 4 °C in saline solution for no more than 4 weeks.

All materials (Table 1) were used in accordance with manufacturers' directions at room temperature (20-21 °C) and at a relatively constant (55-62%) relative humidity. After DBA application, each preparation and dentin disk was restored with the appropriate composite and photocured. After 1 hour in room-temperature water, each restored tooth and each bonded dentin disk was cross-sectioned with a diamond disk at low speed under water and divided into two equal groups, which were assigned to Group 1 or 2. Group 1 was further subdivided into two subgroups, A and B.

Table 1. Materials Used

MATERIALS	MANUFACTURERS
Clearfil Liner Bond 2/Lustre (N=7)	Kuraray Corp, Osaka, Japan
Experimental Clearfil KB 1300/Lustre (N=10)	Kuraray
Prime & Bond 2.0/Dyract (N=5)	De Trey/Dentsply, Konstanz, Germany
Prime & Bond 2.0/TPH (N=5)	De Trey/Dentsply
Prime & Bond 2.1/Dyract (N=5)	De Trey/Dentsply
Scotchbond Multi-Purpose Plus/Z100 (N=7)	3M Dental Products, St Paul, MN 55144
3M Single Bond Dental Adhesive System 3M Bonding System/Z100 (N=10)	3M Dental Products
OptiBond FL/Prodigy (N=5)	Kerr, Romulus, MI 48174
Syntac Single-Component/Tetric (N=5)	Ivoclar/Vivadent, Schaan, Liechtenstein

Subgroup A

Each of the bonded cross sections was polished along the cut surface with a series of wet silicon carbide papers (#600, #800, #1000, and #1200), and then polished further with polishing compounds (polishing paste, L D Caulk, Milford, DE 19963). The samples were stored at room temperature in 2.5% buffered glutaraldehyde solution (pH 7.4) for 2 hours, then gently washed with deionized water and dried with absorbent paper for 2-3 minutes. All samples were exposed to 10% phosphoric acid for 2 minutes followed by rinsing with water. About half the samples were placed in deionized water (pH 7.4) and ultrasonically cleaned for 5 minutes (Cavitron 3000, L D Caulk) before being exposed to the acid to remove superficial debris created during the procedures. All samples were finally gold coated under vacuum and inspected under

SEM (Model 5400, JEOL, Tokyo, Japan). This technique demineralizes any dentin that is not infiltrated with resin. Each of these bonded cross sections was polished along the cut surface with the same series of wet silicon carbide disks (#600, 800, 1000, and 1200), polished with polishing compound, stored in water at room temperature for 2 hours, then gently washed with deionized water.

Subgroup B

All samples were also treated with 1.5% NaOCl gel for 2 minutes, and then copiously washed under tap water and deionized water. This procedure dissolved those collagen fibers that were not enveloped by resin. Specimens in this group were used to measure the thickness of the iRIDL and the resin infiltration from the solid core of the resin tags that filled the tubule lumen, out into the surrounding demineralized peritubular zone (pRIDL). This radial distance was between 0.1-5 µm on either side of the resin core and represented the depth of monomer diffusion from the tubule lumen into the surrounding intertubular dentin needed to hybridize the resin tags with the demineralized dentin. All samples were then stored in the same glutaraldehyde solution described above and washed, dried with paper, and gold coated before SEM inspection.

The thickness of the resin-infiltrated demineralized dentin layer (RIDL) was measured in intertubular dentin (iRIDL) at right angles to the bonded surface and in the peritubular area around the top of the resin tags (pRIDL) (i e, the area immediately around the tubular orifices) at right angles to the long axis of the dentinal tubules. Resin tag length and diameter were measured using SEM pictures obtained with preselected reference points: close to the enamel dentin junction (i e, superficial dentin), 2 .2 and 1.1 mm from the pulp horns, 0.5 mm and in the immediate vicinity of the pulp horns (deep dentin).

Group 2: SEM Examination of Resin Replicas of Bonded Dentin Surfaces

The other half of the sectioned samples were immediately immersed in 20% phosphoric acid for 70 hours to remove the mineral part of dentin, then washed with tap water for 30 minutes and stored in 12.5% NaOCl for 24-30 hours to dissolve all collagen dentinal tissue. Samples were gold coated and inspected under SEM at X1000 to X25,000. This method was used to remove all dentin around the resin that penetrated into dentin. This permitted evaluation of the number and morphology (i e, maximum diameter) of hybridized resin tags and their lateral branches. Theoretically, perfectly resin-infiltrated dentin was not dissolved by the sequential acid and NaOCl treatment.

Shear Bond Strength Measurement

Forty-five newly extracted human third molars were used for shear bond strength tests. The occlusal enamel was completely removed from each tooth using a diamond saw under water. The flat dentin surface was then polished with #600 silicon carbide paper under water. The dentin thickness was measured at this time using a pincer caliper modified to measure the distance from the nearest pulp horn to the prepared dentin surface. Thirty-nine teeth were bonded twice, once to superficial dentin, and again after the removal of about 1 mm of dentin. The first bond strength test was made with a remaining dentin thickness (RDT) of about 2.2 mm from the pulpal horn and the second bond strength test was made at an RDT of about 1.1 mm.

All materials were used in accordance with the manufacturers' directions. After DBA application on the dentin surface, a Teflon tube with an internal diameter of 3.0 mm filled with the manufacturer's corresponding composite resin was applied on the dentin surface and immediately photocured for 60 seconds. Two minutes after beginning the light-curing, a stainless loop was applied to each composite resin/Teflon tube and subjected to a shear force at a cross-head speed of 1 mm/minute using a Universal Testing Machine (A Trovato, Bologna, Italy).

Statistics

Means of iRIDL thickness and pRIDL diameter were calculated by averaging the individual values of each sample evaluated under SEM; ANOVA was performed for statistical analysis of morphological measurements and for shear bond tests. Post hoc multiple comparisons were made with Fisher's PLSD test (Statview 4.01, Abacus Concepts, Inc, Berkeley, CA 94704). Significance was defined as $P < 0.05$. Comparison of the depth of the RIDL and of resin tag length and diameter in superficial versus deeper dentin was made using Student's *t*-test. Correlations between shear bond strength and iRIDL thickness and between remaining dentin thickness and shear bond strength were done by regression analysis.

RESULTS

Scanning Electron Microscopy

In class 5 preparations, superficial dentin was considered to be the area along the preparation walls, close to the cementoenamel junction and the dentinoenamel junction. Deep dentin was considered the area 0.5-1.0 mm (axial walls in class 5s or pulpal walls in class 1s) from the pulp chamber. The measurements of thickness of iRIDL and pRIDL are

Table 2. Thickness of Resin-reinforced Dentin Layer of DBA (mean ± SE) Calculated with SEM (N=74)

MATERIALS	pRIDL	iRIDL THICKNESS
Clearfil Liner Bond 2		
superficial dentin	0.0-0.2 µm	0.5-1.5 µm
deeper dentin	0.0-0.8 µm	1.0-2.0 µm
Clearfil KB 1300		
superficial dentin	0.0-0.0 µm	1.0-1.5 µm
deeper dentin	1.0-1.5 µm	1.0-2.0 µm
Syntac Single-Component		
superficial dentin	0.2-0.5 µm	0.2-1.5 µm
deeper dentin	0.5-1.5 µm	1.0-3.5 µm
Prime & Bond 2.0		
superficial dentin	0.2-0.8 µm	2.0-4.0 µm
deeper dentin	2.0-3.0 µm	3.0-6.5 µm
Prime & Bond 2.1		
superficial dentin	0.2-0.8 µm	2.0-4.0 µm
deeper dentin	2.0-3.0 µm	3.0-7.5 µm
OptiBond FL		
superficial dentin	0.2-0.8 µm	1.0-1.5 µm
deeper dentin	1.5-2.5 µm	3.0-6.5 µm
Scotchbond Multi-Purpose		
superficial dentin	0.2-0.8 µm	2.0-4.5 µm
deeper dentin	1.5-3.5 µm	3.5-7.0 µm
3M Single Bond Dental Adhesive		
superficial dentin	0.2-0.8 µm	1.5-2.5 µm
deeper dentin	1.5-2.5 µm	4.0-6.0 µm

pRIDL = peritubular resin-reinforced dentin layer
iRIDL = intertubular resin-reinforced dentin layer

reported in Table 2.

In Group 1 the multi-step DBAs, Optibond FL and Scotchbond Multi-Purpose, showed iRIDLs ranging from 1.0 to 4.5 µm in deeper dentin but were thinner in superficial dentin (Figures 1 and 2).

The single-bottle DBAs, Prime & Bond 2.0 and 2.1, exhibited similar resin-dentin morphology under SEM. Intertubular RIDL was visible but extremely thin in superficial dentin, and was much thicker in deeper dentin (Figures 3-4). In some samples the RIDL was not uniform (Figures 5-6).

The 3M Single Bond Dental Adhesive system showed a homogeneous RIDL, which was relatively thin in superficial dentin and thicker in deeper dentin. Among the single-component DBAs, the 3M Single Bond system showed the most homogeneous intertubular RIDL (Figure 7).

Syntac Single-Component produced a more variable and granular iRIDL (Figure 8). It was sometimes impossible to detect any type of hybrid layer in superficial dentin in specimens bonded with that system. In deeper dentin, the iRIDL thickness ranged from 0.2 to 3.5 µm, suggesting that this material was the most unpredictable of those tested. All tested DBAs showed a uniform morphology of pRIDL. The pRIDL diameters and morphology obtained with single-bottle DBAs were very similar to those produced by multi-step DBAs (Figures 9 and 10).

The self-etching DBAs, Clearfil Liner Bond 2 and Clearfil KB 1300, produced thinner iRIDL (Figure 11) than the other DBAs. It ranged from 0.5 - 1.5 µm in superficial dentin, to 2.0 µm in deeper dentin, within 0.5 mm of the pulpal chamber. The same morphology was observed in dentin disks and class 5 preparations. In many class 5s, smear plugs not infiltrated by resin were observed occluding dentinal tubules. The smear layer infiltrated by the self-etching primers (and probably by bonding resin) was 6-11 µm thick. This was called resin-infiltrated smear layer. These self-etching DBAs produced a pRIDL of 0 - 1.5 µm in superficial and deep dentin. The thickness of peritubular infiltrated area was generally greater in the self-etching systems than in the other DBAs.

The morphology of Clearfil Liner Bond 2 and KB 1300 tags was different from that of the resin tags produced by the other DBAs. The tag base was larger and more conical. At the apex of the tags, an abrupt narrowing (Figures 12 and 13) was observed, from which extended a thinner portion of resin tag that had parallel walls and a diameter of about 1 µm. This different morphology was probably related to the self-limiting nature of the self-etching primer penetration inside the smear plugs. That is, the buffer capacity of the smear layer and smear plugs may have limited the degree of penetration of self-etching primers more than was seen with more acidic conditioners.

When the dentin was removed from the resin by sequential prolonged acid and base treatment, SEM analysis of the underside of the resin bonded to superficial dentin revealed only rare resin tags 1-1.5 µm in diameter and 0.5-4.0 µm long. No lateral branches to the resin tags were detected. Self-etching DBAs produced more resin tags in deeper dentin.

The base of the resin tags (i e, the area close to the tubule orifice) had different morphology

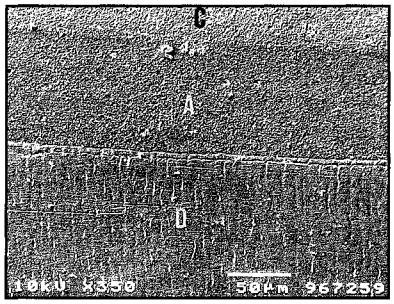

Figure 1. *SEM of polished sectioned surface of dentin treated with OptiBond FL. Resin-infiltrated dentin layer is visible. C = composite; A = resin adhesive; D = dentin.*

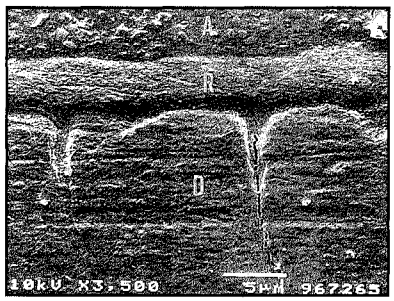

Figure 2. *SEM of interface between OptiBond FL and dentin. The thickness of RIDL is 5.5-6.0 μm. D = medium-deep dentin; A = composite adhesive; R = RIDL.*

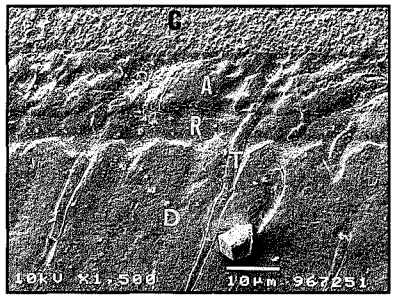

Figure 3. *Cross section of bonded surface of Prime & Bond 2.0. RIDL (R) of about 6-7 μm. The resin tags (T) can be seen inside the thickness of RIDL (R) as they pass through it into the underlying mineralized dentin (D). C = composite; A = adhesive.*

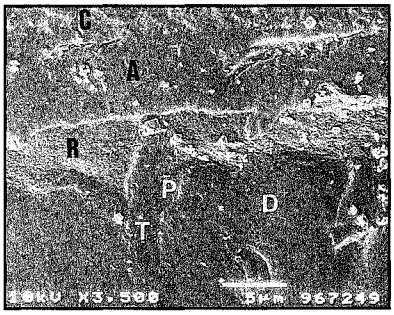

Figure 4. *Cross section of bonded surface of Prime & Bond 2.0 in superficial-medium dentin (D). RIDL (R) thickness of 5.0 μm. Resin tag (T) and peritubular RIDL (P) are visible. C = composite; A = adhesive.*

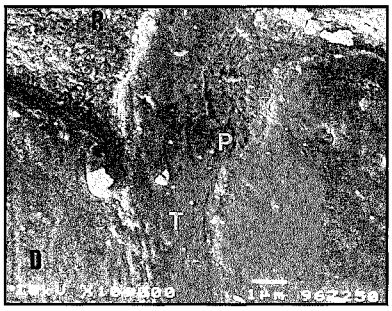

Figure 5. *Cross section of bonded surface of Prime & Bond 2.1 showing resin tags (T), resin-reinforced dentin layer (D), and composite. Peritubular RIDL (P) is from 3 to 0.1 μm in thickness.*

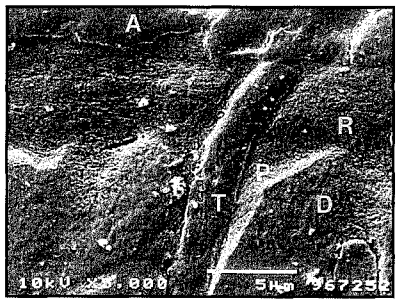

Figure 6. *SEM of cross section of bonded surface of Prime & Bond 2.1 adhesive (A). Tag (T) has the typical morphology with a core of resin and a peritubular RIDL (P). RIDL is also well visible (R). D = dentin.*

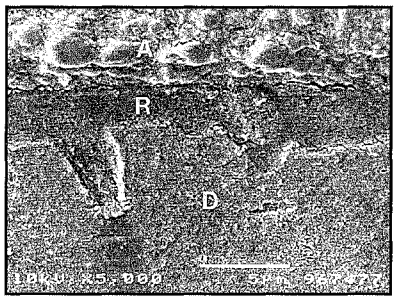

Figure 7. *Cross section of bonded surface of Scotchbond Multi-Purpose. Superficial dentin. Thickness of RIDL (R) was 4.0 μm. D = dentin; A = adhesive.*

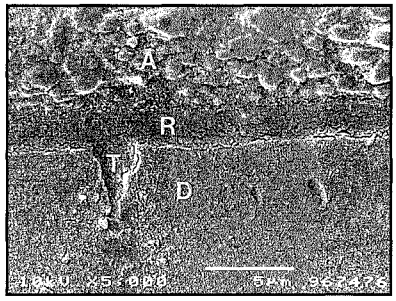

Figure 8. *Cross section of bonded surface of Scotchbond Multi-Purpose (A). Deeper dentin, as confirmed by numerous dentinal tubules filled with resin tags (T). Thickness of RIDL (R) of 4.5 μm. RIDL appeared porous, while resin tags were compacted. D = dentin.*

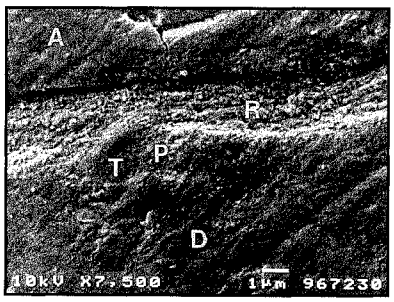

Figure 9. *SEM of interface between 3M Single Bond Dental Adhesive and dentin. The thickness of RIDL was 2.5 μm; resin tag (T) and peritubular RIDL (P) of about 0.8 μm. A = adhesive bonding resin; R = RIDL; D = superficial dentin.*

depending on the bonding agent used. The maximum diameter of the hybridized resin tag base (measured at what was the original dentin surface level), the length, and the number of resin tags are shown in Table 3. In deeper dentin, the resin tags were wider and longer than in superficial dentin (Figures 14-16).

Optibond FL, Scotchbond Multi-Purpose, and especially Prime & Bond 2.0 (Figure 14), had very long resin tags. The bases of the resin tags were

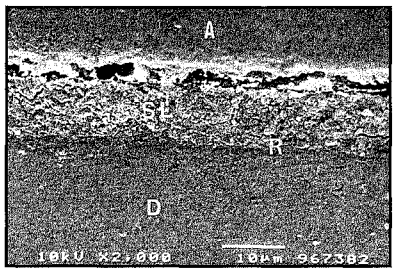

Figure 10. *SEM of interface between Clearfil Liner Bond 2 and dentin. The thickness of smear layer RIDL was 9.0-10.0 µm, and the thickness of RIDL (R) was only 1.0 µm. A = adhesive; SL = smear layer; D = superficial dentin.*

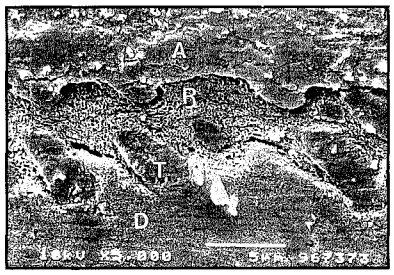

Figure 11. *Cross section of bonded surface of Syntac Single-Component. Deep dentin. Thickness of RIDL (R) was 4.0 µm. The RIDL presented a granular aspect. RIDL was well adapted to dentin (D), but not to bonding adhesive (A). T = resin tag.*

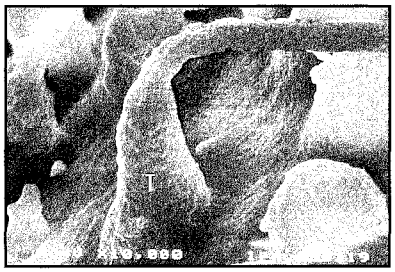

Figure 12. *Demineralized sample. Morphology of resin tags (T) of Clearfil KB 1300. The bases of tags were visible. Long, thin resin "tails" emerge from resin tags. They represent the primer that has filled the dentinal tubules but may have been buffered.*

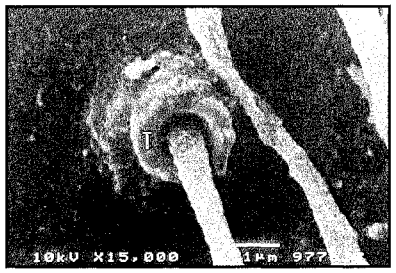

Figure 13. *Demineralized sample. Morphology of resin tags (T). The large base of pRIDL and the long, thin "tail" emerging from resin tags are visible. The tails represent the primer that has filled the dentinal tubules but has not infiltrated the walls of tubules.*

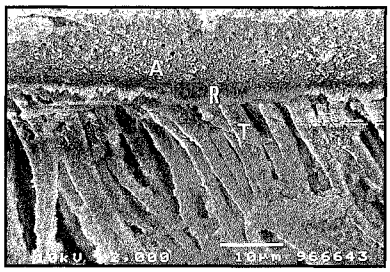

Figure 14. *Fractured and demineralized sample. Deep dentin. A great number of resin tags (T) were visible. RIDL (R) thickness of 3-4 µm. A = Prime & Bond 2.1 composite and adhesive resin.*

Figure 15. *Demineralized sample. Morphology of resin tags (T) of Clearfil Liner Bond 2. The bases of Liner Bond 2 resin tags were larger than those of other bonding systems. Deep dentin*

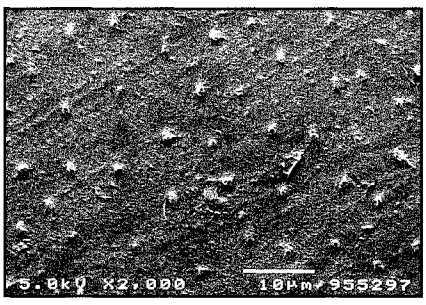

Figure 16. *Demineralized sample. Morphology of resin tags of Clearfil Liner Bond 2. Only a few resin tags were visible in superficial dentin.*

1-2 µm larger than those portions that extended deep into the mineralized dentin. 3M Single Bond Dental Adhesive and Syntac Single-Component systems produced resin tags with similar morphology. In several samples, the resin filled the tubules for 20-120 µm, but these extensions had a completely different morphology than those parts of the resin tags that had hybridized with the surrounding demineralized dentin matrix. These thin resin extensions were relatively smooth (Figure 12).

Due to the collapse of the long resin tag extensions upon themselves, it was not possible to quantitate the numbers of resin tags per unit area. Instead, we simply classified them as "rare" (i e, less than 10% of the surface area occupied by tags) or "many" (i e, more than 30% of the surface area occupied by resin tags).

In many samples, the bases of the resin tags were hollow (Figure 2) since the smear plugs that had existed in the bonded interface had been dissolved by the subsequent acid treatments. No tail-like extensions of resin were present in these specimens, because the tubules had been occluded by the bottom of smear plugs.

Several resin filaments 0.8-1.0 µm wide and 70-220 µm long were identified as exiting from the main resin tag at variable angles in most of the DBAs, but only in deep dentin. The lateral filaments were found mainly around the base of the resin tags and along the

Table 3. Lengths of Resin Tags in Superficial and Deep Dentin (N=45)

MATERIALS	MAXIMUM DIAMETER	TAG LENGTH	TAG NUMBER
Prime & Bond 2.0			
superficial dentin	1.5 µm	4-5 µm	rare
deeper dentin	3-4 µm	20-120 µm	many
Prime & Bond 2.1			
superficial dentin	1.5 µm	4-5 µm	rare
deeper dentin	3-4 µm	20-120 µm	many
OptiBond FL			
superficial dentin	1.0 µm	2-5 µm	rare
deeper dentin	3-4 µm	20-60 µm	many
3M Single Bond Dental Adhesive			
superficial dentin	1.0 µm	2-5 µm	rare
deeper dentin	3-4 µm	20-60 µm	many
Scotchbond Multi-Purpose			
superficial dentin	1.0 µm	2-5 µm	rare
deeper dentin	3-4 µm	20-60 µm	many
Syntac Single-Component			
superficial dentin	1.0 µm	2-5 µm	rare
deeper dentin	3-4 µm	20-60 µm	many
Clearfil Liner Bond 2			
superficial dentin	0.0 µm	2-5 µm	absent
deeper dentin	3-5 µm	8-40 µm	many
Clearfil KB 1300			
superficial dentin	0.0 µm	2-5 µm	absent
deeper dentin	3-5 µm	8-40 µm	many

first 10-20 µm of the resin tag length. All DBAs (except self-etching DBAs) exhibited resin-filled lateral branches.

Resin tags and lateral branches formed a fine resin network that completely infiltrated the intertubular dentin area in deeper dentin. In this area, within 0.5 mm of the pulp chamber, it was difficult, if not impossible, to detect intertubular dentin. In other words, in deep dentin, nearly all of the volume of the hybrid layers were occupied by resin tags and by criss-crossed extensions of peritubular and intratubular dentin, which probably play the most important role in adhesion of resin to deep dentin. This complex three-dimensional resin network was not seen in superficial dentin because of the paucity of tubules and lateral branches in that area.

Bond Strength Measurement

The results of shear bond strength are shown in Table 4. The highest shear bond strengths were obtained using experimental KB 1300, while Prime & Bond 2.0/Dyract and Syntac Single-Component systems showed the lowest bond strengths. About 80% of the fractures were cohesive in composite, adhesive layer, or dentin with the remaining 20% exhibiting adhesive failures. There were no statistically significant correlations found between the remaining dentin thickness and the shear bond strength ($P > 0.5$). However, in general, bond strength in deeper dentin was somewhat lower than in superficial dentin. No statistically significant correlations were found between shear bond strength and the thickness of iRIDL.

DISCUSSION

The depth of resin-infiltrated dentin (peritubular and intertubular) of single-component and multi-step DBAs was generally thinner in superficial than in deeper dentin. The thickness of the iRIDL in deep dentin ranged from 3.5 µm to 7.5 mm (Table 2). This thickness is in accordance with other recent studies. Finger and Fritz (1996) and Tay and others (1996) reported resin-infiltrated dentin thickness values ranging from 2.3 to 9.6 µm for one-bottle DBAs. Van Meerbeek and others (1992), Barkmeier and others (1995), and Yoshiyama and others (1995, 1996) also reported similar RIDL thicknesses for multi-step DBAs using different techniques of evaluation. Judging from the present study, despite the lack of use of a primer as a separate, preliminary step in resin bonding, single-bottle DBAs produced iRIDL thickness and shear bond strengths that were

Table 4. Shear Bond Strength Values of Material Tested (N=12; mean ± SE)

MATERIALS	BOND STRENGTH (MPa±SE)
Syntac Single Component	11.7±1.6
Prime & Bond 2.0	12.3±0.5
Clearfil Liner Bond 2	14.3±1.0
OptiBond FL	14.5±0.6
3M Single Bond Dental Adhesive	16.6±0.7
Scotchbond Multi-Purpose	19.0±2.1
Clearfil KB 1300	19.0±2.1

Values connected by lines in the same vertical plane are statistically not different ($P > 0.05$).

very similar to that of multi-step DBAs. This means that the use of a separate hydrophilic primer is not a necessary step to obtain good resin infiltration and high bond strengths if proper formulations are utilized that contain both hydrophilic and diffusion-promoting monomers.

Despite the relatively low thickness of some iRIDLs (2-4 μm) measured in this study, the interface between resin material and dentin was more homogeneous and void-free in superficial than in deep dentin. The lack of gaps, porosities, and voids undoubtedly improved the quality of the hybrid layer (Tay & others, 1996). Generally, the greater the thickness of the iRIDL, the more numerous the irregularities and more likely the presence of noninfiltrated dentin. This study did not support the hypothesis that thicker RIDL produces higher bond strength. Similar conclusions have been reached by Finger and Fritz (1996) and by Yoshiyama and others (1995, 1996). Thin iRIDLs were difficult to see by SEM if they were thinner than 0.4-0.5 μm, but they may allow sufficient resin infiltration and intertwining with the collagen of demineralized dentin to obtain high bond strengths. The single-bottle DBAs were better than multi-step DBAs in forming more consistent bonding with fewer porosities and gaps. The short time between conditioning and bonding might prevent collapse of the collagen fibril network and allow better penetration of resin. The acidity of the single-bottle systems may have re-etched the demineralized/mineralized dentin junction during their application, providing some apatite crystalites at the bottom of the RIDL that may have improved its physical properties. Interestingly, despite the chemical differences (acetone, alcohol, or water) of the solvents of the three single-bottle DBAs, they all produced similar iRIDL morphology. The treatment in common among all of them, except Clearfil Liner Bond 2 and KB 1300, was the use of phosphoric acid as an acidic conditioner.

Clearfil Liner Bond 2 and KB 1300, the self-etching systems, are applied directly onto an untreated smear layer. These self-etching primers are acidic enough to dissolve the mineral components of the smear layer and to infiltrate through it into the underlying intact dentin. It may be more correct to use the term "resin-reinforced smear layer" rather than RIDL. Yoshiyama and others (1996) reported a significant penetration of self-etching resin through the smear layer and into the underlying sound intertubular dentin for 0.1-0.2 μm. In this condition, bonding resin may have engaged sound dentin to a depth of several collagen fibers (Yoshiyama & others, 1996), sufficient to ensure a relatively high bond strength. According to Yoshiyama and others (1996), this was sufficient to maintain a high bond strength and sealing of intertubular dentin. A similar mechanism may have occurred for peritubular dentin. The durability of such a thin RIDL under function over time remains to be determined.

The morphology of resin tag bases has been reported by Perdigao and others (1994) for All-Bond 2 and Scotchbond Multi-Purpose. Despite several differences in preparation and analysis methods, their description of resin tag morphology was similar to that observed in our study. In deep dentin there was much less demineralized intertubular dentin for resin infiltration between the tubules compared to superficial dentin. However, there were far more and larger dentinal tubules in superficial dentin, and each tubule contained lateral branches. When these larger resin tags hybridized with the surrounding demineralized intertubular dentin, they could provide excellent resin retention, according to Pashley and others (1995a,b).

The tubular seal was critical because lack of adhesion between DBA and the tubule wall (Walshaw & McComb, 1995) may be responsible for fluid leakage flow towards the pulp. A strong and optimal anchorage of DBA via resin tags may, on the contrary, have ensured good pulpal protection (Pashley & others, 1995b).

Typical morphology of resin tags in deep dentin was that of a large base and a smaller apex that continued into the tubule as a very long "tail." The base was larger because it consisted of both a resin core and a zone of hybridized or resin-infiltrated dentin that extended through the circumferentially oriented collagen fibrils at the periphery of the tubule (Titley & others, 1995) into the adjacent intertubular dentin (Van Meerbeek & others, 1996).

The mechanisms responsible for the formation of resin-infiltrated demineralized intertubular dentin by resin permeation into the substrate at right angles to the surface was probably the same as that used to produce radially directed resin infiltration from the long axis of the tubules into the surrounding demineralized dentin. The important variables were the permeability of the demineralized dentin matrix (i e, maintenance of collagen fibril separation) and the diffusivity of the comonomer mixtures used to infiltrate both zones of demineralized dentin. The radial diffusion of monomer from the tubule lumina into the surrounding dentin could only occur if all of the mineralized peritubular dentin matrix was removed by acid etching. This also enlarged the diameter of lateral branches of the tubules, further enhancing lateral permeation of monomers (Chappell & others, 1994; Mjör & Nordahl, 1996; Van Meerbeek & others, 1996; Tay & others, 1996). This lateral infiltration of resin into the surrounding demineralized dentin firmly attached and integrated the resin tags to the hybrid layer, providing both resin retention and tubule sealing. The observation that

the pRIDL was consistently smaller than the iRIDL indicated that acid etching of peritubular dentin was less effective or slower than that of intertubular dentin. Perdigao and others (1996) reported cuffs of residual peritubular dentin matrix in dentinal tubules etched with silica-thickened acidic conditioners. Further resin extension into the regions of the tubules that contain mineralized peritubular dentin matrix probably contributes little to resin retention or tubule sealing.

In deep dentin, despite the presence of smear plugs and debris inside the tubules, the primer and the bonding resin of Clearfil Liner Bond 2 and KB 1300 were able to penetrate inside the tubules for many microns; they were embedded in the resin interdiffusion peritubular zone. A recent study from Barkmeier and others (1995) demonstrated high bond strengths for Clearfil Liner Bond 2 and typical RIDL morphology of dentin after primer application, along with very long projections of resin tags into tubules. Our study confirms their observations. After demineralization and deproteinization (Group 2 samples), many tags exhibited deep holes in their centers in place of the tail-like resin extensions seen with other DBAs. This was probably due to the removal of uninfiltrated resin plugs contained inside the tags by the strong acids and bases used to dissolve all of the dentin from the resin. Using Clearfil Liner Bond 2 and KB 1300, a fine network of lateral branches was observed in medium and deep dentin, in accordance with previous observations by Barkmeier and others (1995).

The resin-infiltrated demineralized dentin layer in superficial dentin was primarily (about 90%) made up of resin that infiltrated into the collagen fibril network of intertubular dentin. The resin-infiltrated layer in deep dentin consisted primarily of hybridized resin tags (about 65-70%) (Pashley & Carvalho, 1997), with resin-infiltrated intertubular dentin playing a minor role (Pashley & others, 1996). Due to the convergence of the tubules from the periphery towards the pulp chamber, the distance between adjacent dentinal tubules became smaller as deeper dentin was prepared. As the volume of intertubular dentin became smaller, the number of lateral branches per unit volume apparently increases, thereby providing more channels for resin infiltration into the intertubular region of deep dentin. However, the requirement for resin to spread and penetrate relatively large fluid-filled tubules in deep dentin may have produced air voids or regions where phase separations of monomers in organic solvents occurred, thereby interfering with resin-infiltration.

The results required rejection of the hypothesis that there are no differences in the thickness of the RIDL in superficial versus deep dentin and that there were no differences in the immediate bond strength of the tested DBAs. The results did support the hypothesis that there was no correlation between the thickness of RIDL and bond strengths.

CONCLUSION

Single-bottle DBAs showed a RIDL morphology and bond strength values similar to multi-bottle DBAs, suggesting that they were able to infiltrate demineralized dentin without requiring a primer. However, self-etching DBAs showed higher bond strengths, despite the presence of very thin RIDL and shorter but larger resin tags. This study suggested that RIDL thickness and resin tags were not the only mechanisms involved in dentin adhesion.

(Received 5 March 1997)

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Bonding of Amalgam and a Gallium Alloy to Bovine Dentin

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Clinical Relevance
The dentin bonding systems used in this study created weak bond strengths to dentin for both Permite C and Galloy.

SUMMARY

The shear bond strengths of an amalgam (Permite C) and a gallium alloy (Galloy) to dentin, mediated by four dentin adhesives (Super-Bond D-Liner, Super-Bond D-Liner II, Paama 2, and Panavia 21), were investigated. Flat labial dentin surfaces were prepared from bovine lower incisor teeth. A 3 mm-in-diameter area of dentin was bonded according to each manufacturer's directions before placement of Permite C or Galloy. The bonds were stressed in shear at a crosshead speed of 1 mm/min. The mean shear bond strengths were analyzed using one-way ANOVA and Student's *t*-test, and fracture modes were assessed under X20 magnification and analyzed using Kruskal-Wallis and Mann-Whitney U tests. Scanning electron micrographs were taken of the bond interface of separate samples. The results showed no significant difference among the bond strengths of Super-Bond D-Liner (2.79 MPa, 2.69 MPa), Super-Bond D-Liner II (3.41 MPa, 2.65 MPa), and Paama 2 (0.70 MPa, 0.50 MPa) bonded to Permite C and Galloy (respective values in parentheses); however, Panavia gave a significantly better bond with Permite C (0.42 MPa) than with Galloy (0 MPa). Super-Bond D-Liner and Super-Bond D-Liner II gave stronger bonds than Paama 2 and Panavia with both Permite C and Galloy. For each dentin adhesive, there was no difference in fracture mode between Permite C and Galloy. It was concluded that, since all bond strengths were very low, none of the dentin adhesives tested would enhance the clinical retention of Permite C or Galloy. However, although the use of Paama 2 with Galloy was originally recommended by the manufacturer for dentin sealing purposes, no adhesion was claimed.

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INTRODUCTION

In 1956, Smith and Caul reported the use of gallium alloys as a possible replacement for dental amalgam. Gallium is the metal that has the second lowest melting point (29.75 °C) next to

mercury (-38.87 °C). To assist alloying at room temperature, the gallium should be liquid, which can be achieved by the addition of other metals such as indium. Waterstrat (1969) introduced gallium-palladium-tin alloys, which were shown to be superior to amalgam in terms of marginal seal and resistance to flow at mouth temperature, and had a thermal expansion comparable to human teeth. However, some gallium alloys were inferior to amalgam with respect to setting expansion (Blair, Whitworth & McCabe, 1995) and corrosion (Okamoto & Horibe, 1991; Henson & others, 1993; Nakajima & others, 1993; Okabe & others, 1993; Oshida & Moore, 1993). The cytotoxicity of amalgam and gallium alloys was found to be similar over a long period of time (Psarras, Wennberg & Dérand, 1992; Wataha & others, 1994). Okamato and Horibe (1991) developed a suitable ratio of components in gallium alloys to form a plastometallic material that was used as a precursor for currently available commercial gallium alloys.

Recently, new gallium-based alloys (Gallium Alloy GF, Tokuriki Honten, Tokyo, Japan; Galloy, Southern Dental Industries, Victoria, Australia) have been introduced as direct metallic restorative alternatives to mercury-based (amalgam) alloys. The absence of mercury alleviates occupational and environmental concerns, and provides reassurance to those patients who are concerned about mercury-based restorations. In addition, amalgam does not adhere to tooth tissue; thus, noncarious tooth structure must be removed in order to obtain mechanical retention. However, gallium alloys still need the extension of cavities to obtain mechanical retention (Miller & others, 1992) and require a resin sealant to protect the dentinal and oral surfaces of the alloy from salivary contamination, which causes excessive expansion and corrosion (Henson & others, 1994; Blair & others, 1995).

Much research has been directed at the use of adhesive techniques with amalgam, in order to enhance retention and reduce microleakage, and several resin dentin bonding systems have been promoted for this application. Many laboratory reports have shown that these adhesive resin systems can reduce microleakage when placed in cavities filled with amalgam (Staninec & Holt, 1988; Charlton, Moore & Swartz, 1992; Turner, St Germain & Meiers, 1995). However, a wide variation of bond strengths of adhesive resin to amalgam have been reported (Table 1). This variation in data is due to different materials being used, as well as different techniques for placement and testing. However, little information exists on the bond strength of gallium-based alloys bonded with resin bonding systems to dentin (Miller & others, 1992; Eakle & others, 1994).

The aim of the present study was to compare the shear bond strength of a gallium alloy and an amalgam to dentin, mediated by four resin dentin bonding systems.

METHODS AND MATERIALS

Freshly extracted bovine lower incisor teeth were stored frozen until use. For each tooth, the labial surface was wet ground with a model trimmer to expose a flat, superficial dentin surface. The root was removed and the crown placed on a glass slab, dentin surface down. A plastic cylinder, 10 mm high x 12 mm in internal diameter, was placed over the tooth and filled with dental stone. When the stone had set, the dentin surface was finished with 600-grit silicon carbide paper under running water. After rinsing and drying, self-adhesive vinyl masking tape with a 3 mm-in-diameter hole was placed on the surface in order to limit the bonding area.

The amalgam (Permite C), gallium alloy (Galloy), and the four dentin bonding systems, their manufacturers, components, and batch numbers are listed in Table 2. The procedure for applying each adhesive

Table 1. Amalgam Bond Strength Investigations

Investigators	Materials	Year	Range (MPa)
Scherer & others	Panavia (+Gluma or +Mirage Bond)	1990	1.40 - 4.00
Covey & Moon	Amalgambond, Panavia, Ketac-Cem, Scotchbond 2	1991	3.26 - 4.87
Cooley & Tseng	Amalgambond	1991	3.38 - 3.84
Kawakami & Staninec	Amalgambond, All-Bond, Panavia, Photobond	1991	1.33 - 6.85
Miller & others	Amalgambond	1991	1.12 - 6.58
Lo, Millstein & Nathanson	Amalgambond (+HPA), All-Bond, Panavia	1995	1.23 - 8.60
Ratananakin, Denehy & Vargas	Amalgambond Plus (+HPA), All-Bond 2, OptiBond	1996	1.40 - 15.13

Table 2. Materials, Components, and Manufacturers

Materials	Components	Batch #	Manufacturer
Super-Bond D-Liner	conditioner: 10% citric acid with 3% ferric chloride primer: 35% aqueous HEMA bond: 4-META, MMA, TBB	50503 50701 catalyst 508023 base 50601	Sun Medical, Kyoto, Japan
Super-Bond D-Liner II	conditioner: 10% citric acid with 35% ferric chloride bond: HEMA, 4-META, MMA, TBB	51003 catalyst 510033 base 51102	Sun Medical
Paama 2	conditioner: 37% phosphoric acid primer: aromatic dimethacrylate, acetone, glycerol dimethacrylate bond: 7,7,9-trimethyl-4,13 dioxo-3,14 dioxa-5,12 diaza hexadecane-1,16 diol dimethacylate, TEGDMA	B60317 51217 60210	SDI, Victoria, Australia
Panavia 21	primer: HEMA, 5-NMSA, phenyl-P, water bond: MDP, fillers, comonomers	Primer A 023 Primer B 029 0056	Kuraray Co, Osaka, Japan
Permite C	spherical/lathe cut admix: alloy 600 mg (Ag 56%, Sn 27.9%, Cu 15.4%, In 0.5%, Zn 0.2%) and mercury 552 mg	B604242	SDI
Galloy	spherical alloy: powder 700 mg (Ag 60.10%, Sn 28.05%, Cu 11.80%, Pt 0.05%); liquid 343 mg	B300395	SDI

HEMA = 2-hydroxyethylmethacrylate; 4-META = 4-[2-(methacryloxyethoxy) carbonyl]phthalic acid; MMA = methylmethacrylate; TBB = tri-n-butylborane; MDP = 10-methacryloyloxydecyldihydrogen phosphate; 5-NMSA = N-methacryloyl-5-aminosalicylic acid; TEGDMA = triethyleneglycol dimethacrylate.

system is listed in Table 3. After the bonding procedure, a 3 mm-in-internal-diameter plastic tube was held firmly by the operator over the hole in the tape. Permite C or Galloy was triturated in an amalgamator for 7 seconds and 8 seconds respectively and condensed into the tube by hand condensation using 1.5 and 2.5 mm condenser tips. The Galloy surface was covered with Paama 2 adhesive resin, which was light cured, in order to prevent moisture contamination. The specimens were stored in tap water at 37 °C for 48 hours prior to testing. Each alloy was used with each bonding system, thus giving eight groups.

Twelve specimens for each group were tested for shear bond strength using a testing jig (Bencor Multi-T, Danville Engineering, San Ramon, CA 94583) on a Universal Testing Machine (Autograph IS 5000, Shimadzu, Tokyo, Japan) at a crosshead speed of 1 mm/min. The force at failure was converted to stress (MPa), and the mean for each

Table 3. Procedure

Materials	Procedures
Super-Bond D-Liner	conditioner: apply 10 seconds, water rinse 15 seconds, dry primer: apply 1 coat, dry gently bond: chemical cure, pack alloy after 20 seconds
Super-Bond D-Liner II	conditioner: apply 10 seconds, water rinse 15 seconds, dry bond: chemical cure, pack alloy after 20 seconds
Paama 2	conditioner: apply 30 seconds, water rinse 30 seconds, dry primer: apply 5 coats with gentle drying bond: light cure 20 seconds
Panavia 21	primer: apply for 60 seconds, dry gently bond: chemical cure, pack alloy

Table 4. Shear Bond Strengths, MPa

Materials	Super-Bond D-Liner	Super-Bond D-Liner II	Paama 2	Panavia 21
Permite C	2.79 + 1.21	3.41 + 1.22	0.70 + 0.27	0.42 + 0.12
Galloy	2.69 + 1.08	2.65 + 1.07	0.50 + 0.20	0.00

Mean + SD; n = 12; lines joining values indicate no signicant difference ($P > 0.05$).

group calculated. Means were compared using one-way ANOVA. Student's *t*-test was used to compare the bond strength of Permite C and Galloy for each dentin adhesive system.

The fractured surfaces were examined at X20 magnification to determine the mode of fracture and classified into one of three types: Type 1) approximately 25% of the bonded area showing adhesive failure between the bonding resin and alloy, combined with approximately 75% of the bonded area showing adhesive failure between the bonding resin and dentin; Type 2) approximately 50% of the area showing adhesive failure between the bonding resin and alloy, combined with approximately 50% of the area showing adhesive failure between the bonding resin and dentin; Type 3) approximately 75% of the bonded area showing adhesive failure between the bonding resin and alloy, combined with approximately 25% of the bonded area showing adhesive failure between the bonding resin and dentin. The fracture mode frequency was analyzed using Kruskal-Wallis and Mann-Whitney U tests.

A further specimen from each group was prepared in the same manner as for the bond test. The 3 mm-in-internal-diameter tube and vinyl masking tape were joined together with a cyanoacrylate (Supa Glue, Selleys Chemical Company Pty Ltd, NSW, Australia) to obtain a stable assembly. The specimens were embedded in an epoxy resin (Daystar, Daystar Australia Pty Ltd, Victoria, Australia) and vertically sectioned through the center. The cross-sectioned surfaces were polished with silicon carbide paper and finished with 6 µm diamond paste (Metadi II, Buehler, Lake Bluff, IL 60044). The specimens were sputter-coated with gold prior to observation using a scanning electron microscope (SEM 515, Phillips, Einhoven, Netherlands).

RESULTS

The mean shear bond strengths to dentin of the four bonding systems are given in Table 4 and Figure 1. The only significant difference between alloys for a given bonding system ($P < 0.05$) was with Panavia 21, which gave a higher bond with Permite C (0.42 MPa) than with Galloy (0.00 MPa). For both alloys, the bond strengths mediated by Super-Bond D-Liner and Super-Bond D-Liner II were significantly higher than those mediated by Paama 2 and Panavia 21 ($P < 0.05$). However, all bond strengths were low, those of Galloy being slightly less than those of Permite C.

The fracture modes for each group are summarized in Table 5. Super-Bond D-Liner II appeared to bond more strongly to Permite C and Galloy than to dentin, because most of the alloy surfaces remained covered with resin (Figure 2). On the other hand, Panavia 21 failed to bond to Galloy, leaving the Galloy surface almost clean of resin and the dentin surface covered with resin (Figure 3). The majority of Super-Bond D-Liner failures were Type 3, whereas there were few Type 3 failures with Super-Bond D-Liner II. For Paama 2 and Panavia 21, failures were evenly distributed between Type 2 and Type 3, except for those using Panavia 21 with Galloy, which were all Type 3. There were no significant differences in fracture mode between Permite C and Galloy among all groups. For Permite C, the fracture mode using Super-Bond D-Liner II was significantly different from the other groups ($P < 0.05$, Table 6). For Galloy, the fracture mode using Super-Bond D-Liner II was also significantly different from the other groups ($P < 0.05$), and the fracture mode using Paama 2 was different from Panavia 21, which failed to bond to Galloy ($P < 0.05$, Table 6).

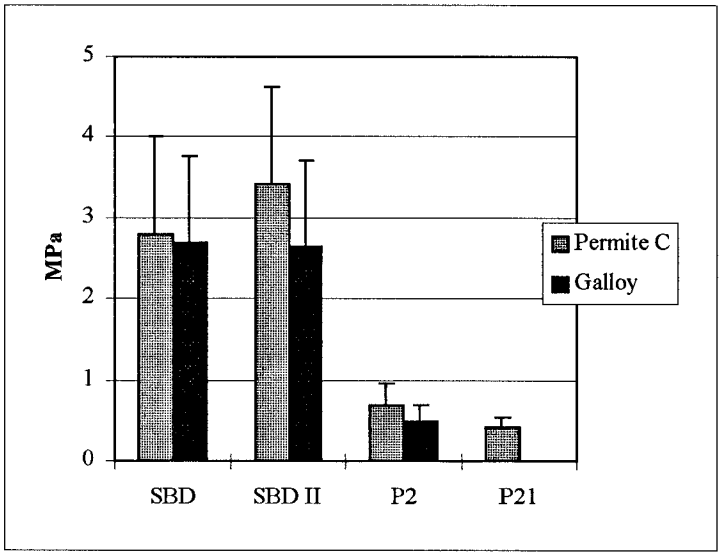

Figure 1. *Mean shear bond strengths (MPA; n = 12)*

Table 5. Failure Mode

Materials	Type 1	Type 2	Type 3	*P*-Value
Super-Bond D-Liner/Permite C	0	2	10	1.0000
Super-Bond D-Liner/Galloy	0	2	10	
Super-Bond D-Liner II/Permite C	4	6	2	0.3753
Super-Bond D-Liner II/Galloy	6	5	1	
Paama 2/Permite C	0	6	6	1.0000
Paama 2/Galloy	0	6	6	
Panavia 21/Permite C	0	5	7	0.0139*
Panavia 21/Galloy	0	0	12	

Types: 1) approximately 25% in area showing adhesive failure between bonding resin and alloy, combined with approximately 75% in area showing adhesive failure between bonding resin and dentin; 2) approximately 50% in area showing adhesive failure between bonding resin and alloy, combined with approximately 50% in area showing adhesive failure between bonding resin and dentin; 3) approximately 75% in area showing adhesive failure between bonding resin and alloy, combined with approximately 25% in area showing adhesive failure between bonding resin and dentin.
P-value compared the failure mode of Permite C and Galloy in each material.
*significant difference ($P < 0.05$).

From the SEM observations, the resin thickness of Super-Bond D-Liner between both alloys and dentin was about 100 μm and was slightly thicker than Super-Bond D-Liner II. Paama 2 resin thickness was about 200 μm at the interface, with amalgam embedded into the resin surface (Figure 4). For Panavia 21, the resin layer separated cohesively during the drying process.

DISCUSSION

Nakamichi, Iwaku, and Fusayama (1983), and Fowler and others (1992) showed that bovine dentin was a good substitute for human dentin in bond strength testing, although slightly lower values were obtained. The results of the present study were therefore valid in demonstrating relative values, and the bond strength results divided the adhesives into two broad groups: D-Liner/D-Liner II, and Paama 2/ Panavia 21.

It should be emphasized at the outset that the manufacturer's instructions for Galloy no longer include the requirement to etch the dentin, as this may result in increased dentinal fluid outflow and contamination of the alloy. In addition, an improved resin sealant is now supplied to protect the Galloy from any dentinal fluid that may be present.

Super-Bond D-Liner/D-Liner II

The bond strengths of Permite C to dentin using Super-Bond D-Liner (2.79 MPa) and Super-Bond D-

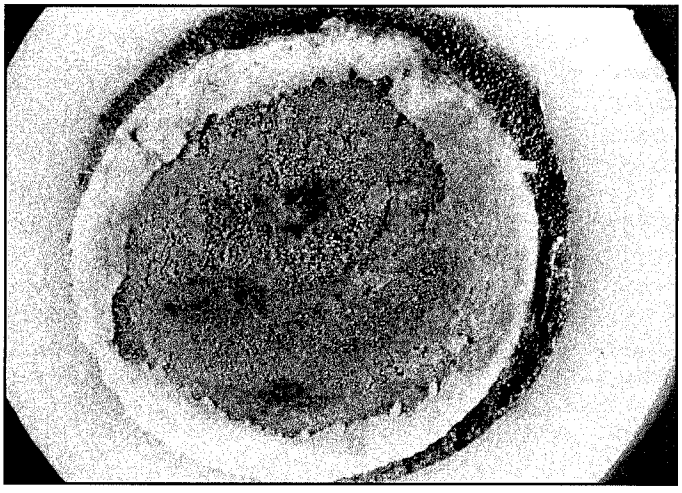

Figure 2. *Fractured surface, showing most of the Galloy surface covered by Super-Bond D-Liner II*

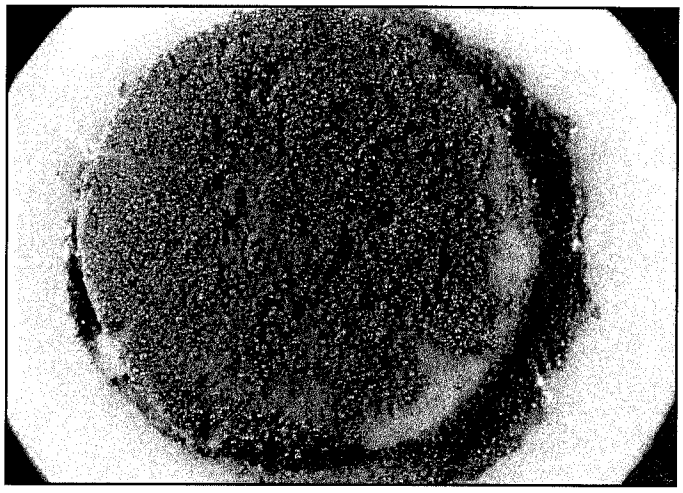

Figure 3. *Fractured surface, showing only a small area of the Galloy surface covered by Panavia 21. The remainder of the Panavia was still attached to the dentin (not shown).*

Table 6. Comparison between Fracture Modes (P-Value)

Permite C	Super-Bond D-Liner	Super-Bond D-Liner II	Paama 2	Panavia 21
Super-Bond D-Liner	—	—	—	—
Super-Bond D-Liner II	0.0018*	—	—	—
Paama 2	0.1782	0.0387*	—	—
Panavia 21	0.3186	0.0205*	0.7553	—
Galloy	**Super-Bond D-Liner**	**Super-Bond D-Liner II**	**Paama 2**	**Panavia 21**
Super-Bond D-Liner	—	—	—	—
Super-Bond D-Liner II	0.0002*	—	—	—
Paama 2	0.1782	0.0045*	—	—
Panavia 21	0.5137	0.0000*	0.0387*	—

*significant difference ($P < 0.05$)

Liner II (3.41 MPa) were not significantly different ($P > 0.05$) and were similar to values obtained by other researchers using 4-META/MMA/TBB systems (Table 1). For Galloy, the values obtained were similar to those reported by Miller and others (1992), using Amalgambond, which was identical to Super-Bond D-Liner. The mechanism of adhesion is not known; however, the SEM observations suggested that there may be some element of micromechanical bonding of the alloy embedded into the resin. In addition, it is known that 4-META can bond to oxides of tin and copper (Yoshida & others, 1996), both of which are present in Permite C and Galloy, and thus there may also be some contribution from chemical bonding.

Examination of the failure mode showed that the failure was predominantly adhesive between alloy and resin for D-Liner, whereas for D-Liner II the failure was approximately equally distributed between resin and alloy, and resin and dentin. It thus appeared that the bond of D-Liner II was weaker to dentin than that of D-Liner, but in general the bond of both alloys to resin was the weakest link in the system.

The reason for the weaker bond of D-Liner II than D-Liner to dentin is probably because of the way in which the components were presented. For D-Liner, 35% aqueous HEMA was used as a primer, after etching, to assist bonding resin penetration and establish a hybrid layer. In the case of D-Liner II, however, the primer and adhesive were combined into one step. It is suggested that in the latter case the penetration of resin into the demineralized dentin may be less complete due to a reduced time for resin to infiltrate, resulting in a poorer quality hybrid layer (Nakabayashi & Takarada, 1992).

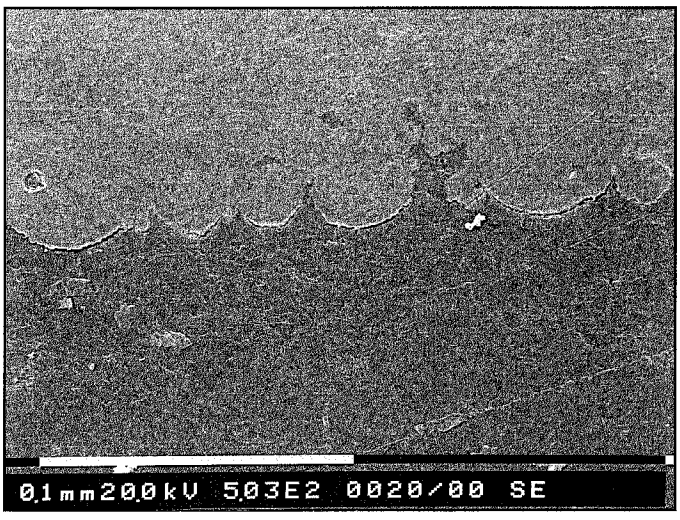

Figure 4. *SEM of Permite C/Paama 2 interface, showing the displacement of Paama into the amalgam surface (bar = 0.1 mm)*

Paama 2/Panavia 21

The bond strengths of Permite C and Galloy to dentin mediated by these two materials were significantly different, but were so low that they were essentially zero, and thus the statistical difference should be discounted.

Paama 2 was used by the manufacturers to isolate Galloy from moisture (dentinal fluid and saliva) during the early phase of setting, and not claimed to bond to Permite C or Galloy, which was confirmed in this study. Paama 2 is photopolymerized before packing the alloys, thus, the opportunity for displacement of the resin into the alloys, and resulting micromechanical retention, is limited, which was confirmed by SEM (Figure 4).

However, Panavia EX, which has the same bonding agent (MDP) as Panavia 21, has been reported to bond to other amalgam alloys (Covey & Moon, 1991: 3.46 MPa; Kawakami & Staninec, 1991: 1.33 MPa; Lo

& others, 1995: 1.23 MPa). Nevertheless, with the exception of the first, these bond strengths were very weak. The lower bond strength in the present study compared with the others was probably due to differences in experimental method, alloy, and type of dentin substrate.

For Permite C, an examination of the failure mode showed that there was no difference between Paama 2 and Panavia 21, and that the alloy/resin interface was predominantly the weakest. The conspicuous difference between the behavior of Permite C and Galloy was the failure mode with Panavia 21. Whereas the failure mode of Permite C was approximately equally distributed between Types 2 and 3, all the Galloy specimens showed Type 3 failures. These data suggest that Galloy bonds somewhat less well to Panavia 21 than does Permite C, and to that extent, these data were consistent with the bond strength data. The reason for the lower bond of Galloy is not known.

Examination of the SEM specimen indicated that there had been a cohesive failure of the Panavia 21 during preparation for both alloy groups. The reason for this is unknown, but may have been the result of shrinkage of Panavia 21 during setting.

General Observation

In the present study, the bond strengths of the dentin adhesive systems bonded to Permite C, Galloy, and dentin were very low. However, there have been many reports promoting the advantages of using dentin adhesive systems with amalgam and gallium alloys, and several dentin bonding systems have been shown to slightly increase the fracture resistance of teeth restored with amalgam (Eakle, Staninec & Lacy, 1992; Boyer & Roth, 1994). Dentin bonding systems can also be used as cavity liners with amalgam to reduce microleakage (Staninec & Holt, 1988; Charlton & others, 1992; Turner & others, 1995) and inhibit caries around amalgam restorations (Torii & others, 1988). Moreover, dentin bonding agents can be used to seal dentin surfaces when amalgam cores are placed after endodontic treatment. This is claimed to prevent alloy corrosion products from penetrating into the dentin, and may also help prevent the progress of secondary caries occurring from an imperfect seal of the amalgam at dentin margins (Zakariasen, 1989; Pashley & others, 1991). For Galloy, even though it has good sealing properties (Winkler & others, 1996), it remains sensitive to initial moisture contact and corrodes (Okamoto & Horibe, 1991; Henson & others, 1994; Nakajima & others, 1993; Okabe & others, 1993; Oshida & Moore, 1993). Paama 2 resin was recommended by the manufacturer to prevent this problem, but an improved resin is now provided.

Gwinnett and others (1994) reviewed the literature on adhesive amalgam restorations and introduced a set of guidelines for clinical use. Amalgam restorations using Amalgambond showed good clinical performance over 15 months with regard to marginal adaptation and retention, and no secondary caries or hypersensitivity after treatment (Olmez & Ulusu, 1995). However, Mahler and others (1996), using Panavia 21, reported there was no difference between bonded and nonbonded amalgam restorations for postoperative sensitivity after 1 or 2 weeks nor for marginal fracture after 1 year. The study also reported some technical difficulties when Panavia 21 was used clinically for amalgam bonding. Bonding amalgam has shown mixed results in laboratory and clinical studies, and further long-term clinical evaluations are needed to clarify the potential value of amalgam bonding systems.

CONCLUSION

The dentin bonding systems used in this study created only a weak bond between the alloys and dentin. It is believed that such low bond strengths would contribute little to the retention of a restoration. The failure modes of the adhesives with Permite C and Galloy were not significantly different, except for Panavia 21. Although Paama 2 was used to prevent moisture contamination of Galloy from the dentin, it was demonstrated that it can also bond weakly to Galloy and amalgam.

Acknowledgments

The authors acknowledge Mr Robert Smith and Mr Lyle Davies (R J Gilberson Pty Ltd, Victoria, Australia) for providing bovine teeth, and the manufacturers for their generous donation of materials.

(Received 24 March 97)

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CLINICAL ARTICLE

Intraoral Repair of the Fractured Porcelain Restoration

J W ROBBINS

SUMMARY

Until recently, there was no predictable technique for repairing the fractured porcelain restoration. However, with the advent of many new products related to bonding porcelain, there are techniques available today to repair fractured porcelain with moderate expectations of success.

INTRODUCTION

"Hey, Doc, you know the porcelain bridge you cemented in my mouth last week...?" This is the telephone call that sends shivers down the spine of every restorative dentist. Until recently, there was no predictable technique for repairing the fractured porcelain restoration. However, with the advent of many new products related to bonding porcelain, there are techniques available today to repair fractured procelain with moderate expectations of success (Fan, 1991).

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PORCELAIN REPAIR

The simplest repair is one in which the fracture is totally in porcelain. This repair can be accomplished by fabricating a piece of porcelain to replace the missing portion or by replacing the fractured area with a porcelain veneer (Berksun & Saglam, 1994); however, this type of repair is most often done with direct placement composite (Rada, 1991). The fractured surface must first be prepared for bonding. Several methods of porcelain preparation have been investigated, including diamond roughening, air abrading with 50-micron aluminum oxide, and etching with 9.5% hydrofluoric acid (HF) (Ceram-Etch, Gresco Products, Stafford, TX 77477; Porcelain Etch, Ultradent Products, South Jordan, UT 84095) or 1.23% acidulated phosphate fluoride (APF). Research indicates that air abrading with 50-micron aluminum oxide is a better method of preparing the surface than roughening with a diamond (Wolf, Powers & O'Keefe, 1992). Researchers (Bertolotti, Lacy & Watanabe, 1989; Nelson & Barghi, 1989; Tylka & Stewart, 1994) have found that both 9.5% HF and 1.23% APF are equally effective in etching the porcelain surface. However, 9.5% HF requires only 2-4 minutes of etching time, while 1.23% APF requires 10 minutes. Clearly, the most effective method of preparing the porcelain for repair is with one of the porcelain etchants (Burkett, Burgess &

Robbins, 1992). A recent study (Kupiec & others, 1996) showed that the effect of etching with 8% HF was enhanced by air abrasion of the porcelain prior to etching. After etching, the porcelain was thoroughly washed and air dried. The etched porcelain had a frosted appearance after using the HF; however, this was not the case when the APF was used.

Hydrofluoric acid is potentially harmful to both hard and soft tissues and should only be used under strict isolation of a rubber dam. When this is not possible, 1.23% APF is the etchant of choice. The next step requires the placement of the organic coupling agent, silane (Bertolotti & others, 1989). There are many brands of silane available; however, based on a large number of laboratory studies (Cochran & others, 1988; Diaz-Arnold & Aquilino, 1989; Diaz-Arnold, Schneider & Aquilino, 1989; Diaz-Arnold & others, 1993; Nicholls, 1988; Pratt & others, 1989; Stokes, Hood & Tidmarsh, 1988; Wolf & others, 1992), Scotchprime (3M Dental Products, St Paul, MN 55144) is an excellent choice. The silane is placed on the etched porcelain and allowed to air dry for 1 minute. The shelf life of silane is an important concern. While the shelf life of many of the current bonding products is in the range of 3 years, silane, even when refrigerated, has a shelf life of only 12 to 18 months, and perhaps even less. Old silane can be detrimental to the final bond strength; therefore, care must be taken to ensure that only fresh silane is used. After the porcelain has been silanated, the repair is completed in a manner similar to bonding composite to enamel. An unfilled resin or adhesive from a dentin bonding kit is placed and light cured. A composite resin is then placed, contoured, light cured, and finished in a conventional manner. If strength is required in the final restoration, a hybrid composite resin should be used rather than a microfilled composite resin (Gregory & Moss, 1990). If the patient has the fractured piece of porcelain, it can be rebonded to the crown by using the etchant, silane, and unfilled resin on both the porcelain remaining on the crown and the fractured porcelain piece, and then bonded with a composite resin (Figures 1-3).

There is a unique system available (Clearfil Porcelain Bond, J Morita, Co, Tustin, CA 92680) that does not require the use of porcelain etch. Not only is it less time consuming, but has shown excellent bond strengths in several laboratory studies (Appeldoorn, Wilwerding & Barkmeier, 1989; Anusavice & others, 1989; Diaz-Arnold & others, 1993; Lei, Mittleman & Thompson, 1989; Llobell & others, 1992; Suliman, Swift & Perdigao, 1993; Wolf & others, 1992).

MIXED PORCELAIN/METAL REPAIR

When the surface to be repaired involves exposed metal, the repair becomes more complicated. If there is enough porcelain remaining on the crown to retain the repair composite resin, then the exposed metal can be opaqued with composite opaquer and the area repaired with composite resin as previously described. However, if it is determined that there is not enough porcelain remaining on the crown to retain the composite repair material, then the metal must be used as an adhesive substrate. Bonding to metal is enhanced by first microetching the metal with 50-micron aluminum oxide (Imbery, Burgess & Naylor, 1992). If it is determined that the metal is high-noble or noble metal, bond strengths can be enhanced by tin plating the exposed metal (Imbery & others, 1992). If the metal is determined to be base metal, tin plating is not necessary. The resin that is placed directly on the metal surface must serve two purposes. First, it must bond to the metal, and second, it must opaque the metal so that the darkness of the metal does not show through the repair composite resin. Standard resin opaquers do not bond to metal; therefore, a bonding agent with the capability to bond to metal must first be placed on the metal surface (i e, All-Bond 2, Bisco, Itasca, IL 60143; C & B Metabond, Parkell, Farmingdale, NY 11735; Panavia 21, J Morita Co). Many of the products that have this capability also have opaquers that bond to metal. After placement of the opaquer and preparation of the remaining porcelain, the unfilled resin is placed

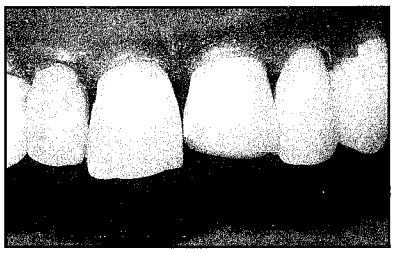

Figure 1. *Fractured incisal porcelain on maxillary left central incisor that is an abutment for a fixed partial denture*

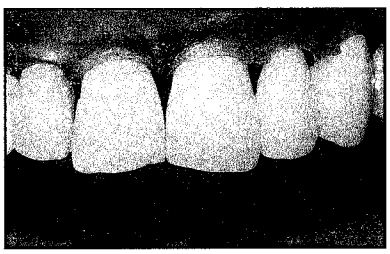

Figure 2. *Fractured piece of porcelain is tried in to ensure correct fit*

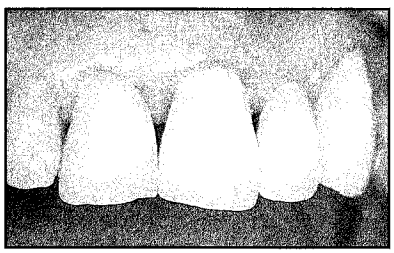

Figure 3. *Two-year postoperative view of repaired crown on maxillary left central incisor*

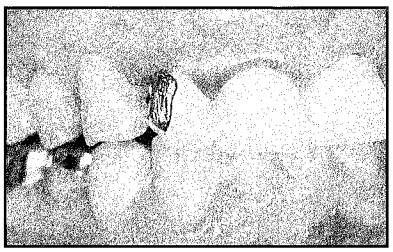

Figure 4. *Mixed porcelain-metal fracture on maxillary right lateral incisor that is an abutment for a fixed partial denture*

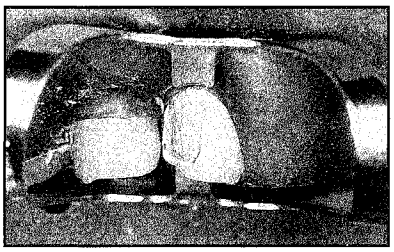

Figure 5. *Metal surface after air abrasion*

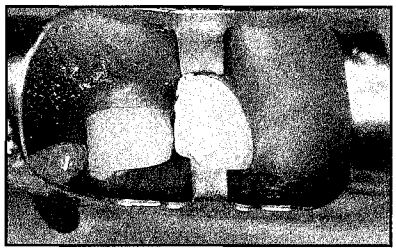

Figure 6. *Resin opaque placed over exposed metal*

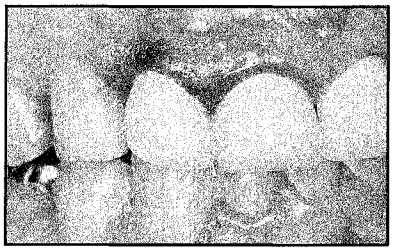

Figure 7. *Repair of maxillary right lateral incisor completed with composite resin*

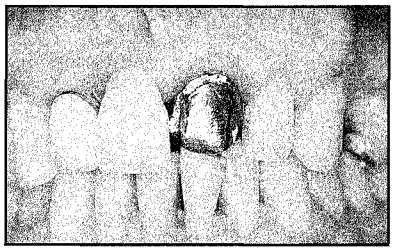

Figure 8. *Complete porcelain fracture on maxillary left central incisor that is an abutment for a fixed partial denture*

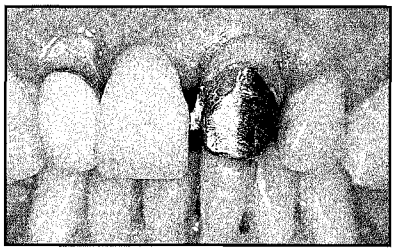

Figure 9. *Deepened preparation to allow additional space for overcasting*

and light cured. The composite resin is then placed, contoured, light cured, and finished (Figures 4-7).

METAL REPAIR

The most difficult repair is one in which there is only exposed metal with minimal or no remaining porcelain. If the crown is a single unit, it is usually best to remove it and remake the crown rather than attempting a repair. Unfortunately, remaking the crown (pontic) is not always practical, especially in the case of a multiunit fixed partial denture. The crown can be repaired with composite resin using the bonding technique described in the previous section. However, a more predictable method of repair is to fabricate an overcasting (Tang, Gordon & Sherman, 1989). If there are small areas of remaining porcelain, they are removed. The crown or pontic is reduced incisally, facially, and lingually to provide room for both metal and porcelain, and to provide margins for the laboratory technician. A shade is selected and an impression of the preparation and adjacent teeth is made. In the laboratory, a thin metal overcasting is fabricated, and porcelain is fused to the metal overcasting in the traditional manner. At the subsequent appointment, the fit of the casting and the occlusion are checked and adjusted. Surface staining is accomplished, if necessary. The metal surface of the area of repair and the inner surface of the overcasting are air abraded as previously described. For maximum retention and resistance, the overcasting should be bonded with an adhesive cement (i e, C & B Metabond, Panavia 21) (Figures 8-14).

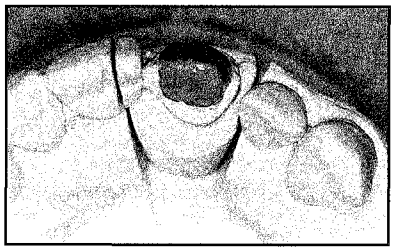

Figure 10. *Incisal view of preparation for overcasting*

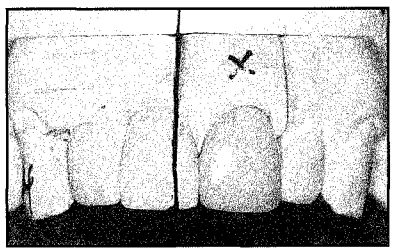

Figure 11. *Completed overcasting on master cast*

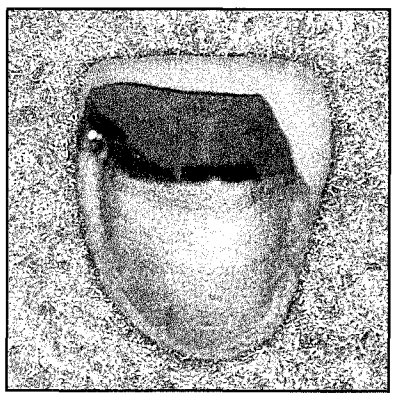

Figure 12. *Lingual and inner surfaces of overcasting showing metal substructure*

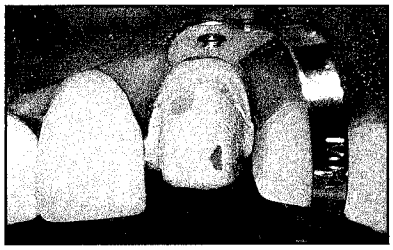

Figure 13. *Tooth isolated and air abraded in preparation for bonding of overcasting*

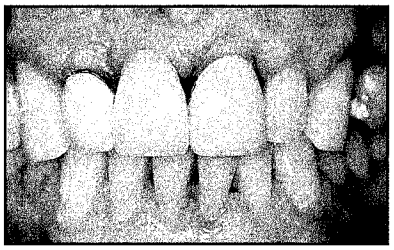

Figure 14. *Two-year postoperative view of overcasting on maxillary left central incisor*

CONCLUSIONS

When attempting to repair a fractured ceramometal restoration, it is important to determine the reason for failure. If the failure is due to occlusion or substructure flexure, the repair will probably fair no better than the original restoration. However, if the fracture is due to trauma or technical error during the construction of the original restoration, a porcelain repair procedure may be the treatment of choice. It is well known that both function and thermal changes are detrimental to the longevity of bonded restorations (Creugers, Snoek & Kayser, 1992; Lei & others, 1989; Pratt & others, 1989). In addition, there are virtually no long-term clinical studies that investigate porcelain repair procedures. Therefore, it is important to inform the patient of the risks associated with repairing a fractured crown. However, with the advent of many newer-generation bonding agents, and a better understanding of the techniques, intraoral repair of fractured porcelain restorations can be a viable and cost-effective treatment.

(Received 24 February 1997)

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DEPARTMENTS

LETTERS

DR PAUL T DAWSON
1901-1998

The death of Paul T Dawson on 16 March 1998 marks the passing of a legend in American dentistry.

Dr Dawson graduated from Loyola Dental School in Chicago and rose to be a full professor and chair of the Department of Operative Dentistry. After retiring from Loyola, he was appointed distinguished professor at Northwestern School of Dentistry, where he continued to teach until he was 82 years old. He was never too busy to help the student in trouble, working noon hours and even organizing evening classes to help the students.

Dr Dawson was a magnificent clinician and a devoted operator and promoter of gold foil restorations. He spent a lifetime teaching sound instrumentation and exactness in cavity preparations no matter what restoring material he used. He immensely enjoyed performing every stage of the gold foil procedure and then loved to show his finished restoration to the faculty and students.

Dr Dawson was a no-nonsense dental educator. His gold foil manual displayed every step of the gold foil process. He had outstanding diagrams for each step and the proper instrumentation. He emphasized serviceable retention points and line angles, and bevels were given special attention. He continuously cautioned against landslides of foil that was not adequately anchored in the retention areas.

He was respected by his students and by his peers. In fact, when he left Loyola and became a faculty member at Northwestern Dental School, he continued teaching constructive gold foil techniques. A gold foil study club was established, and a number of dentists came from out of state to participate in placing gold foil restorations at the monthly sessions. During and after lunch each patient's restoration was examined and evaluated. There was an exchange of ideas on improvements in some of the technical procedures. Later the members honored Dr Dawson by naming it the Paul T Dawson Gold Foil Study Club.

Paul Dawson was the recipient of many honors and memberships in professional colleges. He received the Distinguished Member Award in 1990 from the American Academy of Gold Foil Operators and in 1987 he received the Award of Excellence from the Academy of Operative Dentistry. He also received the Dentist of the Year award from the American Dental Association.

Paul was known and respected by many hundreds of students and dentists. During the Chicago mid-winter meeting it would take an hour for him to cross the lobby of the hotel, as many of his friends greeted him. He will be sorely missed by all who knew him.

RALPH J WERNER
ADALBERT L VLAZNY

COMING TO TERMS WITH TERMINOLOGY

I enjoyed Dr Warren's guest editorial "Coming to Terms with Terminology" [23(3):105-107]. Dr Warren is right on target about language abuse in dentistry. I thought your readers might be interested in a few more examples that make me grind my teeth:

1) When a dental student (or even worse, a fellow dentist) alludes to detecting a "carie." (I sure hope that person never gets bitten slightly by an infected animal and develops a "rabie," or perhaps suffers a small glitch in the Islets of Langerhans and a "diabete" occurs.)

2) Reference to "white fillings" or even worse, "invisible fillings." Everyone knows that such fillings are not white, they are tooth colored. Invisible? Piffle! They are perfectly visible, regardless if they are imperceptible.

3) Using the term "excavation" rather than "debridement" for surgical removal of carious tooth substance. Are we surgeons or land developers?

4) Calling a resin-composite a composite resin. And worse than that, eliminating the most important word altogether: "Hey Al, how much are you getting for an occlusal composite these days?"

5) Consistent misuse of "pathology" for "pathosis": "The x-rays showed no evidence of pathology."

6) Which of course brings up the use of "x-ray" rather than "x-ray film" or "radiograph." "Taking a Panorex" rather than "recording a panograph" fits in here too.

7) And how can teeth that do not approximate *musculus buccinator* have a "buccal" surface? "Porcelain thickness of labial veneers should not extend more than 1 mm to the buccal." (Honest, I really saw that in writing!) Canines and incisors have facial or labial outer surfaces, molars and premolars have facial or buccal outer surfaces.

8) Isn't "air abrasion," that we are hearing so much about, really "air/particulate abrasion"?

9) And of course, that perennial favorite: "I'm sorry, Mrs Malaprop, you need a root canal."

Forgive me for wrapping this up so soon. I could go on all day, but just thinking about these examples, and those of Dr Warren, gives me TMJ.

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ABSTRACTS

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

Influence of different metal restorations bonded with resin on fracture resistance of endodontically treated maxillary premolars. Costa LCS, *Pegoraro LF & Bonfante G (1997) *Journal of Prosthetic Dentistry* 77(4) 365-369.

(*University of São Paulo, School of Dentistry of Bauru, Al Octavioi P Brisola, 9-75, CEP-17043-101, Bauru, São Paulo, Brazil)

The purpose of this study was to evaluate the fracture resistance of endodontically treated maxillary premolars restored with different cast metal restorations after submission to axial compressive forces.

Fifty caries-free first maxillary premolars were extracted for orthodontic purposes. Endodontic treatment was performed with #2 Gates-Glidden drills and final instrumentation with #35 files. Pulp chambers were filled with Herculite XR composite. There were five groups with 10 in each group. Group 1: silver amalgam MOD preparation with isthmus 1/3 the intercuspal distance; Group 2: cast MOD inlay preparation with isthmus width equal to Group 1, luted with Panavia EX; Group 3: cast MOD inlay preparation with isthmus width equal to half the intercuspal distance, luted with Panavia EX; Group 4: cast MOD inlay preparation equal to Group 3 with lingual and approximal extensions, luted with Panavia EX; Group 5: cast MOD onlay preparation with dimensions equal to Groups 3 and 4, luted with zinc phosphate. Restorations were thermocycled 1350 times and subjected to compressive axial load in a Universal Testing Machine at a crosshead speed of 0.5 mm/min. Fracture resistance for the negative control group (conventional amalgam) was significantly lower than for the other groups. Fracture resistance for the positive control group (conventional onlay) was significantly greater than for the other groups. Fractures in Groups 2, 3, and 4 were cohesive, and fractures in Groups 1 and 5 were in the adhesive at the tooth-restoration interface. Conclusions: 1)The greatest statistically significant fracture resistance values were recorded for Group 5, followed by Groups 2, 4, 3, and 1; 2) There were no statistically significant differences among Groups 2, 3, and 4; 3) The increase of fracture resistance by MOD inlay cast restoration bonded with Panavia EX resin suggested valid clinical applications within the conditions of this study.

Effect of nonvital tooth bleaching on microleakage of resin composite restorations. *Barkhordar RA, Kempler D & Plesh O (1997) *Quintessence International* 28 341-344.

(*University of California—San Francisco, School of Dentistry, Department of Restorative Dentistry, San Francisco, CA 94122-2747)

The bleaching of nonvital teeth with hydrogen peroxide and sodium perborate may adversely affect the seal of the final composite restoration. The purpose of this study was to assess the effect of nonvital bleaching on microleakage at the tooth-resin composite interface. Thirty-six extracted, noncarious, intact human incisors were selected, and divided into four groups of nine teeth each. The bleaching agent used was sodium perborate mixed with 30% hydrogen peroxide. Established, uniform, endodontic procedures were performed on all teeth. Group 1 was the control in which a cotton pellet was placed with no bleaching agent and sealed for 7 days with Cavit.

Bleaching agent was used in Groups 2, 3, and 4, each sealed with Cavit for 2, 4, and 7 days respectively. At the elapsed times, the Cavit and cotton pellets were removed, the cavities cleansed with saline and dried. Scotchbond Multi-Purpose dentin bonding agent and Silux Plus were used to restore the teeth. Thermocycling was performed, and the roots sealed with nail varnish. Each tooth was immersed, occlusal side down, into a silver nitrate solution. The teeth were later sectioned and the microleakage dye penetration measured. The results showed no significant difference between Groups 1 and 2 with the least leakage, but found a substantial increase in microleakage in Groups 3 and 4. Therefore, only beyond the 2-day bleaching was there a significant increase in microleakage. The longer the application time of bleaching material in the pulp chamber, the greater the microleakage. It may be concluded that bleaching does affect the seal of the final composite restoration and that bleaching times should be limited to 2 days.

Surface treatment of indirect resin composite surfaces before cementation. *Hummel SK, Marker V, Pace L & Goldfogle M (1997) *Journal of Prosthetic Dentistry* 77(6) 568-562.

(*Baylor University, College of Dentistry, Waco, TX 76711-1656)

The purpose of this study was to examine ways to enhance the bond strength between a composite inlay and a dual-cure resin cement. Nine samples of each of the three composites used were prepared from standard 6 mm dies. Samples were cured in the Dentacolor XS light unit for 120 seconds, mounted in an acrylic block, and sanded smooth with 600-grit wet sandpaper. One of the following six surface treatments was applied to the composite surface before bonding: 1) hydrofluoric acid (HF) for 5 seconds; 2) orthophosphoric acid (PA) for 15 seconds; 3) microetch (ME) 10 seconds, PA for 15 seconds, and ME again for 10 seconds; 4) ME 10 for seconds, HF for 5 seconds, and ME for 10 seconds; 5) ME for 10 seconds and HF for 5 seconds; 6) ME for 10 seconds and PA for 15 seconds. A P-50 composite button was treated with phosphoric acid for 15 seconds and bonded to the study samples using Adhesive Bond II resin and Twinlock cement. Samples were cured for 1 minute and tested to failure on the Instron machine. ANOVA and Scheffé's test for multiple comparison were used for statistical analysis. Results showed none of the sample groups was significantly different from another. Scanning electron microscope analysis of the fractured and treated surfaces were also performed. Failure analysis showed that the majority of the adhesive failures were with the acid etch-alone group. SEM photos of the etch patterns showed etching alone had little effect on the composite surface, microetching and phosphoric acid gave the most consistent surface, and hydrofluoric acid appears to destroy the composite surface. The microscopic studies showed characteristics that mirrored nonstatistically significant trends: 1) Adhesive failures were associated with lower bond strengths, which were associated with acid etching alone; 2) The ME/acid/ME technique produced deep irregularities that were then smoothed by the second microetch; 3) The microetch/phosphoric acid group had the highest bond strengths; 4) While etching the glass particles, hydrofluoric acid is too destructive to the composite resin; 5) The surface roughness seems to come from the microetching, and the acid removes the debris. Even though the statistical analysis did not show a significant difference, the etch patterns seemed to correspond with different bonding strengths. The bond strength depends on the etch pattern, and the microetch/ phosphoric acid gave the best results.

Root reinforcement with a resin-bonded preformed post. *Mendoza DB, Eakle WS, Kahl EA, & Ho RH (1997) *Journal of Prosthodontics* 1 10-14.

(*University of California—San Francisco, School of Dentistry, San Francisco, CA 94122-2747)

The purpose of this study was to evaluate the ability of resin-bonded posts to reinforce endodontically treated teeth against fractures that are structurally weakened in the cervical area by greatly flared canals. Forty extracted mandibular canines were endodontically treated and randomly divided into four groups of 10 as follows: Group 1: #4 Dentatus post cemented with zinc phosphate cement (control group), Group 2: #4 Dentatus post cemented with Panavia, Group 3: #4 Dentatus post cemented with C&B Meta-Bond, and Group 4: # 4 Dentatus post fitted with Z-100 composite and cemented with dual-cure bonding agent. Weakened teeth were simulated by enlarging the canal circumferentially at the cervical region, leaving approximately 1 mm of dentin between prepared canal and outer root surface. The samples were mounted in acrylic block with a rubber coating to within 1 mm of the coronal portion of the root to simulate the periodontal membrane. The cemented posts were loaded in an

Instron machine. The samples were angled at approximately 60 degrees to the long axis of the tooth, and a constantly increasing force was applied until root fracture occurred. The results showed almost all of the samples failed because of vertical root fracture, and the fracture occurred opposite where the force was applied. In the zinc phosphate group the cement began to crumble as force was increased. The precise point of cement failure was unobtainable. The point of failure was taken as the amount of force applied to fracture the root, although the zinc phosphate cement had failed in every sample before this point. The group of roots in which the posts were cemented with Panavia had significantly greater resistance to root fracture than zinc phosphate. The C&B Meta Bond and Z-100 groups also required greater force to fracture the roots than zinc phosphate, but were not significantly different than Panavia. The results suggest that when posts were cemented with resin cements the fracture resistance of the roots is greater, especially with Panavia. Zinc phosphate cement tends to crumble around the post before root fracture with less force applied. In a clinical situation this could result in the loss of retention, post dislodgment, and root fracture. It would appear that resin cements are better for cementation of posts in endodontically treated teeth to provide optimal resistance to fracture.

The effect of eugenol-containing temporary cement on the bond strength of two resin composite core materials to dentin. *Al-Wazzan KA, Al-Harbi AA & Hammad IA (1997) *Journal of Prosthodontics* 6(1) 37-42.

(*King Saud University, College of Dentistry, Department of Restorative Dental Sciences, P O Box 60169, Riyadh 11545, Saudi Arabia)

The purpose of this study was to examine the effect of eugenol-containing temporary cement on the bond strength of two resin composite core materials to dentin.

Sixty specimens were divided into three groups of 20. Dentin was exposed in all three groups. Group 1 received no temporary cement and served as a control. In Groups 2 and 3, the dentin was coated with eugenol-containing and eugenol-free temporary cements respectively. All specimens were stored for 1 week at 37 °C and 100% humidity. The dentin surfaces were cleaned and treated using the GLUMA adhesive system. Each of the two resin core materials, FluoroCore and Ti-Core, was applied to 10 specimens from each of the three groups and allowed to set according to the manufacturer's instructions. Debonding of the core material was accomplished using the Accuforce Elite test system. Force was applied at a crosshead speed of 0.05 in/min until failure occurred. There was a significant reduction in bond strength for the specimens covered with eugenol temporary cement ($P < 0.0001$) but no significant difference was found between the control group and the group treated with eugenol-free temporary cement. Bond strength of the Ti-Core material to dentin was significantly higher than that of FluoroCore ($P < 0.0001$). Phenolic compounds, such as eugenol, interfere with resin composite polymerization by scavenging the free radicals. Consequently, incomplete polymerization may diminish the bond strength of resin composite material. Results of this study indicated that contamination of dentin with eugenol-containing temporary cement adversely affects the bond strength between composite core materials and dentin.

Ultrastructure of the resin-dentin interface following reversible and irreversible rewetting. *Tay FR, Gwinnett AJ & Wei SHY (1997) *American Journal of Dentistry* 10 77-82.

(*Department of Children's Dentistry and Orthodontics, Prince Philip Dental Hospital, University of Hong Kong)

The purpose of this in vitro study was to investigate the effect of reversible and irreversible rewetting on the application of One Step, a single-bottle, water-free, acetone-based primer/adhesive.

Moisture plays a crucial role in preventing the demineralized collagen from collapsing and provides the structural and theoretical background for the concept of wet bonding. Keeping the collagen network moist is particularly important for water-free acetone-based systems, since the absence of water does not offer dehydrated dentin a chance to remoisten.

Thirty 1 mm dentin disks were prepared from extracted third molars that were each conditioned with 10% phosphoric acid for 20 seconds and rinsed for 20 seconds. They were randomly divided into five groups: conditioned dentin bonded visibly moist; bonded after drying for 3 seconds; drying for 3 seconds and rewetting with distilled water; drying for 3 seconds, stored in 8% glutaraldehyde for 15 minutes, rinsed in distilled water and dried for 3 seconds; and drying for 3 seconds, stored in glutaraldehyde for 15 minutes, rinsed with distilled water, and bonded visibly moist. One Step was applied in two coats, cured, then the disks were paired together in

each group by bonding them with a chemical-cure resin (Pre-Bond), demineralized in EDTA, and prepared for TEM examination.

Complete resin infiltration into the zone of demineralized dentin was observed in Groups 1 and 3. In Group 2, resin infiltration was limited to the surface and base of the demineralized network apparently along the lateral branches of the dentin tubules, with a middle zone of suboptimal infiltration noted. In Groups 4 and 5, minimal resin infiltration was only observed along the base of the demineralized network upon their fixation in a collapsed state with glutaraldehyde.

It was concluded that in the absence of irreversible denaturation of collagen in acid-conditioned dentin, water helps to restore the plasticity and permeability of the demineralized collagen fibrillar network during rewetting. This is critical for optimal hybridization to occur, and thus a stronger bond.

Influence of dentinal adhesives and a prefabricated post on fracture resistance of silver amalgam cores. Donald HL, *Jeansonne BG, Gardiner DM & Sarkar NK (1997) *Journal of Prosthetic Dentistry* 77(1) 17-22.

(*Louisiana State University Medical Center, School of Dentistry, Department of Endodontics, Box 135, 1100 Florida Avenue, New Orleans, LA 70119)

The purpose of this study was to test the fracture resistance of silver amalgam cores bonded with All-Bond 2 and Amalgambond Plus in the presence and absence of preformed posts. Sixty extracted molars were selected, the occlusal surfaces were flattened, and the diameters of their pulp chambers were standardized. The depth of each pulp chamber was noted. All canals were cleansed and shaped using a step-back technique with K-files and Gates-Glidden drills. Mesial canals were no larger than a #30 and distal canals no larger than a #50. After preparation and final obturation with injectable gutta-percha and Roth's 811 sealer, the teeth were restored with a standardized Tytin amalgam. Teeth were randomly assigned to one of six groups: Group A received amalgam-only cores; Group B amalgam cores used All-Bond 2; Group C used Amalgambond Plus; Group D used a Moyco PD preformed post cemented 3 mm beyond the cavosurface at a radicular depth of 8 mm with Fleck's zinc phosphate cement; Group E additionally used All-Bond 2; and Group F used Amalgambond Plus. A Universal Testing Machine loaded each restoration at 45°, and the force was measured in kilograms. Two-way ANOVA demonstrated that there was a significant difference in the fracture resistance when using adhesives; however, there was no significant difference in using a post regardless of the use of an adhesive. One-way ANOVA demonstrated a significant difference in core fracture resistance using Amalgambond Plus over All-Bond 2 with no post. Also there was no significant difference in retention due to the depths of pulp chambers, which ranged from 3.0 - 5.5 mm. At no time was there a fracture of the tooth or root. This study demonstrates that with the use of an adhesive, there is a significant difference in the fracture resistance of the silver amalgam core and preformed posts. There is, however, no significant difference in the use of posts over silver amalgam cores.

Considerations for the aesthetic restoration of endodontically treated anterior teeth following intracoronal bleaching. *Rivera EM, Vargas M & Ricks-Williamson R (1997) *The Aesthetic Chronicle* 9 117-121.

(*University of Iowa, Department of Endodontics, Iowa City, IA 52242-1001)

The purpose of this article was to review the considerations that should be made when placing aesthetic restorations in the pulp chamber and access opening of endodontically treated teeth following intracoronal bleaching. Attention must be given to aesthetics, function, access preparation, remaining tooth structure, type of restorative material, minimization of microleakage, and prevention of iatrogenic perforation. The restorative material should protect the remaining tooth structure and minimize the chance of fracture. It has been demonstrated that the shear bond strength of composite resins to enamel and dentin is reduced after bleaching. This loss of bond strength may be transient and reversible following removal of the bleaching agent. Any debris or endodontic material left in the pulp chamber can potentially cause discoloration or a change in the translucency of the tooth. Careful attention should be given to removal of necrotic debris in pulp horns or residual blood products in access openings. Gutta-percha should be removed 2 mm to 3 mm below the level of the facial cementoenamel junction (CEJ) prior to bleaching. But this removal of gutta-percha necessitates the use of an intracoronal isolating barrier (base material) just apical to this level to afford protection to the root cementum and periodontal tissues from the caustic bleaching agents. Studies have found that

there is no one perfect barrier, and microleakage occurs with all materials.

The selection of restorative material may have an impact on potential discoloration. It is well established that the use of amalgam results in gray discoloration. Endodontic sealers, particularly those containing silver powder, may cause stains that are almost impossible to remove. New composite, resin-bonded and glass-ionomer restorative materials are used quite often. These materials also have demonstrated changes in color following exposure to bleaching agent. The possible need for endodontic retreatment and/or rebleaching dictates the use of a restorative material that is readily removable and easily differentiated from tooth structure. The authors recommend placing white gutta-percha material in the pulp chamber and a composite restoration in the access opening. Methods that avoid excessive removal of tooth structure and iatrogenic facial perforation must be used.

BOOK REVIEWS

OROFACIAL PAIN: GUIDELINES FOR ASSESSMENT, DIAGNOSIS, AND MANAGEMENT

Edited by Jeffrey P Okeson

Published by Quintessence Publishing Co, Inc, Chicago, 1996. 285 pages, 31 illustrations. $28.00, softbound.

This text is the result of three years of committee activity in the accumulation of the most current research and clinical documentation regarding orofacial pain disorders. The committee was formed because the AAOP felt the role of the clinician in the diagnosis and management of various orofacial pain problems has demanded a greater understanding of the anatomy, physiology, and pathology of the head and neck. The committee was chaired by Dr Jeffrey P Okeson, DMD, who is well known and respected internationally as an expert in the field of craniomandibular pain assessment, diagnosis, and treatment. Dr Okeson directs a pain center and master's program in facial pain, and instructs undergraduate dental students in this field at the University of Kentucky School of Dentistry. He has frequently presented information on this subject around the world. It is easy to recognize Dr Okeson's abundant qualifications to act as editor of this text.

The purpose of the text is stated as: "It is intended to give better insight to the assessment, diagnosis, and management of all pain conditions associated with the orofacial pain structures, and some areas, such as TMD, are presented in great detail to integrate new scientific information in this field."This book is a welcome addition to the knowledge base, especially if the clinician considers the outcomes from the May 1995 NIH Technology Assessment Conference held at NIH, which provided no defined protocols for the clinician to use in treating patients suffering with orofacial pain.

The introductory material provided in the text gives an excellent refresher in the anatomy, physiology, and clinical examination techniques used in the management of orofacial pain patients.

At this point it seems necessary to address the fact that there are very few figures and tables used in this publication, but it does not seem to suffer in presenting adequate information because of the small number of figures and tables, or the lack of illustrations. The figures and tables present appropriate, concise, factual, and adequate information to supplement the text. These figures and tables are supported by legends that provide clear and direct information to lead to complete understanding of the committee's intent.

After the presentation in the first two chapters (44 pages total) of the introductory material, examination techniques, and recommendation of diagnostic testing procedures for specific examination findings, the committee provides a very short but important chapter entitled "Diagnostic Classification of Orofacial Pain Disorders." This five-page section presents diagnostic classifications numbered by International Headache Society and AAOP systems. For the rest of the text, whenever possible, all conditions are referenced with these classification numbers and corresponding organization. In the chapter "Odontogenic Pain" the World Health Organization (WHO) "Classification of Injuries to the Teeth and Periodontium" system is presented and again referred back to in the text as appropriate topics are explained. The committee has made a significant contribution to clinicians in this field for easing their communication with each other and insurance carriers by arranging the information in this manner.

The remaining chapters in the book present material in a sequential manner on the topics of vascular and nonvascular intracranial disorders, primary headache, neuralgias, intraoral pain, TMD, referred pain, and mental disorders. The end of each chapter includes an exhaustive and current bibliography. In fact the TMD chapter has 742 citations alone.

One of the several jewels in this text is the 45-page glossary. This comprehensive section seems to include every term pertaining to this area of study and for that reason alone is worthy of mention. The last section of the glossary is titled "Unfavorable Terms,"

which includes terminology no longer recognized as state of the art and each of these "unfavorable" terms has a suggestion for a replacement term. This section offers considerable support for the production of written reports when necessary for orofacial pain patients.

In conclusion, the committee has produced a text that is a bulls-eye for their stated purpose and acknowledges that this work will need to be updated at frequent intervals because of the expansion of knowledge in the field of orofacial pain. Clinicians that treat and manage orofacial pain patients should not be without this text in their library, but beyond that, every clinician would benefit from this text as a reference to define and understand the issues in the treatment of orofacial pain.

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TOOTH-COLORED RESTORATIVES: AN INTRODUCTORY TEXT FOR SELECTING, PLACING AND FINISHING DIRECT SYSTEMS Eighth Edition

Harry F Albers

Published by Alto Books, Santa Rosa, CA, 1996. 336 pages, 300 illustrations. $94.00, softbound.

This text is an update in a series of editions. The first edition was published in 1980. Dr Albers has a wide range of credentials in restorative dentistry, which includes active involvement in clinical practice, education, and research. He has been a clinical study group director for more than 15 years, having directed over 500 dentists and 150 laboratory technicians, and is also the editor of the adhesive and cosmetic dentistry *Adept Report* newsletter.

Dr Albers' stated purpose in writing this book is to help the clinician understand the basics of how direct tooth-colored restorative materials work, which contributes to their appropriate clinical selection. Although this book would be excellent for use in the advanced clinical phases of undergraduate dental education, it may be more suited to graduate-level esthetic and restorative programs and also to general dentists in private practice. This book would also lend itself for use in study clubs as a valuable and up-to-date clinical technique resource on direct tooth-colored restoratives.

The black-and-white illustrations were done personally by Dr Albers and are of outstanding quality and easy to understand. A brief background in materials science is presented at the beginning of the text and approached with a special regard for clinical relevance. The chapter on diagnosis, which includes magnification, caries diagnosis, and clinical photography, presents a unique perspective, which updates traditional approaches. There is also special attention devoted to the etiology and diagnosis of cervical lesions. A definite strong point in this book and one of the most up-to-date sections is the material presented on glass-ionomer cements. The various formulations of glass-ionomer cements are categorized according to chemistry and physical properties along with clinical technique guidelines. Although brand names aren't mentioned very often, it is possible to determine how products fit into the category schemes from the tables and figures provided. It would be worthwhile to purchase this book just for this information on glass-ionomer cements. Extensive references are also listed at the end of the section and throughout the book.

The chapters devoted to composite resins contain information on visible light-curing units and a very thorough update on currently available dentin bond agents. Clinical techniques for cavity preparations are presented for class 3, 4, and 5 situations, along with descriptions for the proper position of the light-curing unit. Finishing of tooth-colored restoratives is explained from the perspective of both the "inherent" and "acquired" surface polish of these materials. The section on direct posterior restorations is approached logically starting with pit-and-fissure sealants, and progressing to preventive resin restorations and conservative class 2 cavity preparation applications. Based on extensive clinical observation, this text strongly recommends that posterior composite restorations be kept conservative and out of occlusal stress-bearing areas. Dr Albers presents advanced particle-beam technology (sandblasting) as a conservative and valuable adjunct to the caries diagnosis of stained pits and fissures.

In all regards, this text meets the stated objectives with a theme of practicality, and also effectively blends the "why" with the "how" for the practicing dentist. It is strongly recommended that this well-written text on direct tooth-colored restoratives become a part of your library.

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OPERATIVE PEARLS

Please submit your own wonderful, yet secret, tips for practicing at a higher level and/or comments regarding this section via FAX (206) 543-7783 or via e-mail to rmccoy@u.washington.edu.

MORE PROFOUND OR COMFORTABLE ANESTHESIA
Contributed by:
Dr Warren Johnson, Seattle, WA

For more profound anesthesia: With a tuberculin syringe remove 0.1 - 0.2 cc of hyaluronidase (Wydase) from a reconstituted vial. Take a carpule of anesthetic and inject the 0.1 - 0.2 cc of hyaluronidase into the carpule. The plunger will be partially extruded past the end of the carpule. This way one knows that that carpule has hyaluronidase in the solution. I use this method routinely for mandibular injections and hard-to-get-anesthetized areas in the maxilla.

For more comfortable anesthesia: Sodium bicarbonate may also be added to the anesthetic solution by the same method to reduce the stinging effect that the anesthetic solution has on some individuals. The use of a 30-gauge needle is also preferred.

CEMENT BASE MIXING AND PLACEMENT
Contributed by:
Dr Warren Johnson, Seattle, WA

Place liquid and powder for zinc phosphate on a glass slab or polycarboxylate powder and liquid on a mixing pad. Incorporate the powder into the liquid and mix to the consistency for cementation. Place a portion of the mixture to one side and with the remaining portion mix to the consistency of a base. With a Dycal applicator or an appropriate instrument, line the walls of the area, where the base is to be placed, with the thin cement mixture. Now place the base portion into the area where the cement liner was placed and pack firmly into place, making sure excess soft cement is expressed out at the periphery. Excess base may be removed at this time with a packing instrument, IPC, or any other suitable instrument. The preparation may now be completed to ideal dimensions.

HEMOSTATIC AGENT INGREDIENTS
Contributed by :
Dr Warren Johnson, Seattle, WA

To make one's own hemostatic agent for use in tissue retraction, mix the following ingredients for a 25% solution of aluminum chloride: 12.5 gm of aluminum chloride crystals with 50 cc of distilled water.

For an anesthetic hemostatic solution, mix 12.5 gm of aluminum chloride crystals with 50 cc of 4% lidocaine. This can be used to pack and retract tissue that has not been anesthetized, such as the palatal area, for greater patient comfort. (Taught by Dr Richard D Tucker)

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Department of Restorative Dentistry
Division of Dental Materials
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JULY-AUGUST 1998 • VOLUME 23 • NUMBER 4 • 161-216

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