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

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EDITORIAL

The Operative Academy's Relationship to Amalgam

The Academy of Operative Dentistry is enjoying its Silver Anniversary year. It seems appropriate to discuss silver restorative material from a position of support and appreciation for all it has done for the profession. Truly, there is no need to overstate the obvious benefits of silver amalgam; however, some of its characteristics certainly apply to the Academy at this time.

Amalgam is durable. The longevity of a restoration is dependent upon the one who creates it and the one who cares for it over time. Our founding fathers were truly inspired to do what they did! With sincere devotion and tireless energy, they went about the task of creating an organization that had the framework for success—just as they would have restored a tooth with an artfully crafted amalgam. As the benefactors of their labors, we who are the current members must care for what they have done for us so that we can ensure that the entity is useful and healthy for as long as possible. Without the founders, we would have nothing; we must be ever grateful for the service they provided for us. Oh, that our patients should feel the same gratitude for the restorations that we so carefully place!

Amalgam is also forgiving. It can be subjected to all sorts of abuses and still serve well. We all know that when we put a piece of our lives into a patient's mouth, we cannot be around forever to ensure that all is cared for as we know it should be. We must trust that the patients will not only care for themselves on a daily basis but that they will receive proper professional care from someone who is dedicated to the same principles of excellence as the ones who originated the restorations. Our founders have cared for their creation for twenty-five years. They have also allowed the Academy to be cared for by others; though their passions will never be equalled, their creation can serve well when properly cared for by others who share their dedication.

Amalgam has many more characteristics that are appropriate descriptions for the Academy: bright, strong, making a positive contribution to the lives of many people, providing maximum benefit that is rewarding for invested time, and being a lively topic for discussion among professionals—the list could go on.

But during this year, let us remember primarily durability and forgiveness, not ditching, creep, fracture, and marginal deterioration. We must be mindful of the potential presence of these problems but keep them at bay by proper care so that our silver can last another twenty-five years. Then, those members can discuss the Academy from a golden perspective during the fiftieth anniversary. Don't we all wish we will be there to see it happen?

JOEL M WAGONER
President
Academy of Operative Dentistry

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ORIGINAL ARTICLES

Effect of Desiccation on Microleakage of Five Class 5 Restorative Materials

M R BOUSCHLICHER • M A VARGAS • G E DENEHY

Clinical Relevance
Increased microleakage, following a period of desiccation corresponding to typical treatment times, indicates that clinicians need to protect previously placed restorations from undue drying during subsequent dental treatment.

SUMMARY

Resin-modified glass ionomers, combinations of resin and glass-ionomer chemistry, have resulted in materials with longer working times and command set by visible light activation. These materials are easier to use and more resistant to early moisture contamination and fracture. A glass-ionomer or resin-modified glass-ionomer restoration may be inadvertently desiccated by isolation of the same quadrant for subsequent restorative procedures. The present study is an assessment of the effects of desiccation on microleakage of three resin-modified glass-ionomers: Vitremer, Photac-Fil, Fuji II LC; a glass-ionomer, Ketac-Fil; and a microfill resin, Silux Plus. Fifty extracted molars were prepared with class 5 preparations buccal and lingual and randomly assigned to 10 groups (n=10). Restorations were placed according to the manufacturers' specifications and finished wet after the manufacturers' specified setting interval. All samples were thermocycled 300 cycles between 50 and 500 °C. Samples were stored in water at all times until the five groups to be desiccated were air dried and stored dry for 45 minutes. Desiccated groups were then rehydrated for 24 hours prior to $AgNO_3$ staining. Teeth were sectioned mesiodistally and four buccolingual sections (0.6 mm thick) through each class 5 restoration were obtained with a Silverstone-Taylor hard tissue microtome. Each section was scored on a scale of 0-4 for microleakage, and the highest score for dye penetration was used as the score for that restoration. An increase in microleakage was observed in all desiccated groups. Three materials showed a statistically significant increase in microleakage ($P < 0.05$) following desiccation. Microleakage increases following a brief period of desiccation corresponding to typical treatment times indicate that clinicians need to protect previously placed restorations from undue drying during subsequent dental treatment.

The University of Iowa, College of Dentistry, Department of Operative Dentistry, Iowa City, IA 52242

M R Bouschlicher, DDS, graduate student

M A Vargas, DDS, MS, assistant professor

G E Denehy, DDS, MS, professor

INTRODUCTION

Glass-ionomer cements possess certain physical and chemical characteristics that have made them attractive for clinical use. Advantages of glass-ionomer cements include fluoride release (Swartz, Phillips & Clark, 1984), potential cariostatic activity (Swift, 1989; Ingram & Donly, 1993), biocompatibility (Tobias & others, 1978), bond to enamel and dentin (Hotz & others, 1977), low setting shrinkage (McLean, 1992a), and a coefficient of thermal expansion similar to tooth structure (Hirota & others, 1988). When compared to composite resins, glass ionomers are unesthetic and difficult to use due to short

working times and extended setting times. During this extended setting time glass-ionomer cements undergo a complex setting reaction and are easily damaged by moisture or desiccation (Mount & Makinson, 1982; Walls, 1986; Wilson, 1989). Glass ionomers also have low flexural strength and low fracture toughness (Walls, 1986; Wilson, 1989). To overcome these disadvantages, several manufacturers have developed resin-modified glass ionomers, which have also been referred to as "resin ionomer restoratives," "hybrid-glass ionomers," or combinations of glass-ionomer cements and visible-light-activated composite resins.

These materials are not true combinations of glass ionomers and composite resins. In some formulations a small portion of the pendant carboxyl (-COOH) groups of the polyacrylic acid has been modified with isocyanatoethyl methacrylate, which introduces unsaturated (vinyl) groups pendant on the polymer backbone. As a result, the polyacrylic acid is less soluble in water, and to overcome this problem HEMA has been added as a co-solvent. Photoinitiators are added to the liquid. The unsaturated (vinyl) groups pendant on the polyacrylic acid backbone polymerize under the action of light and further cross-link the cement matrix, increasing rigidity and making it less prone to crazing. In addition HEMA, which has an unsaturated group, will polymerize and co-polymerize with the modified polyacrylic acid (McLean, 1992b).

Resin-modified glass ionomers have longer working times and command set when exposed to a curing light, which makes them easier to use and more resistant to early moisture contamination and fracture (Antonucci, 1988; Rusz & others, 1992). Resin-modified glass-ionomer studies have demonstrated bond strengths approximately twice as high as their chemical-cure correlates (McCaghren & others, 1990; Hinoura, Miyazaki & Onose, 1991; Mitra, 1991; Burgess & Burkett, 1993). Fluoride ion release (potential cariostatic activity) is present in resin-modified glass ionomers that have a classic glass-ionomer acid-base reaction, and the potential for releasing fluoride is equivalent to that of conventional glass-ionomer cements (Momoi & McCabe, 1993).

Desiccation of glass-ionomer cements must be avoided, as such desiccation can cause crazing, loss of translucency, and sometimes partial loss of material (Craig, 1993). Watson, Billington and Williams (1991), in a confocal optical microscope study of the interfacial region of the tooth/glass ionomer, noted that mature restorations subjected to desiccation may be severely stressed and compromised by the resultant shrinkage. Wilson and Paddon (1993) found that the contraction of glass-ionomer cements under desiccation conditions was far greater than the expansion by water absorption, although an increase in time of maturation of the restorative material reduced the extent of this contraction.

The current study evaluates the effects of desiccation on the microleakage of mature restorative materials. Three resin-modified glass-ionomer restorative materials, a glass ionomer, and a microfilled composite resin were compared for microleakage under hydrated conditions (undesiccated) versus a period of desiccation and subsequent rehydration.

METHODS AND MATERIALS

Fifty extracted human third molars stored at room temperature in 0.02% thymol were used for this study within 3 months of extraction. All teeth had at least two-thirds root formation. Teeth were hand scaled, cleaned with a water slurry of flour of pumice in a rubber prophylaxis cup at low speed, and examined for the presence of craze lines, cracks, restorations, or carious lesions that could have influenced dye penetration.

Standardized class 5 cavity preparations 3 mm wide, 2 mm high, and 2 mm deep were made on the buccal and lingual surfaces using constant water spray coolant and high speed #55 (ISO size number 008) carbide burs (five cavity preparations per bur). The preparations were located with half of the preparation on enamel and the other half below the cementoenamel junction. The cervical and occlusal cavosurface margins were finished to a 90° angle. The preparations were then randomly assigned to five groups of 20 each. The enamel cavosurface margin was beveled to a 45° and 0.5 mm width for the group of 20 preparations to be restored with microfilled resin.

Before any restorative procedure, the roots tips were sealed with GC Pattern Resin (GC America Inc, Chicago, IL 60658) (self-curing acrylic resin), and two coats of acid-resistant nail varnish were applied to within 1 mm of the margins of the restorations.

The teeth were restored using one of four restorative materials: Fuji II LC (GC America Inc), Vitremer (3M Dental Products, St Paul, MN 55144), Photac-Fil (ESPE-Premier, Norristown, PA 19404), Ketac-Fil (ESPE-Premier), or a microfilled composite resin with a dentin bonding agent: Scotchbond Multi-Purpose/Silux Plus (3M). The manufacturer's instructions were followed for each restorative material.

Group 1: GC Dentin Conditioner (10% polyacrylic acid) was applied for 20 seconds to the cavity preparation, rinsed with water for 30 seconds, and air dried for 5 seconds. Encapsulated Fuji II LC (shade A3) was triturated for 10 seconds at high speed using a Vari-Mix II amalgamator (L D Caulk/Dentsply, Milford, DE 19963). The material was

injected into the cavity preparation, avoiding the incorporation of air bubbles, the excess removed with a plastic instrument, and the material light cured for 40 seconds using an Optilux 401 visible-light activation unit (Demetron Research, Danbury, CT 06810).

Group 2: Vitremer Primer (3M Dental) (polyalkenoic polymer, HEMA, and ethanol) was applied to the cavity preparation for 30 seconds, then dried for 15 seconds to ensure complete solvent and water removal, and light cured for 20 seconds. Two scoops of Vitremer Powder (shade C2) and two drops of Vitremer Liquid were mixed within 45 seconds, loaded into a Centrix syringe (Centrix Inc, Shelton, CT 06484), and injected into the preparation. The excess material was removed and the restoration light cured for 40 seconds.

Group 3: Ketac Conditioner (ESPE-Premier) (25% polyacrylic acid) was applied to the cavity preparation for 10 seconds, rinsed with water for 30 seconds, and air dried for 5 seconds, avoiding desiccation. Photac-Fil Aplicap (ESPE-Premier) (shade A2) was triturated for 15 seconds at high speed and injected into the cavity preparation. The excess material was removed and the restoration light cured for 40 seconds.

Group 4: Ketac Conditioner (25% polyacrylic acid) was applied to the cavity preparation for 10 seconds, rinsed with water for 30 seconds, and air dried for 5 seconds, avoiding desiccation. Ketac-Fil Aplicap was triturated for 10 seconds at high speed and injected into the preparation; excess material was then removed with a plastic instrument. Ketac-Glaze was applied and light cured for 10 seconds immediately after contouring.

Group 5: Scotchbond Multi-Purpose Etchant (35% phosphoric acid) was applied to the cavity preparation for 15 seconds, rinsed with water for 30 seconds, and excess water removed with air, leaving a moist surface. Scotchbond Multi-Purpose Primer was applied to enamel/dentin and air dried for 5 seconds, leaving a shiny surface. Scotchbond Multi-Purpose Adhesive was applied to primed enamel/dentin, brush thinned, and light cured for 10 seconds. The cavity preparation was filled with Silux Plus (shade A2) in two increments, with the occlusal increment placed first. Each composite resin increment was light cured for 40 seconds.

After placement of restorative materials, all samples were stored in distilled water for 24 hours prior to finishing. The restorations were finished wet with #7901 carbide finishing burs and Sof-Lex XT Pop-On disks (3M) to a shiny, scratch-free surface. The samples were then stored in distilled water at 37°C for 5 days.

Samples were thermocycled 300 cycles between (50±5) °C and (5±5) °C with a dwell time of 30 seconds and a transfer time of 13 seconds.

Ten samples, randomly selected from each group, were air dried and left to dry to simulate the drying of the restoration in clinical situations (rubber dam isolation). After 45 minutes the samples were placed back in distilled water at 37°C and allowed to rehydrate for 24 hours before being immersed in a 50% by weight $AgNO_3$ solution for 2 hours in darkness. Following immersion, the samples were thoroughly rinsed for 5 minutes in running distilled water and then developed in a Microdol-X solution (Eastman Kodak Company, Rochester, NY 14650). The Microdol-X solution was periodically agitated, and supplemental light was applied for an 8-hour treatment interval. Following treatment with Microdol-X, the samples were again rinsed in running distilled water to eliminate any residues.

Each tooth was sectioned mesiodistally and each half was then sectioned buccolingually through the class 5 restoration with a Silverstone-Taylor hard tissue microtome, resulting in four buccolingual sections 0.6 mm thick. End sections that were intersected by the mesial or distal cavity wall where the restorative material measured less than 2 mm in axial extent (the full axial extent of the restoration was not represented in the section) were not scored, for the extent of microleakage could not be accurately scored using these measurements, or would have resulted in more extreme scores in teeth that had a cervical cross-sectional morphology that required more divergence in the mesial and distal cavity walls to maintain a 90° cavosurface angle. The resulting sections allowed multiple surface scoring of dye penetration. The highest score from the multiple sections for a given restoration was chosen as an indicator of the greatest extent of ingress.

The sections were examined under X40 magnification, and the extent of dye penetration was measured according to the following rank scores from the cavosurface margin along the gingival and axial walls:

0 = No evidence of dye penetration;

1 = Dye penetration extending less than or up to one-third of the cavity depth;

2 = Dye penetration extending greater than one-third the cavity depth but less than or up to two-thirds the cavity depth;

3 = Dye penetration greater than two-thirds of the cavity depth but not extending beyond the junction of the gingival and axial wall; and

4 = Penetration involving the axial wall.

The restoration section showing the greatest extent of dye penetration was used to establish the leakage score of that restoration.

The results were analyzed by the Kruskal-Wallis one-way analysis of variance by ranks. The

Table 1. Summary of Microleakage Scores

Group	Material	Condition	Degree of Marginal Leakage					Total Restorations
			0	1	2	3	4	
1	Fuji II LC	control	2	5	2	1	0	10
		desiccated	0	6	0	2	1	9*
2	Vitremer	control	0	10	0	0	0	10
		desiccated	0	4	5	1	0	10
3	Photac-Fil	control	0	6	2	1	1	10
		desiccated	0	0	2	6	2	10
4	Ketac-Fil	control	1	2	0	7	0	10
		desiccated	0	0	3	2	5	10
5	Silux Plus	control	0	9	1	0	0	10
		desiccated	0	4	4	1	1	10

*lost sample

Wilcoxon rank sum test was used as a Wilcoxon 2-Sample Test to compare control groups with desiccated groups for each of the five restorative materials.

RESULTS

No leakage was observed from the enamel margins in either the desiccated or control groups. All groups displayed degrees of microleakage at the gingival margins. The results of the dye penetration from the gingival margins of the specimens are reported in Table 1.

The results were analyzed by the Kruskal-Wallis one-way analysis of variance by ranks. Comparisons of the 10 groups showed a significant difference at the 0.0001 level. The Wilcoxon rank sum test was used as a Wilcoxon 2-Sample Test between control and desiccated groups for each restorative material. A trend toward higher microleakage scores was observed in all desiccated groups when compared to undesiccated controls. Groups 2 (Vitremer), 3 (Photac-Fil) and 5 (Silux Plus) showed statistically significant increases in microleakage scores following desiccation, $P < 0.05$. Microleakage scores were not significantly different between control and desiccated treatment in Groups 1 (Fuji II LC) and 4 (Ketac-Fil). Table 2 shows the proportion of restorations that had microleakage scores > 1.

DISCUSSION

Following placement of glass ionomer or resin-modified glass ionomer, the clinician needs to be concerned with subsequent procedures performed in the same arch where isolation, resulting in a sustained period of desiccation, may have deleterious effects such as increased microleakage, especially if a relatively short time span has elapsed between appointments.

Resin-modified glass-ionomer restorations placed in individuals who are mouth breathers may be expected to function clinically in a relatively desiccated state. Since this type of material is often advocated for restoration of class 5 and class 3 carious lesions, one would question the degree of hydration of the restorative material necessary to maintain good marginal seal.

The present study was conducted on samples that had been placed 1 week prior to thermocycling and 2 weeks prior to the 45-minute period of desiccation that preceded $AgNO_3$ immersion. The proportion of tightly bound or nonevaporable water contained in the glass-ionomer matrix has been shown to progressively increase with time. The proportion of loosely held water in the glass-ionomer matrix, which decreases with increasing maturation of the glass ionomer, increases the magnitude of volumetric shrinkage in desiccated samples. Hornsby (1980) found a linear relationship between water loss (%) and volumetric shrinkage (%), linear to approximately 5% water loss, with deviations from linearity becoming more pronounced with samples of greater maturity. Cements of increasing age have greater dimensional stability, due to their progressive hydration and concurrent development of matrix strength. Wilson and Paddon (1993) found that contraction of

Table 2. Proportions of Restorations with Microleakage Score > 1

Group	Material	Condition	
		Control	Desiccated
1	Fuji II LC	0.30	0.33*
2	Vitremer**	0.00	0.60
3	Photac-Fil**	0.40	1.00
4	Ketac-Fil	0.70	1.00
5	Silux Plus**	0.10	0.70

*lost sample
**statistically significant differences between control and desiccated group; $P < 0.05$

glass-ionomer cements under desiccating conditions was far greater than the expansion by water sorption. Increased maturation time for glass-ionomer cements reduced markedly the extent of this effect.

Mount (1990) states that if a new restoration, less than 6 months old, is to be exposed to desiccation for longer than a few minutes, it is desirable to protect it with an unfilled resin. After 6 months, the cement is generally mature enough to withstand such stress. It could then be expected that the glass-ionomer cement would display higher microleakage after desiccation because of water loss from the loosely bound water component of a relatively immature restoration. Less than half the initial drying shrinkage in glass-ionomer cements is recoverable on subsequent resaturation, a possible consequence of enhanced cross-linking in the matrix during the desiccation period (Hornsby, 1980). Since initial contraction due to evaporation may occur at a different rate than the expansion resulting from water sorption, the 24-hour period selected for resaturation may have had an effect on the degree of microleakage observed.

We did not anticipate any effect with the microfilled composite, but it also showed increased microleakage. Since microfills have a higher matrix content, they are more susceptible to water sorption, and this hygroscopic expansion serves to relax polymerization contraction stresses (Feilzer, de Gee & Davidson, 1990). Desiccation may reverse this stress relaxation and open any previously existing polymerization contraction gaps. Koike and others (1990) evaluated volume change of microfilled composite caused by water sorption on adaptation to the dentin cavity wall. An initial contraction gap in microfills placed without dentin bonding was closed completely by water sorption in 48 hours. Light-cured microfilled restorations placed with dentin bonding agents were more resistant to polymerization shrinkage marginal gap formation initially; this gap was closed rapidly by storage in water, and no marginal gap could be observed by light microscopy. Marginal seal may have been adversely affected by desiccation shrinkage in the composite as well as the glass-ionomer materials and marginal seal, or lack of a contraction gap is not equivalent to bonding. If contraction under desiccating conditions disrupts the bond at the cervical margin or is far greater than the expansion by water absorption, as in glass ionomers (Wilson & Paddon, 1993), there could be a resultant increase in microleakage. Torstenson and Brännström (1988) studied hygroscopic expansion effects on contraction gaps by utilizing compressed air to remove fluid from the marginal gap prior to impregnating the gap with resin containing a fluorescent dye. Microfilled composites stored in water for 2 to 3 weeks showed considerable reduction in width of the gap at the cervical wall. The current study used a similar technique to air dry the desiccated samples at the start of the 45-minute period of desiccation of the experimental groups. The 24-hour period of water sorption subsequent to desiccation and prior to dye immersion may have been insufficient for the hygroscopic effect to close a possible marginal gap that existed prior to desiccation and increased in dimension following desiccation.

The extent of microleakage increases in the current in vitro study may be due to the more extreme desiccation of the surrounding dentin than would occur in the typical clinical situation with a vital pulp present to help maintain dentin hydration. Although the magnitude of the effect of desiccation on microleakage may have been due in part to desiccation of dentin, significant differences occurred between groups of materials . Fuji II LC did not show a significant difference between the control and desiccated groups. Vitremer and Photac-Fil, resin-modified glass ionomers, and Silux Plus, a microfill resin, demonstrated statistically significant increases ($P < 0.05$). Ketac-Fil, a glass ionomer, which had the highest proportion of restorations with microleakage scores > 1 for the desiccated and undesiccated groups combined, did not show a significant difference between the two conditions, a possible ceiling effect due to the high leakage scores present in the undesiccated control. Fuji II LC, which had lower microleakage scores initially, also failed to demonstrate a significant increase in microleakage with desiccation.

Future studies could address the possible relationship between rehydration time following desiccation and degree of microleakage. The current study indicates that increased microleakage scores with several types of restorative materials can result if samples are inadvertently desiccated prior to dye immersion. It is imperative that all treatment groups in microleakage studies be stored in a hydrated condition and handled in a like fashion unless desiccation is a variable.

CONCLUSIONS

Increased microleakage, following a period of desiccation corresponding to typical treatment times, indicates that clinicians need to protect previously placed restorations from undue drying during subsequent dental treatment. Correct treatment sequencing and/or selective isolation of teeth to be treated should be treatment considerations to avoid desiccation of glass ionomers or resin-modified glass ionomers placed in the previous 6 months.

Fuji II LC did not show a significant difference

between the control and desiccated groups. Vitremer, Photac-Fil, and Silux Plus demonstrated statistically significant increases ($P < 0.05$) in microleakage following desiccation. Ketac-Fil had the highest proportion of microleakage scores > 1 for desiccated and control groups, and although there was a trend for desiccation to increase microleakage further, it was not statistically significant.

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Effect of Triturator Speed Variation on Physical Properties of Encapsulated Glass-Ionomer Luting Cements

D C RUPP • C B HERMESCH • D G CHARLTON

Clinical Relevance
Decreased mixing speed prolongs working and setting times of glass-ionomer luting cements.

SUMMARY

This in vitro study evaluated the effect of variation of triturator mixing speed on the physical properties of two encapsulated glass-ionomer luting cements. Physical properties evaluated were working time, setting time, film thickness, and 24-hour and 7-day compressive strengths. Encapsulated glass-ionomer luting cements were mixed at 3000, 3500, 4000 (control), and 4500 cycles per minute (cpm). An oscillating rheometer was used to determine working and setting times. Film thickness and compressive strength were determined using methods described in ANSI/ADA Specification No 66 for dental glass-ionomer cements. Results of the study indicated that decreased mixing speed may prolong working and setting times for Ketac-Cem Maxicap and Fuji Cap I. Within the range of 3500 to 4500 cpm, variations in mixing speed do not significantly affect compressive strength or film thickness values for either cement. Excessively slow mixing speed (3000 cpm) often resulted in the presence of unmixed powder expressed from the capsule nozzle prior to the expression of mixed cement. The presence of this unmixed powder results in a decreased powder/liquid ratio, which may have an adverse effect on the physical properties of the set cement.

Wilford Hall Medical Center, Lackland AFB, TX 78236-5551

David C Rupp, Lt Col, USAF, DC, resident, Department of General Dentistry

Charles B Hermesch, Colonel, USAF, DC, chief, Dental Research

David G Charlton, Lt Col, USAF, DC, officer-in-charge, Materials Evaluation, Dental Investigation Service, Brooks AFB, TX 78235-5117

INTRODUCTION

Encapsulated glass-ionomer luting cements mixed in a dental triturator are designed to produce consistent, homogenous mixes in a convenient and efficient manner. However, obtaining an acceptable mix with encapsulated cements depends on proper triturator performance.

Triturators have been shown to exhibit significant variations in their mixing speed (DuBois, Haisch & Rinne, 1982; Brackett, 1985; Schultz, Modjean & Hampel, 1986). Dubois and others (1982) evaluated 40 5-year-old triturators of the same type and found that their mixing speed at the medium setting had increased by an average of 38% from the expected speed of 3600 cycles per minute (cpm). Brackett (1985), in a study of several brands of triturators, reported that mixing speed can vary with line

voltage, age of the triturator, and weight of the capsule. Although some new triturators were able to compensate for changes in capsule weight and line voltage, older variable speed units could not, and generally exhibited greater variations in speed. In a study of 10 calibrated and 10 uncalibrated 8-year-old triturators of the same type, Schultz and others (1986) reported that no triturator could perform within ±200 cpm of the manufacturer's stated speed of 3600 cpm. Recalibrated triturators had a range from 2580 to 4200 cpm, while uncalibrated triturators ranged from 1800 to 4220 cpm.

The effect of triturator speed on encapsulated glass-ionomer cements has been studied. Bass and Wing (1988) noted that both mixing time and triturator oscillation speed can affect the working time of a glass-ionomer restorative material. Gee and Pearson (1993) reported that variation in mixing speed had little effect on the mechanical properties of some encapsulated glass-ionomer restorative materials. However, the tolerance of encapsulated glass-ionomer luting agents for variations in triturator speed is unknown and requires study. It is conceivable that wide variations in triturator speed observed in clinical practice may affect important physical properties such as working time, setting time, film thickness, and compressive strength. The purpose of this study was to determine if variation in triturator mixing speed affects the working time, setting time, film thickness, and 24-hour and 7-day compressive strengths of encapsulated glass-ionomer luting cements.

METHODS AND MATERIALS

Two encapsulated glass-ionomer luting agents, Ketac-Cem Maxicap (ESPE GmBh, Seefeld, Germany) and Fuji Cap I (GC Dental Corporation, Tokyo, Japan) were investigated. The manufacturers of these products recommend that they be mixed in a high-speed triturator at 4000 cpm for 10 seconds.

Mixing of Specimens

Immediately prior to activation, each capsule was tapped several times on its base to displace any powder that may have been present in the dispensing tip. After activation according to manufacturer's instructions, the capsules were placed in a triturator for mixing. The triturator used in this study was a Kerr Automix Computerized Mixing System (Kerr Mfg Co,Romulus, MI 48174) that had been specially modified by the manufacturer to achieve a maximum speed of 4500 cpm. All capsules were mixed at room temperature (23 ± 2 °C) for 10 seconds. The mixing speeds used were 3000 cpm, 3500 cpm, 4000 cpm (control), and 4500 cpm. These represented triturator mixing speed variations of -25%, -12.5%, and +12.5% from the recommended speed (4000 cpm), an expected range for triturators in clinical use. The desired mixing speed was verified during each mix with a stroboscope (Strobotac, Model 631-BL, General Radio Co, Cambridge, MA 02138). The Automix triturator was found to be extremely accurate because it incorporates internal electronic feedback circuitry, which automatically corrects variations in oscillation frequency. The line voltage to the triturator was held at a constant 120 volts by using a variable transformer (Powerstat Variable Autotransformer, Superior Electric Co, Bristol, CT 06010).

Working Time

Working time was determined using an oscillating rheometer (Sabri Enterprises, Inc, Downers Grove, IL 60515). Immediately after mixing, the cement material was placed on the lower platen of the rheometer, and the upper platen was lowered into position so the thickness of cement between the two platens was 1.0 mm. The cement was allowed to set and the setting reaction tracing was evaluated to determine working time. The rheometer's chart recorder voltage range selector was set at 1 volt, and the temperature of the platens was maintained at 23 ± 1 °C throughout the test run. A sample size of six was used for each group.

Setting Time

Setting time was also determined by using an oscillating rheometer. Two minutes after the start of mixing, the cement material was placed on the lower platen and the upper platen lowered into position so the thickness of cement between the two platens was 1.0 mm. The cement was allowed to set, and the tracing was evaluated to determine setting time. The chart recorder's voltage range selector was set at 2 volts, and the temperature of the platens was maintained at 37 ± 1 °C throughout the test run. A sample size of six was used for each group.

Film Thickness

Film thickness was determined using the methods described in ANSI/ADA Specification No 66 for dental glass-ionomer cements. Two optically flat glass plates with an approximate contact area of 200 mm^2 were stacked and their combined thickness was measured with a micrometer (Mitutoyo Corp, Tokyo, Japan) to an accuracy of ±1 micron. Immediately after mixing, a small amount of cement was placed over the center of one plate, and the second plate was placed centrally over the first plate. Two

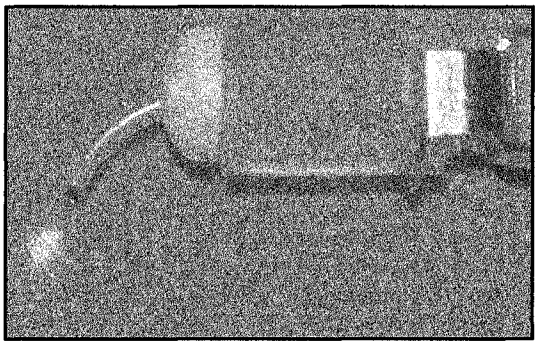

Figure 1. *Unmixed powder expressed from a Ketac-Cem Maxicap capsule*

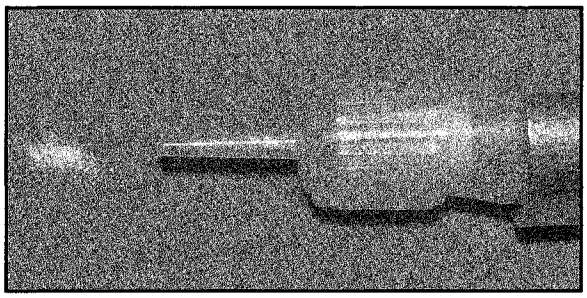

Figure 2. *Unmixed powder expressed from a Fuji Cap I capsule*

minutes after the start of mixing, a 15 kg load was placed vertically on the top plate. Ten minutes after the start of mixing, the load was removed and the plates were examined to ensure cement completely filled the space between the glass plates. The overall thickness of the cement film and the glass plates was measured to an accuracy of ±1 micron, and the cement film thickness was calculated by determining the difference between the two measurements. A sample size of six was used for each group.

Table 1. Mean Working Times of Glass-Ionomer Luting Cements (Seconds)

	Ketac-Cem Maxicap		Fuji Cap I	
Mixing Speed	**Mean**	**SD**	**Mean**	**SD**
3000 cpm	244.8	24.6	239.3	11.1
3500 cpm	217.5	25.0	242.5	13.6
4000 cpm	207.5	12.9	229.0	11.1
4500 cpm	186.5	19.5	218.8	6.9

Means connected by vertical lines are not significantly different at the 0.05 probability level; N = 6.

Compressive Strength

Compressive strength specimens were made using the methods described in ANSI/ADA Specification No 66 except for the size of specimens, which calls for molds 12 mm x 6 mm. Two stainless steel plates and a stainless steel split mold with internal dimensions of 8 ± 0.1 mm in height and 4 ± 0.1 mm in diameter were fabricated. The internal surfaces of the split mold and the top and bottom plates were evenly coated with a thin layer of silicone lubricant (Buehler Ltd, Lake Bluff, IL 60044). The entire mold assembly was preconditioned to 23 ± 1 °C. In order to have enough material to fill the specimen mold, it was necessary with Fuji Cap I to mix two capsules sequentially and incorporate the mixes together. The mixes were loaded in a placement syringe (Mark IIIp Speed Slot, Centrix Inc, Shelton, CT 06484) and injected into the split mold that had been placed on one of the plates. After the mold had been completely filled, the second metal plate was placed on top of the split mold, and the entire assembly was placed in an oven maintained at 37 ± 1 °C and 100% humidity within 3 minutes of the start of mixing. The mold assembly was removed from the oven 60 ± 5 minutes after the start of mixing. The structure of this assembly precluded the chance that ambient air could contact the external surface of the specimens. The endplates were removed, and the ends of the specimen were ground flat using 320-grit silicon carbide abrasive paper. The specimen was then removed from the mold and examined for air voids or chipped edges. Defective specimens were discarded. Acceptable specimens were immersed in distilled water maintained at 37 ± 1 °C until testing. Compressive strengths were determined at either 24 hours or 7 days. Immediately prior to testing, the diameters of the cement cylinders were calculated by taking the mean of four measurements. Two measurements, each to an accuracy of ±0.01 mm, were made at the end of each specimen at right angles to each other. The compressive strengths of the specimens were measured using a testing machine (Tinius Olsen, series 1000, Tinius Olsen Machine Co, Inc, Willow Grove, PA 19090) with a crosshead speed of 1.0 mm/min. A sample size of six per group was used.

Unmixed Powder

While dispensing the mixed cement from some of the capsules, it was observed that unmixed powder was expressed from the tip of the capsule nozzle prior to the expression of mixed cement (Figures 1 and 2). In an attempt to determine if this phenomenon was related to mixing speed, the incidence was recorded. A sample size of 12 was used for each group.

RESULTS

The mean working time values are presented in Table 1. A two-way ANOVA (mixing speed and cement brand) revealed significant main effects and a significant interaction between mixing speed and cement brand. *Interaction*, a statistical term, refers to the differing effect that mixing speed has on working time based on the different glass-ionomer brands. Because of the interaction, no attempt was made to further compare Ketac-Cem Maxicap to Fuji Cap I with regard to working time. One-way ANOVAs and Tukey multiple comparison tests at the 0.05 significance level were then performed within each cement brand to determine the effect of mixing speed on working time. For Ketac-Cem Maxicap the working time at 3000 cpm was significantly longer than the working times at 4000 and 4500 cpm ($P \leq 0.05$). For Fuji Cap I the working times at 3000 and 3500 cpm were significantly longer than the working time at 4500 cpm ($P \leq 0.05$).

Table 2. Mean Setting Times of Glass-Ionomer Luting Cements (Seconds)

	Ketac-Cem Maxicap		Fuji Cap I	
Mixing Speed	**Mean**	**SD**	**Mean**	**SD**
3000 cpm	305.4	24.2	366.8	33.4
3500 cpm	333.2	14.7	315.2	17.2
4000 cpm	307.2	19.8	300.1	9.3
4500 cpm	273.9	9.3	308.3	7.2

Means connected by vertical lines are not significantly different at the 0.05 probability level; N = 6.

Table 3. Mean Film Thicknesses of Glass-Ionomer Luting Cements (Microns)

	Ketac-Cem Maxicap		Fuji Cap I	
Mixing Speed	**Mean**	**SD**	**Mean**	**SD**
3000 cpm	28.0	7.1	46.2	4.6
3500 cpm	24.5	8.7	37.0	3.2
4000 cpm	21.3	2.7	39.3	4.9
4500 cpm	24.3	3.9	36.2	2.2

Means connected by vertical lines are not significantly different at the 0.05 probability level; N = 6.

Mean setting time values are listed in Table 2. A two-way ANOVA (mixing speed and cement brand) showed significant main effects and a significant interaction between mixing speed and cement brand. Due to the interaction, no attempt was made to further compare Ketac-Cem Maxicap to Fuji Cap I with regard to setting time. One-way ANOVAs and Tukey multiple comparison tests at the 0.05 significance level were then performed within each cement brand to determine the effect of mixing speed on setting time. The setting time for Ketac-Cem Maxicap at 4500 cpm was significantly shorter than the setting times for the other mixing speeds ($P \leq 0.05$). For Fuji Cap I the setting times at 3500, 4000, and 4500 cpm were significantly shorter than the setting time at 3000 cpm ($P \leq 0.01$).

Mean film thickness values are reported in Table 3. The mean film thickness for Ketac-Cem Maxicap ranged from 21.3 to 28.0 microns and for Fuji Cap I from 36.2 to 46.2 microns. A two-way ANOVA performed at the 0.05 significance level revealed that film thickness was significantly affected by mixing speed and cement brand. There was no significant interaction between mixing speed and cement brand. A Tukey multiple comparison test at the 0.05 significance level was then performed. There were no statistically significant differences in film thickness for Ketac-Cem Maxicap at the different mixing speeds. For the Fuji Cap I groups, the film thickness at 3000 cpm was significantly greater than the film thickness at 4500 cpm ($P \leq 0.05$).

The results for 24-hour and 7-day

Table 4. Mean Compressive Strengths of Glass-Ionomer Luting Cements (MPa)

	Ketac-Cem Maxicap 24 hours		Ketac-Cem Maxicap 7 days		Fuji Cap I 24 hours		Fuji Cap I 7 days	
Mixing Speed	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
3000 cpm	132.05	5.18	141.83	18.56	126.21	9.75	141.61	23.63
3500 cpm	123.26	12.08	138.28	9.72	156.14	13.14	151.02	8.59
4000 cpm	116.42	9.49	143.08	14.73	153.02	7.97	151.13	23.89
4500 cpm	122.04	9.27	139.77	15.23	155.37	12.94	158.56	19.96

Means connected by vertical lines are not significantly different at the 0.05 probability level; N = 6.

compressive strengths are listed in Table 4. In comparing mixing speed versus cement brand at 24 hours, a two-way ANOVA was performed and revealed significant main effects and a significant interaction. Due to the interaction, comparisons for compressive strengths at 24 hours between Ketac-Cem Maxicap and Fuji Cap I were not appropriate. One-way ANOVAs followed by a Tukey multiple comparison test at the 0.05 significance level were then performed on the 24-hour data to determine the effect of speed variation within each brand. For Ketac-Cem Maxicap there were no statistically significant differences in 24-hour compressive strengths between various mixing speeds. Significant differences between 24-hour compressive strengths were found for Fuji Cap I with the compressive strength at 3000 cpm significantly lower than the compressive strengths at 3500, 4000, and 4500 cpm ($P \leq 0.01$).

The 7-day compressive strength data for Ketac-Cem Maxicap and Fuji Cap I were also evaluated using a two-way ANOVA at the 0.05 significance level to determine the effects of mixing speed and cement brand. No significant main effects or interaction between brand and speed were found at 7 days. There were no statistically significant differences for the 7-day compressive strengths for either Ketac-Cem Maxicap or Fuji Cap I.

The incidence of unmixed powder expressed from the capsules at the beginning of dispensing is presented in Table 5. At 3000 cpm, 50% of Ketac-Cem Maxicap capsules and 66.7% of Fuji Cap I capsules had unmixed powder expressed during dispensing. At 3500 cpm, 8.3% of Ketac-Cem Maxicap capsules and 16.7% of Fuji Cap I capsules exhibited this phenomenon. Unmixed powder was not found in either brand at speeds of 4000 and 4500 cpm.

Table 5. Number of Capsules with Unmixed Powder Expressed at the Beginning of Cement Dispensing (N = 12)

	Ketac-Cem Maxicap		Fuji Cap I	
Mixing Speed	**Number**	**%**	**Number**	**%**
3000 cpm	6	50	8	66.7
3500 cpm	1	8.3	2	16.7
4000 cpm	0	0	0	0
4500 cpm	0	0	0	0

DISCUSSION

The triturator used in this study was the Automix Computerized Mixing System manufactured by Kerr. With this triturator, mixing speed and time can be set manually by programming specific oscillation speeds in cycles per minute and mixing times in seconds. The Automix proved to be extremely reliable in maintaining accurate mixing speeds and times during this study.

Care was taken prior to mixing each capsule to ensure all powder and liquid was available for mixing. Following manufacturer's instructions, each Fuji Cap I capsule was lightly tapped, prior to activation, with the dispensing nozzle upward to dislodge any powder in the nozzle. Ketac-Cem Maxicap capsules were activated using 4 seconds of pressure on the activator lever to ensure all liquid was expressed from the internal foil pouch. In spite of these efforts, unmixed powder was often initially expressed from the capsules immediately prior to the expression of mixed cement. The presence of this unmixed powder was associated with mixing speed. At low mixing speeds (i e, 3000 cpm), residual powder was expressed from two-thirds of the Fuji Cap I capsules and from one-half of the Ketac-Cem Maxicap capsules. At mixing speeds of 4000 and 4500 cpm, residual powder was not expressed from any capsule. It appears that at low mixing speed, inadequate energy is applied to the capsule to incorporate all the available powder into the mix. Bass and Wing (1988) have previously reported the production of unsatisfactory mixes at low mixing speeds with an encapsulated glass-ionomer restorative material.

If unmixed powder is present, the resulting cement has a lower powder/liquid ratio. Decreased powder/liquid ratio can have significant effects on the clinical behavior of glass-ionomer luting agents (Wilson & others, 1977; Crisp, Lewis & Wilson, 1976; Christensen & Muir, 1987; Smith & Ruse, 1986). Decreased powder/liquid ratios can also result in decreased compressive strength (Wilson & others, 1977; Crisp & others, 1976; Christensen & Muir, 1987), longer working and setting times (Crisp & others, 1976), increased post cementation pulpal sensitivity (Council on Dental Materials, Instruments, and Equipment, 1984; Smith & Ruse, 1986), decreased film thickness (Wilson & others, 1977; Christensen & Muir, 1987), and increased solubility (Crisp & others, 1976). Many of the findings of the present study may be due to decreased powder/liquid ratios caused by low mixing speed.

Mixing speed affects the working time of Ketac-Cem Maxicap and Fuji Cap I. Both brands generally exhibited shorter working times with increased mixing speed. The working time of Ketac-Cem Maxicap at 3000 cpm was almost 60 seconds longer than the working time at 4500 cpm. The working times for Fuji Cap I at 3000 cpm and 3500 cpm were

only 20 to 25 seconds longer than the working time at 4500 cpm. The working times for Ketac-Cem Maxicap and Fuji Cap I, as determined in the present study, are all longer than their manufacturer's claimed working times of 180 seconds for Ketac-Cem Maxicap and 150 seconds for Fuji Cap I.

Consideration must be given to the fact that the working time as determined by an oscillating rheometer may not be an accurate reflection of clinical working time, because it is based on a change in viscosity of the mix. Some authors (Gee & Pearson, 1993; White & Yu, 1993) believe that the loss of free surface acid or "loss of gloss" is a practical method to determine clinical working time. This loss of free acid on the surface may decrease the adhesion between the glass-ionomer cement and the tooth surface. In the present study, loss of gloss occurred approximately 2 minutes after the start of mixing and did not appear to be affected by mixing speed. Loss of gloss consistently occurred before the end of working time as determined by the oscillating rheometer. This is not in agreement with the findings of Bass and Wing (1988), who noted that loss of gloss was affected by changes in mixing speed of a glass-ionomer restorative material.

Variation in mixing speed affected setting time for Ketac-Cem Maxicap and Fuji Cap I. Decreased mixing speed resulted in longer setting times for both brands. As with working time, this finding is not in agreement with results found for restorative glass-ionomer materials (Gee & Pearson, 1993). Setting times for Ketac-Cem Maxicap ranged from approximately 274 to 333 seconds, which are much shorter than the manufacturer's purported setting time (420 seconds). Fuji Cap I setting times ranged from approximately 300 to 367 seconds, which are close to the manufacturer's claimed setting time of 330 seconds. Setting times for Fuji Cap I are not significantly affected by mixing speeds from 3500 to 4500 cpm.

Decreased working and setting times observed with increased mixing speed may be the result of a more thorough mixing of powder and liquid at higher speeds, which results in a faster chemical reaction. Increased mixing speed may also increase the temperature of the mix and increase the rate of reaction. These mechanisms may be responsible for the shorter working and setting times found when mixing speeds of 4000 and 4500 cpm were used where all the powder appeared to be incorporated into the mix. Improper powder/liquid ratios, as indicated by unmixed powder, may also contribute to longer working and setting times at very low mixing speeds.

Film thickness for Ketac-Cem Maxicap was not significantly affected by the mixing speeds used in this study. The majority of the film thickness values for Ketac-Cem Maxicap are below the ADA/ANSI specification requirement of 25 microns. Film thickness values for Fuji Cap I were all greater than 25 microns. Similar findings for hand-mixed Fuji luting cements have been reported (McComb, Sirisko & Brown, 1984; Finger, 1983). Film thickness of Fuji Cap I mixed at 3000 cpm was significantly greater than when the cement was mixed at 4500 cpm. With the increased presence of unmixed powder observed at 3000 cpm and the resultant decreased powder/liquid ratio, lower film thickness would be expected. In the present study the opposite is seen. Two mechanisms, acting alone or in combination, may explain this increased film thickness. Inadequate mixing speed may result merely in surface wetting and inadequate dissolution of the powder granules. Alternatively, lower mixing speed may not impart sufficient energy to the cement powder particles to break them down into smaller particles, which would promote lower film thickness values.

The compressive strength values for Ketac-Cem Maxicap and Fuji Cap I are comparable to values reported in other studies (McComb & others, 1984; Finger, 1983; White & Yu, 1993). Variation in mixing speed does not appear to affect the compressive strength of Ketac-Cem Maxicap at either 24 hours or 7 days. Although 50% of Ketac-Cem Maxicap capsules mixed at 3000 cpm exhibited unmixed powder, this did not affect the compressive strength when compared to higher mixing speeds.

Compressive strength for Fuji Cap I was affected only at the 3000 cpm mixing speed. At 24 hours, the compressive strength for Fuji Cap I mixed at 3000 cpm was significantly lower than the values for higher mixing speeds. At 7 days, although not statistically significant, the mean compressive strength at 3000 cpm was lower than the mean values at higher mixing speeds. These lower compressive strength values at 24 hours and 7 days can probably be attributed to the incomplete powder incorporation at a mixing speed of 3000 cpm.

Overall, mixing speed variations in the range of -25% to +12.5% of the recommended speed have little effect on the compressive strength and film thickness of Ketac-Cem Maxicap. Increased mixing speed generally results in shorter working and setting times for this cement. These same trends were observed for Fuji Cap I except when the cement was mixed at the lowest mixing speed. Mixing Fuji Cap I at low speeds often results in incomplete powder incorporation, which significantly reduces compressive strength and prolongs setting time.

CONCLUSIONS

It is not uncommon to find that triturators exhibit significant variations from their purported mixing

speeds. Because of the widespread use of encapsulated glass-ionomer products, it is important to determine if these variations have an effect on the physical properties of glass-ionomer materials. This study found that variations of -12.5% to +12.5% from the manufacturers' recommended mixing speed for Ketac-Cem Maxicap and Fuji Cap I glass-ionomer luting agents do not significantly affect their compressive strengths or film thicknesses. Decreased mixing speed, however, prolongs their working and setting times. The presence of unmixed powder is a clinical indicator of an excessively slow mixing speed.

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Surface Roughness of Light-activated Glass-Ionomer Cement Restorative Materials after Finishing

H A ST GERMAIN, Jr • J C MEIERS

Clinical Relevance
The surface left by a Mylar strip provides the best surface for light-activated glass-ionomer cement materials; however, if additional finishing is required, either ET finishing diamonds or a series of Sof-Lex disks will provide the smoothest surface.

SUMMARY

The purpose of this study was to compare the effect of various finishing sequences on the surface roughness of four new light-activated (LAGIC) restorative materials. Restorative materials included a polyacid-modified composite resin (Variglass VLC) and three resin-modified glass-ionomer cements (Vitremer, Photac-fil, and Fuji II LC). Thirty specimens of each material were prepared in Macor dies and randomly divided into six finishing sequence groups (n=5): (1) Mylar strip (control), (2) carbide bur/Sof-Lex XT disks, (3) ET finishing diamonds, (4) carbide bur/Enhance polishing system, (5) carbide bur/Politip rubber finishers, and (6) carbide bur alone.

Average surface roughness (R_a) in micrometers was measured with a Mitutoyo Surftest 401 Surface Roughness Tester and the data compared using ANOVA, Student-Newman-Keuls Multiple Comparison tests, and Dunnett's test at $P \leq 0.05$. Surface topography was also assessed using the scanning electron microscope (SEM) on epoxy replicas from samples of each group.

The Mylar strip produced the smoothest surface and finishing sequences; (2) and (3) were significantly smoother than (4), (5), and (6). There were no significant differences between restorative materials when all finishing sequences were combined. SEM analysis was consistent with the profilometer results. Materials with higher (R_a) values appeared to have rougher surfaces. Rubber abrasives and polishing pastes seem to preferentially remove the polysalt and resin matrix of these materials.

University of Nebraska Medical Center, College of Dentistry, Section of Operative Dentistry, Department of Adult Restorative Dentistry, 40th and Holdrege Streets, Lincoln, NE 68583-0740

Henry A St Germain, Jr, DMD, MSD, MEd, director

Jonathan C Meiers, DMS, MS, director, Materials Testing & Evaluation, NDRI Detachment, National Naval Dental Center, Naval Dental School, Bethesda, MD 20889-5602

INTRODUCTION

The use of glass-ionomer cement as a restorative material has increased significantly since its introduction to the dental profession in the early 1970s (Wilson & Kent, 1972; McLean, 1988). Favorable characteristics and properties such as adhesion to tooth structure, fluoride release, compatible coefficient of thermal expansion, and a proven clinical track record of biocompatibility and clinical longevity has contributed to the popularity of this material (Matis & others, 1991; Croll, 1992; *The Dental Advisor*, 1990).

New restorative materials that combine the chemistry of both glass-ionomer cements and light-

activated composite resins have recently been developed to improve the toughness of conventional glass-ionomer cement materials, while retaining their favorable physical properties (Wilson, 1990). These new materials are less brittle and have lower solubility, while maintaining fluoride release and adhesion to tooth structure. Also there may be less sensitivity to dessication, surface crazing may be minimized, and finishing may commence immediately after light activation (Wilson, 1990; Mathis & Ferracane, 1989; Christensen, 1993).

McLean, Nicholson, and Wilson (1994) have described two additional categories of materials to help classify the similarities and differences in currently available light-activated glass-ionomer cement (LAGIC) products. In addition to the traditional glass-ionomer cements, they have recommended that one category be referred to as resin-modified glass-ionomer materials, which have a significant acid-base reaction in the setting reaction and will set without exposure to visible light. Materials that do not have an acid-base reaction and will not set unless exposed to a visible light source are referred to as polyacid-modified composite resins.

In general, finishing sequences similar to those recommended for both composite resin and glass-ionomer cement have been suggested for these new LAGIC restorative materials (Sturdevant & others, 1995; Baum, Phillips & Lund, 1995; *The Dental Advisor Plus*, 1992). Established clinical procedures for finishing composite resins include multi-fluted carbide burs, fine-grit diamonds, and various disk systems to contour and remove gross excess. Carbide hand instruments or a #12 scalpel blade may also be used for margination. Final polishing is achieved with fine disks, rubber abrasive points, or a sequence of polishing pastes (Sturdevant & others, 1995; Baum & others, 1995; Jordan, 1993). With traditional glass-ionomer cements, the finishing sequence has been referred to as "a consideration of damage limitation" (Council on Dental Materials, Instruments, and Equipment, 1990). Ideally, hand instrumentation alone should be used to marginate the restoration, but if contouring is required, disks or micron finishing diamonds used in a wet field with a final polish of aluminum oxide polishing paste is recommended (Sturdevant & others, 1995; Baum & others, 1995). The use of special protective varnishes or unfilled resin bond agents may also be used as a final protective measure (Espe-Premier, 1991; McLean, 1992). Laboratory research on the finishability of composite resins and traditional glass-ionomer cements have used surface roughness (R_a) measurements and SEM photomicrographs to categorize various finishing sequences. It is conceded that the best surface is obtained by that left by the Mylar strip (Sturdevant & others, 1995; Baum & others, 1995). If the surface of a composite resin restoration has to be instrumented, the smoothest surface resulted from the use of a series of abrasive aluminum oxide disks and extra-fine finishing diamonds, according to one in vitro study (Pratten & Johnson, 1988). In the case of glass-ionomer cements it has been found that disks, either sandpaper/cuttle or a sequence of Sof-Lex disks (3M Dental Products, St Paul, MN 55144), provided the best finish (Eide & Tveit, 1990).

There is minimal independent laboratory research currently available and a lack of long-term clinical performance data to help select an appropriate finishing sequence for this new category of LAGIC restorative materials. Manufacturers' recommendations for individual products vary and do not reach a consensus opinion on a single, most desirable finishing sequence. Investigations are currently ongoing, and a recent laboratory study evaluated the surface roughness of various Type II visible-light-cured glass-ionomer cements and concluded that a sequence of microfine diamonds created a significantly smoother surface on these materials than did a series of aluminum oxide disks (Johnson & Fasbinder, 1995).

The purpose of this study was to compare a variety of finishing sequences on a representative group of currently available LAGIC restorative materials using a profilometer and the scanning electron microscope.

METHODS AND MATERIALS

Seventy-two Macor squares (19 mm x 19 mm x 4 mm) (Macor-Corning machinable glass ceramic, Wesgo/Duramic Precision Engineered Ceramics, Fairfield, NJ 07004) were fabricated as molds for the placement and finishing of the light-activated glass-ionomer cement (LAGIC) materials. A 6.25 mm carbide drill bit was used to prepare two standardized cylindrical preparations 2 mm deep in each of the Macor molds. The 6.25 mm x 2 mm cylindrical preparations were centered approximately 5 mm from the edge of the mold to facilitate finishing procedures with the dental handpiece. Eighteen molds with two cylindrical preparations were used for each of the restorative materials.

Materials used in this study were a polyacid-modified composite resin restorative material: Variglass (L D Caulk), and three resin-modified glass-ionomer restorative materials (Vitremer, 3M); Photac-fil (Espe-Premier, Norristown, PA 19404; and Fuji II LC (GC America, Inc, Chicago, IL 60658). Powder and liquid components were used, with the exception of Photac-fil, which was used in precapsulated form. The materials were mixed according to the manufacturers' recommendations,

syringed into the cylindrical preparations with a slight overfill, covered with a 0.002" Mylar matrix strip (Du Pont polyethylene terephthalate matrix, Union Broach Corporation, Division of Moyco Industries, Emigsville, PA 17318) pressed flat with a microscopic glass slide and light activated with The Max Lite (L D Caulk) for a total of 60 seconds. The Max Lite intensity was checked before each sample run using a Demetron 100 curing radiometer (Demetron Research Corp, Danbury, CT 06810). Immediately after the light-activation cycle, the molds were placed in 37 °C deionized water for 24 hours.

The specimens were finished using each of the following finishing sequences (n=5/sequence) performed in a randomized manner: **(1)** The restorative material was left undisturbed after the removal of the Mylar strip (control); **(2)** A 12-fluted carbide bur (#7901, Sybron/Midwest, Des Plaines, IL 60018) in a high-speed handpiece with water spray followed by a sequential series of three (medium, fine, and superfine) Sof-Lex XT disks; **(3)** 25 μ and 15 μ ET finishing diamonds (Brasseler USA, Inc, Savannah, GA 31419) in a high-speed handpiece with water spray; **(4)** a 12-fluted carbide bur in a high-speed handpiece with water spray followed by the Enhance finishing and polishing system (L D Caulk); **(5)** a 12-fluted carbide bur in a high-speed handpiece with water spray followed by the series of Politip-F (gray) and Politip-P (green) silicone rubber finishers (Ivoclar North America, Amherst, NY 14228); and **(6)** a 12-fluted carbide bur in a high-speed handpiece with water spray. All specimens were kept wet during the finishing sequences and were stored in 37 °C deionized water for at least 24 hours prior to surface roughness readings.

Average surface roughness (R_a) of the control and finished specimens was measured using a Mitutoyo Surftest-401 Surface Roughness Tester (Mitutoyo Corporation, Tokyo, Japan). Three separate measurements of (R_a), each parallel to the others and perpendicular to the finishing direction and edge of the mold, were made for each specimen surface. Specimens with a (R_a) closest to the mean were prepared using a replica model technique by making a polyvinylsiloxane impression (Extrude, Sybron/Kerr, Glendora, CA 91740) of the original specimen and using an epoxy die material (Epoxy-Die, Ivoclar North America). Replicas were sputter coated with gold (SPI-Module sputter coater, SPI Supplies, Division of Structure Probe, Inc, West Chester, PA 19381) and examined using a JEOL JSM-5300 Scanning Electron Microscope (JEOL LTD, Tokyo, Japan). Photomicrographs at a dual magnification of X500 and X2000 were taken at a 55-degree tilt to facilitate surface topography comparisons.

(R_a) data were subjected to a one-way ANOVA at a significance level of $P < 0.05$. If the ANOVA indicated significant differences, Student-Newman-Keul's Multiple Comparison tests were performed to determine the significant group comparisons. Additionally, a Dunnett's test was performed using the Mylar strip group as the control versus the various finishing techniques for each material (Glantz, 1992).

Table 1. Comparisons of the Average Surface Roughness (R_a) Data among Restorative Materials within Each Finishing Sequence

Surface Roughness (R_a) in Micrometers (mean ± SD)*

	(1)	(2)	(3)	(4)	(5)	(6)
Va	0.64 ± 0.33	1.05 ± 0.27	0.91 ± 0.37	1.50 ± 0.30	3.41 ± 1.32	4.79 ± 1.47
Vi	1.26 ± 0.46	1.44 ± 0.70	1.45 ± 0.55	1.95 ± 0.81	4.02 ± 0.92	3.74 ± 1.22
PF	0.70 ± 0.29	1.25 ± 0.60	1.20 ± 0.43	2.12 ± 0.66	3.03 ± 0.85	2.64 ± 0.66
F	0.72 ± 0.29	1.51 ± 0.35	1.70 ± 0.90	2.60 ± 0.30	2.79 ± 1.05	2.82 ± 0.84

*Vertical lines with brackets connect means that are not significantly different at $P \leq 0.05$.

Materials

Va: Variglass
Vi: Vitremer
PF: Photac-fil
F: Fuji II LC

Finishing Methods

1. Mylar strip
2. Carbide bur/Sof-Lex XT disks
3. ET finishing diamonds
4. Carbide bur/Enhance polishing system
5. Carbide bur/Politip rubber finishers
6. Carbide bur

Table 2. Comparisons of the Average Surface Roughness (R_a) Data among Finishing Sequences within Each Restorative Material

Surface Roughness (R_a) in Micrometers (mean± SD)*

	Variglass	Vitremer	Photac-fil	Fuji II LC
1.	0.64 ± 0.33	1.26 ± 0.46	0.70 ± 0.29	0.72 ± 0.29
2.	1.05 ± 0.27	1.44 ± 0.70	1.25 ± 0.60	1.51 ± 0.35
3.	0.91 ± 0.37	1.45 ± 0.55	1.20 ± 0.43	1.70 ± 0.90
4.	1.50 ± 0.30	1.95 ± 0.81	2.12 ± 0.66	2.60 ± 0.30
5.	3.41 ± 1.32	4.02 ± 0.92	3.03 ± 0.85	2.79 ± 1.05
6.	4.79 ± 1.47	3.74 ± 1.22	2.64 ± 0.66	2.82 ± 0.84

*Vertical lines with brackets connect means that are not significantly different at $P \leq 0.05$.

Finishing Methods

1. Mylar strip
2. Carbide bur/Sof-Lex XT disks
3. ET finishing diamonds
4. Carbide bur/Enhance polishing system
5. Carbide bur/Politip rubber finishers
6. Carbide bur

RESULTS

Average surface roughness (R_a) values of the LAGIC materials obtained with the statistically significant groupings are provided in Tables 1 and 2. There were no significant differences in (R_a) of the restorative material groups when all finishing sequences were combined as shown in Figure 1.

Figure 2 displays the cumulative (R_a) data for all LAGIC materials combined within each finishing sequence. The Mylar strip control group (finishing sequence 1) had the lowest cumulative (R_a) value and was significantly different from all of the other finishing sequences (Figure 4). Finishing sequences 2 and 3, carbide bur/Sof-Lex XT disks (Figure 5) and ET finishing diamonds respectively, produced a similar and significantly smoother surface than the other finishing sequences. Finishing sequence 6 (carbide bur) had the highest cumulative (R_a) value and was statistically similar to sequence 5 (carbide bur/Politip rubber finishers) (Figure 6). Higher (R_a) appeared to correlate with a rougher surface topography on SEM evaluation. There appeared to be a preferential removal of the polysalt and resin matrix with finishing sequences having higher (R_a) values.

Comparisons of the (R_a) data between LAGIC materials within each finishing sequence are presented in Table 1 and Figure 3.

Comparisons of the (R_a) data between finishing sequences within each restorative material group were also made and are presented in Figure 3. The individual data and significant intergroup finishing sequence comparisons are shown in Table 2.

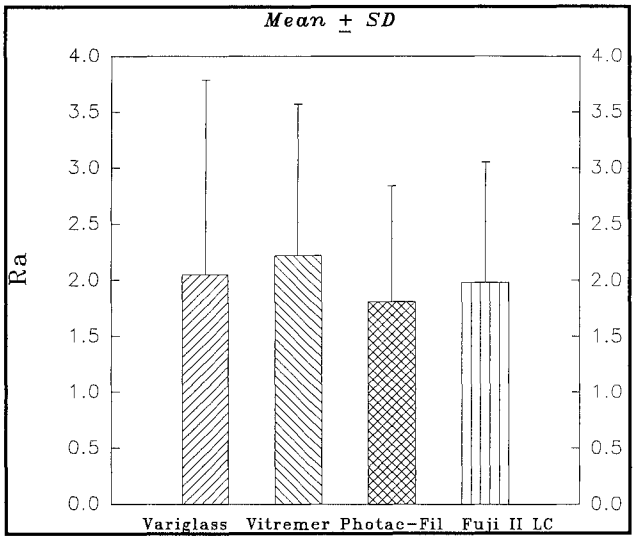

Figure 1. *Surface roughness (R_a) values combining all finishing sequences within each restorative material*

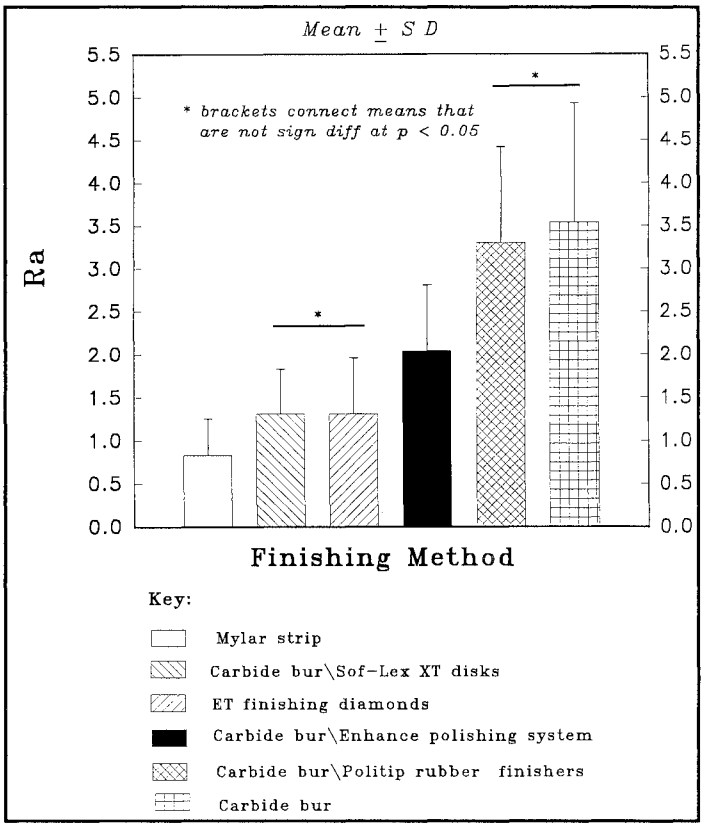

Figure 2. *Surface roughness (R_a) values combining all restorative materials within each finishing sequence*

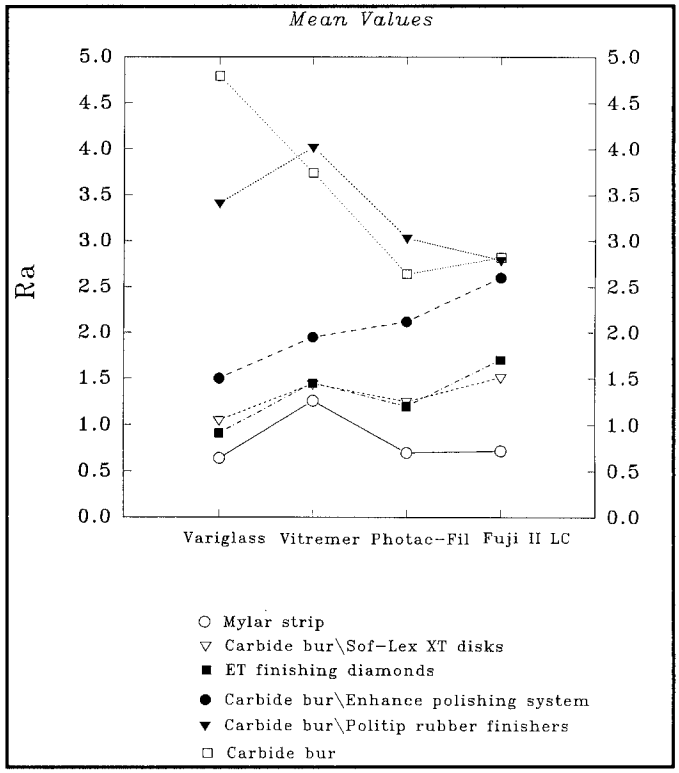

Figure 3. *Surface roughness (R_a) values for each restorative material within each finishing sequence*

DISCUSSION

The results of this study indicate that for the LAGIC materials tested none of the various finishing sequences could reproduce the smoothness of the surface initially created by a Mylar strip (Figure 4). This observation is consistent with similarly designed laboratory studies that compared the Mylar strip to various finishing sequences for composite resin, glass-ionomer cement, and LAGIC materials

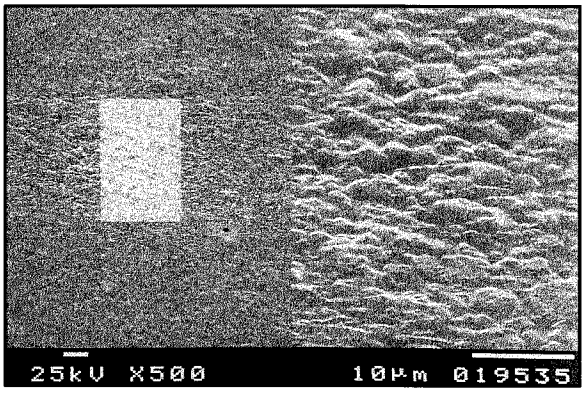

Figure 4. *SEM of Photac-fil after removal of the Mylar strip (X250 and X1000 dual photomicrograph)*

(Pratten & Johnson, 1988; Johnson & Fasbinder, 1995; Eide & Tveit, 1990; Horton & others, 1977; Knibbs & Pearson, 1984; Dennison, Fan & Powers, 1981). Our data indicated that although there were similarities among the test materials with the Mylar strip surface, Vitremer had a significantly higher (R_a) value than the other LAGIC materials. This observation may possibly be the result of surface crazing due to dessication after removal of the Mylar strip. Whether this inherent higher surface roughness would be a disadvantage clinically is unknown; however, the manufacturer does suggest the placement of an unfilled resin as an option to maximize esthetics.

The smoothest surface produced for all LAGIC materials when a finishing sequence was performed was that achieved by a carbide bur/Sof-Lex XT sequence (Figure 5) or ET finishing diamonds. Figure 5 was also representative of the appearance of the ET finishing diamond sequence and shows a rougher appearance than the Mylar strip in Figure 4. The carbide bur/Sof-Lex XT sequence produced the most consistent intergroup LAGIC material (R_a)

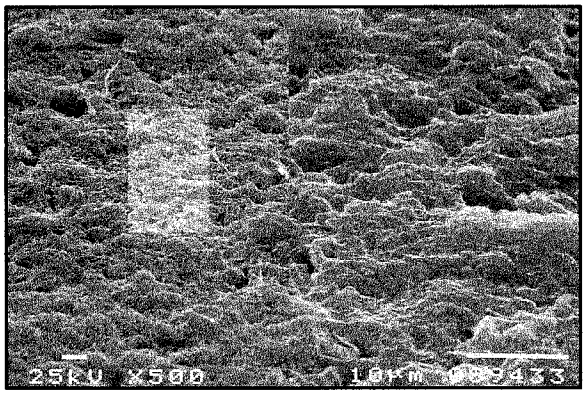

Figure 5. *SEM of Photac-fil finished with the carbide bur/Sof-Lex XT disk sequence (X250 and X1000 dual photomicrograph)*

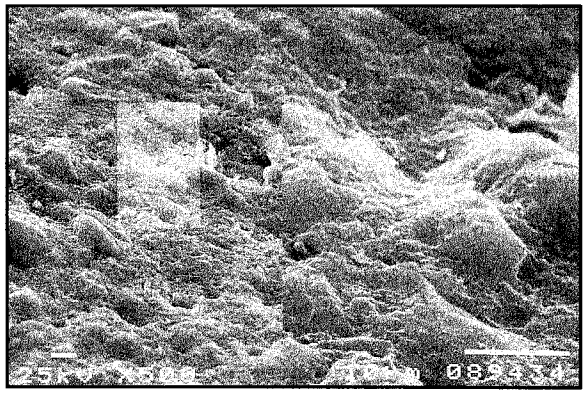

Figure 6. *SEM of Photac-fil finished with the carbide bur/Politip rubber finisher sequence (X250 and X1000 dual photomicrograph)*

values. This observation is consistent with other in vitro and clinical observations on various finishing techniques for composite resin, glass-ionomer cement, and LAGIC materials (Pratten & Johnson, 1988; Horton & others, 1977; Mount, 1993; Eide & Tveit, 1990). An exception, however, was a study done by Johnson and Fasbinder (1995), in which a sequence of microfine diamonds produced a significantly smoother surface than aluminum oxide disks on both LAGIC materials and traditional glass-ionomer cements. In our study, a carbide bur was used initially to simulate a contouring or premargination process and was followed by the series of Sof-Lex XT disks, and this may have been a factor in the ability of the disks to produce a smoother final surface.

The higher (R_a) values obtained with the carbide bur/Enhance finishing sequence may have been due to the inability of the proprietary rubber disk abrasive or polishing pastes to remove the surface scratches created by the carbide bur. Jeffries and others (1989) looked at the effect of 1 μ aluminum oxide polishing pastes after initial finishing by Sof-Lex disks, and found that the polishing pastes when used with a porous synthetic foam pad improved the (R_a) of some of the materials. It may be that the rubber abrasive and polishing pastes preferentially abrade the softer polysalt and resin matrix and have a minimal effect on the filler particles with these LAGIC materials.

Finishing sequences that used carbide bur/Politip rubber finishers (Figure 6) or just the carbide bur alone produced the highest (R_a) values for all of the LAGIC materials. The Politip rubber finishers did not improve significantly the surface left by the carbide bur, with the exception of Variglass. Figure 6 appears rougher than Figures 4 and 5 and shows that there is a more aggressive removal of the polysalt and resin matrix with the aluminofluorosilicate filler particles visibly protruding from the surface. This observation is similar to previously reported results for composite resins and glass-ionomer cements. Rubber abrasives have been reported to leave a rough, matte surface and do not effectively contour composite resin restorations; however, Vivadent rubber abrasive finishers have been shown to be capable of producing a surface smoothness similar to that produced by the Sof-Lex disks (Wilson, Heath & Watts, 1990; Northeast & van Noort, 1988; Stoddard & Johnson, 1991). Another study evaluating finishing sequences for glass-ionomer cement indicated that a rubber abrasive polishing cup had no effect on the surface left by an Arkansas stone and was significantly rougher than the surface left by a sequence of Sof-Lex disks (Eide & Tveit, 1990). The Politip rubber finishers were primarily designed for the final polishing of composite resin materials, and therefore they may not be suitable for finishing traditional glass-ionomer cements or the new LAGIC materials. Studies have also indicated that a 12-fluted carbide bur produces a rough surface and may damage the surface of composite resins and especially adversely affect microfilled resins (Lutz, Setcos & Phillips, 1983; Boghosian, Randolph & Jekkals, 1987; Herrgott, Ziemiecki & Dennison, 1989).

There were no significant differences in (R_a) among LAGIC materials when all finishing sequences were combined. Therefore we cannot recommend a certain finishing sequence that was particularly effective for an individual LAGIC material (Figure 1). Although manufacturers provide differing recommendations for finishing their own restorative materials, the efficacy of following a different finishing sequence for each LAGIC restorative material in clinical practice may be questionable. The effect of a variety of other available finishing sequences should be investigated with these LAGIC materials and compared with the results of this study.

The results from this in vitro study only correlate to the clinical situations where there are accessible and relatively flat surfaces. When finishing complex surfaces with limited access, the effectiveness of the finishing sequences may be different, and future laboratory studies should attempt to simulate concave and convex surfaces.

CONCLUSIONS

Profilometer and SEM analysis of currently available light-activated glass-ionomer cement (LAGIC) restorative materials indicated that the surface left by the Mylar strip provided the smoothest surface.

However, if these materials require additional finishing, a carbide bur/disk sequence or a sequence of finishing diamonds will produce the next best surface, with the carbide bur/disk sequence providing the most consistent (R_a) values for all LAGIC materials. Surface topography generally correlated with (R_a) values, with rougher-appearing materials having higher (R_a) values. As the surface roughness of these LAGIC materials increased, there appeared to be a more aggressive removal of the matrix material than the filler particles.

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Influence of Bonded Amalgam Restorations on the Fracture Strength of Teeth

J P OLIVEIRA • M A COCHRAN • B K MOORE

Clinical Relevance
Bonding dental amalgam to tooth structure with resin adhesives may provide an increase in fracture resistance to the restored tooth.

SUMMARY

This study evaluated the effect of bonded amalgam on the fracture strength of teeth using five adhesive systems: Panavia 21, Amalgambond Plus, Imperva Dual Bond, All-Bond 2 Primer/Bonding Resin, and All-Bond 2 Primer/Liner F. Intact teeth and amalgam lined with Copalite were used as control groups. Large MOD preparations were made in 20 extracted maxillary premolars for each group. The teeth were restored with Tytin. All groups were stored in water at 37 °C for 15 days and thermocycled 2500 times, over 8-48 °C. The specimens were preloaded five times in compression to 10 kg using a 5 mm-in-diameter, cylindrical steel indenter that contacted the teeth only on the cuspal inclines. Then the teeth were loaded to failure at 5.0 mm/min. The failure mode was recorded (amalgam failure, cusp fracture, or failure at the tooth/amalgam interface). The mean fracture strengths were analyzed using ANOVA and Newman-Keuls multiple comparisons.

The Imperva Dual Bond group showed the highest mean forces followed by All-Bond 2 Primer/Bonding Resin. The All-Bond 2 Primer/Liner F and Amalgambond Plus groups demonstrated lower means and were not significantly different from the Copalite group. The Panavia 21 group was in between these two groups and was not statistically different from either group. The mean strength of intact teeth was the highest, but its very large coefficient of variation (60%) prevented effective use of these data for statistical comparison.

Analysis of the mode of fracture showed that Panavia 21, All-Bond 2 Primer/Bonding Resin, and Amalgambond Plus failed cohesively in the amalgam in 35%, 25%, and 15% of the specimens respectively. This fracture type is a good indication of effective bonding between tooth and amalgam. The most common type of fracture for all the restored groups was the one that occurred at the tooth/restoration interface. This would suggest that current bonding procedures could be improved.

Indiana University School of Dentistry, Department of Restorative Dentistry, 1121 West Michigan Street, Indianapolis, IN 46202-5186

José P Oliveira, DDS, MSD, graduate student in Operative Dentistry

Michael A Cochran, DDS, MSD, professor and director, Graduate Operative Dentistry

B Keith Moore, PhD, professor and director, Graduate Dental Materials

INTRODUCTION

One of the disadvantages of a large amalgam restoration is the fact that dental amalgam does not bond to tooth structure and hence will not reinforce or strengthen the remaining tooth structure in a

significantly compromised tooth. In fact, the need to place mechanical retention for the amalgam often results in further weakening of the remaining tooth structure (Mondelli & others, 1980; El-Sherif & others, 1988). The development of successful dentin and enamel bonding agents has resulted in widespread acceptance of the bonded resin restoration. It has been demonstrated that a bonded class 2 resin restoration will actually strengthen the restored tooth (Share, Mishell & Nathanson, 1982; Landy & Simonsen, 1984).

Recently, resin bonding agents have been introduced to provide an adhesive interface between tooth structure and dental amalgam. Laboratory tests have demonstrated that these adhesive systems will reduce microleakage and form retentive bonds to amalgam (Saiku, St Germain & Meiers, 1993; Staninec & Holt, 1988; Staninec, 1989; Lacy & Staninec, 1989; Cooley, Tseng & Barkmeier, 1991). Another study has suggested that the use of an adhesive resin liner beneath an amalgam restoration might increase the fracture resistance of the restored tooth (Eakle, Staninec & Lacy, 1992), although a similar study (Santos & Meiers, 1994) did not yield positive results.

The objective of this study was to investigate the influence of a number of different amalgam bonding agents on the fracture resistance of teeth containing large MOD restorations.

METHODS AND MATERIALS

The five commercial resin amalgam adhesives shown in Table 1 were employed in this study. Two control groups were also prepared: one with intact teeth and a second with amalgam restorations lined with copal varnish. A sample size of 20 per group was employed.

One hundred and forty, defect-free, extracted human maxillary premolars were collected from the clinics within the school of dentistry. These teeth were stored in 10% formalin immediately after extraction. The teeth were rinsed, then immersed in a hypochlorite solution, and any external debris was removed with a sonic scaler (Titan Sonic Scaler, Sintex Dental Products Inc, Valley Forge, PA 19482). After cleaning the teeth were stored in water at 8 °C. The roots of the teeth were embedded up to the cementoenamel junction in acrylic tray resin cylinders 1.5 cm in diameter with the cusp tips aligned in the same plane to ensure a more equal distribution of the load during testing. The teeth were divided into seven groups and stored in water at 37 °C. One group was marked as the intact positive control and the other six groups were prepared and restored in the following manner.

Table 1. Materials Used in the Study

Group	Adhesive	Manufacturer
PAN	Panavia 21	Kuraray Co, Osaka, Japan
AMB	Amalgambond Plus	Parkell, Farmingdale, NY 11735
IMP	Imperva Dual Bond	Shofu, Menlo Park, CA 94025
AB2	All-Bond 2	Bisco, Itasca, IL 60143
ABF	All-Bond & Liner-F	Bisco
COP	Copalite Varnish (control)	Cooley & Cooley, Ltd, Houston, TX 77041
intact	none (control)	

Cavity Preparation

Large MOD cavity preparations were made using a 245 bur (Brassler USA, Savannah, GA 31419) in a high-speed handpiece with air/water spray. A new bur was employed for each 10 teeth. The size of the preparation was made proportional to the dimensions of the tooth to minimize variations resulting from tooth size (Figure 1):

- The occlusal isthmus had a facial-lingual width of 1/3 of the distance between cusp tips.
- The box floor depth was 2/3 of the mean height of the cusps above the cementoenamel junction.
- The facial-lingual width of the approximal boxes was 1/3 of the maximum facial-lingual width of the tooth.
- The floor of the approximal box was established 1 mm above the cementoenamel junction.

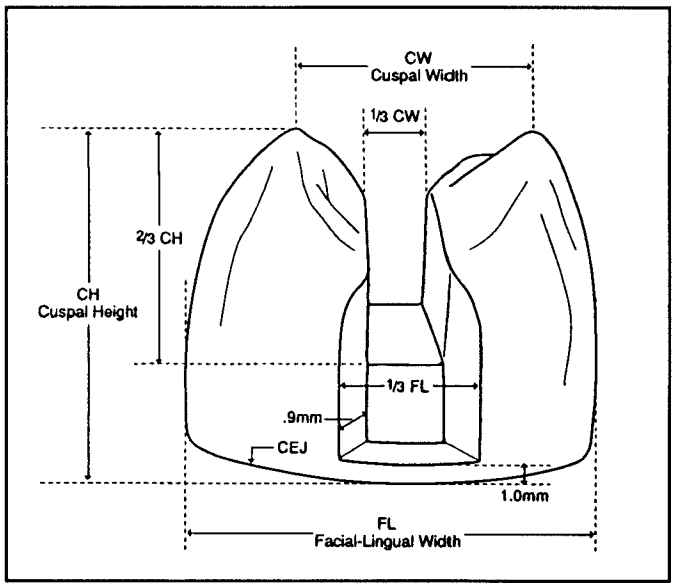

Figure 1. *Tooth preparation parameters*

• The approximal box depth (mesial-distal) was 0.9mm.
• All internal line angles were rounded, and no additional mechanical retention was cut.

Liner Application and Restoration with Amalgam

The cavity walls of specimens in the negative control group were lined with two coats of Copalite cavity varnish (Cooley & Cooley, Ltd, Houston, TX 77041) prior to amalgam placement.

The cavity walls of specimens in the remaining groups were coated with one of the five adhesive liner systems prior to amalgam placement. The adhesive systems were Panavia 21 (Kuraray Co, Osaka, Japan), Amalgambond Plus (Parkell Bio-Materials Division, Farmingdale, NY 11735), Imperva Dual Bond (Shofu Dental Corp, Menlo Park, CA 94025), All-Bond 2 Primer/Bonding Resin (Bisco Inc, Itasca, IL 60143) and All-Bond 2 Primer/Liner F. Application of all materials followed the manufacturers' instructions for dispensing, mixing, and placement, and the recommended times for each procedure were monitored by stopwatch.

Each tooth was restored immediately following adhesive application with a spherical single-composition high-copper precapsulated alloy, Tytin (800 mg regular set batch # 31132 Kerr/Sybron Mfg Co, Romulus, MI 48174). A metal No 1 Adult Universal matrix band was placed in a Tofflemire matrix retainer (Teledyne Getz, Elk Grove Village, IL 60007) and positioned on the tooth. The amalgam was triturated with a Kerr Automix Computerized Mixing System, Model No 23425 (Kerr). Trituration time and speed followed the manufacturer's recommendations (3570 rpm for 6.8 seconds). The plastic amalgam was hand condensed into the cavity while the adhesive liners were still wet (unset). The matrix band was removed and the restoration carved and finished to the original margins and anatomy. The exact techniques utilized for each adhesive material were as follows:

Panavia 21: One drop of each ED primer, Liquid A and Liquid B, was dispensed into a mixing well and mixed for 3 to 5 seconds. The mixture was applied to dentin and enamel simultaneously with a sponge pledget. After 60 seconds a gentle stream of air was blown into the cavity. The Panavia 21 catalyst and universal pastes were dispensed by slowly rotating the syringe knob one full turn clockwise until it clicked. The pastes were mixed thoroughly and brushed onto the entire cavity surface previously primed. After amalgam condensation and carving, Oxigard II was applied over the margins for 3 minutes and removed with a cotton roll and water spray. Any small excess of set paste was removed at this time.

Amalgambond Plus: Dentin Activator was dispensed into a mixing well, applied to the enamel and dentin walls for 30 seconds, and then rinsed and air dried. Three drops of base, one drop of catalyst, and one scoop of HPA (High Performance Additive) were dispensed into a mixing well and gently stirred. The mixture was applied in a thin layer to the cavity walls.

Imperva Dual Bond: The enamel margins were acid etched (37% phosphoric) for 30 seconds, rinsed, and air dried. The Dentin Primer was applied to dentin walls, agitated with a sponge for 30 seconds, and dried with compressed air. A layer of the Bonding Agent was applied to the enamel and dentin. The excess was removed, and the Bonding Agent was light cured for 30 seconds. One scoop of powder and one drop of the Imperva Dual were dispensed on the mixing pad. They were mixed and applied to the entire cavity preparation. While the mixture was still wet, the amalgam was condensed and carved in the same manner as for the previous groups. Before the cement hardened, the excess was removed. The margins were light cured for 30 seconds on the occlusal surface. The approximal margins were covered with Oxy-Barrier for 4 minutes, which was then removed with water spray and gauze.

All-Bond 2 Primer/Bonding Resin: The All-Etch technique gel was used to acid etch dentin and enamel. The 10% H_3PO_4 was applied on the enamel and dentin for 15 seconds with agitation. It was thoroughly rinsed and air dried for 1 second to remove the excess water without desiccation. Primers A and B were dispensed into a mixing well and applied to all surfaces in five consecutive layers. The surface was dried for 5 to 6 seconds and light cured for 20 seconds. The Dentin/Enamel Bonding Resin and Pre-Bond Resin were dispensed on the mixing pad and brushed onto the entire cavity surface. Compressed air was used to thin the coat.

All-Bond 2 Primer/Liner F: The same procedures used in the previous group for etching and primer application were repeated in this group. After primer application, equal amounts of Liner-F Catalyst and Base were mixed and brushed onto the entire cavity preparation.

Testing

The restored teeth were stored in water at 37 °C for 15 days prior to testing. During this storage time, the teeth were subjected to 2500 thermocycles between 8 and 48 °C with a dwell time of 30 seconds. The teeth were tested in compression in an Instron 1123 testing machine (Instron Corp, Canton, MA 02021) using a 5 mm-in-diameter, cylindrical, hardened steel rod that contacted only the occlusal inclines of the facial and lingual cusps (Figure 2).

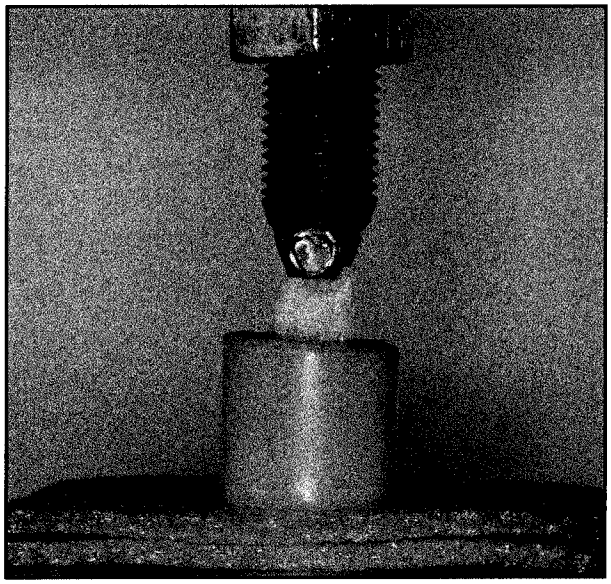

Figure 2. *Fracture testing setup*

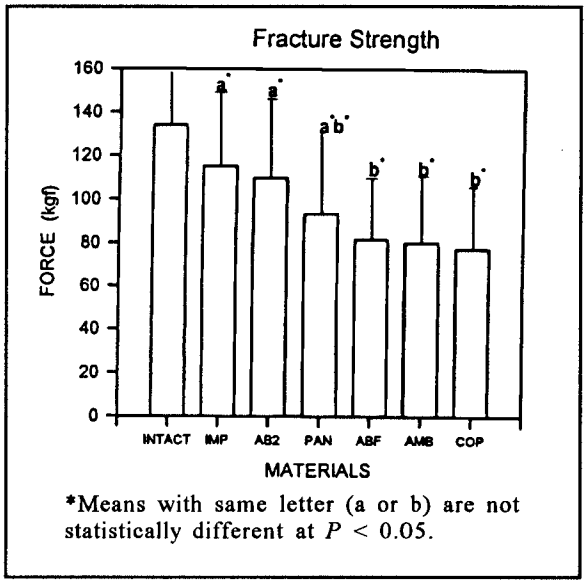

Figure 3. *Fracture strengths*

The mounted teeth were placed on a foam cushion on the Instron platen that permitted even seating of the load. The teeth were preloaded to a maximum force of 10 kgf at a speed of 5mm/min a total of five times before testing to failure. The preloading procedure was introduced to simulate intraoral forces and improve uniform loading of the tooth. Then the teeth were tested to failure at a speed of 1 mm/min and the force recorded. Fractured specimens were examined in a stereomicroscope and the failure recorded as: amalgam fracture, adhesive failure, or fracture of the tooth cusps. Scanning electron micrographs were taken of typical failures from each group of materials.

The data collected in this study were submitted to Bartlett's test for homogeneity of variance. Variances were not homogeneous at the $P < 0.10$ level of significance. The highest mean value was 134.02 kgf for the unrestored (positive control) group with a standard deviation of 79.2, which made one-way analysis of variance (ANOVA) unfeasible.

The unrestored group was omitted and Bartlett's test repeated on the remaining six groups. Since the variances were homogenous, these data were subjected to a one-way analysis of variance (ANOVA) followed by the Newman-Keuls multiple comparison test.

RESULTS

The data for mean load at failure and standard deviation are shown in Table 2. Figure 3 illustrates these data and also shows the results of the statistical analysis. The ANOVA indicated that the liners employed had a significant influence on strength. Imperva Dual Bond, All-Bond 2 Primer/Bonding Resin, and Panavia 21 formed a group with significantly higher mean strengths. Similarly Panavia 21, All Bond 2 Primer/ Liner F, and Amalgambond Plus formed a second group with strengths not significantly different from the Copalite control.

Table 2 and Figure 4 show the data for the type of failures observed. Three types of fractures were observed: fracture involving only the tooth structure (Figure 5A), fractures in the adhesive at the tooth-

Table 2. Mean Fracture Strengths and Fracture Modes

	intact	IMP	AB2	PAN	ABF	AMB	COP
strength (std) kg	134[79.2]	115[34.9]	110[35.8]	93[37.8]	82[28.3]	80[30.8]	78[29.1]
%failure amalgam	0	0	25	35	0	15	0
% failure tooth	100	35	15	15	35	25	25
% failure interface	0	65	60	50	65	60	75

Mean strength values underlined were not statistically different at $P < 0.05$.

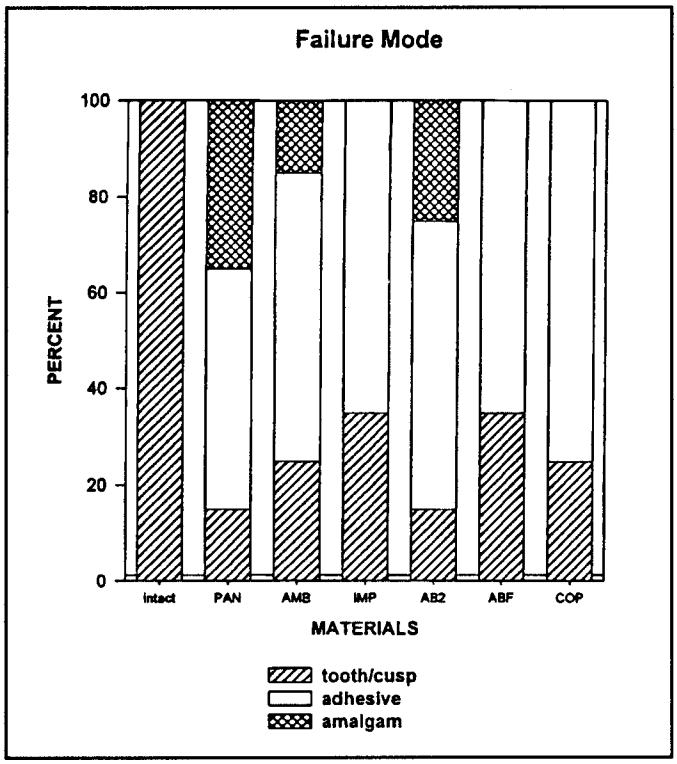

Figure 4. *Failure modes*

amalgam interface (Figure 5B), and fractures through the amalgam restoration (Figure 5C). Panavia 21 had the highest percentage of amalgam fractures (35%), followed by All-Bond 2 Primer/Bonding Resin (25%) and Amalgambond Plus (15%). The other groups did not exhibit this type of failure. With the exception of the unrestored group, failure at the adhesive interface was the predominate failure mode for all groups.

The cavity design employed resulted in considerably reduced coefficients of variation when compared to that of the intact teeth. The variances for all restored groups were homogeneous. A pilot study also indicated that the use of preloading and a cushion beneath the tooth mount helped equalize force distribution and reduced the variation between specimens within groups.

DISCUSSION

The data demonstrated that use of the adhesive liners Imperva Dual Bond and All-Bond 2 Primer/Bonding Resin significantly increased the strength of the teeth when compared to the varnish-lined control. However, All-Bond 2 Primer/Liner F and Amalgambond Plus were not statistically different from the varnish control group. Panavia 21 was intermediate in strength between the high and low groups. Although the All-Bond 2 groups (Primer/Bonding Resin and Primer/Liner F) are quite similar, their use resulted in statistically different strengths. All-Bond 2 Primer/Liner F has been particularly recommended for use with amalgam but, in this study, resulted in lower strengths compared to All-Bond 2 Primer/Bonding Resin.

The failure mode is also of interest. It has been shown previously that placement of amalgam restorations does not strengthen a prepared tooth. However, in this study, all of the failures for the varnish group occurred in tooth structure or at the tooth-amalgam interface. Three of the adhesive groups, however, demonstrated cohesive failure in the amalgam restoration. This is an indication that the adhesive bond transferred sufficient stress to the amalgam to result in its cohesive failure. This would imply strengthening of the tooth. The difficulty with this assumption is that only one of the materials that showed amalgam failure (All-Bond 2 Primer/Bonding Resin) also had a strength significantly greater than that of the varnish group. An alternative hypothesis is that the adhesive liner lowered the strength of the amalgam. Other research has indicated that significant amounts of the adhesive can be incorporated into the amalgam during condensation (Charlton, Murchison & Moore, 1991). The adhesive group with the highest strength, Imperva Dual Bond, demonstrated 35% tooth fracture but no cohesive failure in the amalgam.

The fact that the major failure mode seen in the adhesive groups (65%) was at the adhesive interface indicates that improvements still remain to be made to achieve a bonded amalgam restoration.

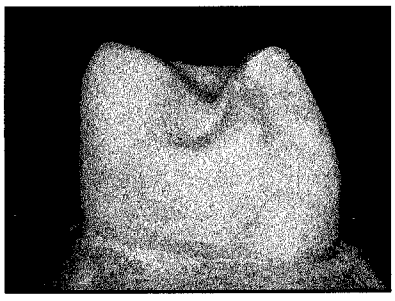

Figure 5A. *Fracture involving only the tooth structure*

Figure 5B. *Fracture in the adhesive at the tooth-amalgam interface (most common fracture type)*

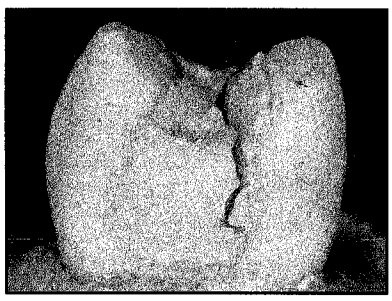

Figure 5C. *Fracture through the amalgam restoration*

Caution should be used in applying these results to clinical practice. This was a laboratory experiment that attempted to duplicate a large MOD restoration. Although thermocycling was used to stress the restored teeth, the total storage time was short. Longevity of the adhesive bond that was demonstrated remains an important question. However, the results do indicate that some of the adhesives tested result in reinforcement of the tooth, and their use might reduce the amount of mechanical retention needed. This in turn would preserve tooth structure and should strengthen the restored tooth.

CONCLUSIONS

The proportional cavity design and loading method employed appear to be useful testing methodologies for testing the strength of restored teeth. The use of natural teeth introduces significant variation into such an experiment, and anything that can be done to reduce this variation is important. The use of unrestored teeth as a control is questionable due to the very large coefficient of variation.

Two of the adhesives tested, Imperva Dual Bond and All-Bond 2 Primer/Bonding Resin, resulted in strengths significantly greater than the varnish control group. Two others, All-Bond 2 Primer/Liner F and Amalgambond Plus, were not significantly different. The remaining adhesive, Panavia 21, was intermediate.

The cohesive failure observed in the amalgam for Panavia 21, All-Bond 2 Primer/Bonding Resin, and Amalgambond Plus would imply effective stress transfer between tooth and amalgam. However, the majority of failures seen for the adhesive groups were at the tooth/amalgam interface, which indicates improvements in bonding still need to be made.

Acknowledgments

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Effect of Dentin Primer on the Shear Bond Strength between Composite Resin and Enamel

G A WORONKO, Jr • H A ST GERMAIN, Jr • J C MEIERS

Clinical Relevance
This study suggests that the effect of primer on bonded composite resin to etched enamel is material specific.

SUMMARY

The purpose of this investigation was to determine the effect of dentin primers from Scotchbond Multi-Purpose, ProBond, All-Bond 2, and Syntac on the shear bond strength of composite resin to etched enamel. Two groups of extracted human molar teeth with flattened enamel surfaces (n=12) were randomly assigned to each enamel/dentin bonding system. Following manufacturers' instructions enamel surfaces were etched, rinsed, and dried. Composite bonding procedures were conducted similarly in both groups for each enamel/dentin bonding system, except that in one of the two groups, dentin primer was applied prior to adhesive resin and composite placement. Samples were thermocycled and tested in shear until failure. Fracture analysis was performed on enamel surfaces with both light and scanning electron microscopy. Shear bond values (Mean ± SD, MPa) were: Scotchbond Multi-Purpose unprimed 22.4±3.2, primed 17.9±5.9; ProBond unprimed 19.4±6.2, primed 18.3±3.3; All-Bond 2 unprimed 19.0±3.6, primed 17.3±3.0; and Syntac unprimed 26.2±9.0, primed 22.0±5.4. The only significant difference found between primed and unprimed groups was with Scotchbond Multi-Purpose, though there was a trend for primer application to decrease enamel bond strengths. Fracture surface analysis revealed that most failures were cohesive within the composite resin. These data suggest that the effect of primer on bonded composite resin to etched enamel is material specific.

National Naval Dental Center, Naval Dental School, Bethesda, MD 20889-5602

George A Woronko, Jr, DDS, resident, Comprehensive Dentistry

Henry A St Germain, Jr, DMD, MSD, MEd, director, University of Nebraska College of Dentistry, Section of Operative Dentistry, Department of Adult Restorative Dentistry, Lincoln, NE 68583-0740

Jonathan C Meiers, DMD, MS, director, Dental Materials Testing and Evaluation

INTRODUCTION

A major factor for clinical failure of composite resin restorations is marginal microleakage (Barkmeier & Cooley, 1992; Wieczkowski & others, 1992). This leads to discoloration and staining of the margins, gap formation with possible sensitivity, and the increased risk of recurrent decay. During composite resin curing, stresses occur within the resin due to polymerization shrinkage. To prevent marginal microleakage, the bond between tooth structure and composite resin must be stronger than the stress induced on the margins from polymerization shrinkage. Munksgaard, Irie, and Asmussen (1985) predicted that a shear bond strength of at least 17 MPa is needed to withstand polymerization shrinkage stresses. Bond strengths of composite resin restorative materials to etched enamel are in the range of 16-24 MPa (Barkmeier, Shaffer & Gwinnett, 1986; Barkmeier & Cooley, 1992; Craig, 1989; Bowen & Cobb, 1983). Additionally, the use of acid

treatment of enamel margins in vitro virtually eliminates marginal microleakage when an unfilled bonding resin with a composite resin restorative is used (Wieczkowski & others, 1992; Barkmeier & Cooley, 1992; Sparrius & Grossman, 1989).

Manufacturers are currently marketing fourth-generation enamel/dentin bonding systems, which are reported to result in shear bond strengths to dentin ranging from 6-20 MPa (Barkmeier & Cooley, 1992; Mandras, Retief & Russell, 1993). Although each system is unique in the components and steps needed to obtain a bond to dentin, the common factor is alteration or removal of the smear layer with an acid or acidic component. This treatment opens the dentinal tubules and exposes collagen fibers which, after treatment with a hydrophilic monomer, allows adhesive unfilled resin to penetrate into the walls of the tubules and attach micromechanically (Van Meerbeek & others, 1992; Erickson, 1992). One component of these currently available enamel/dentin bonding systems is a dentin primer. From a clinical standpoint, since the dentin primer is a very low viscosity hydrophilic monomer, it is virtually impossible to prevent primer from flowing onto the enamel margins. Hadavi and others (1993) noted that the manufacturers of these systems do not address the potential effects on bond strength when dentin primer contacts acid-treated enamel. These investigators found a significant decrease in the shear bond strengths when dentin primer was placed on etched enamel prior to the bonding agent. Since this original study, which used two second-generation and two third-generation enamel/dentin bonding systems, most manufacturers state that the dentin primer is not detrimental to the shear bond strength of composite resin to etched enamel. Barkmeier and Gwinnett (1989) tested the enamel shear bond strengths of three dentin bonding systems and also found that when dentin primer was applied before placement of the bonding agent there was a decrease in bond strength. SEM analysis showed that when the primer was applied, the etched enamel surface morphology pattern significantly changed and was no longer clear, because the microporosities were occluded. This is a significant finding because of the importance of micromechanical retention in establishing an etched enamel/unfilled resin bond that will consistently withstand the stresses of polymerization shrinkage and provide a stable, reliable bond, preventing marginal microleakage of composite resin restorations.

The purpose of this study was to evaluate four fourth-generation enamel/dentin bonding systems to determine the effect of dentin primer application to etched enamel on enamel/composite resin shear bond strengths.

MANUFACTURERS' INSTRUCTIONS

Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144)

a. Apply etchant gel (10% maleic acid) for 15 seconds, rinse, dry.
b. Apply primer, dry gently without waiting.
c. Apply adhesive (bonding agent) and light cure for 10 seconds.

Prisma ProBond (L D Caulk, Milford, DE 19963)

a. Apply tooth conditioner gel (37% phosphoric acid) for 15-30 seconds, rinse with a forceful water spray for 15 seconds and dry.
b. Apply primer (do not scrub) as needed to keep tooth surface wet for 30 seconds, dry for 5-10 seconds.
c. Apply adhesive and light cure for 10 seconds.

All-Bond 2/Uni-Etch (Bisco, Itasca, IL 60143)

a. Apply Uni-Etch (32% phosphoric acid) for 15 seconds on enamel, rinse, air dry for 1 second. Do not dessicate; All-Bond 2 prefers moist enamel.
b. Mix Primer A and Primer B and apply five consecutive coats of mixed primer to enamel, dry for 5-6 seconds.
c. Apply enamel/dentin bonding resin and light cure for 20 seconds. Note: Enamel was thoroughly dried to assure etch, then remoistened with a drop of water with a BendaBrush prior to placement of primer or adhesive resin.

Syntac (Vivadent, Schaan, Liechtenstein)

a. Apply etchant gel (37% phosphoric acid) for 30-60 seconds, rinse, dry.
b. Apply primer for 15 seconds and dry.
c. Apply adhesive and dry.
d. Apply Heliobond (unfilled resin) and cure for 20 seconds.

METHODS AND MATERIALS

Ninety-six extracted human molars stored in 0.2% sodium azide were rinsed thoroughly to remove residual sodium azide. A flat, 5 mm-in-diameter area on an enamel surface was produced with a microgrinder using 500-grit silicon carbide abrasive paper (Exakt Medical Instruments, Oklahoma City, OK 73148) with water coolant/lubrication. A random number table was generated to determine the sequence of sample preparation. Four enamel/dentin bonding systems were tested: Scotchbond Multi-Purpose, Prisma ProBond, All-Bond 2, and Heliobond/Syntac, with the experimental design having eight groups (n=12), representing two groups for each enamel/dentin bonding system, one with primer and the other without. The surface of each tooth was rinsed with distilled water and dried with oil-free air, then etched with the acid etchant of that particular enamel/dentin bonding system per the manufacturers' instructions (table). After rinsing, the enamel surface was dried and then the unfilled resin or primer was applied per the manufacturers' instructions. To ensure a consistent bonding area between teeth, a

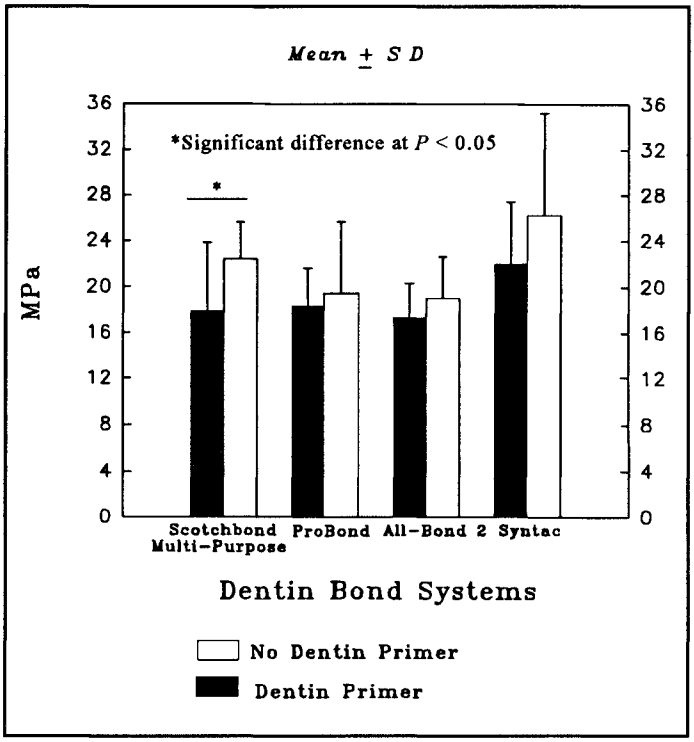

Figure 1. *Shear bond strength of composite resin to etched enamel within each enamel/dentin bonding system*

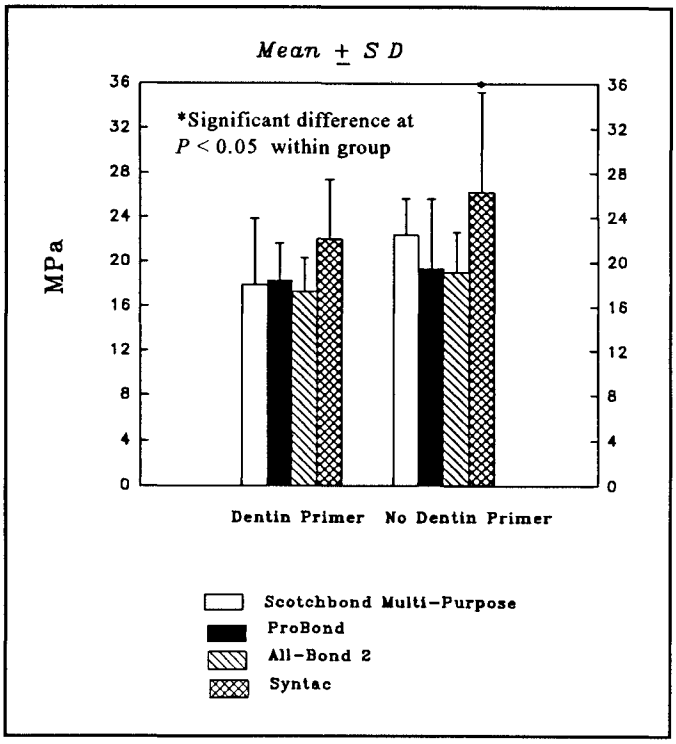

Figure 2. *Shear bond strength of composite resin to etched enamel between primed and unprimed groups of enamel/dentin bonding systems*

3 mm high x 3 mm in-inner-diameter plastic cylinder (Becton Dickinson Labware, Franklin Lakes, NJ 07417) was secured to this surface with sticky wax. Tetric (Vivadent) light-cured hybrid composite resin was condensed into the cylinder and polymerized with visible light for a total of 80 seconds (40 seconds above the cylinder and 40 seconds below) using a Max-Lite (The Max, L D Caulk) visible-light curing unit. Curing efficacy was verified with a Demetron 100 radiometer (Demetron Research Corp, Danbury, CT 06810) to measure light intensity before each sample run.

All bonded specimens were stored for 24 hours in distilled water at 37 °C. An acrylic jig was used to mount the specimens into a cylinder of orthodontic resin that aligned the flattened surface parallel to the floor. The embedded bonded specimens were thermocycled between 5 °C and 55 °C for 1000 cycles using a 30-second dwell time. Bonded specimens were placed into a positioning device to orient them perpendicular to a chisel-shaped rod that was aligned adjacent to the bonded composite/enamel interface. Specimens were tested in shear until failure using an Instron Model 1000 (Instron, Canton, MA 02021) testing machine at a crosshead speed of 5 mm/min. Surface fracture/debond analysis of the enamel specimens was performed with a binocular light scope at X20 magnification to determine the nature of the fracture: cohesive within the enamel/dentin bonding system/composite resin (>80% resin remaining on the etched enamel surface), adhesive (<20% resin remaining on the etched enamel surface), or mixed. Selected fractured enamel specimens along with control specimens of enamel etched with 37% phosphoric acid or 10% maleic acid and those etched and treated with a primer from each of the enamel/dentin bonding systems tested were sputter-coated with gold and evaluated with a Scanning Electron Microscope (SEM, Jeol JSM-5300, Jeol USA, Inc, Peabody, MA 01961) using an acceleration voltage of 25 kv to help elucidate the nature of the fractured interface.

Shear bond strengths were analyzed using a two-way ANOVA with product type and primers versus no primer as factors, Student-Newman-Keuls test, and *t*-test at a significance level of $P < 0.05$.

RESULTS

Mean shear bond strengths in MPa (Mean ± SD) for the eight test groups were: Scotchbond Multi-Purpose 22.4 ± 3.2, Scotchbond Multi-Purpose with primer 17.9±5.9; Prisma ProBond 19.4±6.2, Prisma ProBond with primer 18.3±3.3; All-Bond 2 19.0±3.6, All-Bond 2 with primer 17.3±3.0; Syntac 26.2±9.0, Syntac with primer 22.0±5.4 (Figure 1). Scotchbond Multi-Purpose showed a significantly lower composite resin to etched enamel shear bond strength for primer versus unprimed enamel, though there was

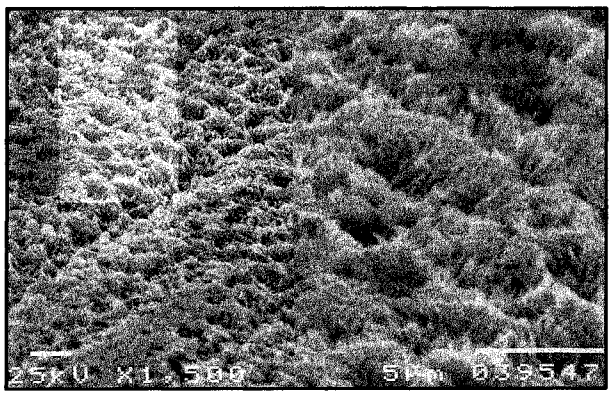

Figure 3. *Dual magnification shot of etched enamel pattern produced by 37% phosphoric acid. Original magnification X750; highlighted area in box represents X2250.*

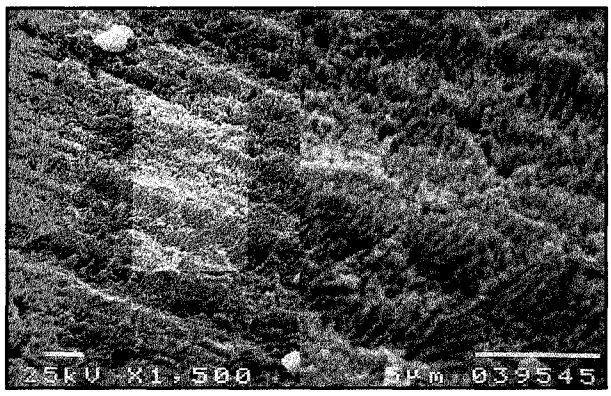

Figure 4. *Dual magnification shot of etched enamel pattern produced by 10% maleic acid. Original magnification X750; highlighted area in box represents X2250.*

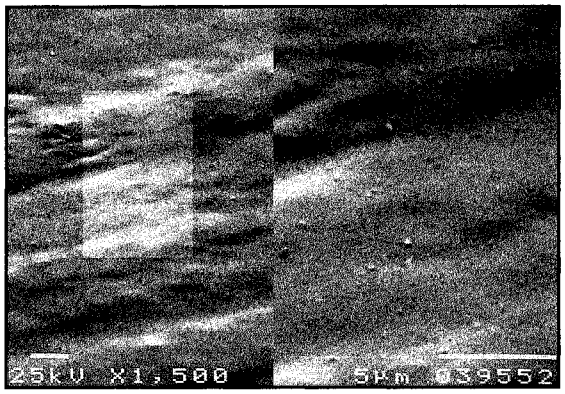

Figure 5. *Dual magnification shot of ProBond primer on 37% phosphoric acid-etched enamel. Original magnification X750; highlighted area in box represents X2250. Primer coating completely masks etched surface.*

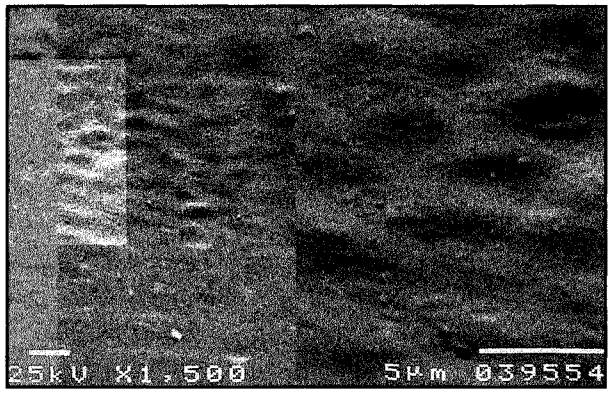

Figure 6. *Dual magnification shot of All-Bond 2 primer on 37% phosphoric acid-etched enamel. Original magnification X750; highlighted area in box represents X2250. Primer coating completely masks etched surface.*

a trend in all the test enamel/dentin bonding systems toward higher bond strengths when primer was not applied to the etched enamel. Within the unprimed enamel groups, Syntac had significantly higher bond strengths than Scotchbond Multi-Purpose, Prisma ProBond, and All-Bond 2 (Figure 2), and the greatest amount of variability. Within the primed enamel groups, there was no significant difference among the test enamel/dentin bonding systems in enamel shear bond strengths.

Surface fracture/debond analysis of the enamel specimens with a binocular light scope at X20 magnification determined that the majority of the fractures, 81% (78/96), were cohesive within the composite sytem and that a fine layer of resin remained on > 80% of the enamel surface. It was difficult to differentiate between cohesive within the composite resin system fractures and adhesive fractures under the light scope, because the resin layer could not be readily detected on the tooth surface. Adhesive fractures (<20% visible resin on the bonded enamel surface) occurred in 12% (11/96), and mixed fractures occurred in 7% (8/96) of the specimens throughout all the test groups.

SEM comparison of the control etched-and-primed enamel surfaces versus the control acid-etched enamel surfaces revealed that a "coating" was produced for all the test systems that masked the architecture of the underlying etched enamel (Figures 3-8). The "coating" for the Scotchbond primer to the 10% maleic acid-etched enamel was minimal in comparison to those produced by the Syntac, ProBond, and All-Bond primers to 37% phosphoric acid-etched enamel. From evaluation of the SEMs of the four enamel/dentin bonding system primers to etched enamel, the thickness of the primer coating was determined to be All-Bond = ProBond = Syntac > Scotchbond.

SEM analysis of the fractured specimens for the eight test groups showed fracture patterns similar to each other. A definitive coating remained on the etched enamel surface, indicating that these fracture patterns were cohesive within the enamel/dentin bonding system/composite resin (Figures 9 & 10).

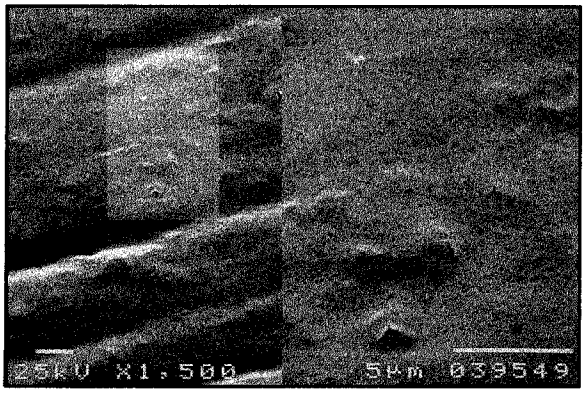

Figure 7. *Dual magnification shot of Syntac primer on 37% phosphoric acid-etched enamel. Original magnification X750; highlighted area in box represents X2250. Primer coating completely masks etched surface.*

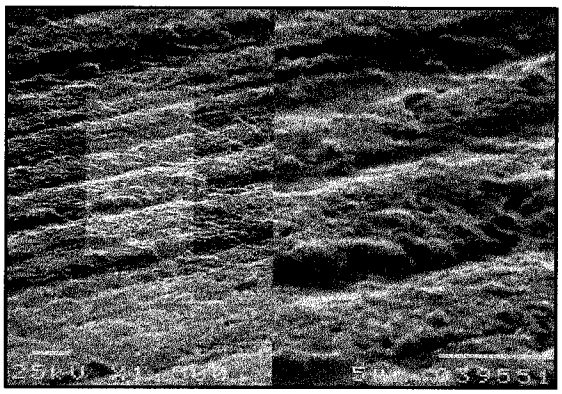

Figure 8. *Dual magnification shot of Scotchbond Multi-Purpose primer on 10% maleic acid-etched enamel. Original magnification X750; highlighted area in box represents X2250. Primer does not mask underlying etched enamel to the same extent as previous three primers.*

Figure 9. *Dual magnification shot of typical fracture pattern observed on etched enamel surface when only unfilled resin was applied prior to composite resin. Original magnification X750; highlighted area in box represents X2250. There is a cohesive fracture, close to enamel interface.*

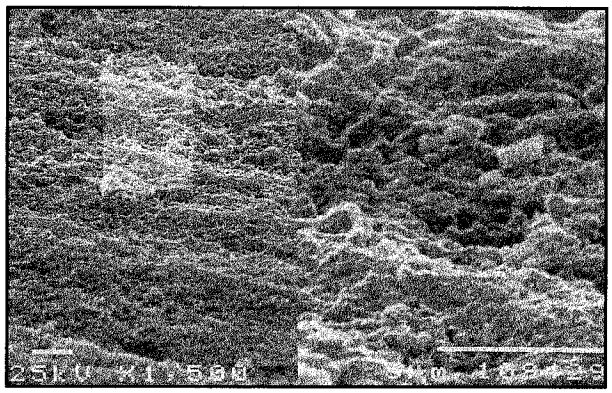

Figure 10. *Dual magnification shot of typical fracture pattern observed when primer and unfilled resin was applied prior to composite resin. Appearance is similar to Figure 9.*

DISCUSSION

Acid etching enamel results in the formation of a porous decalcified zone into which an unfilled resin bonding agent micromechanically locks. Results of this investigation support some manufacturers' claims that dentin primers do not have an effect on shear bond strength to etched enamel, but it does not apply universally. Our results demonstrated that the only significant decrease in shear bond strength between primed versus unprimed etched enamel was seen within the Scotchbond Multi-Purpose enamel/dentin bonding system groups. Syntac, Prisma ProBond, and All-Bond 2 showed no significant difference between primed and unprimed groups, though there was a trend for decreased composite resin to etched enamel shear bond strength in all the primed groups. These results do not totally support the conclusions of Hadavi and others (1993), who found a significant difference between primed and unprimed groups in all enamel/dentin bonding systems tested, but they are similar to a study by Hanson and others (1995), who found that dentin primers of tested fourth-generation enamel/dentin bonding systems had no significant impact on enamel shear bond strength. Our study tested current fourth-generation enamel/dentin bonding systems, whereas Hadavi and others (1993) tested two second- and two third-generation enamel/dentin bonding systems.

Scotchbond Multi-Purpose, which was the only system to exhibit a signficant difference between primed and unprimed groups, was also the only system to utilize 10% maleic acid as the etching agent and a single layer application of the primer. Syntac and ProBond use 37%, and All-Bond 2 uses 32% phosphoric acid as the etching agent with multiple applications of primers until a "shiny surface" was visible. Currently, 3M has changed the enamel etching procedure to 37% phosphoric acid. At the time this study was performed, 10% maleic acid was

still being advocated. SEM analysis of representative specimens after application of primers revealed a noticeable difference between Scotchbond and the other three. Scotchbond had a very thin "coating" in which the etched enamel pattern was still discernible, whereas the "coating" after application of ProBond, All-Bond 2, and Syntac primers completely masked the etched enamel patterns. After the specimens were fractured and SEM analyzed, the thickness of the unfilled resin bonding agents was similar in all eight groups. SEM analysis of the representative specimens from each group yielded the observation that the majority of fractures were cohesive within the enamel/dentin bonding systems, with fracture occurring very close to the etched enamel/bonding agent (with or without primer) interface. Fractures observed in this study are in accordance with those observed by Zidan, Asmussen, and Jorgensen in their 1982 study of fractured composite resin/etched enamel bonds in which, except for the rare cases of enamel failure, the fracture always occurs within the restorative resin. This would indicate that all enamel/dentin bonding systems with or without primer were able to produce a maximum bond to acid-etched enamel because the fractures occurred within the composite system. Why Scotchbond Multi-Purpose produced a significant difference with the use of the dentin primer on etched enamel is not fully understood at this time. A possible explanation could be that the etch pattern produced by the 10% maleic acid and coated with primer somehow altered the inherent stresses within the composite resin system close to the enamel/resin interface that allowed crack initiation and propagation within the system at a lower force. The use of 37% phosphoric acid etchant on the enamel may have provided different results.

Since most primers are hydrophilic monomers that thoroughly wet the surfaces they come in contact with and contain some of the same components of the unfilled bonding resins, a future study comparing the results we obtained to shear bond strengths of specimens prepared with application of only primer prior to composite resin placement may provide some valuable information.

CONCLUSION

Results of this study support some manufacturers' claims that contact of etched enamel with dentin primer does not significantly affect the bond strength. Of the four enamel/dentin bonding systems tested, only Scotchbond Multi-Purpose showed a significant difference in shear enamel bond strengths when etched enamel was coated with dentin primer.

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Fatigue of Resin-bonded Amalgam Restorations

E BONILLA • S N WHITE

Clinical Relevance
The strengthening effect of an adhesive resin on teeth restored with MOD amalgam restorations was transient.

SUMMARY

Standardized MOD cavities were prepared in 80 human premolars, which were treated with either adhesive resin or copal varnish and then restored with amalgam. Fracture resistance of these groups was compared after 24 hours of storage, 4 weeks of storage with thermocycling, and after 500 days of storage. The buccal cusps were loaded at an angle of 30° to the tooth long axis until fracture occurred. Additionally, survival curves were compared for adhesive resin and copal varnish groups that had been repeatedly load cycled until fracture occurred. The 24-hour adhesive resin group was significantly stronger than the corresponding copal varnish group ($P < 0.05$). However, no significant differences between adhesive resin and copal varnish were found for the other thermocycling, extended 500-day storage, or load cycling tests. In conclusion, the strengthening effect of an adhesive resin on teeth restored with MOD amalgam restorations was transient.

University of Southern California, School of Dentistry #4112, Department of Restorative Dentistry, Pincus Biomaterials Research Laboratory, Los Angeles, CA 90089-0641

Esteban Bonilla, DDS, clinical assistant professor

Shane N White, BDentSc, MS, MA, assistant professor, director of clinical research

INTRODUCTION

The ability to form a durable bond between amalgam and tooth structure would be of great clinical advantage. Such a bond could potentially decrease marginal leakage, allow more conservative cavity preparation, and strengthen restored teeth. Following the introduction of BIS-GMA-based resins as bonding agents to dentistry by Buonocore (1955), many adhesives that bond to enamel, dentin, and restorative materials have been developed, including the 4-META MMA/TBB system (Nakabayashi, 1992). Numerous laboratory studies have reported that this system can achieve substantial bond strengths between amalgam and dentin (Staninec & others, 1992; Hasegawa & others, 1992; Vargas, Denehy & Ratananakin, 1994). However, relatively few studies have tested the durability of this system with amalgam restorations in complex class 2 cavities (Eakle, Staninec & Lacy, 1992; Ianzano, Mastrodomenico & Gwinett, 1993; Santos & Meiers, 1994). The long-term fatigue resistance of resin-bonded MOD amalgam restorations has not yet been comprehensively evaluated. Therefore, the purpose of this study was to evaluate the fatigue resistance of a 4-META MMA/TBB bonding agent in MOD amalgam restorations.

METHODS AND MATERIALS

One hundred twenty freshly extracted, intact, previously unrestored human premolars were collected. These teeth were ranked in order from

smallest to largest. To improve standardization, the 20 smallest and the 20 largest teeth were excluded from the study. The remaining 80 study teeth were carefully scaled to remove the periodontium and stored in 37 °C water. For ease of handling, the teeth were mounted in acrylic blocks (Self-Curing Acrylic, Lang Mfg Co, Inc, Wheeling, IL 60090). The long axes of the teeth were aligned vertically. The roots of the teeth were embedded in the acrylic up to 1 mm from the most apical part of the cementoenamel junction.

Standardized MOD preparations were made according to established procedures (Eakle & others, 1992). Water spray was used during the entire preparation. The cavosurface margins of the approximal boxes were placed in dentin-cementum. All other margins were placed in enamel. After cavity preparation the 80 study teeth were randomly assigned to copal varnish (Copalite, Cooley & Cooley, Ltd, Houston, TX 77041) or adhesive resin (Amalgambond Plus, Parkell, Farmingdale, NY 11735) treatment groups. The varnish or resin was applied to the prepared teeth according to the manufacturers' instructions. The specimens were then immediately packed with a high-copper amalgam (Valiant PhD, Vivadent, Schaan, Liechtenstein), carved, and burnished. Ten minutes after restoration all the specimens were placed in an atmosphere of 100% humidity at 37 °C for 1 hour. Then the 40 copal varnish and 40 adhesive resin specimens were each randomly assigned to four groups of 10 samples. The following four separate experiments were performed using the 80 specimens.

24-Hour Test: One copal varnish and one adhesive resin group were stored in water at 37 °C for 24 hours. These specimens were mounted in a vise bolted to the platen of a servohydraulic testing machine (1350, Instron Corp, Canton, MA 02021). The vise tilted the teeth buccally to an angle of 30° from the vertical. The teeth remained under water in the vise. The buccal cusp tips were loaded at a crosshead rate of 2.5 mm per minute until fracture occurred. The failure load and mode were recorded. The copal varnish group was compared with the adhesive resin group using a Student's *t*-test ($P < 0.05$).

Artificial Aging: A second set of copal varnish and adhesive resin groups was stored in water at 37 °C for 4 weeks and then artificially aged by thermocycling, from 5-55 °C with a dwell time of 30 seconds and a travel time of 10 seconds, for 1500 cycles. These specimens were subjected to chemical/aqueous, thermal, and mechanical fatigue. They were then tested as above. The copal varnish group was compared with the adhesive resin group using a Student's *t*-test ($P < 0.05$).

500-Day Storage: A third set of copal varnish and adhesive resin groups were stored in water at 37 °C for 500 days and tested as above. These specimens were subjected to chemical/aqueous fatigue. The copal varnish group was compared with the adhesive resin group using a Student's *t*-test ($P < 0.05$).

Dynamic Load Cycling: A fourth set of copal varnish and adhesive resin groups were stored in water at 37 °C for 4 weeks and then mounted as above and subjected to repeated loads on the buccal cusp tips. The load used was half the mean failure load of the weakest 24-hour storage group (Goodman,

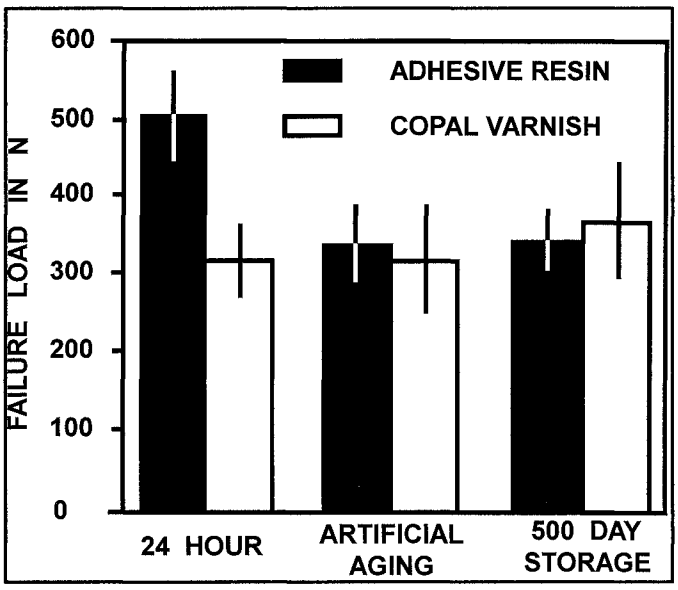

Figure 1. *Mean failure loads and standard errors of adhesive resin and copal varnish groups in N*

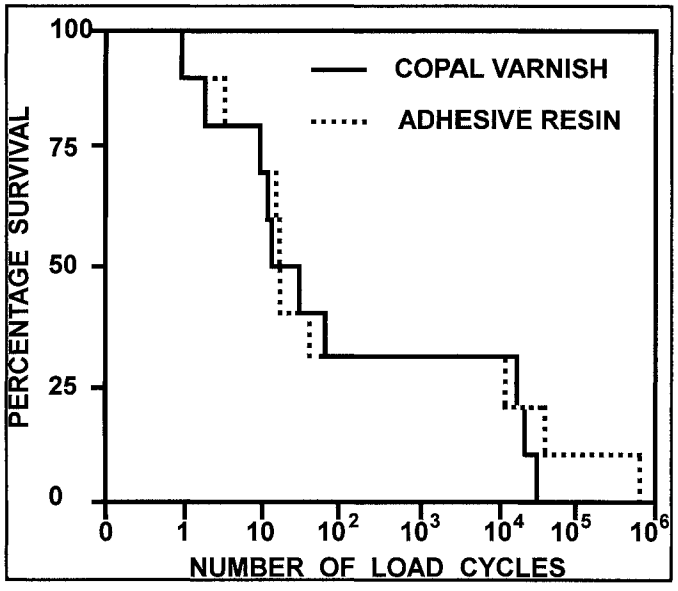

Figure 2. *Survival curves for load cycled adhesive resin and copal varnish groups*

1899; Bannantine, Comer & Handrock, 1990). Loading was repeated at a frequency of 1 Hz until failure occurred. These specimens were subjected to chemical/aqueous and cyclic mechanical fatigue. The number of cycles to failure was automatically recorded. Survival curves for copal varnish and adhesive groups were plotted. The survival curves were then compared using a Mann-Whitney U test ($P < 0.05$).

The specimens were qualitatively examined after fracture using toolmakers (TM, Unitron, Newton Highlands, MA 02161) and metallurgical (N, Unitron) microscopes at X5-500 magnifications using tungsten and xenon light sources. One researcher made all observations. However, as the copal varnish and adhesive resin groups were visibly different under magnification, the researcher could not be blinded.

RESULTS

This study showed that the strengthening effect of an adhesive resin on teeth restored with MOD amalgam restorations was transient (Figures 1 and 2).

Group means and their standard errors are displayed in Figure 1 and listed in the table below. At 24 hours the adhesive resin group was significantly stronger than the copal varnish group (t statistic = -2.7, $P = 0.015$). At 24 hours the failure site for the adhesive resin group was mostly within superficial tooth structure, often with partial enamel delamination. In contrast, the copal varnish specimens failed at the tooth-amalgam interface and within deep tooth structure. Thus, for the 24-hour specimens, the clinical relevance of the different failure modes may have been more important than the difference in mean failure load. However, after artificial aging the adhesive resin and copal varnish groups were similar (t statistic = -0.15, $P = 0.88$), and failure occurred at the tooth-amalgam interface and within deep tooth structure for all specimens. Likewise, after extended storage the adhesive resin and copal varnish groups were similar (t statistic = 0.29, $P = 0.78$), and failures occurred at the tooth-amalgam interface and within deep tooth structure for all specimens. Complex failure of the adhesive occurred, as patches of adhesive were discerned on both tooth and amalgam surfaces.

Mean Failure Loads in N

Test Type	Treatment Group	n	Mean	Standard Error
24-hour	adhesive resin	10	503.9	57.3
	copal varnish	10	308.1	41.8
Artificial Aging	adhesive resin	10	342.0	51.3
	copal varnish	10	310.7	71.8
500-day Storage	adhesive resin	10	330.0	46.5
	copal varnish	10	354.8	73.3

The force used for the repeated load cycling was 154 N. The survival curves for the load cycled teeth are illustrated in Figure 2. The curves appear to be very similar. The Mann-Whitney U test showed that the median survival times of both curves were not significantly different ($Z = 0.19$, $P = 0.85$). Failures again occurred at the tooth-amalgam interface.

DISCUSSION

The short-term strengthening effect might be clinically useful in preventing fracture of severely mutilated teeth after caries removal, following endodontic treatment, or between amalgam core placement and cementation of a cast restoration (Hansen & Asmussen, 1993). The consequences of failure of the adhesive resin might be greater than simple strength loss. Copal varnish gradually dissolves, but amalgam corrosion products gradually fill the tooth-amalgam void. However, the presence of a thin layer of debonded resin between tooth structure and amalgam might prevent amalgam corrosion products from reaching the tooth surface and forming a seal. Therefore, the long-term effects of resinous adhesives on microleakage of amalgam restorations should be investigated.

Despite efforts to achieve standardization, high variances were discerned. This is not surprising, because natural teeth of different dimension, age, and experience were used. In addition, multiple procedures were performed on each test specimen. Furthermore, fatigue data are notoriously deviant (Heller, 1972). However, the sample sizes were sufficient to allow valid conclusions to be made.

The 24-hour, artificial aging, and extended storage tests applied quasi-static loading (at a constant crosshead speed) to the fatigued specimens until failure occurred. Although such forces can easily be applied to posterior teeth, lesser repetitive forces are usually used for chewing. Therefore, a repeated load cycling test was also included. In humans potential damage may be avoided by neural feedback, preventing forces that cause discomfort being applied to teeth. These tests may have been more severe than normal oral conditions; however, valid comparisons were made between the two treatments. Furthermore, similar conclusions were reached by the artificial aging, extended storage, and repeated loading experiments.

The reason for failure of the adhesive was not determined, but this study showed that extended storage in water was sufficient to cause failure. Possibly, water sorption by the largely unfilled methylmethacrylate-based resin caused deterioration

of physical properties. Methylmethacrylate is less cross-linked than other dental resins and is more susceptible to water sorption. Several recent studies have questioned the durability of the 4-META MMA/TBB materials. White and Yu (1993) showed that a similar material (C & B Metabond, Parkell) contains minimal filler and readily undergoes plastic deformation. Tani and others (1994) related the low filler content of a similar material (Superbond D-Liner system, Sun Medical, Kyoto, Japan) to its comparatively low bond strengths. Hansson (1994) reported an exceptionally high early failure rate of resin-bonded bridges cemented with C & B Metabond. Possibly, other adhesive resins might perform better than that used in this study.

Several other studies have also addressed fracture resistance of teeth restored with resin-bonded amalgam restorations. Eakle and others (1992) studied MOD preparations in premolars and found a small but significant strengthening effect. However, their specimens only received 240 thermocycles and 3 days of storage before testing. The conditions in that study could be viewed as being intermediate between the 24-hour storage group and the storage with thermocycling groups in this study. Ianzano and others (1993) studied the removal of amalgam mesiolingual cusp restorations from mandibular molars. They reported that a significant strengthening effect existed after 7 days of storage. Again, the conditions in that study could be interpreted as being intermediate between the 24-hour storage group and the storage with thermocycling groups in this current study. Santos and Meiers (1994) studied fracture resistance of resin-bonded MOD restorations in premolars. They found no difference between copal varnish and adhesive groups that had been stored for 7 days, stored for 7 days with 3500 thermocycles, stored for 67 days, or stored for 67 days with 3500 thermocycles. Collectively, these prior studies and this study indicate that an initial strengthening effect exists, but that after extended storage and/or artificial aging the effect is lost.

Few studies have investigated the effect of repeated load cycling on restored teeth. Fissore, Nicholls, and Yuodelis (1991) studied the effect of cyclic loading on premolar MOD cavities restored with a dentin bonding agent and a posterior composite resin. Like the present study, they concluded that tooth reinforcement by the adhesive restoration was lost after a number of load cycles that were within the physiologic chewing range.

Amalgam is not only the most widely used material, but also one of the most tried and tested in restorative dentistry. It has good compressive strength, but poor tensile and shear strengths. Thus cavity preparations must be designed to load the restoration in compression, not in tension or shear, i e, resistance form. Amalgam creeps with continued application of force, but when a sudden force is applied it becomes quite brittle. It also undergoes dimensional change on setting, first contracting and then expanding. Thus it may be naive to expect an adhesive bond between amalgam and tooth structure to permanently resist such dimensional changes and to compensate for the other physical shortcomings of amalgam.

Despite physical shortcomings, conventional class 2 amalgam restorations have remarkably high survival rates (Qvist, Qvist & Mjör, 1990; Martin & Bader, 1995); surprisingly, class 2 restorations may have similar longevities to other restoration classes (Qvist & others, 1990). Martin and Bader (1995) reported that large four- and five-surface amalgam restorations have good 5-year prognoses. Possibly, even higher success rates could be achieved if adhesives were capable of reducing tooth fracture and secondary caries (Qvist & others 1990; York & Arthur, 1993). However, the results of this experiment indicate that a particular adhesive may not be sufficiently durable to improve long-term fracture resistance of teeth restored with MOD amalgam restorations.

CONCLUSIONS

Although resin bonding initially improved the resistance of restored teeth to fracture, the strengthening effect was transient. Storage combined with artificial aging or extended storage alone both caused loss of the strengthening effect. Repeated load cycling after storage revealed that the copal varnish and adhesive groups behaved in similar ways. Hence, the long-term value of the adhesive procedure in improving fracture resistance of teeth restored with MOD amalgam restorations must be questioned.

Acknowledgment

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DEPARTMENTS

ABSTRACTS

The editor wishes to thank the second-year residents of the General Dentistry Residency program at Wilford Hall Medical Center, Lackland Air Force Base, TX, for their assistance in the preparation of these abstacts.

Effect of mouthguard bleaching on enamel surface. *Ben-Amar A, Liberman R, Gorfil C & Bernstein Y (1995) *American Journal of Dentistry* 8 29-32.

(*Tel Aviv University, The Maurice and Gabriela Goldschleger School of Dental Medicine, Department of Operative Dentistry, Tel Aviv 69978, Israel)

The purpose of this in vitro study was to evaluate the effect of bleaching on the shear bond strength of the resin to enamel bond. Thirty extracted human teeth were divided into two groups. One group was bleached with 10% carbamide peroxide gel (Opalescence) for 8 hours on 21 consecutive days to simulate clinical use with mouthguard carriers. The other group served as the control using only water. Seventy-two hours after completion of the bleaching, Silux-Plus resin composite was bonded to the enamel with the Scotchbond 2 dental adhesive system. The resin was loaded in shear to failure. The shear bond strength was significantly lower in the bleached teeth (7.65 Kg) than in the unbleached teeth (10.76 Kg).

Clinical behavior of repaired amalgam restorations: a two-year study. *Cipriano TM & Santos JF (1995) *Journal of Prosthetic Dentistry* 73 8-11.

(*University of São Paulo, Faculty of Dentistry, Dental Materials Department, São Paulo, Brazil)

The purpose of this in vivo study was to assess the clinical success of repaired amalgams placed 2 years previously by direct (clinical examination and color slides) and indirect (stone casts) means. A sample of 45 class 1, 2, and 5 restorations were repaired due to recurrent caries (64.5%); marginal ditching, faulty approximal contact, or enamel fracture (22.2%); and amalgam fracture during original placement (13.3%). The repair technique involved preparation of undercuts into at least one wall of existing amalgam prior to condensation of the new amalgam. Dispersalloy or New True Dentalloy was used for the repairs. The repaired restorations were clinically evaluated every 6 months for 2 years for secondary caries, surface texture, luster, and junctional discrepancy. Results revealed no secondary caries formation during the evaluation period. All restorations were rated clinically acceptable for luster and surface texture. Only one restoration was a clinical failure due to fracture at the junction of the old and new amalgam. The results indicate that amalgam repairs provide short-term clinical success and support the conservative practice of repairing amalgam in lieu of more aggressive alternatives.

Incidence of invasive cervical resorption in bleached root-filled teeth. *Heithersay GS, Dahlstrom SW & Marin PF (1994) *Australian Dental Journal* 39 82-87.

(*188 North Terrace, Adelaide, South Australia 5000)

The purpose of this study was to examine the incidence of invasive cervical resorption in endodontically treated teeth that had been bleached using a standardized technique. A total of 204 teeth in 158 patients with a median follow-up period of 4 years (range of 1-19 years) were evaluated. Of these teeth, 77.9% had a history of traumatic injury. All of the teeth had a history of gutta-percha and AH26 obturation and had been treated one to four times with a combination of thermocatalytic and walking bleach procedures using 30% hydrogen peroxide. A protective sealing cement was not placed over the canal filling material prior to bleaching procedures. The root filling material was located at the height of the cementoenamel junction (CEJ) in 54.4%, below the CEJ in 18.6%, and above the CEJ in 26.9% of the study teeth. The study found 1.96% of the teeth developed invasive cervical resorption during the evaluation period. The resorbing teeth all had a history of trauma and gutta-percha at the level of the CEJ. The number of bleaching treatments was not statistically related to the development of invasive cervical resorption. The results suggest a relatively low risk of invasive cervical resorption and a lower incidence than previously reported.

Densitometric comparisons of Ultra-speed, Ektaspeed, and Ektaspeed Plus intraoral films for two processing conditions. *Ludlow JB & Platin E (1995) *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* 79 105-113.

(*University of North Carolina School of Dentistry, Diagnostic Sciences Department, Chapel Hill, NC 27599-7450)

The purpose of this study was to compare the resolution, contrast, exposure latitude, and film speed of a new film, Ektaspeed Plus, to Ultra-speed and Ektaspeed. Ektaspeed Plus is claimed to provide reduced radiation exposure, improved image sharpness, and greater consistency under different processing conditions than the traditional Ektaspeed film. The three films were exposed in a standardized manner and processed in an automatic processor in a university dental clinic for 5 days. Differences in density, contrast and film speed were assessed. Ektaspeed Plus demonstrated significant improvement over Ektaspeed in film speed and contrast. Additionally, the response of Ektaspeed Plus was less affected by different processing conditions than either Ektaspeed or Ultra-speed. Ektaspeed Plus demonstrated a significant advantage over Ektaspeed in contrast between relatively radiolucent and radiopaque structures. However, the similarity of their responses in the lower density range suggests neither would have an advantage in the detection of incipient lesions in enamel. For incipient caries, Ultraspeed appears to have the advantage. This study suggests that dental practitioners, who have avoided use of Ektaspeed film due to its sensitivity to variable processing conditions, may now provide this radiation-sparing technology to their patients.

Light and setting times of visible-light-cured orthodontic adhesives. *Oesterle LJ, Messersmith ML, Devine SM & Ness CF (1995) *Journal of Clinical Orthodontics* 29 31-36.

(*University of Colorado Health Sciences Center, School of Dentistry, Department of Growth and Development, Campus Box C-284, 4200 E Ninth Ave, Denver, CO 80626)

The purpose of this study was to determine the effect of increasing the curing time or the setting time on the shear bond strength of visible-light-cured precoated orthodontic brackets. One hundred bovine incisors were collected within a few hours after slaughtering and divided into 10 groups of 10 teeth each. The facial surface enamel of each tooth was acid etched. Transbond primer was applied to the enamel and air thinned. Precoated Mini-Uni-Twin brackets (0.022-inch slot) were positioned and visible-light cured as close as possible to the mesial and distal of the bracket-tooth interface. Curing times were 20 or 40 seconds. The brackets were loaded in shear at 2 minutes, 5 minutes, 20 minutes, 30 minutes, or 24 hours after bonding. The results showed that brackets receiving 40 seconds of visible light curing had significantly higher shear strength than those receiving 20 seconds. Brackets tested at 24 hours had significantly higher shear strength than all other times. There was a nonsignificant increase in shear strength as the setting time increased from 2 to 30 minutes. The findings suggest that a longer visible-light-curing time increases shear bond strength. It was suggested to wait 5 minutes before tying in an archwire.

The dentist's exposure to elemental mercury vapor during clinical work with amalgam. *Pohl L & Bergman M (1995) *Acta Odontologica Scandinavica* 53 44-48.

(*Umeå University, Faculty of Odontology, Department of Dental Materials Science, S-901 87 Umeå, Sweden)

The purpose of this study was to measure the mercury vapor in the breathing zone of a dentist during normal operative dentistry procedures utilizing amalgam. Mercury vapor was measured with atomic absorption spectrophotometry. Fifty large amalgam fillings were removed and replaced. At a second appointment the 50 restorations were polished along with 30 other previously placed amalgam restorations. It was not reported whether a rubber dam was used in the study. Three methods of suction were used during these procedures: a high-volume evacuator (150 l/minute), a saliva ejector(20 l/minute), and a mirror and evacuation combination device (40 l/minute). The results showed that the high-volume evacuator reduced the mean time-weighted mercury vapor levels in the breathing zone of the dentist to 1-2 μg mercury m^{-3}, the same magnitude as the background levels in the dental operatory. The saliva ejector resulted in mean time-weighted levels of 6-7 μg mercury m^{-3}. During the polishing procedure the background levels were not exceeded even without the high-volume evacuation,

provided that water coolant was used during polishing. The results are all well below the present occupational threshold limit time-weighted value of 50 μg mercury m^{-3}.

Successful marginal adaptation of a dentin-enamel bonding system in vitro and in vivo. Kanca J & *Gwinnett AJ (1994) *Journal of Esthetic Dentistry* 6 286-294.

(*SUNY at Stony Brook, School of Dental Medicine, Department of Oral Biology and Pathology, Stony Brook, NY 11794-8702)

The purpose of this study was to evaluate the marginal adaptation of the resin-dentin interface in vitro and in vivo with a combined acid etch of dentin and enamel. Twenty human teeth were restored in vitro and 20 in vivo (treatment planned for removal for orthodontic therapy). V-shaped preparations were cut into the cervical areas of each tooth and restored with the all-etch version of the All-Bond Dentin-Enamel Bonding System and P-50 resin composite. The teeth in the in vivo and in vitro parts of the study were divided in two equal groups. Group 1: Dentin and enamel were etched with 10% phosphoric acid, rinsed, and air dried for 5 seconds. Primer was applied and a layer of bonding resin applied to the primed surface and light cured. P-50 resin composite was placed in two increments. Ten teeth in both the in vitro and in vivo groups were restored in this manner. Group 2: The teeth were restored as in Group 1 except following rinsing of the etchant, the surfaces were not air dried and were left visibly moist. The teeth in the in vivo part of the study were extracted immediately following restoration. All teeth were stored in water for 48 hours prior to SEM evaluation.

The restored teeth were sectioned longitudinally through the restoration. An impression was made of half of the sectioned tooth and prepared for SEM examination. The other half was demineralized and prepared for SEM evaluation. The in vivo and in vitro samples all showed no evidence of gap formation at X400 regardless of the dry or wet dentin technique. The dry dentin technique in both in vivo and in vitro teeth demonstrated resin strings into the dentin tubules that were short and of variable length. The in vivo wet dentin technique showed more thorough penetration of the tubules by the resin. Resin penetration into dentin tubules was more thorough when the primer was applied to wet dentin than dry dentin.

A comparison of the marginal and internal adaptation of titanium and gold-platinum-palladium metal ceramic crowns. Valderrama S, Van Roekel N, Andersson M, *Goodacre CJ & Muñoz CA (1995) *International Journal of Prosthodontics* 8 29-37.

(*Loma Linda University, School of Dentistry, Loma Linda, CA 92350)

The purpose of this study was to compare the marginal and internal adaptation of metal ceramic titanium crowns fabricated by electrical discharge machining (EDM) to conventional cast Au-Pt-Pd metal ceramic alloys. Titanium is an alternative to traditional alloys for metal ceramic restorations. EDM is a spark erosion technique used in the dental laboratory to improve the fit of titanium crowns. Crowns (10 copings with and 10 copings without ceramic placement) of both materials were fabricated from a master pattern and luted with zinc phosphate cement. The crowns were sectioned in diagonal and buccolingual planes. Optical microscopy was used to measure gaps at nine sites under each crown. The study found the average marginal gaps were not significantly different between the titanium and the Au-Pt-Pd crowns. The external marginal gaps were 61 μm for the titanium and 47 μm for the Au-Pt-Pd ceramic crowns. The titanium crowns showed significantly greater gaps at all internal adaptation points except the cusp tips. The addition of the ceramic caused no significant change in the external marginal gaps of either the titanium or the Au-Pt-Pd metal copings.

Bond strength to etched enamel and dentin contaminated with saliva. Vargas MA, *Denehy GE & Silberman JJ (1994) *American Journal of Dentistry* 7 325-327.

(*University of Iowa, College of Dentistry, Department of Operative Dentistry, Iowa City, IA 52242)

The purpose of this study was an in vitro evaluation of the effect of a hydrophilic primer (Scotchbond Multi-Purpose) on both enamel and dentin surfaces contaminated with saliva after acid conditioning.

Eighty extracted human teeth were used to make four groups of 10 flat dentin surfaces and four groups of 10 flat enamel surfaces. Enamel and dentin surfaces groups were conditioned with 37%

phosphoric acid and 10% maleic acid respectively. The groups were then surface treated by 1) contaminating with whole human saliva; 2) contaminating with whole human saliva and rinsed with water; 3) contaminating with whole human saliva, rinsed with water, and reconditioned for 15 seconds; 4) left uncontaminated. A hybrid resin composite (Z-100) was then bonded to form cylinders. Following thermocycling shear bond strength testing was performed.

The four enamel groups showed no significant differences. The saliva-contaminated dentin group showed slightly lower, but not significantly different shear bond strength than the uncontaminated group. Dentin groups that were contaminated and then rinsed or rinsed and reconditioned had significantly lower shear bond strength than the uncontaminated and saliva-contaminated groups.

BOOK REVIEWS

BELL'S OROFACIAL PAINS
Fifth Edition

Jeffrey P Okeson, DMD

Published by Quintessence Publishing Co, Inc, St Louis, 1995. 500 pages, 180 illustrations. $68.00

The fifth edition of *Bell's Orofacial Pains* is a just tribute to its original author. The dental profession manages pain on a daily basis, but few dental schools teach courses on pain and pain management. Dr Okeson's goals for this text were to introduce the latest research findings in the complex study of pain and to introduce the reader to the neuroanatomy and neurophysiology of pain early in the text so that a more thorough understanding of pain may be appreciated. He met both goals. This book provides the background information and framework necessary to help the clinician better understand the neurophysiology of pain and orofacial pain disorders. The author is a well-known authority and lecturer in the field of temporomandibular disorders and orofacial pain who has that rare ability to make an otherwise very difficult subject understandable.

The book is divided into three main sections: 1) "The Nature of Pain," 2) "Clinical Considerations of Orofacial Pains," and 3) "Clinical Pain Syndromes." The first section consists of four chapters that review the neural anatomy, neurophysiology, and processing of pain. Terminology in this area can be very confusing and ambiguous. To prevent any misunderstanding of the material, this section is preceded by several pages of definitions for commonly used terms. These chapters address one of Dr Okeson's primary goals: to help the reader understand and better appreciate pain pathways, and the processing of pain. A variety of figures and diagrams are utilized to help the reader better understand complex models and concepts.

Section two contains five chapters that discuss the psychology, classification, diagnosis, and general considerations for managing orofacial pain. A detailed discussion outlining the step-by-step evaluation of the pain patient is presented. Physical signs and symptoms and psychological factors that will assist the clinician in classifying orofacial pain disorders are identified. Pharmacologic, physical, and psychological therapeutic modalities for managing pain patients are reviewed.

Nine chapters in the last section deal with behavioral considerations, differential diagnosis, and therapeutic options for a variety of pain syndromes. Thirty-five case scenarios are included that describe different types of pain complaints. Each scenario includes a complete case history, examination results, clinical impression, and diagnosis.

These examples are extremely helpful to students and clinicians. Examination forms and classification systems help us organize our thoughts, but there is no replacement for the information gained from a real patient case scenario.

Information in the field of orofacial pain is expanding and changing daily. A large percentage of the general population has some sign or symptom of orofacial pain and may require restorative dentistry. Clinicians need to have a good understanding of orofacial pain and dysfunction to develop sound treatment plans. This text provides the background information, references, diagnostic guidelines, and current therapeutic modalities required for managing orofacial pain patients. This easy-to-read, in-depth, and well-referenced book is highly recommended for dental students, researchers and any clinician managing orofacial pain patients. I have studied previous editions of Bell's text in my graduate education, and plan to utilize this revised edition as a reference for future orofacial pain lectures and as a text for graduate seminars.

A DALE EHRLICH, MS, DDS
Naval Dental School
8901 Wisconsin Avenue
Bethesda, MD 20889-5602

VOYAGE: VISIONS IN COLOR AND FORM

Claude Sieber

Published by Quintessence Publishing Co, Inc, Chicago, 1995. 143 pages, 256 color illustrations. $148.00.

The purpose of this book, as stated by the author, is to challenge the reader to review things with sensitivity from another vantage point, the natural tooth. Claude Sieber is one of the premier technicians of our time. His background includes numerous lectures worldwide as well as his instrumental research and development of new metal and full ceramic porcelain systems. The author has presented a flawlessly documented and exquisitely photographed selection of teeth and natural settings.

The book is broken down into two areas and an information index. The first section is dedicated to photographing teeth in different light sources, histologic sections, and selected backgrounds. The author would like for the reader to discover and experience the thrill of viewing the natural tooth from a new aspect.

The second section of the book is actual case presentations of restored teeth interspersed with histologic sections and other still photographs. The Explanation Key to this section is the color/form and case study index directly following. Simple explanations of photographs and light distributions as well as case studies showing initial photographs of patients prior to restoration are depicted.

This is not a text of teaching and technique or how to achieve this incredible ceramic result but a photographic experience of natural teeth and viewing as a work of art.

Although the work seen in the book is flawlessly photographed, this text is not for everyone. As the author states, it is not written for people who are always in a hurry. Dental technicians and restorative dentists who are committed to developing the highest ability to replace natural color and form will benefit most from reviewing this book. However, there is no written text for specific techniques for those who are interested. After review by clinicians, this text may be best suited for a waiting-room reference for patients.

TIMOTHY J BUTSON, DMD, MSD
Assistant Professor
University of Washington
School of Dentistry
Department of Restorative Dentistry
Box 357456
Seattle, WA 98195-7456

BUILDING YOUR MILLION DOLLAR SOLO PRACTICE

Edward L Silker, DDS

Published by Silk Pages Publishing, Lakeshore, MN, 1995. 416 pages, 40 color illustrations. $59.95 plus $2.00 shipping, softbound.

A recent practice management publication by a self-styled author/publisher provides a rambling, chatty expose about building a high-volume dental practice. The author's expertise appears to be more in entrepreneurial skills and conversational writing than in clinical skills. It is reported that Dr Silker was a very successful businessman prior to attending dental school. After private practice experiences over 20 years that involved conventional practice as well as creation of a "group practice empire," the author set out to establish his own solo practice. This book provides an opportunity for him to share his thoughts, strategies, inspirational references, and plans used to accomplish this goal.

In 31 chapters, the reader is provided with an abridged offering composed of suppositions and empirical findings on a variety of subjects. Superficial coverage is given to learning theory, efficiency, scheduling, patient relations, tray and operatory set-ups, interpersonal skills, third-party involvement, marketing, accounting, banking, goal setting, and building the office—its equipment along with support systems.

Less than one-third of the printed material relates to clinical activity. Briefly covered are tips on pedodontics, root canal treatment, prosthetics, operative dentistry, and relations with laboratories. An emphasis is placed on use of the "Modified Rubber Dam Technique." The author admits it "may seem crude by Ivory Tower standards" and defends it as being functional and valuable. The stated object is to keep the cheek and tongue out of the operating field, allow visiblity of the tooth/teeth being operated upon, and keep debris out of the patient's mouth. This technique differs from that taught in dental schools, where floss is passed through the contacts and the dam is inverted around the cervical area.

This book could help an inexperienced clinical dentist attempting to establish, organize, and operate a practice. The writing style and structure make for easy reading. It would be of less value to a person in search of direction in operative dentistry. This reviewer takes issue with the author's selected clinical assumptions. However, astute dentists are able to selectively choose content for their constructive benefit. Recognizing that professionals are individually responsible for their actions, reference is made to the included Warning/Disclaimer section on page 12. The author states that he "shall have neither

liability nor responsibility to any person or entity with respect to any loss or damage caused, or alleged to be caused directly or indirectly by the information contained in this book" and suggests that the reader is "to tailor the information to your individual needs."

This practice management exposition contains a brief bibliography and is void of an index. A listing is provided of over 500 companies that can be reached by 1-(800) numbers. Photographs included are mostly of tray set-ups. Others, nine in number, show unspectacular intraoral views of rubber dam technique, position of hand mirror, and condensation of amalgam. "It is not the purpose of this text to reprint information that is otherwise available in the field of Dentistry, but to complement, amplify and supplement other texts." He claims a wide range of subjects for inclusion and shares his empirical findings "from the trenches where we (as dentists) live." Due to the ease of expressing one's thoughts and techniques without critical review prior to publication, the author appears to have accomplished his stated purpose.

HARVEY A STRAND, DDS
Former Director of the DAU & TEAM Programs
and the Applied Dental Practice Program
University of Washington
School of Dentistry
Department of Restorative Dentistry
Box 357456
Seattle, WA 98195-7456

ORTHODONTIC CEPHALOMETRY

Athanasios E Athanasiou

Published by Mosby-Wolfe, St Louis, 1995. 296 pages, 346 illustrations. $132.00.

Since its introduction in 1931, by Broadbent in the United States and Hofrath in Germany, orthodontic cephalometry has become one of the most important methods to study facial growth, dental development, and the effects of orthodontic treatment. In addition to its use by researchers, orthodontic cephalometry is used routinely by the clinician in the diagnosis and treatment planning of skeletal and dental malocclusions.

In this book the editor and 19 contributing authors provide a comprehensive review of the theoretical and practical aspects of orthodontic cephalometry. Chapters range from basic considerations such as "The Technique of Cephalometric Radiography" and "Sources of Error in Lateral Cephalometry" to more sophisticated issues such as "Clinical Research Applications of Cephalometry" and "Computerized Cephalometric Systems." The chapter I enjoyed the most was entitled "Anatomy, Radiographic Anatomy and Cephalometric Landmarks of Craniofacial Skeleton, Soft Tissue Profile, Dentition, Pharynx and Cervical Vertebrae." In this chapter the author effectively correlates with figures and photographs the relationships between anatomical features of the skull, the cephalometric radiograph and cephalometric tracing. Another particularly interesting chapter, "Postanterior (Frontal) Cephalometry," describes the identification of important anatomical landmarks on frontal radiographs and their use in various cephalometric analyses.

The book is well illustrated; the photographs and schematic drawings are of high quality. The references at the end of each chapter are selective and appropriate. This is a very good book, which the editor claims is "a starting point for the newcomer to the field of cephalometry but is also an 'all-inclusive' reference source for academics, researchers, and clinicians." While I agree with this statement, it should be pointed out that this text will not be of great interest or value to the person who does not use orthodontic cephalometry on a regular basis.

PETER SHAPIRO, DDS, MSD
University of Washington
School of Dentistry
Department of Orthodontics
Box 357446
Seattle, WA 98195-7446

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