OPERATIVE DENTISTRY

september-october 1996 • volume 21 • number 5 • 181-228

(ISSN 0361-7734)

OPERATIVE DENTISTRY

SEPTEMBER-OCTOBER 1996 • VOLUME 21 • NUMBER 5 • 181-228

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

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

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

Subscriptions
Yearly subscription in USA and Canada, $55.00; other countries, $70.00 (sent air mail printed matter); dental students, $25.00 in USA and Canada; other countries, $34.00; single copy in USA and Canada, $14.00; other countries, $17.00. For back issue prices, write the journal office for quotations. Make remittances payable (in US dollars only) to OPERATIVE DENTISTRY and send to the above address.

Contributions
Contributors should study the instructions for their guidance printed inside the back cover and should follow them carefully.

Permission
For permission to reproduce material from *Operative Dentistry* please apply to Operative Dentistry at the above address.

Editorial Office
University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

Subscription Manager
Judy Valela

The views expressed in *Operative Dentistry* do not necessarily represent those of the Academies or of the Editors.

©OPERATIVE DENTISTRY, 1996, 21, 181

EDITORIAL

Majestic Mediocrity

The most important mission of any dental school today is the same as it always has been: to prepare students to provide the highest quality of dentistry for their patients. Unfortunately, too many dental schools are on roller coasters speeding towards majestic mediocrity. This is not without reason, however, for intense pressure by parent universities and state legislatures continues to put the squeeze on dental schools to "pay their own way." To comply with these demands, dental school administrations look towards the major, many times the only, area they have for increasing revenues—clinic income. Most dental schools are already pushing the limit on fees for dental work. Increasing clinic requirements and/or increasing the number of students per class requires the availability of more patients, which is difficult or impossible to obtain in many geographic areas. That leaves the only area for aggressive pursuit by dental school administrations: increase the amount of time students are in the clinic. It can come from decreasing preclinical training and/or by increasing the length of the school year. New, or not so new, programs like "comprehensive dental groups" and "general practice clinics" are springing up at dental schools everywhere with the full expectation that clinic income will increase significantly. Administrations call this "total patient care" and expound on it loquaciously to all who will listen.

This increased clinical time must come from somewhere. Behold: Curriculum change is on the horizon! The teaching method of the future has become interactive video with highly sophisticated laboratories where each student has his or her own monitor and the ability to call up various aspects of preclinical teaching. Of course, this revolutionary teaching change is expected to significantly decrease the amount of time needed to prepare students for the clinic, NOT to supplement and enhance current teaching modalities. This evolution is the "majestic" quality of mediocrity! Don't get the feeling that I am against change. Those of us who are responsible for major preclinical courses are changing and, hopefully, improving our material and methods every year. We are always looking for ways to increase our ability to bring important information and techniques to our students. However, there is far too much to teach and far too little time to think naively that any of these new "cutting edge" resources will automatically decrease the time required to prepare students for the clinical practice of dentistry. What is distressing is that curricular changes are being decided by administrators and curriculum committees stacked with basic science researchers who have no true concept of what is involved in preparing students for clinical practice. Yet they have a certain expectation, or hope, that the faculty who must make the changes work will miraculously support their decisions. Why not have the key clinical faculty decide curricular issues involving clinical teaching? The problem is that these people often ask the difficult question, "If it isn't broken, why do we have to fix it?" The reasons given by administrations that "accreditation requires it," or "to stay on the cutting edge of progress" are seen as no more than smoke and mirrors by seasoned faculty. Whether additional clinical time is generated or not, the pressure to increase clinical productivity is a reality. It is also a given that, in addition to increasing clinic income, clinical departments are expected to maintain a standard of the highest quality of clinical performance, regardless of whether there is enough faculty or time. Unfortunately, the result is that students end up with enough time to do acceptable dentistry but not enough time to accomplish superior dentistry. Thus mediocrity is perceived as the ultimate goal by students, as they have never been pushed to strive for perfection! Regional Dental Examination Boards have not helped. They have endorsed this level of competence by gearing evaluation standards to an "acceptable" level, thereby eliminating the leverage needed by clinical departments to retain valuable curriculum hours. Ironically, the military is taking proactive steps to fill the gap left by this mediocrity. The Navy, for example, is increasing the number of Advanced Education in General Dentistry (AEGD) programs available for new graduates with the goal of placing every new dental officer in such a program for one year after graduation. No matter what avenues are taken to increase clinic income, one thing is for sure: The future of clinical and preclinical education in our dental schools is snowballing towards majestic mediocrity.

RICHARD B McCOY
Editor

©OPERATIVE DENTISTRY, 1996, 21, 182-184

CLINICAL ARTICLE

Establishing Approximal Contacts in Class 2 Composite Resin Restorations

S DOUKOUDAKIS

SUMMARY

Ensuring adequate approximal contacts when performing class 2 composite resin restorations is a significant challenge for the dentist. Fabrication of custom composite cylinders for placement into prepared cavity preparations enables the dentist to wedge the matrix band firmly against adjacent teeth, as well as eliminating the curing contraction variable that occurs when composite restorations are placed. Thus, predictable approximal contacts are obtained when class 2 composite restorations are completed.

INTRODUCTION

Composite resins have been successfully used for 30 years for the restoration of anterior teeth. The beveling of the enamel margins, the enamel etching, the use of bonding agents, and the improvement of the light-activated composites contributed to superior esthetic results in short clinical sessions.

In contrast, the use of composite resins to restore class 2 cavity preparations has always been problematic, since the procedure is very technique sensitive. The technique requires control of the operating field with use of the rubber dam, accurate cervical adaptation of the matrix band, and incremental placement and polymerization of the composite to minimize polymerization shrinkage. In addition to these factors, establishing contact areas with the neighboring teeth is very difficult, since composite resins cannot be condensed like the amalgam, which gains positive interproximal contact by condensing against the matrix band adjoining the approximal areas of adjacent teeth. For class 2 composites, thinner matrix bands and better matrix band adaptations are necessary to achieve adequate interproximal contact (Vanherle & Smith, 1985).

Even with improvement in the composition and physical properties of composite resins by manufacturers and the use of special Teflon instruments for placing the composite materials, the problem of inadequate approximal contact areas still remains. The use of a wedge that separates the two teeth prior to the cavity preparation is a solution only in conservative preparations, where upon completion of the restoration and the removal of the wedge, part of the contact will be on natural tooth structure. The use of the wedge technique is suggested only in the presence of minimal decay (Baratieri, 1993; Jordan, 1988; Marzouk, Simonton & Gross, 1985).

This paper presents a technique which ensures the establishment of contact points irrespective of the size of the cavity preparation.

TECHNIQUE

Accepted principles for class 2 cavity preparations are to be followed. Upon completion of the preparation (Figure 1), especially in MODs, the

National Kapodistrian University of Athens, Department of Operative Dentistry, Thivon 2, Goudi 115 27, Athens, Greece

Spiridon Doukoudakis, DDS, MS, FICD, instructor

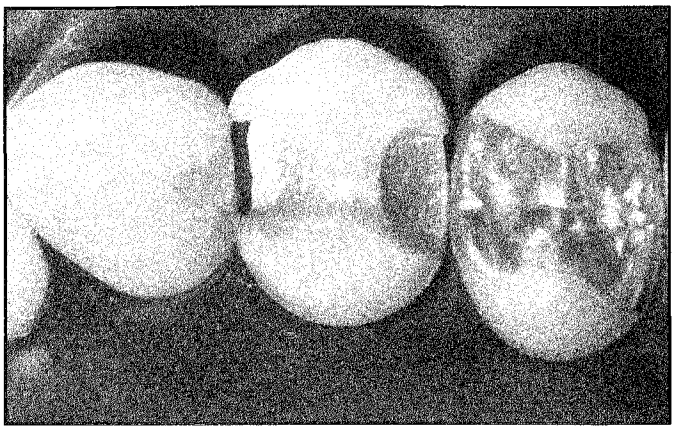


Figure 1. *An MOD cavity preparation on the first upper premolar with open contact areas*

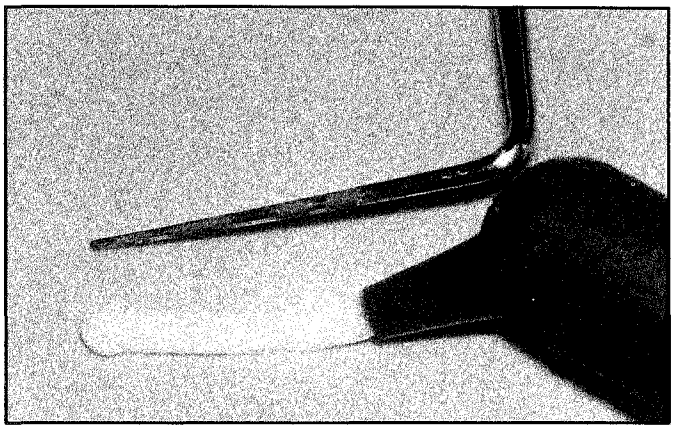


Figure 2. *Using the probe to measure resin cylinders*

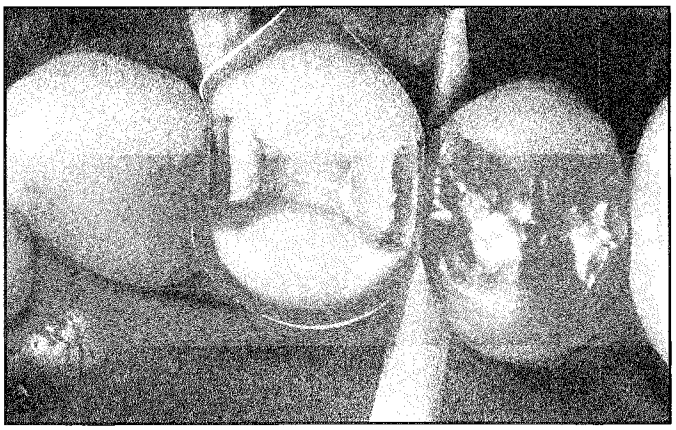


Figure 3. *Application of the matrix band and wedge*

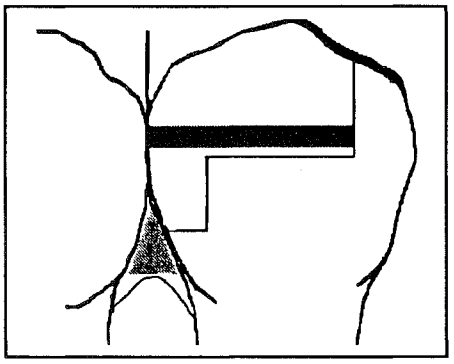


Figure 4. *Drawing of the cross section of a two-surface preparation with the composite bar in position*

approximal portion(s) of the cavity preparation is(are) evaluated to determine the distance from the adjacent tooth(teeth) to the reciprocating wall of the preparation or contact area of the tooth on the other side of the preparation. In these cases a periodontal probe is used to measure the distance from the approximal surface of the neighboring tooth to the mesial or distal wall for MO and DO cavity preparations. For MOD cavity preparations, we measure the distance between the approximal surface areas of the adjacent teeth. Using the measurement of the probe (Figure 2), three composite resin cylinders are prepared, the first with the exact measurement of the length, the second approximately 0.2 mm longer, and the third 0.5 mm longer. In this way, one of them will obtain a "tight" fit. The cylinders are prepared by using the compule system as the material comes out of the syringe and sectioned at the right length prior to the polymerization. Cylinders can be prefabricated in various sizes and kept with the composite resin kit. Cylinders should be preferably fabricated from dark shades for esthetic reasons. The procedure continues with the placement of a 0.025 mm Tofflemeyer matrix band, which is secured in place with the help of any kind of wedges that create a marginal seal (Figure 3). The cylinders are then wedged in position between the approximal surface of the matrix band and the mesial or distal wall of the cavity preparation (Figure 4). In MOD cavity preparations the cylinders are wedged between the

two approximal surfaces of the matrix (Figure 5).

If needed, the cylinders can be shortened, but they must fit very tightly. After placement of the cylinder, continue with the acid-etching of all the necessary areas (Figure 6), followed by application of the preferred bonding agent.

The incremental application and polymerization of the composite resin starts from the approximal boxes, taking special care in covering margins without creating voids until the entire restoration is completed and the cylinder is embedded within the composite resin (Figure 7). The matrix is removed and the restoration is completed following conventional finishing and polishing procedures (Figure 8). Approximal overhangs can be eliminated using fine diamonds, carbide finishing burs, composite resin finishing strips, or a suitable composite trimming instrument.

As these procedures are taking place, the darker-colored cylinder provides an excellent esthetic result, as it appears as a minute internal stain.

A final examination using dental floss indicates that a superb contact has been achieved that is not always possible with other existing placement techniques for class 2 composite restorations.

(Received 20 June 1995)

References

BARATIERI LN (1993) *Advanced Operative Dentistry* Chicago: Quintessence Pub Co, pp 483-486.

JORDAN RE (1988) *Esthetic Composite Bonding: Techniques and Materials* Philadelphia: B C Decker Inc, p 223.

MARZOUK MA, SIMONTON AL & GROSS RD (1985) *Operative Dentistry: Modern Theory and Practice*, 1st ed, St Louis: Ishiyaku EuroAmerica Inc, p 189.

VANHERLE G & SMITH D, eds (1985) *International Symposium on Posterior Composite Dental Restorative Materials* Utrecht, The Netherlands: Peter Szulc Pub Co, p 166.

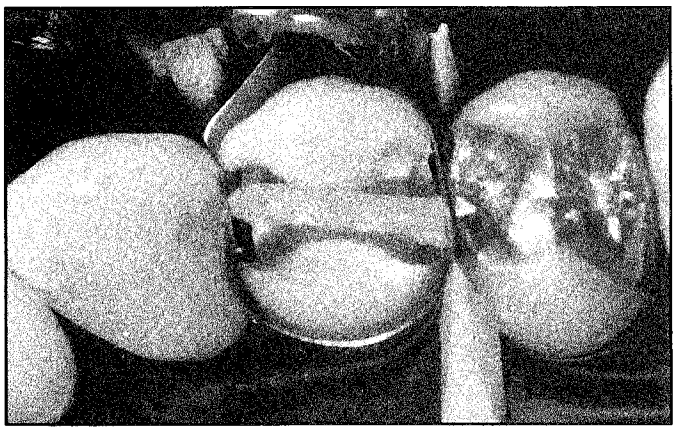
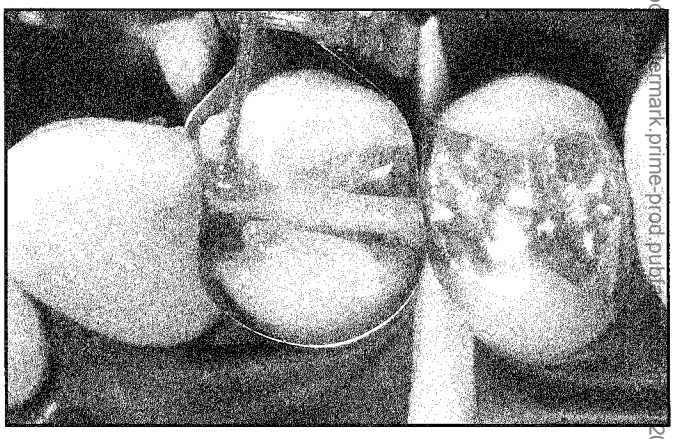


Figure 5. *Placement of the polymerized composite bar*



Legend 6. *Application of the acid-etch gel*

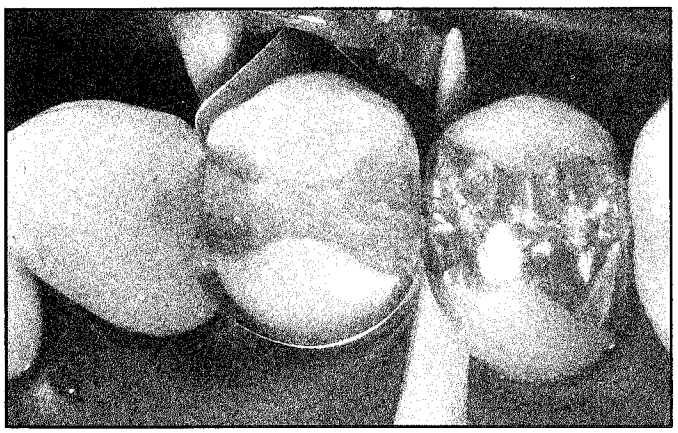


Figure 7. *Incremental application of the composite resin*

Figure 8. *The completed final restoration*

©OPERATIVE DENTISTRY, 1996, 21, 185-190

ORIGINAL ARTICLES

Fluoride Release from Fluoride-containing Materials

F B de ARAUJO • F GARCÍA-GODOY
J A CURY • E N CONCEIÇÃO

Clinical Relevance
All fluoride-containing materials tested continued to release a small amount of fluoride at 28 days.

SUMMARY

This in vitro study evaluated the amount of fluoride released from fluoride-containing materials over a period of 28 days. Six disk samples (2.06 ± 0.06 cm²) were prepared of each material and divided at random into seven groups: Group 1: Chelon-Fil; Group 2: Chelon-Silver; Group 3: VariGlass; Group 4: Dyract; Group 5: Vitremer; Group 6: Vitremer + Scotchbond Multi-Purpose; Group 7: Fuji II LC. The cements were mixed according to the manufacturers' recommendations, placed in plastic molds, and pressed between two glass plates. Paraffined dental floss was incorporated into the cements during setting to serve as attachments. The materials in Groups 3, 4, and 5 were light cured (Heliolux) in two different positions for 40 seconds each. In Group 6, the adhesive was light cured in two different positions on both sides for 10 seconds each. The samples were stored at 100% relative humidity for 24 hours. Each sample was then suspended in individual plastic tubes containing 5 ml of deionized water and submitted to constant agitation at 25 °C. The water was changed every 24 hours. Fluoride release was determined at 1, 2, 3, 4, 5, 7, 14, and 28 days after buffering the solution with equal volume of TISAB. Fluoride release was measured with a fluoride ion-specific electrode (Orion 96-09) and an ionanalyzer (Orion EA 940) previously calibrated with standard solutions containing 0.05 to 5.00 µgF/ml. Fluoride release was expressed as ppm in solution and µgF/cm². ANOVA and Student-Newman-Keuls tests were used to evaluate the data. The results revealed that Chelon-Fil released significantly ($P < 0.001$) more fluoride for the first 7 days than all the other products. This was followed by Fuji II LC, which exhibited significantly more fluoride release than the rest of the materials for the same 7 days. At days 14 and 28, Chelon-Fil, Dyract, and Fuji II LC released similar amounts of fluoride that were significantly greater than the other products. Group 6 (Vitremer + Scotchbond Multi-Purpose) released significantly less fluoride than the other materials at all time intervals. Fluoride release for all products at days 1 and 2 was significantly greater than the rest of the time intervals, except for Chelon-Silver, which released similar amounts of fluoride

University of Texas Health Science Center at San Antonio, Departments of Pediatric Dentistry and Restorative Dentistry, 7703 Floyd Curl Drive, San Antonio, TX 78284-7888

Fernando Borba de Araujo, DDS, PhD, associate professor, Federal University of Rio Grande do Sul, Department of Pediatric Dentistry, Porto Alegre, Brazil

Franklin García-Godoy, DDS, MS, professor

Jaime A Cury, DDS, PhD, professor of biochemistry and cariology, University of Campinas, Faculty of Dentistry, Piracicaba, São Paulo, Brazil

Ewerton Nocchi Conceição, DDS, PhD, associate professor, Federal University of Rio Grande do Sul, Department of Dental Materials, Porto Alegre, Brazil

for days 2, 3, 4, and 5. Although significance for the remaining time intervals varied for all materials, all fluoride release decreased from day 1 to day 28.

INTRODUCTION

Secondary caries has been reported in 53% of extracted teeth with the lesion found adjacent to the cavosurface margins of restorations (Mertz-Fairhurst & Newcomer, 1988). This is a major reason for restoration failure (Mjör, 1981; York & Arthur, 1993).

Cavity varnishes are used to prevent microleakage; however, controversial results are found in the literature regarding their effectiveness, with some showing dissolution of the varnish in the oral environment (Smith, Wilson & Combe, 1978; Advokaat, Akerboom & Borgmeijer, 1981; Jeblinger & Lutz, 1987), a limited effect on microleakage affecting the marginal adaptation of amalgam restorations (Jeblinger & Lutz, 1987), or enhancement of microleakage when a copal varnish is used (Mazer, Rehfeld & Leinfelder, 1988).

Glass ionomers have been suggested as bases for composite restorations (McLean & Wilson, 1977; McLean & Gasser, 1985; García-Godoy & others, 1988; García-Godoy & Jensen, 1990; Jensen, García-Godoy & Wefel, 1990; Powis & others, 1982). These materials adhere to dentin and enamel (Crisp, Lewis & Wilson, 1976), have a stable matrix structure (Forsten, 1977), release fluoride (Swartz, Phillips & Clark, 1984; Meryon & Smith, 1984; Olsen & others, 1989; García-Godoy & others, 1990; DeSchepper & others, 1990; Swift, Bailey & Hansen, 1990; García-Godoy & Chan, 1991) and reduce microleakage (McLean & Wilson, 1977; García-Godoy & Malone, 1987). The adhesive properties, compressive strength, radiopacity, and fluoride release from glass ionomers have prompted some authors to recommend them as bases for amalgam restorations, reducing microleakage and the occurrence of secondary caries (García-Godoy & others, 1988; García-Godoy & Jensen, 1990). Studies have revealed that secondary caries was reduced around restorations that release fluoride (Hotz, 1979) or that have been lined with a fluoride-releasing liner (García-Godoy & others, 1988; García-Godoy & Jensen, 1990; Tveit, 1980).

This study compared the amount of fluoride released from different autopolymerized and light-cured glass ionomers and newer fluoride-releasing materials over a period of 28 days.

Table 1. Materials Used

Group	Material	Manufacturer
1	Chelon-Fil	ESPE, Seefeld/Oberbay, Germany
2	Chelon-Silver	ESPE
3	VariGlass	L D Caulk, Milford, DE 19963
4	Dyract	L D Caulk
5	Vitremer	3M Dental Products, St Paul, MN 55144
6	Vitremer + Scotchbond Multi-Purpose	3M
7	Fuji II LC	G-C America, Chicago, IL 60658

METHODS AND MATERIALS

A pilot study was conducted revealing that a sample size of six specimens displayed a standard deviation no greater than 10%. Therefore, six disks (mean and standard deviation diameter of 2.06 ± 0.06 cm^2) were prepared of each material tested and divided at random into seven groups as shown in Table 1.

The cements were mixed according to the manufacturers' recommendations, placed in plastic molds, and pressed between two glass plates. Paraffin dental floss was incorporated into the cements during setting to suspend the samples in the testing medium.

The materials in Groups 3, 4, and 5 were light cured (Heliolux, Vivadent, Schaan, Liechtenstein) in two different positions for 40 seconds each. In Group 6, the adhesive was light cured in two different positions on both sides for 10 seconds each.

The samples were stored at 100% relative humidity for 24 hours. Each sample was then suspended in individual plastic tubes containing 5 ml of deionized water and submitted to constant agitation at 25 °C. The water was changed every 24 hours.

Fluoride release was determined at 1, 2, 3, 4, 5, 7, 14, and 28 days after buffering the solution with equal volumes of TISAB (Total Ionic Strength Adjustor, pH 5.0, used to provide constant background ionic strength, decomplex fluoride and adjust solution pH). Fluoride release was measured with a fluoride ion-specific electrode (Orion 96-09, Orion Research Inc, Boston, MA 02129) and an ionanalyzer (Orion EA 940, Orion Research Inc) after previous calibrations with standard solutions containing 0.05 to 5.00 µgF/ml. Fluoride released was expressed as ppm in solution and µgF/cm^2. The concentration of the quantity of fluoride released in the different time periods was evaluated, not the cumulative effect.

Means and standard deviations of fluoride release were calculated for the seven materials at eight time periods. Means and standard deviations were

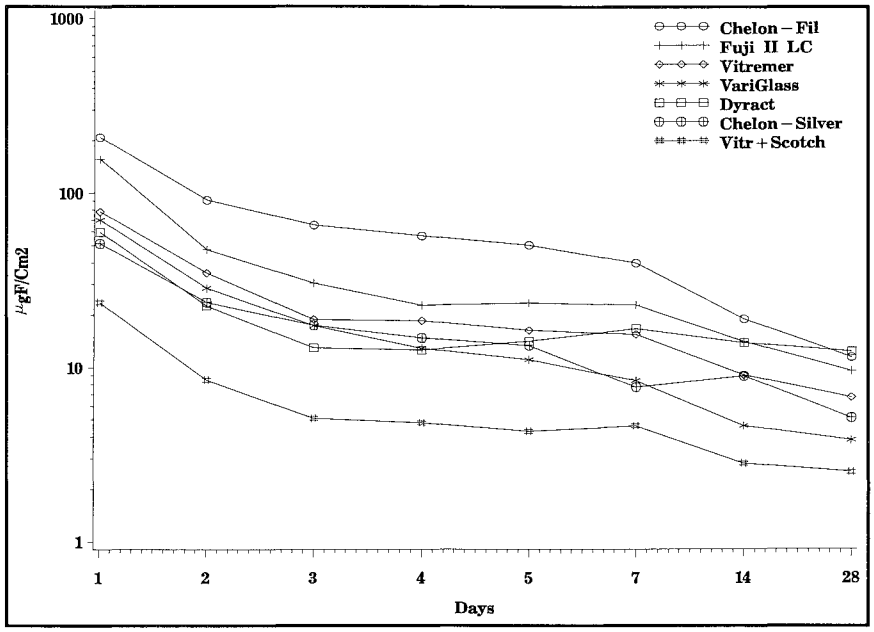


Figure 1. *Fluoride release (µmF/cm²) for the seven fluoride-containing materials*

significantly correlated ($r = 0.93$, $P < 0.001$), which suggested that log transformations should be performed on the data prior to performing an Analysis of Variance (ANOVA). Fluoride release values were multiplied by 100, and common logarithms were then calculated. Means and standard deviations of the log-transformed data were not significantly correlated ($r = 0.07$, $P > 0.001$) between types of materials and time points. One-way ANOVAs were then performed to compare types of materials for each time point. Also, one-way ANOVAs were performed to compare time points. Student-Newman-Keuls tests were performed to identify group differences for each ANOVA. To represent a plot of the fluoride release data, means of the untransformed values were multiplied by 10 and then plotted on a logarithmic scale.

RESULTS

Figure 1 reveals the fluoride release in µmF/cm² and Figure 2 the release in parts per million (ppm). All materials released significantly more fluoride in the first 2 days than during the rest of the time frames, except for Chelon-Silver, which released similar amounts of fluoride for days 2, 3, 4, and 5. After day 2, fluoride release decreased gradually through day 28 with varying significant differences shown within materials.

Table 2 displays the results of ANOVA and Student-Newman-Keuls tests comparing the fluoride-containing materials for each day, and Table 3 compares fluoride release within each material for the indicated time frames.

At day 1, Chelon-Fil released significantly higher amounts of fluoride than all the other products evaluated. This was followed by Fuji II LC, which also released significantly higher fluoride amounts than the rest of the products. The fluoride release from Vitremer and VariGlass were not significantly different. However, both released significantly more fluoride than Dyract, Chelon-Silver, and Vitremer + Scotchbond Multi-Purpose. Dyract and Chelon-Silver released similar amounts of fluoride. All materials released significantly more fluoride at all time frames during the 28 days than Vitremer + Scotchbond Multi-Purpose.

At day 2, Chelon-Fil and Fuji II LC showed significantly more fluoride release than other products similar to day 1. Vitremer and VariGlass released similar amounts of fluoride; however, VariGlass was not significantly different from Chelon-Silver and Dyract.

At days 3 and 5, Chelon-Fil released the greatest amount of fluoride, followed by Fuji II LC. Vitremer,

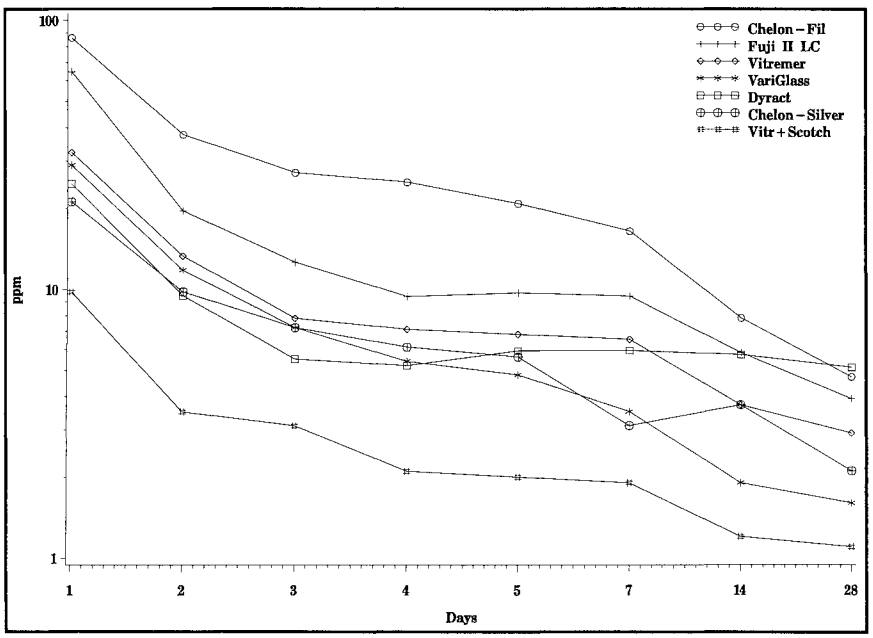


Figure 2. *Fluoride release (ppm) for the seven fluoride-containing materials*

Table 2. Comparisons of Fluoride-containing Materials for Each Day [Results of ANOVA and Student-Newman-Keuls ($P < 0.05$); > indicates statistical significance.]

Day	Differences
1	CF > FLC > V,VG,D,CS > V+SMP Also V > D,CS and VG > CS
2	CF > FLC > V,VG,CS,D > V+SMP Also V > CS,D
3	CF > FLC > V,VG,CS,D > V+SMP
4	CF > FLC > V,CS,VG,D > V+SMP
5	CF > FLC > V,D,CS,VG > V+SMP Also V > VG
7	CF > FLC > D,V > VG,CS > V+SMP
14	CF,FLC,D > V,CS > VG > V+SMP
28	D,CF,FLC > V > CS > VG > V+SMP

CF=Chelon-Fil; FLC=Fuji II LC; V=Vitremer; VG=VariGlass; D=Dyract; CS=Chelon-Silver; V+SMP=Vitremer+Scotchbond Multi-Purpose.

Chelon-Silver, VariGlass, and Dyract showed no significant differences in fluoride release.

At day 7, Chelon-Fil released a significantly greater amount of fluoride, followed by Fuji II LC. Vitremer and Dyract released similar amounts of fluoride. These materials were followed by Chelon-Silver and VariGlass, which displayed similar results.

At day 14, a different trend was observed. Chelon-Fil, Fuji II LC, and Dyract released equal amounts of fluoride—significantly more than the other products. Vitremer and Chelon-Silver released similar amounts of fluoride, which were significantly higher than VariGlass and Vitremer + Scotchbond Multi-Purpose.

At day 28, Dyract, Chelon-Fil, and Fuji II LC released similar amounts of fluoride, significantly greater amounts than all the other materials. Vitremer released significantly more fluoride than Chelon-Silver, VariGlass, and Vitremer + Scotchbond Multi-Purpose.

The statistical analysis showed that at days 1-7, Chelon-Fil released statistically significantly ($P < 0.001$) more fluoride than all the other products. However, at days 14 and 28, the release was not significantly different from Fuji II LC and Dyract.

Every product tested showed significantly higher fluoride release at all time frames than Vitremer protected with Scotchbond Multi-Purpose.

The results also showed differences between the fluoride release profile of the different products tested. All products showed very high fluoride release (over 2 ppm) during the first day of testing except Vitremer protected with Scotchbond Multi-Purpose, which released approximately 1 ppm. After the first day, all products revealed a sharp drop in fluoride release. Chelon-Fil released over 1 ppm of fluoride during the first 7 days, while Fuji II LC did so for the first 3 days only. Vitremer and VariGlass released over 1 ppm for the first 2 days only and Dyract for the first day only.

DISCUSSION

Fluoride released from glass ionomers concentrates in the enamel of the teeth that have been in contact with them for 2 weeks (Forsten, 1977; Hotz, 1979; Hicks, Flaitz & Silverstone, 1986; Retief & others, 1984). Glass-ionomer-lined amalgam restorations have shown fluoride release (Olsen & others, 1989; García-Godoy & others, 1990) as well as a cariostatic effect at the cavosurface margins (Jensen & others, 1990).

In this study, Chelon-Fil released significantly more fluoride than all the other materials, possibly because Chelon-Fil was the only glass ionomer tested without additional resin or silver added. All the other products were combinations: a glass ionomer with silver particles sintered to the glass, resin composites with glass-ionomer properties, or resin-modified glass ionomers, all of which may have limited the amount of fluoride available for release.

Fluoride-releasing dental materials are effective in preventing secondary caries or caries on adjacent teeth (Hotz, 1979). Some fluoride-releasing materials can reduce enamel solubility (Tveit, 1980) and acid production by bacteria that initiate caries (Maltz & Emilson, 1982; Okuda & Frostell, 1982; Brown & others, 1980). Therefore, restorations lined with fluoride-releasing liners might show less plaque accumulation. Although the fluoride-releasing materials might not be in contact with the cavosurface margins of the cavity preparation, the anticariogenic effect of the fluoride release has been demonstrated (Jensen & others).

Most manufacturers recommend placing a resin or varnish immediately after curing the glass ionomer, mainly to protect it from dehydration. In the present

Table 3. Comparisons of Days for Each Fluoride-containing Material [Results of ANOVA and Student-Newman-Keuls ($P < 0.05$); > indicates statistical significance.]

Material	Differences
CF	1 > 2 > 3,4,5,7 > 14 > 28 Also 3,4 > 7
FLC	1 > 2 > 3 > 4,5,7 > 14 > 28
V	1 > 2 > 3,4,5,7 > 14 > 28
VG	1 > 2 > 3 > 4,5 > 7 > 14,28
D	1 > 2 > 3,4,5,7,14,28
CS	1 > 2,3,4,5 > 7,14 > 28 Also 2 > 4,5
V+SMP	1 > 2 > 3,4,5,7 > 14,28

CF=Chelon-Fil; FLC=Fuji II LC; V=Vitremer; VG=VariGlass; D=Dyract; CS=Chelon-Silver; V+SMP=Vitremer + Scotchbond Multi-Purpose.

study, this procedure reduced the amount of fluoride released, but it did not prevent it. With the protected Vitremer, the highest amount of fluoride released at day 1 was similar to the amount released at day 3 by the unprotected Vitremer. However, at all times, the protected Vitremer released significantly less fluoride than the unprotected Vitremer. In the clinical environment, the protective bonding agent would be lost due to wear produced, for example, by chewing, occlusal grinding, and toothbrushing, and at some point the fluoride release could be similar to the unprotected Vitremer.

Another consideration is that glass ionomers are fluoride rechargeable (Forsten, 1991a; Marinelli & Donly, 1993). In the clinical situation this would mean that fluoride would be constantly released as long as the subject continues rinsing, brushing, or chewing fluoridated products.

The quantitative fluoride release values presented in studies have no precise clinical significance, as the exact minimal fluoride concentration for caries inhibition has not been determined. Also, due to the multifactorial nature of dental caries, perhaps every individual would require a minimal fluoride concentration. Until these data are determined, the use of a dental material with the highest long-term fluoride release would be preferable, especially in patients with moderate to high caries activity.

The amount of fluoride released in the present study was determined in a neutral environment; however, fluoride release is increased by lowering the pH of the storage medium (Forsten, 1991b). In the oral environment this could be the case, especially with a plaque-induced acidogenic challenge.

The amount of fluoride release in deionized water could be different from that found in the oral cavity, because saliva is a constantly changing medium with respect to temperature, pH, protein content, and many other factors. However, hydrodynamic stimuli (osmotic, thermal, tactile, air blasts) produce rapid shifts of the contents of dentin tubules (convective transport) (Pashley & Pashley, 1991). This is accompanied by permeation of materials in both directions: inwards and outwards. Simultaneously, there is a slow seepage of dentin fluid in the opposite direction, which tends to reduce the rate of inward diffusion of exogenous material (Pashley & Pashley, 1991). This is possible because the pulpal pressure is higher than that of the mouth; therefore, fluids slowly filter across dentin toward the surface. This convective fluid movement tends to oppose the inward diffusion of bacterial toxins (Pashley & Pashley, 1991) and could be responsible for the transport of fluoride from the glass-ionomer base to the outer enamel surface. This is more likely to occur in vivo, as this convective transport does not occur in vitro (Pashley & Pashley, 1991). Corrosion products of the amalgam could also affect the amount of fluoride released from the glass-ionomer-lined amalgam restorations by forming a barrier at the interface gap. However, with the newer high-copper amalgams, this corrosion will take years to form, and from a clinical standpoint it could be of little or no benefit.

Further studies should evaluate the potential cariostatic effect of glass-ionomer-lined amalgam restorations.

CONCLUSIONS

1. At days 1-7, Chelon-Fil released significantly ($P < 0.001$) more fluoride than all the other products. Fuji II LC followed Chelon-Fil and released significantly more fluoride than the rest of the products.
2. Significantly greater amounts of fluoride were released during the first 2 days for all materials than for the rest of the time periods. The exception was Chelon-Silver, which released similar amounts of fluoride for days 2, 3, 4, and 5.
3. Fluoride release leveled off from days 3 to 28. However, perceptible levels of fluoride were still being released from all products at day 28.

(Received 1 June 1995)

References

ADVOCAAT JGA, AKERBOOM HBM & BORGMEIJER PJ (1981) The influence of use of Copalite on the marginal breakdown of amalgam restorations. Results after one year *Journal of Dental Research* **60** *Abstracts of Papers* p 1212 Abstract 1285.

BROWN LR, HANDLER SF, HORTON IM, STRECKFUSS JL & DREIZEN S (1980) Effect of sodium fluoride on the viability and growth of Streptococcus mutans *Journal of Dental Research* **59** 159-167.

CRISP S, LEWIS BG & WILSON AD (1976) Glass ionomer cements: chemistry of erosion *Journal of Dental Research* **55** 1032-1041.

DeSCHEPPER EJ, BERRY EA, CAILLETEAU JG & TATE WH (1990) Fluoride release from light-cured liners *American Journal of Dentistry* **3** 97-100.

FORSTEN L (1977) Fluoride release from a glass ionomer cement *Scandinavian Journal of Dental Research* **85** 503-504.

FORSTEN L (1991a) Fluoride release and uptake by glass ionomers *Scandinavian Journal of Dental Research* **99** 241-245.

FORSTEN L (1991b) Short- and long-term fluoride release from glass ionomer based liners *Scandinavian Journal of Dental Research* **99** 340-342.

GARCÍA-GODOY F & CHAN DCN (1991) Long-term fluoride release from glass ionomer-lined amalgam restorations *American Journal of Dentistry* **4** 223-225.

GARCÍA-GODOY F, DRAHEIM RN, TITUS HW & CHIESA D (1988) Microleakage of composite restorations with etched and non-etched glass ionomer bases *American Journal of Dentistry* **1** 159-162.

GARCÍA-GODOY F & JENSEN ME (1990) Artificial recurrent caries in glass ionomer-lined amalgam restorations *American Journal of Dentistry* **3** 89-93.

GARCÍA-GODOY F & MALONE WF (1987) Microleakage of posterior composite restorations after rebonding. *Compendium* **8** 606-609.

GARCÍA-GODOY, OLSEN BT, MARSHALL TD & BARNWELL GM (1990) Fluoride release from amalgam restorations lined with a silver-reinforced glass ionomer. *American Journal of Dentistry* **3** 94-96.

HICKS MJ, FLAITZ CM & SILVERSTONE LM (1986) Secondary caries formation *in vitro* around glass ionomer restorations *Quintessence International* **17** 527-532.

HOTZ PR (1979) Experimental secondary caries around amalgam, composite and glass ionomer cement fillings in human teeth *Helvetica Odontologica Acta* **23** 9-39.

JEBLINGER P & LUTZ F (1987) Influence of varnishes and bases on the marginal amalgam adaptation *Journal of Dental Research* **66** *Abstracts of Papers* p 1456 Abstract 1456.

JENSEN ME, GARCÍA-GODOY F & WEFEL JS (1990) Artificial root caries in amalgam restorations: effect of light-cured fluoride releasing liners *American Journal of Dentistry* **3** 295-298.

MALTZ M & EMILSON CG (1982) Susceptibility of oral bacteria to various fluoride salts *Journal of Dental Research* **61** 786-790.

MARINELLI CB & DONLY KJ (1993) Effects of a fluoridated dentifrice on fluoride release of composite resin and glass ionomer cement *Journal of Dental Research* **72** *Abstracts of Papers* p 317 Abstract 1707.

MAZER RB, REHFELD R & LEINFELDER KF (1988) Effect of cavity varnishes on microleakage of amalgam restorations *American Journal of Dentistry* **1** 205-208.

McLEAN JW & GASSER O (1985) Glass-cermet cements *Quintessence International* **16** 333-343.

McLEAN JW & WILSON AD (1977) The clinical development of the glass-ionomer cements. I. Formulation and properties *Australian Dental Journal* **22** 31-36.

MERTZ-FAIRHURST EJ & NEWCOMER AP (1988) Interface gap at amalgam margins *Dental Materials* **4** 122-128.

MERYON SD & SMITH AJ (1984) A comparison of fluoride release from three glass ionomer cements and a polycarboxylate cement *International Endodontic Journal* **17** 16-24.

MJÖR I (1981) Placement and replacement of restorations *Operative Dentistry* **6** 49-54.

OKUDA K & FROSTELL G (1982) The effect of fluoride on the acid production of Streptococcus mutans and other oral streptococci *Swedish Dental Journal* **6** 29-36.

OLSEN BT, GARCÍA-GODOY F, MARSHALL TD & BARNWELL GM (1989) Fluoride release from glass ionomer-lined amalgam restorations *American Journal of Dentistry* **2** 89-91.

PASHLEY DH & PASHLEY EL (1991) Dentin permeability and restorative dentistry: A status report for the American Journal of Dentistry *American Journal of Dentistry* **4** 5-9.

RETIEF DH, BRADLEY EL, DENTON JC & SWITZER P (1984) Enamel and cementum fluoride uptake from a glass ionomer cement *Caries Research* **18** 250-257.

SMITH GA, WILSON NHF & COMBE EC (1978) Microleakage of conventional and ternary amalgam restorations *in vitro British Dental Journal* **144** 69-73.

SWARTZ ML, PHILLIPS RW & CLARK HE (1984) Long-term F release from glass ionomer cements *Journal of Dental Research* **63** 158-160.

SWIFT EJ Jr, BAILEY SJ & HANSEN SE (1990) Fluoride release from fast-setting glass ionomer restorative materials *American Journal of Dentistry* **3** 101-103.

TVEIT AB (1980) Fluoride uptake by cavity walls following application of Duraphat around amalgam restorations *Journal of Oral Rehabilitation* **7** 167-174.

YORK AK & ARTHUR JS (1993) Reasons for placement and replacement of dental restorations in the United States Navy Dental Corps *Operative Dentistry* **18** 203-208.

©OPERATIVE DENTISTRY, 1996, 21, 191-195

Effect of Condensation Techniques on Amalgam Bond Strengths to Dentin

T RATANANAKIN • G E DENEHY • M A VARGAS

Clinical Relevance
Condensation technique does not have an effect on shear bond strength on amalgam bonded to dentin under these tested conditions.

SUMMARY

This in vitro study determined the shear bond strengths of Tytin amalgam to dentin using All-Bond 2, Amalgambond Plus, Amalgambond Plus with HPA powder, and OptiBond with hand and mechanical (Condensaire) condensation. The occlusal enamel surfaces were ground flat to expose the dentin surfaces, and polished with 600-grit SiC paper. The dentin surfaces were treated with one of the combinations of a dentin bonding agent and a condensation technique. All specimens were thermocycled 300 cycles in water between 5-55 °C, and shear bond strengths were determined with a Zwick Universal Testing Machine. Two-way ANOVA and Duncan's tests showed no significant differences ($P > 0.05$) in shear bond strength between hand and mechanical condensation of the paired groups, with the exception of Amalgambond Plus, where hand condensation was shown to be significantly better. For both condensation techniques, shear bond strength of Amalgambond Plus with HPA powder was significantly higher than the other materials. For mechanical condensation, OptiBond was significantly higher than either Amalgambond Plus or All-Bond 2, and no significant difference was found between Amalgambond Plus and All-Bond 2. For hand condensation, OptiBond was only significantly higher than All-Bond 2, while there was no significant difference between OptiBond and Amalgambond Plus or between Amalgambond Plus and All-Bond 2. In conclusion, for both condensation techniques, Amalgambond Plus with HPA powder performed the best in bonding amalgam to dentin. The two different condensation techniques did not significantly affect shear bond strength, except with Amalgambond Plus.

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

Thanin Ratananakin, DDS, MS, is in private practice in Bangkok, Thailand

Gerald E Denehy, DDS, MS, professor

Marcos A Vargas, DDS, MS, assistant professor

INTRODUCTION

Although silver amalgam is the only self-sealing restorative material, until recently it was not bondable. The concept and indications for bonded amalgam were proposed by several authors (Zardiackas & Stoner, 1983; Shimizu, Ui & Kawakami, 1986; Varga, Matsumaura & Masuhara, 1986). Polyacrylate cements and adhesive resins that contain BIS-GMA or 4-META/MMA-TBB can bond amalgam directly to tooth structure (Zardiackas & Stoner, 1983; Varga & others, 1986; Swift, 1989; Covey & Moon, 1991). Advantages of bonded amalgams over their unbonded

counterparts are: increased fracture resistance of restored teeth (Staninec & Holt, 1988), reduced marginal microleakage (Edgren & Denehy, 1992), and decreased or eliminated postoperative sensitivity (Clinical Research Associates, 1994).

Proper amalgam condensation is essential to obtain optimal physical properties of the amalgam restoration. The size of a condenser tip as well as the direction and the magnitude of condensing force depend on the type of amalgam. With high-copper spherical amalgam, a vertical and lateral condensation with vibration is recommended (Craig, 1993). This step of amalgam condensation can be produced with either hand or mechanical condensation.

For hand condensation, when a given force is applied, the smaller the condenser the greater the pressure exerted on the amalgam. If the condenser tip is too large, the operator cannot generate sufficient pressure to adequately condense the amalgam and force it into retentive areas.

The procedures and principles of mechanical condensation are the same as those for hand condensation, including the need to use small amalgam increments. The only difference is that mechanical condensation is done by an automatic device. Various mechanisms are implemented for these instruments. Some provide an impact type of force, while others use rapid vibration. Whether the device is of the impact or vibratory type, less energy is required than for hand condensation (Phillips, 1991). One advantage of mechanical condensation is the capability of applying a consistent condensing force. This prevents lamination of amalgam, as successive increments are condensed by forcing excess mercury to the surface. Different condensation techniques may affect shear bond strengths of amalgam bonded with adhesive resins, yet little or no information currently exists regarding these effects.

This study compared the shear bond strengths developed between a spherical high-copper amalgam (Tytin, S S White, Lakewood, NJ 08710) to dentin, when three different bonding systems were used in conjunction with either hand or mechanical condensation.

METHODS AND MATERIALS

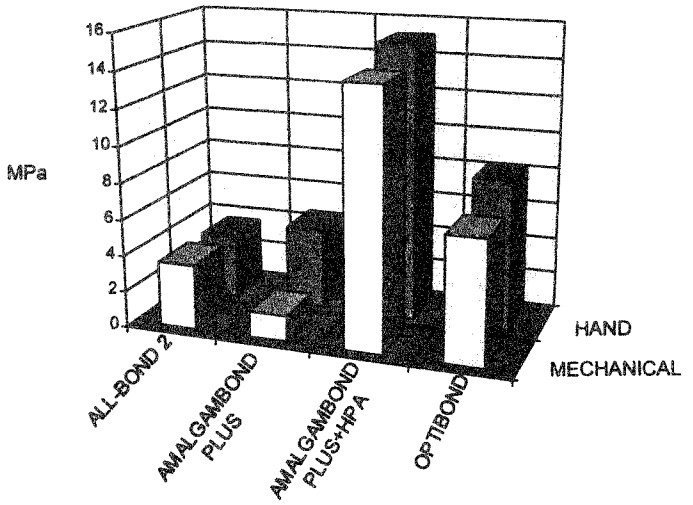
Eighty extracted intact human molars, stored in distilled water with thymol crystal for at least 6 months, were embedded in acrylic resin with the crowns left exposed at a level of 1 mm above the cementoenamel junctions. The occlusal enamel surfaces were ground to expose flat peripheral dentin surfaces perpendicular to the long axes of the teeth and polished with successive grits of 240-, 320-, 400-, and 600-grit SiC abrasive papers to create a uniform smear layer. Specimens were stored in distilled water at room temperature for 24 hours before bonding to prevent dehydration. Three different dentin bonding systems were used: a self-cure system (Amalgambond Plus and Amalgambond Plus with HPA powder, Parkell, Farmingdale, NY 11735); a dual-cure system (All-Bond 2, Bisco, Itasca, IL 60143); and a light-cure system (OptiBond, Kerr Mfg Co, Romulus, MI 48174). All specimens were randomly assigned to eight groups of 10 each to receive one of the following treatment combinations: Group 1) All-Bond 2 and hand condensation; Group 2) All-Bond 2 and mechanical condensation; Group 3) Amalgambond Plus and hand condensation; Group 4) Amalgambond Plus and mechanical condensation; Group 5) Amalgambond Plus + HPA powder and hand condensation; Group 6) Amalgambond Plus + HPA powder and mechanical condensation; Group 7) OptiBond and hand condensation; and Group 8) OptiBond and mechanical condensation.

Before dentin conditioning, the dentin surface was repolished with 600-grit SiC paper to produce a fresh smear layer, rinsed, and gently air dried. Dentin bonding agents were used according to the manufacturers' instructions. After being etched, the dentin surfaces of all samples were rinsed and gently air blown to remove excess water and to keep the etched dentin moist. A visible-light-curing unit, Optilux 150 (Demetron/Kerr, Danbury, CT 06810) was monitored to ensure an intensity reading at least 400 MW/cm^2 and used with bonding agents that required light curing.

A split Teflon mold with a cylindrical hole (3.0 mm in diameter, 2.5 mm in height) was attached to the treated dentin surface. A high-copper spherical amalgam alloy, Tytin (regular set), was triturated for 6.0 seconds and condensed into the mold by either hand condensation using a double-end condenser (PLG 2T, Hu-Friedy, Chicago, IL 60618) or mechanical condensation using a mechanical condenser, Amalgam Condensair (Densco, Denver, CO 80207), with a 1.1 mm round tip diameter and a condensing pressure of 0.8 Kg.

Table 1. Mean [SD] Shear Bond Strengths in MPa for Each Treatment Group (N=80; n=10)

Materials	Condensations	Mean [SD]
Amalgambond Plus + HPA	Hand	15.13 [5.16]
	Mechanical	14.01 [3.66]
OptiBond	Hand	8.24 [4.96]
	Mechanical	6.76 [3.36]
All-Bond 2	Hand	3.58 [3.69]
	Mechanical	3.58 [1.91]
Amalgambond Plus	Hand	4.47 [2.62]
	Mechanical	1.40 [1.88]



Mean shear bond strengths of amalgam bonded with four dentin bonding agents using two condensation techniques. Values given in Table 1.

Fifteen minutes after condensation, the Teflon mold was carefully separated and removed. After storage in distilled water at room temperature for 48 hours, the specimens were thermocycled together 300 times in water between 5 ± 5 °C and 55 ± 5 °C, with a 30-second dwell time and a 13-second transfer time, then stored in distilled water at room temperature for 24 hours before testing.

The shear bond strengths between amalgam and dentin were determined by using a Zwick Universal Testing Machine (Zwick of America, Inc, East Windsor, CT 06088) with a 0.5 cm-wide, knife-edged probe at a crosshead speed of 5 mm/min. The types of failure were determined with a light microscope at X20 and identified as adhesive, cohesive, or mixed adhesive/cohesive failure.

A two-way analysis of variance (ANOVA) determined the effect of three dentin bonding systems and two condensation techniques on the amalgam shear bond strengths. Duncan's multiple range tests for pairwise contrasts followed the F-test to compare specific mean values using the SAS statistical software system (SAS Institute Inc, Cary, NC 27513) at a significance level of $\alpha = 0.05$.

Table 2. Duncan's Multiple Range Test for Hand Condensation Technique (n=10)

Materials	Mean Shear Bond Strength	Duncan's Test*
Amalgambond Plus + HPA	15.13	|
OptiBond	8.24	|
Amalgambond Plus	4.47	|
All-Bond 2	3.58	|

*Values connected with vertical lines were not significantly different at $P \leq 0.05$.

Table 3. Duncan's Multiple Range Test for Mechanical Condensation Technique (n=10)

Materials	Mean Shear Bond Strength	Duncan's Test*
Amalgambond Plus + HPA	14.01	|
OptiBond	6.76	|
All-Bond 2	3.58	|
Amalgambond Plus	1.40	|

*Values connected with vertical lines were not significantly different at $P \leq 0.05$.

RESULTS

The mean (standard deviation) shear bond strengths in MPa for each combination group are presented in Table 1 and illustrated in the figure. Two-way ANOVA showed no statistically significant interaction between the dentin bonding agents tested and the condensation techniques, and no significant difference between the two (hand and mechanical) condensation techniques. The only statistically significant difference is found among the four materials tested.

The Duncan's Multiple Range Tests for hand and mechanical condensation techniques are shown in Tables 2 and 3 respectively. For both condensation techniques, shear bond strength of Tytin amalgam bonded with Amalgambond Plus with HPA powder was significantly higher than the other bonding agents tested. OptiBond was significantly stronger than both Amalgambond Plus and All-Bond 2 with mechanical condensation, but only significantly stronger than All-Bond 2 with hand condensation. All-Bond 2 and Amalgambond Plus produced the lowest bond strength with no significant difference between the two (Tables 2 and 3).

No significant difference ($P > 0.05$) in shear bond strength was found using hand or mechanical condensation with the exception of Amalgambond Plus, where hand condensation was shown to produce significantly higher bond strength than mechanical condensation (Table 4).

Table 4. Duncan's Multiple Range Tests of Condensation Techniques for Dentin Bonding Agents Tested (n=10)

Materials	Condensations	Mean [SD]	Duncan's Test*
Amalgambond Plus + HPA	Hand	15.13 [5.16]	
	Mechanical	14.01 [3.66]	
OptiBond	Hand	8.24 [4.96]	
	Mechanical	6.76 [3.36]	
All-Bond 2	Hand	3.58 [3.69]	
	Mechanical	3.58 [1.91]	
Amalgambond Plus	Hand	4.47 [2.62]	
	Mechanical	1.40 [1.88]	

*Values connected with vertical lines were not significantly different at $P \leq 0.05$.

The dentinal surfaces were optically evaluated. Most failures were adhesive in nature. Adhesive failures were those in which surfaces were even and clear, representing fracture at the interface between the dentin surface and amalgam. None of the specimens showed complete cohesive failure either in amalgam or in dentin. Mixed failures, mostly found in Groups 5 and 6, were those in which the amalgam was still partially bonded to the dentin, but without dentin fracture.

DISCUSSION

This study is in agreement with a similar study performed by Tjan, Tan, and Berry (1994) with the conclusion that OptiBond performed better than Amalgambond (without HPA) and All-Bond 2 in bonding Tytin amalgam to dentin. It also corresponds to the study by Vargas, Denehy, and Ratananakin (1994) where Amalgambond Plus with HPA performed better than OptiBond, while All-Bond 2 was lower.

The results of this study indicate differences in shear bond strengths among the groups. These may be due to the different chemical agents used in the pretreatment procedures. Although the chemistries of these bonding systems are somewhat different, several similarities do exist. Both adhesive agents in Amalgambond Plus and primers in OptiBond contain HEMA, a bifunctional molecule that is analogous to methyl methacrylate, as an adhesion promoter to enhance the monomer diffusion into dentin and the exposed collagen to form a hybrid layer (Nakabayashi & Takarada, 1992). HEMA is also used in combination with dentin adhesives to improve wettability and hydrophilicity and to increase the bond strength of adhesive resin to teeth. The bond strength is not determined by the thickness of the hybrid layer. However, if the resin-impregnated layer is less than the depth of etched decalcification, this may create a weakened base beneath the hybrid layer that will have a negative impact on restorations over time (Pashley, Horner & Brewer, 1992).

Most amalgam debonding occurs by fractures along the interface of bonding agent with amalgam. Eakle, Staninec, and Lacy (1992) examined the sections of amalgam bonded to teeth with Panavia resin liner, a BIS-GMA-based resin, and found that amalgam was intermixed with the resin liner at the interface between alloy and tooth. The interlock between amalgam and resin probably accounts for most of the retention between the materials instead of any chemical bonds that might occur. In this study, it is possible that the initial set of Amalgambond may have occurred rapidly, minimizing the degree of interlock with Tytin.

Examination of the fractured amalgam surfaces in this study also revealed that most failures were adhesive, occurring along the dentin-amalgam interface. These adhesive failures occurred at either the dentin-adhesive resin or adhesive resin-amalgam interface. The fracture patterns of all materials tested were also related to their bond strength. Amalgambond Plus with HPA showed the higher bond strength with the higher percentage of mixed failure.

The concept of bonding amalgam to tooth structure needs continued investigation. Much is still unknown about durability, marginal integrity, caries resistance, tooth strength enhancement, and corrosion effect of alloys on the bond strength of bonded restorations over time in the mouth. Further investigations may be focused on the effect of different condensation techniques on microleakage and/or on bond strength of different types of amalgam alloys bonded with different dentin bonding agents, or alternative condensation techniques that incorporate condensed amalgam with a dentin bonding agent by using either layering technique or physical mixing.

CONCLUSIONS

Under the conditions of this in vitro study, with the materials tested for both condensation techniques, Amalgambond Plus with HPA powder performed better than OptiBond in bonding Tytin amalgam to human dentin, while Amalgambond Plus and All-Bond 2 were lower. The two condensation techniques did not have a significant effect on shear bond strengths of Tytin amalgam bonded to human dentin, except with Amalgambond Plus.

(Received 7 June 1995)

References

CLINICAL RESEARCH ASSOCIATES (1994): Adhesives, silver amalgam *Clinical Research Associates Newsletter* **18** 2-3.

COVEY DA & MOON PC (1991) Shear bond strength of dental amalgam bonded to dentin *American Journal of Dentistry* **4** 19-22.

CRAIG RG (1993) *Restorative Dental Materials* 9th ed St Louis: C V Mosby, pp 214-247.

EAKLE WS, STANINEC M & LACY M (1992) Effect of bonded amalgam on the fracture resistance of teeth *Journal of Prosthetic Dentistry* **68** 257-260.

EDGREN BN & DENEHY GE (1992) Microleakage of amalgam restorations using Amalgambond and Copalite *American Journal of Dentistry* **5** 296-298.

NAKABAYASHI N & TAKARADA K (1992) Effect of HEMA on bonding to dentin *Dental Materials* **8** 125-130.

PASHLEY DH, HORNER JA & BREWER PD (1992) Interactions of conditioners on the dentin surface *Operative Dentistry* **Supplement 5** 137-150.

PHILLIPS RW (1991) Chapter 17, Dental amalgam alloys: Amalgam structures and properties and Chapter 18, Dental amalgam: Technical considerations In *Skinner's Science of Dental Materials*, 9th ed Philadelphia: W B Saunders Company, pp 303-325 and 327-347.

SHIMIZU A, UI T & KAWAKAMI M (1986) Bond strength between amalgam and tooth hard tissues with application of fluoride, glass ionomer cement and adhesive resin cement in various combinations *Dental Materials* **5** 225-232

STANINEC M & HOLT M (1988) Bonding of amalgam to tooth structure: tensile adhesion and microleakage tests *Journal of Prosthetic Dentistry* **59** 397-402.

SWIFT EJ Jr (1989) New adhesive resins. A status report for the American Journal of Dentistry *American Journal of Dentistry* **2** 358-360.

TJAN AHL, TAN DE & BERRY FA (1994) Shear bond strength of amalgam to dentin pretreated with OptiBond *Journal of Dental Research* **73** *Abstracts of Papers* p 221 Abstract 958.

VARGA J, MATSUMURA H & MASUHARA E (1986) Bonding of amalgam filling to tooth cavity with adhesive resin *Dental Materials* **5** 158-164.

VARGAS MA, DENEHY GE & RATANANAKIN T (1994) Amalgam shear bond strength to dentin using different bonding agents *Operative Dentistry* **19** 224-227.

ZARDIACKAS LD & STONER GE (1983) Tensile and shear adhesion of amalgam to tooth structure using selective interfacial amalgamation *Biomaterials* **4** 9-13.

©OPERATIVE DENTISTRY, 1996, 21, 196-202

Early Bonding of Resin Cements to Dentin—Effect of Bonding Environment

M F BURROW • T NIKAIDO
M SATOH • J TAGAMI

Clinical Relevance
Early bond strengths strongly indicate that newly cemented restorations should not be loaded for at least 1 hour after insertion and that excess cement should be removed before setting.

SUMMARY

The aim of this study was to evaluate early tensile bond strengths of three commercial resin cements (a dual-cured and two chemically cured) to bovine dentin. Bonding was performed in two environmental conditions, namely room environment (23 °C/50% RH) and oral environment (30 °C/80% RH). Tensile bond strengths were recorded at 10 minutes, 1 hour, and 1 day after the bonding procedure was completed and were analyzed using one-way ANOVA, Fisher's PLSD test, and Student's *t*-test. The results showed that bond strengths were statistically greater for all materials ($P < 0.05$) over time, except for Bistite Resin Cement between 10 minutes and 1 hour ($P > 0.05$). Variation between the bonding environments was observed only for Bistite Resin Cement at both 10 minutes and 1 hour, and Panavia 21 at 10 minutes. It was concluded that bond strengths were initially weak for the chemically cured materials, and all materials showed significantly greater bond strengths over the first 24 hours, but bonding environment had little influence.

University of Melbourne, School of Dental Science, 711 Elizabeth Street, Melbourne, Victoria 3000, Australia

M F Burrow, MDS, PhD, lecturer; Tokyo Medical and Dental University, honorary lecturer

T Nikaido, DDS, PhD, instructor, Tokyo Medical and Dental University, Department of Operative Dentistry

M Satoh, DDS, PhD, instructor, Tokyo Medical and Dental University, Department of Operative Dentistry

J Tagami, DDS, PhD, professor and chairman, Tokyo Medical and Dental University, Department of Operative Dentistry

INTRODUCTION

Adhesive dentistry has made tremendous advances since the initial idea of enamel etching using phosphoric acid (Buonocore, 1955). Today, the use of tooth bonding systems has become widespread for direct restorative procedures. More recently, this technology has been introduced into the field of indirect restorations by the creation of what may be termed "complete bonding systems" for resin cement. "Complete bonding" is defined by the inclusion of an acidic conditioner and/or priming agent in association with a resin cement. Nikaido and others (1992) have shown that to obtain good bonding with a resin cement, it is necessary for both a conditioner and primer to be included. Through this, bonding enamel and dentin can be achieved successfully (Kitasako & others, 1995).

The use of resin cements has become important for cementation of indirect porcelain and resin composite restorations. A significant difference between bonding for direct and indirect restorations is that indirect restorations are placed in nonundercut cavities, and can range from single inlays to very complex long-span fixed partial dentures. The use of light-cured resin cements for these types of restorations may not be possible, since command setting by light curing will be rendered impossible due to the materials used. Because of this, unlike direct restorations, which are maintained in place regardless of resin adhesion, indirect restorations are dependent upon the cement to ensure retention. Most patients expect that normal oral function can occur soon after final insertion of the restoration, especially indirect restorations. Such early function can place these types of restorations under great stress, especially during mastication. To ensure that the restoration remains fixed in place, the luting cement must achieve either good adhesion or a high strength shortly after insertion.

Resin materials are also considered to be more susceptible to dentinal moisture contamination, which has been shown to adversely affect bonding. Previous studies have shown that variation in dentin depth and permeability can have a significant influence on the bond strength of direct restorative systems (Prati, Pashley & Montanari, 1991; Tao, Tagami & Pashley, 1991; Davidson, Abdalla & De Gee, 1993; Kanca, 1992; Gwinnett, 1992; Perdigao, Swift & Cloe, 1993). In addition, the effects of the oral environment must be considered.

To date, most laboratory studies have been performed at room temperature and 50% Relative Humidity (RH). However, Yoshida (1983) and Plasmans and others (1993) have recorded that temperatures of between 27 °C and 30 °C and RH of over 75% exist in the oral cavity. Such environmental conditions may cause some variation in

Table 1. Materials, Manufacturers, and Batch Numbers

Resin Cement	Manufacturer	Batch Number	Components
Bistite Resin Cement	Tokuyama Co, Tokuyama, Japan	Conditioner: CO5	10% citric acid with 3% ferric chloride
		Primer A: 600	ethanol, accelerator
		Primer B: 600	MAC-10, ethanol
		Cement Base: 101	filler, 2,2-Bis[4-(methacryloxy)phenyl]propane, neopentyldimethacrylate, activators
		Catalyst: 801	filler, MAC-10, 2,2-Bis[4-(methacryloxy)phenyl]propane, neopentyldimethacrylate, initiators
Superbond C&B	Sun Medical Co, Kyoto, Japan	Conditioner: 31102	10% citric acid with 3% ferric chloride
		Liquid: 31201	4-META-MMA
		Catalyst: 312067	tri-butyl borane
		Powder: 31102	PMMA
Panavia 21	Kuraray Co, Osaka, Japan	Primer A: 005	HEMA, MDP, 5-NMSA, water, accelerator
		Primer B: 004	5-NMSA, accelerator, water
		Cement: 11155	MDP, co-monomers, filler, BPO, amine--TPBSS

MAC-10 = 11-methacryloxy-1,1-undecanedicarboxylic acid; 4-META = 4-[2-(methacryloxyethyloxy)carbonyl] phthalic acid anhydride; MMA = methylmethacrylate; PMMA = polymethylmethacrylate; HEMA = 2-hydroxy ethylmethacrylate; MDP = 10-methacryloyloxydecyl dihydrogen phosphate; 5-NMSA = N-methacryloyl-5-amino salicylic acid; BPO = benzoyl peroxide.

*Table 2. Bonding Procedures for the Tested Cements**

	Bistite Resin Cement	Superbond C&B	Panavia 21
Conditioning	10 seconds wash and dry	10 seconds wash and dry	none
Priming	liquids A+B (30 seconds) dry	none	liquids A+B (60 seconds) dry
Cementation	dual-cure cement (light cure--60 seconds)	liquid and catalyst and PMMA powder (chemical cure)	universal and catalyst cements place oxyguard (chemical cure)

*Bonding was performed in 25 °C/50% RH and 30 °C/80% RH environments.

the rate of cure and success of adhesion of resin cements. It has been shown for direct restorative materials that bond strengths continue to increase over the first day after bonding in a laboratory environment, and that a simulated oral environment of 30 °C and 80% RH can cause some variation in bond strength and fracture mode (Burrow & others, 1995). The use of a simulated oral environment has also been shown to cause variation in tensile bond strengths of the 4-META/MMA-TBB system, Superbond C&B (Nikaido & others,1991; Satoh & others, 1991).

The purpose of this study was to determine the tensile bond strength at 10 minutes, 1 hour, and 1 day of three commercially available resin cements when subjected to two different bonding environments, namely 23 °C/50% RH (room environment) and 30 °C/80% RH (oral environment).

METHODS AND MATERIALS

The resin cements, manufacturers, and batch numbers are listed in Table 1. The dentin substrate was from bovine lower incisor teeth that had been stored frozen prior to use. Superficial dentin surfaces were exposed using a model trimmer with copious running water and finished with 600-grit silicon carbide paper, also under running water. The area for bonding was demarcated by placing a piece of vinyl tape on the prepared surface in which a 4 mm-in-diameter hole had been cut. The teeth were then placed into a controlled humidity and temperature chamber (Isuzu μ series low temperature and humidity test chamber, Isuzu Co Ltd, Tokyo, Japan) and left for several minutes before bonding was performed to warm the teeth to the test environment temperature. The procedure for bonding was performed in one of two test environments: either 23 °C/50% RH, which represented normal room temperature or 30 °C/80% RH, which represented the situation close to that found in the region of the occlusal surface of posterior teeth (Yoshida, 1983).

The dentin was conditioned, primed (where a primer was present), and bonded according to each manufacturer's instructions (Table 2). Bistite Resin Cement is a dual-cured material, and Superbond C&B and Panavia 21 are both chemically cured cements. The resin cements were placed onto the prepared dentin surfaces, and then a composite rod, in which a wire loop was placed for the tensile test, was cemented to the dentin. Bistite Resin Cement was light cured from three directions for 20 seconds each. Panavia 21 is strongly air inhibited, so all exposed cement was covered with Oxyguard (Kuraray Co) to ensure setting of the cement. Ten teeth were tested for each material at each time and environmental test condition.

The tensile bond test was performed on a universal testing machine (Shimadzu AG-500B, Kyoto, Japan) at a crosshead speed of 2 mm/min. The bonds were tested at 10 minutes, 1 hour, and 24 hours after completion of light curing or placement of the rod for the chemically cured materials. The 10-minute and 1-hour samples were placed on a bench in air at 23 °C, and the 24-hour samples were stored in distilled water at 37 °C prior to the tensile test. After fracture of the bonds, the surface was visually inspected to determine if obvious changes in the fracture pattern occurred for the materials in the two environmental test conditions.

The tensile bond test results were calculated as the mean for each group. Analysis by one-way ANOVA and Fisher's PLSD test was performed for each material and environment for the three test times, and Student's *t*-test was used to determine if differences could be detected between the two test environments of each material. In addition, comparison was made of the tensile bond strength at 10 minutes among the three materials for each environment to examine variation between the dual- and chemically cured materials. This was done by one-way ANOVA and Fisher's PLSD test.

RESULTS

The results for the tensile bond test are shown in Table 3. All materials showed statistically significant differences in tensile bond strength for both environments between 10 minutes and 1 hour, and 1 hour and 1 day ($P < 0.01$), with the exception of Bistite Resin Cement between 10 minutes and 1 hour in both environments. Statistical differences of tensile bond strength between environments were observed for Bistite Resin Cement at 10 minutes and 1 hour

Table 3. Mean Tensile Bond Strengths, MPa ± SD (n=10)

	Bistite Resin Cement		Superbond C&B		Panavia 21	
Time	**RE**	**OE**	**RE**	**OE**	**RE**	**OE**
10 minutes	5.8 ± 1.7	3.6 ± 1.2	1.5 ± 0.8	2.2 ± 0.7	0.6 ± 0.2	2.5 ± 0.7
1 hour	6.6 ± 1.9	3.6 ± 0.7	7.2 ± 2.7	6.7 ± 1.4	3.6 ± 1.0	4.4 ± 1.1
1 day	9.6 ± 1.8	10.1 ± 2.0	12.1 ± 4.2	12.5 ± 3.2	7.2 ± 1.8	8.4 ± 1.5

RE = room environment (23 °C/50% RH); OE = oral environment (30 °C/80% RH). Horizontal and vertical lines on the same plane indicate no statistical difference ($P > 0.05$). The broken horizontal lines are a comparison of the dual- and chemically cured cement at 10 minutes. Broken horizontal line on the same plane indicates no statistical difference ($P > 0.05$).

($P < 0.01$) and Panavia 21 at 10 minutes ($P < 0.01$). Superbond C&B showed no significant differences in tensile bond strength between the two environments throughout ($P > 0.05$), and the other two cements showed no difference in tensile bond strength between the environments at 1 day ($P > 0.05$). Statistical analysis among the materials at the 10-minute period was performed to determine whether the dual-cured material, Bistite Resin Cement, produced higher tensile bond strength than the two chemically cured materials. For both test environments the dual-cured material produced a stronger tensile bond strength ($P < 0.02$), and no statistical differences were noted between Panavia 21 and Superbond C&B ($P > 0.05$).

Visual inspection showed adhesive failures occurred in all specimens between the cement and dentin for all materials at 10 minutes and 1 hour, independent of the test environment. At 1 day, both Bistite Resin Cement and Panavia 21 showed adhesive failure between the dentin and cement in all specimens, but Superbond C&B showed a large increase of failures involving partial adhesive failure and cohesive failure in the resin. This was more marked for the room temperature specimens, where five specimens showed partial adhesive failure and five cohesive failures of the resin. In the case of the 30 °C/80% RH environment, five specimens showed adhesive failure, three partial adhesive, and two cohesive failure in the resin. The failure pattern of Panavia 21, although adhesive, was somewhat different from the other materials tested. It was often observed that failure of the cement at 10 minutes and 1 hour was adhesive between both the resin composite rod and the dentin surface. This left a small sliver of cured resin cement. This could be a function of entrapment of air at the two interfaces, causing inhibition of the curing of the cement.

DISCUSSION

Until very recently, the field of adhesive dentistry has been limited to direct restorative materials. However, as the expectations of society change towards more esthetic restorative needs, caries rates continue to decline, and people retain their teeth for longer periods of time, the need for more complex restorations beyond the limitations of amalgam and direct resin composites are becoming more widespread. The result will likely be an increase in the use of resins for indirect inlay/onlay systems, porcelain inlay/onlays, and increased placement of crowns and fixed partial dentures.

To date, luting materials have been centered around zinc phosphate and glass polyalkenoate cements. The advantage of these materials has been their quick setting, allowing almost immediate function of restorations. However, the great disadvantages have been solubility and weak physical properties. Additionally, zinc phosphate cement does not adhere to tooth structure and has been shown to cause damage to the dentin (Abe & others, 1984; Shimada & others, 1995). The adhesive strength of chemically cured glass polyalkenoate cement has also been reported to be lower than adhesive resin materials (Nitta, 1992; Tyler & others, 1994).

Resin-bonded bridges were introduced over 10 years ago; this brought about the need for and manufacture of resin cements. At that time, adhesion was directed principally towards bonding to enamel for Rochette and Maryland type bridges (Rochette, 1973; Livaditas, 1980; Thompson, Del Castillo & Livaditas, 1983). However, with the advent of much-improved bonding to dentin, in association with the use of resins for indirect restorations, and more recently porcelain, the need for better cements became necessary. These new systems have employed the technology of the direct systems, including

conditioning agents to remove or modify the smear layer and often a primer to assist the formation of a hybrid layer. The current systems tested in this study have been shown to form hybrid layers of different thicknesses (Nakabayashi, Kojima & Masuhara, 1982; Kitasako & others, 1995).

However, the one large disadvantage of resin materials is their sensitivity to moisture. When bonded to dentin of different depths, or dentin perfused with simulated pulpal fluids, conventional bonding systems have shown large decreases in tensile bond strength (Prati & others, 1991; Tao & others, 1991; Nikaido & others, 1995). With removal of the smear layer, an increase in permeability has been shown to occur (Pashley, Michelich & Kehl, 1981; Tagami & others, 1991). Resin cement systems often require smear layer removal prior to bonding, therefore the same effect on dentin permeability would also be expected. In addition to these factors, another source of moisture contamination is that from the oral cavity environment. During operative procedures, patients often breathe through their mouths. In such an event, the RH recorded in this region has been shown to be very high, being close to 100% RH in the region of the third molars (Yoshida, 1983; Plasmans & others, 1993). High RH has been shown to cause a decrease in bond strength if the bonding substrate is not kept completely dry prior to bonding (Satoh & others, 1991), especially when the RH exceeds 92%. In addition, if the tooth is dried and left undisturbed for only 1 minute before bonding, a significantly lower tensile bond strength occurs due to water condensation on the tooth surface (Nikaido & others, 1991).

The results of the current study, however, did not show any variation in tensile bond strength between the environments. This was probably because the teeth were dried immediately before placement of the cement and a RH no greater than 80% was used, although Bistite Resin Cement and Panavia 21 did show some differences at 10 minutes and 1 hour. In the case of Bistite Resin Cement, the reason for the lower tensile bond strength in the oral environment at 10 minutes and 1 hour cannot be explained, as the results at 1 day showed little difference. For Panavia 21, the higher strength observed in the oral environment specimens was probably a result of a greater degree of polymerization at 10 minutes and 1 hour. This same effect was also observed for the chemically cured Superbond C&B, although for this material, the tensile bond strength was only slightly greater for the warmer environment. By 1 day, these differences in tensile bond strength were no longer evident for all the cements. The effect of temperature could be detected for the two chemically cured materials, but was absent for the dual-cured cement, Bistite Resin Cement. By light curing the cement, polymerization of the material has been shown to be very rapid, which produced a much higher tensile bond strength compared with the chemically cured materials (Tsukada & others, 1995).

All materials showed greater tensile bond strength over the 24-hour test period. This could be explained by a maturation of the cement, and is almost identical to direct bonding systems that have been evaluated previously (Burrow & others, 1994; Burrow & others, 1995). The chemically cured materials showed the largest increase in tensile bond strength. The initial tensile bond strength recorded could be considered very low, especially during the first hour following placement. The implication of this is that restorations that are cemented with a resin cement, especially those that are chemically cured, should not be subjected to heavy loads or stresses until the cement has sufficiently hardened. This applies for both physical properties and adhesive properties of the cements (Kitasako & others, 1995). Should loading of a large restoration occur too early, the bond may be partially disrupted, leading to leakage, possible pulpal damage, and formation of secondary caries at a later period. Such a situation would be less likely to occur with the dual-cured materials, because the curing of these materials is initially rapid, which can lead to a stronger bond. However, their use is severely limited by the need to be light cured. Not only are metallic restorations a contraindication for the use of a dual-cured material, but also large porcelain restorations may be too opaque to allow adequate light transmittance to initiate sufficient curing (Blackman, Barghi & Duke, 1990; Cardash & others, 1993).

A further implication of low bond strengths just after placement is that removal of excess cement must be performed with great care and in such a way that the restoration is not loaded. It is recommended that excess material be removed while the cement is still uncured.

The influence of the environment was observed to be minimal, and provided careful moisture control is employed, the formation of good bonding appears to be attainable. Satoh and others (1991) found, however, that when a RH of 92% was used, a significantly lesser bond strength was observed. In such regions as the buccal sulcus or lingual surface of lower molars, a RH approaching 92% can be expected (Yoshida, 1983). Therefore, either the use of high-velocity evacuation and/or rubber dam is recommended when restorations are being placed in these regions.

The failure mode of these materials was chiefly adhesive, particularly for Bistite Resin Cement and Panavia 21. However, in the case of Superbond C&B, failure within the resin was observed at 1 day. This was more evident in the room environment

specimens. This difference in failure mode may be related to the viscosity of the materials. Superbond C&B uses a methyl-methacrylate-based bonding resin to which PMMA powder is added. Prior to addition of the PMMA powder, the liquid of the 4-META/MMA-TBB solution is first placed onto the conditioned dentin. By doing this, the liquid phase of the material can easily penetrate the decalcified dentin to form a hybrid layer. On the other hand, the two other cements tested consisted of viscous cements that contained fillers. These cements may be considered to flow less easily into the conditioned dentin surface. All of these materials have been shown to produce a hybrid layer (Kitasako & others, 1995), but the quality and extent of resin infiltration around the decalcified collagen fibers has yet to be investigated. It may be advantageous if resin cement systems included an unfilled bonding resin to ensure adequate penetration into the conditioned dentin surface to ensure excellent hybridization.

CONCLUSIONS

The bond strengths of resin cements, either dual- or chemically cured, increase significantly over the first 24 hours and need a period for maturation of the cement to occur. The early bond strengths recorded for the chemically cured materials suggest that careful removal of excess cement should be performed, and that restorations should not be subjected to heavy loads for at least 1 hour after insertion.

The dual-cured resin cement was able to achieve a significantly higher bond strength at 10 minutes after completion of light curing. The warmer oral environmental temperature produced an increase in the bond strengths of the chemically cured materials, presumably by increasing the rate of cure.

No effect of the simulated oral environment was observed in this study for bond strengths of resin cements after 1 day. However, in the clinical setting, careful moisture control through the use of high-velocity evacuation or rubber dam in the clinical setting is strongly advised, since a RH greater than 80% can exist, which may affect bond strengths.

(Received 22 June 1995)

References

ABE Y, MIZUNUMA T, NAKAMURA M & NAKABAYASHI N (1984) Effect of zinc phosphate cement on dentin *Journal of the Japanese Society of Dental Materials and Devices* **3** 79-84.

BLACKMAN R, BARGHI N & DUKE E (1990) Influence of ceramic thickness on the polymerization of light-cured resin cement *Journal of Prosthetic Dentistry* **63** 295-300.

BUONOCORE M (1955) A simple method of increasing adhesion of acrylic filling materials to enamel surfaces *Journal of Dental Research* **34** 849-853.

BURROW MF, TAGAMI J, NEGISHI T, NIKAIDO T & HOSODA H (1994) Early tensile bond strengths of several enamel and dentin bonding systems *Journal of Dental Research* **73** 522-528.

BURROW MF, TANIGUCHI Y, NIKAIDO T, SATOH M, INAI N, TAGAMI J & TAKATSU T (1995) Influence of temperature and relative humidity on early bond strengths to dentine *Journal of Dentistry* **23** 41-45.

CARDASH HS, BAHARAV H, PILO R & BEN-AMAR A (1993) The effect of porcelain color on the hardness of luting composite resin cement *Journal of Prosthetic Dentistry* **69** 620-623.

DAVIDSON CL, ABDALLA AI & De GEE AJ (1993) An investigation into the quantity of dentine bonding systems for accomplishing a durable bond *Journal of Oral Rehabilitation* **20** 291-300.

GWINNETT AJ (1992) Moist versus dry dentin: its effect on shear bond strength *American Journal of Dentistry* **5** 127-129.

KANCA J III (1992) Effect of resin primer solvents and surface wetness on resin composite bond strength to dentin *American Journal of Dentistry* **5** 213-215.

KITASAKO Y, YAMADA T, NIKAIDO T, HARADA N, BURROW MF, INOKOSHI S, TAKATSU T & MASUHARA E (1995) Tensile and shear bond strengths of adhesive resin cements *Journal of the Japanese Society of Dental Materials and Devices* **14** 117-130.

LIVADITIS GJ (1980) Cast metal resin-bonded retainers for posterior teeth *Journal of the American Dental Association* **101** 926-929.

NAKABAYASHI N, KOJIMA K & MASUHARA E (1982) The promotion of adhesion by infiltration of monomers into tooth substrates *Journal of Biomedical Materials Research* **16** 265-273.

NIKAIDO T, BURROW MF, TAGAMI J & TAKATSU T (1995) Effect of pulpal pressure on adhesion of resin composite to dentin: Bovine serum versus saline *Quintessence International* **26** 221-226.

NIKAIDO T, INAI N, SATOH M, NEGISHI T, TAGAMI J, TAKATSU T, HOSODA H & NAGATA K (1991) Effect of an artificial environment on bonding 4-META/MMA-TBB resin to dentin *Japanese Journal of Conservative Dentistry* **34** 1430-1434.

NIKAIDO T, TAKADA T, BURROW MF, SATOH M & HOSODA H (1992) Early bond strengths of dual cured resin cement to enamel and dentin *Journal of the Japanese Society of Dental Materials and Devices* **11** 910-915.

NITTA Y (1992) Effect of surface treatment on microleakage and tensile bond strength of glass polyalkenoate cement *Japanese Journal of Conservative Dentistry* **35** 1346-1373.

PASHLEY DH, MICHELICH V & KEHL T (1981) Dentin permeability: effects of smear layer removal *Journal of Prosthetic Dentistry* **46** 531-537.

PERDIGAO J, SWIFT EJ & CLOE BC (1993) Effects of etchants, surface moisture, and resin composite on dentin bond strengths *American Journal of Dentistry* **6** 61-64.

PLASMANS PJJM, REUKER EAJ, VOLLENBROCK-KUIPERS L & VOLLENBROCK HR (1993) Air humidity: a detrimental factor in dentine adhesion *Journal of Dentistry* **21** 228-233.

PRATI C, PASHLEY DH & MONTANARI G (1991) Hydrostatic intrapulpal pressure and bond strengths of bonding systems *Dental Materials* **7** 54-58.

ROCHETTE AL (1973) Attachment of a splint to enamel of lower anterior teeth *Journal of Prosthetic Dentistry* **30** 418-423.

SATOH M, INAI N, NIKAIDO T, NEGISHI T, TAGAMI J, TAKATSU T, HOSODA H & NAGATA K (1991) An in vitro study on dentin bonding using a simulated clinical environment *Adhesive Dentistry* **9** 158-162.

SHIMADA Y, KONDOH Y, SHONO T, GOTOH H, INOKOSHI S & TAKATSU T (1995) Dentin decalcification caused by dental cements *Adhesive Dentistry* **13** 1-7.

TAGAMI J, TAO L, PASHLEY DH, HOSODA H & SANO H (1991) Effects of high-speed cutting on dentin permeability and bonding *Dental Materials* **7** 234-239.

TAO L, TAGAMI J & PASHLEY DH (1991) Pulpal pressure and bond strengths of Superbond and Gluma *American Journal of Dentistry* **4** 73-76.

THOMPSON VP, Del CASTILLO E & LIVADITIS GJ (1983) Resin-bonded retainers.Part I: Resin bond to electrolytically etched nonprecious alloys *Journal of Prosthetic Dentistry* **50** 771-779.

TSUKADA G, TOKIWA K, YAMASHITA H, IJICHI H, NAGAOKA S, INOUE K (1995) Setting characteristics of resin cements *Japanese Journal of Conservative Dentistry* **38** 415-421.

TYLER MW, FITZGERALD M, DENNISON JB & HEYS DR (1994) The effect of pulpal fluid flow on tensile bond strength of a glass-ionomer cement: an in vivo and in vitro comparison *Operative Dentistry* **19** 116-120.

YOSHIDA Y (1983) The effect of environmental temperature and humidity on the adhesion of composite resins to the enamel surface *Japanese Journal of Conservative Dentistry* **26** 412-426.

OPERATIVE DENTISTRY, 1996, 21, 203-208

In Vitro Microleakage of Etched and Rebonded Class 5 Composite Resin Restorations

G A MUNRO • T J HILTON • C B HERMESCH

Clinical Relevance
Rebonding the gingival margins of class 5 composite resin restorations significantly reduced microleakage under laboratory conditions.

SUMMARY

The purpose of this study was to measure the effect rebonding, with and without etching restoration margins, had on the microleakage of class 5 composite restorations. Eighty-two class 5 composite restorations were placed in extracted human molars with one margin on etched enamel and one below the cementoenamel junction. After finishing with disks, the teeth were divided into seven margin treatment groups: 1) restorations with no rebonding (control), 2) restoration margins rebonded with Universal Bond 3 primer, 3) restoration margins etched with 37% phosphoric acid and rebonded with Universal Bond 3 primer, 4) restoration margins rebonded with Universal Bond 3 adhesive, 5) restoration margins etched and rebonded with Universal Bond 3 adhesive, 6) restoration margins rebonded with Fortify, and 7) restoration margins etched and rebonded with Fortify. After storage in a chlorine-based disinfectant for 1 week, the restorations were thermocycled and then soaked in dye. After sectioning, microleakage was assessed by measuring the extent of dye penetration along the restoration-tooth interface. At the enamel margins there was no statistical difference in microleakage rebonded with or without etching. On the gingival margins there was a statistically significant reduction in microleakage for the nonetched Universal Bond 3 adhesive rebonded group compared to the nonrebonded control.

Dunn Dental Clinic, Department of General Dentistry, 59th Medical Wing/DSG, 1615 Truemper Street, Lackland AFB, TX 78236-5551

Glenn A Munro, III, DDS, program director, General Practice Residency, Naval Medical Center, San Diego, CA 92134-5001

Thomas J Hilton, DDS, assistant chairman for resident education

Charles B Hermesch, DMD, director of research

INTRODUCTION

One of the unfortunate physical properties of composite resins that clinicians must contend with is polymerization shrinkage (Goldman, 1983; Bandyopadhyay, 1982; de Gee, Davidson & Smith, 1981). Polymerization shrinkage can result in microgap formation, particularly at the gingival margin (Davidson, de Gee & Feilzer, 1984; Bausch & others, 1982; Hansen, 1982). Polymerization shrinkage can also cause microcrack formation at the enamel margin of a composite restoration (Prati & others, 1992; Staninec & others, 1986). Although composite resin undergoes hygroscopic expansion when exposed to water, this expansion is not sufficient to completely close the polymerization contraction gap (Hansen & Asmussen, 1989; Torstenson & Brännström, 1988). Gap formation between composite resin and cavity preparation walls allows microleakage to occur (Bergenholtz & others, 1982; Brännström & Nyborg, 1973; Brännström & Nyborg, 1974). The resultant negative clinical consequences include staining due to marginal breakdown, postoperative sensitivity, and recurrent caries (Bauer & Henson, 1984; Pashley, 1990; Triadan, 1987; Phillips, 1965).

Acid etching enamel to increase bond strength and protect against marginal decay was first proposed by Buonocore (1955) and has proven effective at limiting microleakage (Baharloo & Moore, 1974). However, the gingival margin continues to be a significant source of microleakage. Various techniques have been advocated to reduce microgap formation and subsequent microleakage. Incremental filling techniques have been used to limit polymerization shrinkage (Hansen, 1986). This technique has been shown in vitro to reduce the marginal polymerization contraction gap by 25% (Torstenson & Oden, 1989). While this technique minimizes the contraction gap, it has not eliminated it (Crim, 1991). Significantly less leakage at the restoration margin has been reported by utilizing a glass-ionomer base in the "sandwich technique" (Sidhu & Henderson, 1992). Dentin bonding agents have proven to be effective at reducing, but not eliminating microleakage (Saunders, Strang & Ahmad, 1991; Blunck & Roulet, 1989; Munksgaard, Hansen & Asmussen, 1984). Indirect placement techniques have been advocated as an alternative to direct techniques to take advantage of the ability to cure the material prior to placement. When compared to direct placement restorations, microleakage is reduced (Douglas, Fields & Fundingsland, 1989). Unfortunately, these indirect composite systems leak significantly when placed on a gingival margin (Scott, Saunders & Strang, 1992). All efforts to date have failed to completely eliminate the marginal contraction gap and prevent in vitro microleakage in class 5 composite restorations with gingival margins on dentin or cementum.

Rebonding with low-viscosity resins applied to the margins of polymerized class 5 composites has been reported as a practical clinical method to seal contraction gaps (Judes & others, 1982). Significant reduction in microleakage has been reported with rebonding of enamel margins (Judes & others, 1982; García-Godoy & Malone, 1987) and gingival margins (Tjan & Tan, 1991). However, it is unclear whether the rebonding resin should be applied before or after finishing and polishing procedures. Some investigators have applied the rebonding resin after polymerization but before finishing (Reid, Saunders & Chen, 1991; Torstenson, Brännström & Mattsson, 1985). This has been recommended, since finishing may block the gap with debris and prevent the penetration of the rebonding agent into the gap (Torstenson & others, 1985; Hansen & Asmussen, 1987). However, when the composite is finished any excessive heat generated during finishing could result in the permanent reopening of the marginal gap due to the large difference in the coefficient of thermal expansion between composite and tooth structure (Yu & others, 1990). Others have placed the rebonding agent after finishing the margins (García-Godoy & Malone, 1987; Tjan & Tan, 1991).

Etching the margins of completed composite restorations has been advocated to remove the microscopic particles that can clog the microgaps. The particles that result from smear layer generation have an enormous surface area-to-mass ratio, making them subject to dissolution when in contact with acidic fluids (Pashley, 1990). While rebonding has been shown to be effective at sealing composite margins, no studies have examined the effects of etching prior to the rebonding procedure. The purpose of this study was to measure the effect rebonding with a dentin primer or adhesive, with and without etching restoration margins, had on the microleakage of class 5 composite restorations.

METHODS AND MATERIALS

Forty-two extracted human molar teeth, visually free of cracks and restorations, were scaled, cleaned with a slurry of pumice and water, and stored in 0.5% Chlormine-T (Sigma Chemical Co, St Louis, MO 63178), except during manipulation. Class 5 direct composite restoration preparations were prepared on the mesial and distal surfaces of each tooth. Preparations were cut using a #330 bur under air-water spray in a high-speed dental handpiece. Cavity dimensions were standardized utilizing a template to trace a preparation 1.5 mm above, 1.5 mm below the cementoenamel junction, and 4 mm buccolingually (Figure 1). The depth was kept constant at 2 mm axially by a mark on each #330 bur used. A 1 mm bevel was placed on the occlusal enamel margin with a #7902 carbide finishing bur. New burs were used after every five preparations. Eighty-two composite resin restorations were inserted using hybrid composite resin (Prisma TPH Composite, L D Caulk/Dentsply, Milford, DE 19963).

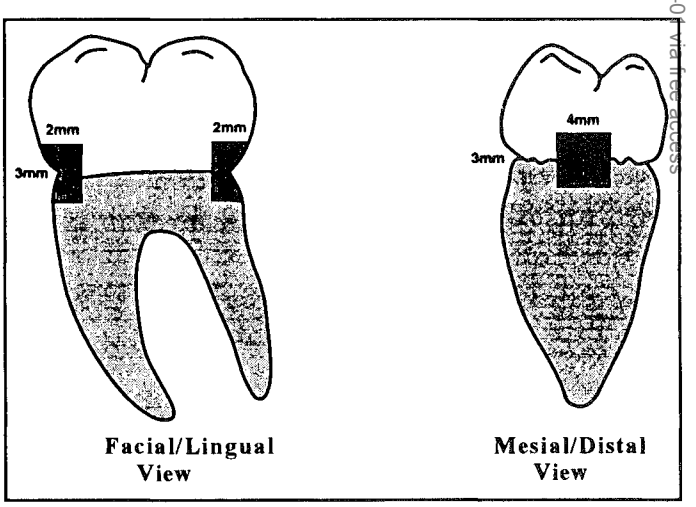


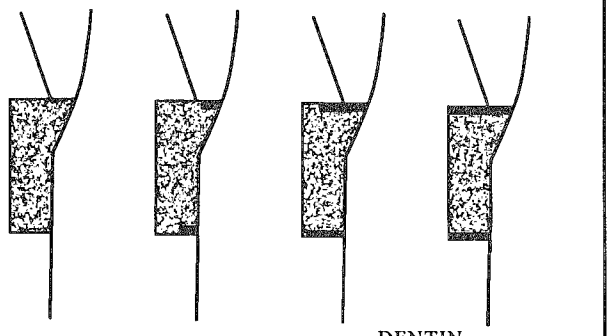
Figure 1. *Preparation design*

Table 1. Margin Treatment Groups

Class 5 Composite Resin Restorations		Batch #	Manufacturer
Group 1	No rebonding		
Group 2	Margins rebonded with Universal Bond 3 primer	921112	L D Caulk
Group 3	Margins etched for 10 seconds with 37% H_3PO_4 then rebonded with UB3 primer	930107 921112	L D Caulk L D Caulk
Group 4	Margins rebonded with UB3 adhesive	930111	L D Caulk
Group 5	Margins etched for 10 seconds with 37% H_3PO_4 then rebonded with UB3 adhesive	930107 930111	L D Caulk L D Caulk
Group 6	Margins rebonded with Fortify	129042	Bisco
Group 7	Margins etched for 10 seconds with 37% H_3PO_4 then rebonded with Fortify	930107 129042	L D Caulk Bisco

according to the manufacturer's instructions. The enamel margins were acid etched with 37% H_3PO_4 (Tooth Conditioner Gel, L D Caulk/Dentsply) for 20 seconds, rinsed for 15 seconds with water, then air dried using a dental unit three-way syringe. Universal Bond Primer (L D Caulk/Dentsply) was brushed on the preparation and left undisturbed for 30 seconds then dried with an air stream from the three-way syringe. A uniform layer of adhesive was placed and the excess removed by a gentle air stream. The cavity preparation was cured for 10 seconds with an Optilux 400 visible light curing unit (Demetron Research Corp, Danbury, CT 06810). A two-step incremental filling technique (occlusal half first, then the gingival half) was used to place the composite resin. Each increment was placed with a plastic instrument and light cured for 60 seconds. The restorations were completely finished with coarse, medium, fine, and very fine Sof-Lex disks (3M Dental Products, St Paul MN 55144) under water irrigation prior to rebonding procedures. The 42 restored teeth were then randomly divided into the following seven groups of six teeth each (Table 1): group 1 was not rebonded; group 2 was rebonded with Universal Bond 3 primer (to determine how its ultralow viscosity and high penetration ability would affect the seal); group 3 was etched and then rebonded with Univeral Bond 3 primer; group 4 was rebonded with Universal Bond 3 adhesive; group 5 was etched and then rebonded with Universal Bond 3 adhesive; group 6 was rebonded with Fortify (Bisco, Itasca, IL 60143); group 7 was etched and then rebonded with Fortify. Etching of the finished margins was done with 37% H_3PO_4 gel for 10 seconds followed by a 20-second water rinse and compressed air drying prior to rebonding. Rebonding agents were placed on the margins of the restorations with a fine-tipped camel hair brush. Excess was carefully avoided, and each agent was thinned with a dry brush if necessary. Each rebonding agent was cured for 20 seconds after placement.

Following rebonding, specimens were stored in Chloramine-T for 1 week then thermocycled in water for 800 cycles between 5 and 55 °C with dwell times of 30 seconds in each bath. The specimens were then prepared for dye exposure. Apical openings were occluded with composite resin (Concise White Sealant System, 3M Dental Products). Occlusal pits and fissures were etched and sealed with the same resin sealant. Two coats of red nail polish were applied to the entire tooth to within 2 mm of the restoration margins. After the nail polish had dried, specimens were immersed in a 2% solution of methylene blue for 4 hours. Each tooth was cleaned with a toothbrush for 30 seconds under running tap water after removal from the dye. The teeth were then embedded in blocks of clear acrylic resin (Orthodontic Acrylic resin, L D Caulk/Dentsply) to facilitate sectioning. Longitudinal sectioning of the teeth with a diamond saw (Isomet Diamond Saw, Buehler, Ltd, Lake Bluff, IL 60044) in a mesiodistal direction was done, taking care to bisect both restorations in the tooth. Twelve specimens per group were viewed under a X25 stereoscopic microscope (Nikon Inc, Instument Group, Melville, NY 11747) on the same day as sectioning. The occlusal and gingival margins of the buccal section were qualitatively evaluated separately and ordinally scored for dye penetration according to the following scale (Figure 2). Occlusal margin: 0 = no evidence of dye penetration at the tooth/restoration interface; 1 = evidence of dye penetration at the tooth/restoration interface extending up to but not past the dentinoenamel junction; 2 = dye penetration along the tooth/restoration interface extending past the dentinoenamel junction but not to the axial wall; 3 = dye penetration to the axial wall or beyond. Gingival margin: 0 = no evidence of dye penetration at the tooth/restoration interface; 1 = evidence of dye penetration at the tooth/restoration interface extending less than one-half the distance to the axial wall; 2 = dye penetration along the tooth/restoration interface extending greater than one-half the distance to the axial wall but not penetrating to the



ENAMEL
0 = No leakage.
1 = Leakage between cavosurface and DEJ.
2 = Leakage between DEJ and the axial wall.
3 = Leakage to, or beyond, the axial wall.

DENTIN
0 = No leakage.
1 = Leakage less than or equal to half the distance from the cavosurface to the axial wall.
2 = Leakage more than half the distance from the cavosurface to the axial wall but not including the axial wall.
3 = Leakage to, or beyond, the axial wall.

Figure 2. *Schematic and numerical scoring scale for microleakage of both enamel and dentin margins*

axial wall; 3 = dye penetration to the axial wall or beyond.

Two experienced evaluators (not including the experimenter who prepared the specimens) were calibrated in using these rating scales and independently scored each specimen. Evaluators were blinded as to which group was being evaluated. Discrepancies were rescored to reach consensus. One tooth in group 5 was rejected due to enamel flaws detected after sectioning. The nonparametric data were analyzed using Kruskal-Wallis analysis of variance by ranks at the 0.05 level of significance. A Mann-Whitney U test was used to compare the differences between groups.

RESULTS

Table 2 presents the distribution of the microleakage scores. There was no statistical difference in microleakage at the enamel margins in any of the groups ($P = 0.13$). Generally all rebonding groups demonstrated a trend, though not significant, for less microleakage at the gingival margins than the control (group 1). Group 4 (rebonding with Universal Bond 3 adhesive without etching the margins) had significantly less microleakage at the gingival margins than the control ($P = 0.02$). Etching the gingival margins tended, though not significantly, to increase the microleakage in groups 5 (etched and rebonded with Universal Bond 3 adhesive) and 7 (etched and rebonded with Fortify). Rebonding with Universal Bond 3 primer did not perform as well as Universal Bond 3 adhesive or Fortify without etching.

DISCUSSION

The etched enamel-composite resin technique provides a high-quality, dye penetration-resistant interface. The minimal dye penetration at the enamel resin interface in this study is consistent with past studies (Baharloo & Moore, 1974; Draheim, García-Godoy & Titus, 1989). Attempts to further reduce dye penetration at the enamel margin with various combinations of etching and rebonding were not successful in the present study. Suzuki, Gwinnett, and Jordan (1989) showed that the bond strength of composite to enamel in class 5 restorations is strong enough to withstand polymerization forces within the resin materials. However, in dentin the resin pulled away from the entire dentin-composite interface, resulting in gap formation. The dye penetration found in the gingival margins of the present study may be a result of such gap formation.

Tjan and Tan (1991) found that low-viscosity resins used to rebond the gingival margins of class 5 composite resin restorations significantly reduced microleakage. Similar trends were obtained with all groups in the present study; however, only group 4 (Universal Bond 3 adhesive rebond, no etch) had statistically less dye penetration than group 1 (no rebonding). Etching the gingival margin with 37% H_3PO_4 prior to rebonding compared to its unetched counterpart did not improve the ability of the rebonding agent to prevent microleakage. In fact, it appeared to increase microleakage slightly in groups

Table 2. Distribution of Microleakage Scores

		Category of Microleakage				
Group	**Enamel Margins**	**0**	**1**	**2**	**3**	***n***
1	No rebonding	11	0	0	1	12
2	Rebond (UB3 Primer)	11	1	0	0	12
3	Etch & rebond (UB3 Primer)	11	1	0	0	12
4	Rebond (UB3 Adhesive)	7	5	0	0	12
5	Etch & rebond (UB3 Adhesive)	9	1	0	0	10
6	Rebond (Fortify)	12	0	0	0	12
7	Etch & rebond (Fortify)	10	0	0	2	12
Group	**Dentin/Gingival Margins**	**0**	**1**	**2**	**3**	***n***
1	No rebonding	2	0	0	10	12
2	Rebond (UB3 Primer)	4	0	0	8	12
3	Etch & rebond (UB3 Primer)	6	1	0	5	12
4	Rebond (UB3 Adhesive)	9	1	0	2	12
5	Etch & rebond (UB3 Adhesive)	2	1	2	5	10
6	Rebond (Fortify)	7	1	0	4	12
7	Etch & rebond (Fortify)	5	0	0	7	12

5 and 7 compared to groups 4 and 6. The specimens in which etching was done prior to rebonding demonstrated an interesting phenomenon. Dye penetration was observed both at the restoration interface and through tubules of the exposed dentin not covered by nail polish or rebonding agent. The etchant may have opened more dentinal tubules than were sealed by the rebonding agent. The surface cementum may have been removed during finishing, creating a smear layer. Pashley and Galloway (1985) showed that exposing the dentinal smear layer to acids for as little as 10 seconds could dissolve the mineral phase and increase dentinal permeability. While etching was confined as much as possible to the margin, the smear layer of the exposed dentin was probably removed during etching, allowing the opened tubules to take up the methylene blue dye (Figure 3). Clinically this could result in postoperative sensitivity. Etching the gingival margin prior to rebonding would seem to be contraindicated. Alternatively, hand instrument finishing (tungsten carbide-tipped composite finishing knife, Brassler USA, Savannah, GA 31419) of the gingival margin of composite restorations could result in less opening of the dentin tubules and reduce the risk of ditching the cementum.

The longevity of a rebonding agent in the contraction gap is unknown. Torstenson and others (1985) found that the rebonding agent penetrates into the contraction gap 0.5 to 2 mm from the gingival margins. De Wet and Ferreira (1980) showed that the surface glaze over composite resin lasts from 6 months to 1 year in vivo. Further investigation on the longevity of the rebonding procedure is warranted.

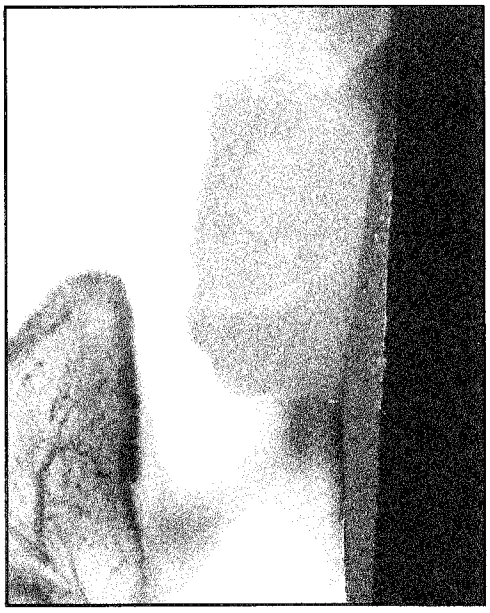


Figure 3. *The smear layer of the exposed dentin was removed during etching, allowing the opened tubles to take up the methylene blue dye.*

CONCLUSIONS

Based on the in vitro conditions of this study the following conclusions were reached:

1. Rebonding the gingival margin of class 5 composite restorations with Universal Bond 3 adhesive significantly reduced microleakage when compared to the unrebonded margin.
2. Etching the gingival margin prior to rebonding with Universal Bond 3 adhesive or Fortify did not significantly improve the seal against microleakage.
3. Enamel margins were not significantly improved when rebonded with or without etching compared to the unetched group.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Defense of other departments of the U S Government.

(Received 28 June 1995)

References

BAHARLOO D & MOORE DL (1974) Effect of acid etching on marginal penetration of composite resin restorations *Journal of Prosthetic Dentistry* **32** 152-156.

BANDYOPADHYAY S (1982) A study of the volumetric setting shrinkage of some dental materials *Journal of Biomedical Materials Research* **16** 135-144.

BAUER JG & HENSON JL (1984) Microleakage: a measure of the performance of direct filling materials *Operative Dentistry* **9** 2-9.

BAUSCH JR, de LANGE K, DAVIDSON CL, PETERS A & de GEE AJ (1982) Clinical significance of polymerization shrinkage of composite resins *Journal of Prosthetic Dentistry* **48** 59-67.

BERGENHOLTZ G, COX CF, LOESCHE WJ & SYED SA (1982) Bacterial leakage around dental restorations: its effect on the dental pulp *Journal of Oral Pathology* **11** 439-450.

BLUNCK U & ROULET JF (1989) In vitro marginal quality of dentin-bonded composite resins in Class V cavities *Quintessence International* **20** 407-412.

BRÄNNSTRÖM M & NYBORG H (1973) Cavity treatment with a microbicidal fluoride solution: Growth of bacteria and effect on the pulp *Journal of Prosthetic Dentistry* **30** 303-310.

BRÄNNSTRÖM M & NYBORG H (1974) Bacterial growth and pulpal changes under inlays cemented with zinc phosphate cement and Epoxylite CBA 9080 *Journal of Prosthetic Dentistry* **31** 556-565.

BUONOCORE M (1955) A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces *Journal of Dental Research* **34** 849-853.

CRIM GA (1991) Microleakage of three resin placement techniques *American Journal of Dentistry* **4** 69-72.

DAVIDSON CL, de GEE AJ & FEILZER A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63** 1396-1399.

de GEE AJ, DAVIDSON CL & SMITH A (1981) A modified dilatometer for continuous recording of volumetric polymerization shrinkage of composite restorative materials *Journal of Dentistry* **9** 36-42.

de WET FA & FERREIRA MR (1980) The durability of dental glazes *Journal of Prosthetic Dentistry* **44** 300-306.

DOUGLAS WH, FIELDS RP & FUNDINGSLAND J (1989) A comparison between the microleakage of direct and indirect composite restorative systems *Journal of Dentistry* **17** 184-188.

DRAHEIM RN, GARCÍA-GODOY F & TITUS HW (1989) Microleakage of microfilled composite in enamel using two rebonding methods *Transactions of the Academy of Dental Materials* **2** 27-28.

GARCÍA-GODOY F & MALONE WF (1987) Microleakage of posterior composite restorations after rebonding *Compendium* **8** 606-609.

GOLDMAN M (1983) Polymerization shrinkage of resin-based restorative materials *Australian Dental Journal* **28** 156-161.

HANSEN EK (1982) Visible light-cured composite resins: polymerization contraction, contraction pattern and hygroscopic expansion *Scandinavian Journal of Dental Research* **90** 329-335.

HANSEN EK (1986) Effect of cavity depth and application technique on marginal adaptation of resins in dentin cavities *Journal of Dental Research* **65** 1319-1321.

HANSEN EK & ASMUSSEN E (1987) Effect of postponed polishing on marginal adaptation of resin used with dentin-bonding agent *Scandinavian Journal of Dental Research* **96** 260-264.

HANSEN EK & ASMUSSEN E (1989) Marginal adaptation of posterior resins: effect of dentin-bonding agent and hygroscopic expansion *Dental Materials* **5** 122-126.

JUDES H, ELI I, LIEBERMAN R, SEREBRO L & BEN AMAR A (1982) Rebonding as a method of controlling marginal microleakage in composite resin restorations *New York Journal of Dentistry* **52** 137-143.

MUNKSGAARD EC, HANSEN EK & ASMUSSEN E (1984) Effect of five adhesives on adaptation of resin in dentin cavities *Scandinavian Journal of Dental Research* **92** 544-548.

PASHLEY DH (1990) Clinical considerations of microleakage *Journal of Endodontics* **16** 70-77.

PASHLEY DH & GALLOWAY SE (1985) The effects of oxalate treatment on the smear layer of ground surfaces of human dentine *Archives of Oral Biology* **30** 731-737.

PHILLIPS RW (1965) New concepts in material used for restorative dentistry *Journal of the American Dental Association* **70** 652-661.

PRATI C, VALDRE G, MONGIORGI R, BERTOCCHI G & SAVINO A (1992) Changes in enamel and dentin interface around composite class V restorations *Journal of Dental Research* **71** *Abstracts of Papers* p 1014 Abstract 12.

REID JS, SAUNDERS WP & CHEN YY (1991) The effect of bonding agent and fissure sealant on microleakage of composite resin restorations *Quintessence International* **22** 295-298.

SAUNDERS WP, STRANG R, AHMAD I (1991) Effect of Mirage Bond primer on microleakage of resin composite restorations *American Journal of Dentistry* **4** 211-213.

SCOTT JA, SAUNDERS WP & STRANG R (1992) Microleakage of a composite inlay system *American Journal of Dentistry* **5** 177-180.

SIDHU SK & HENDERSON LJ (1992) In vitro marginal leakage of cervical composite restorations lined with a light-cured glass ionomer *Operative Dentistry* **17** 7-12.

STANINEC M, MOCHIZUKI A, TANIZAKI K, JUKUDA K & TSUCHITANI Y (1986) Interfacial space, marginal leakage, and enamel cracks around composite resins *Operative Dentistry* **11** 14-24.

SUZUKI M, GWINNETT AJ & JORDAN RE (1989) Relationship between composite resins and dentin treated with bonding agents *Journal of the American Dental Association* **118** 75-77.

TJAN AH & TAN DE (1991) Microleakage at gingival margins of Class V composite resin restorations rebonded with low-viscosity resin systems *Quintessence International* **22** 565-573.

TORSTENSON B & BRÄNNSTRÖM M (1988) Contraction gap under composite resin restorations: effect of hygroscopic expansion and thermal stress *Operative Dentistry* **13** 24-31.

TORSTENSON B, BRÄNNSTRÖM M & MATTSSON B (1985) A new method for sealing composite resin contraction gaps in lined cavities *Journal of Dental Research* **64** 450-453.

TORSTENSON B & ODON A (1989) Effects of bonding agents and incremental techniques on minimizing contraction gaps around resin composites *Dental Materials* **5** 218-223.

TRIADAN H (1987) When is microleakage a real clinical problem? *Operative Dentistry* **12** 153-157.

YU XY, WIECZKOWSKI GW, DAVIS EL & JOYNT RB (1990) Influence of finishing technique on microleakage *Journal of Esthetic Dentistry* **2** 142-144.

©OPERATIVE DENTISTRY, 1996, 21, 209-212

Tensile Dislodgment Evaluation of Two Experimental Prefabricated Post Systems

X LEPE • D J BALES • G H JOHNSON

Clinical Relevance
The ParaPost XT system can be used when a more retentive design with a passive apical end is desired.

SUMMARY

This study tested the tensile dislodgment forces of two experimental post designs that are threaded 7 mm into the most coronal aspect of the root. Experimental post systems ParaPost XT-7 (XT-7), and ParaPost XT-10 (XT-10) were compared to the Flexi-Post (FP) and to the Standard ParaPost (SP). The XT-7 prototype post measured 7 mm in length, while all other post systems were 10 mm. The XT-7 and the FP are active post systems that are threaded throughout their entire length. The SP is a passive serrated post system, and the XT-10 is a combination active/passive design that has a 7 mm coronal thread with a passive serrated apical end. All systems tested were titanium alloy except the SP system, which was stainless steel. The purpose of this study was to compare an active and a passive post design to the experimental designs of the XT-7 active post and the combined active/passive design of the XT-10. This study clearly demonstrated highest retention for the active post system, least retention for the passive post, with an intermediate retentiveness for the combined design.

University of Washington, School of Dentistry, Department of Restorative Dentistry, Box 357456, Seattle, WA 98195-7456

Xavier Lepe, DDS, MS, assistant professor

David J Bales, DDS, MSD, associate professor

Glen H Johnson, DDS, MS, professor

INTRODUCTION

Many different prefabricated post designs are available for the restoration of pulpless teeth (Rosenstiel, Land & Fujimoto, 1994). A variety of shapes and surface characteristics are used in post design to enhance retention and to favorably distribute stress to the root. Each post system has its own unique retentive characteristics. Post shape, length, and surface characteristics play a major role in their retentive abilities. Most studies have shown that luting agents alone do not affect retention (Krupp & others, 1979; Hanson & Caputo, 1974; Standlee, Caputo & Hanson, 1978), and a controversy still exists on whether resin cements improve retention (Tjan, Tjan & Greive, 1987; Burns, Douglas & Moon, 1993). Ruemping, Lund, and Schnell (1979) demonstrated that post designs and retention vary depending on their shape and surface features from the least retentive passive tapered smooth-sided design to the most retentive active parallel threaded design. It is well documented that parallel-shaped posts are 4.5 times more retentive than tapered posts (Johnson & Sakamura, 1978). It is also well known that smooth-sided posts are the least retentive,

serrated posts are intermediate, and threaded posts are the most retentive (Standlee & others, 1978). While retention characteristics of a post system may be important, it is also necessary to take into consideration the stress distribution. Some studies have demonstrated that screw-retained designs can cause a considerable amount of stress to the root during delivery and function (Standlee & others, 1972; Standlee, Caputo & Holcomb, 1982). Most screw posts, if not all, are threaded over their total length. The purpose of this study was to compare the tensile dislodgment forces of two experimental ParaPost XT designs that are only threaded 7 mm into the most coronal aspect of the root to the Flexi-Post threaded over its entire length and to the Standard ParaPost serrated over its entire length (Figures 1 & 2, table). Although it is unknown what the required retention values should be for posts, there are circumstances where more retention is necessary (for example: short roots, curved roots, and bridge abutments).

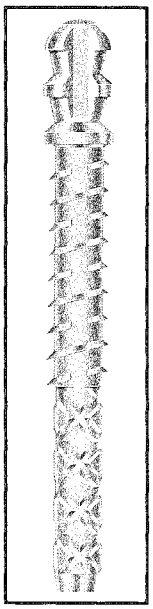


Figure 1. *ParaPost XT, U S Pat No 5, 096, 618*

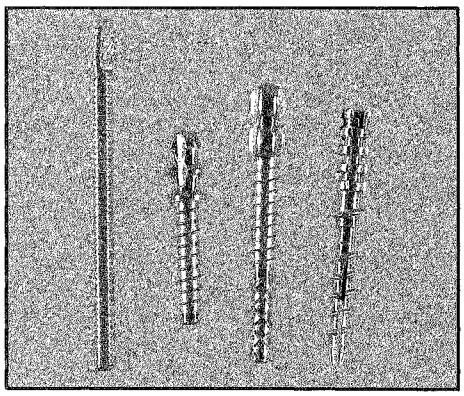


Figure 2. *Post systems tested (from left to right): Standard ParaPost, ParaPost XT-7, ParaPost XT-10, and Flexi-Post*

METHODS AND MATERIALS

Recently extracted single-canal teeth were stored in 0.1% thymol for treatment as follows: 1. The root was curetted and then sectioned slightly above the cementoenamel junction with a separating disk. 2. Retention grooves for the resin (≅1 mm in depth) were made on the buccal and lingual surfaces of the root with the separating disk (Figure 3). 3. Teeth were evenly distributed by root length into four groups of 10 samples each, so that the average length of the roots of each group was approximately the same, ranging from 12.5 to 18 mm in length. 4. Post room was prepared following manufacturers' instructions, using the most similar twist drill diameters possible between systems (FP=1.2 mm; SP, XT-10, and XT-7=1.25 mm). 5. Roots were embedded along the long axis in a resin block by positioning them first in the center of a clear acrylic tubing piece, using each system's twist drill on a surveyor and later filling the tubing piece with a cold cure resin (Figure 4). 6. Threaded posts were manually threaded all the way into the prepared channel, then unthreaded, and cutting debris removed. 7. Zinc Phosphate cement (Mizzy Inc, Cherry Hill, NJ 08002) was placed in the canals by use of a Lentulo spiral (L D Caulk Co, Milford, DE 19963). Threaded, serrated, and

Post Characteristics of Systems Tested

Post System	Manufacturer	Length (mm)	Drill Diameter (mm)	Shank Characteristics
ParaPost XT-7	Coltène/Whaledent Inc, Mahwah, NJ 07430	7	1.25	parallel, interrupted threads and sparsely threaded total length of post, flat end, beveled tip
ParaPost XT-10	Coltène/Whaledent	10	1.25	parallel, interrupted threads and sparsely threaded 7 mm at coronal portion, raised diamond serrated apical extension, flat end, beveled tip
Flexi-Post	Essential Dental Systems, S Hackensack, NJ 07606	10	1.2	parallel, sparsely threaded total length of post, split shank, countersink, tapered end
Standard ParaPost	Coltène/Whaledent	10	1.25	parallel, serrated, flat tip

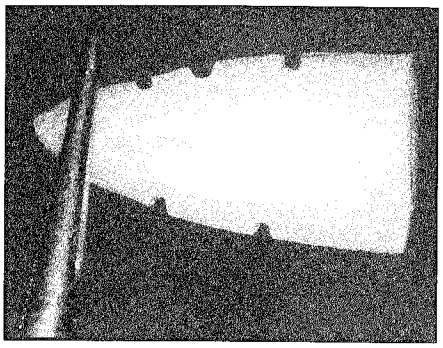


Figure 3. *Curetted and sectioned root with retention grooves*

combined design posts were coated with cement and delivered. Both threaded and combined post designs were backed off 1/4 turn following delivery. The cement was sealed with Copalite varnish (Harry J Bosworth Co, Skokie, IL 60076). The samples were then stored in 100% humidity for 24 hours until tested (Figure 5). 8. Posts were gripped securely then pulled along the long axis on the Instron Universal Testing Machine (Instron Corp, Canton, MA 02021) at a speed of 5 mm/min (Figure 6). A one-factor analysis of variance (ANOVA) was employed to test for main effects at $\alpha = 0.05$ with $n = 10$. Given significant main effects, the Student-Newman-Keuls test was used for differences among means.

RESULTS

Ten samples for each group were tested for tensile dislodgment. Mean values ranged from 46.4 to 79.2 kg, and the standard deviations ranged from

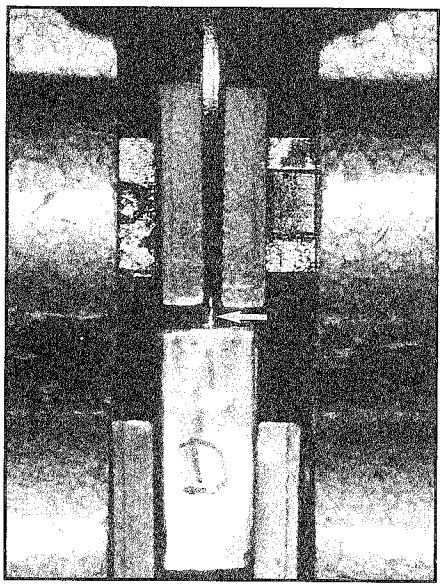


Figure 6. *Post (arrow) securely gripped on Instron Universal Testing Machine*

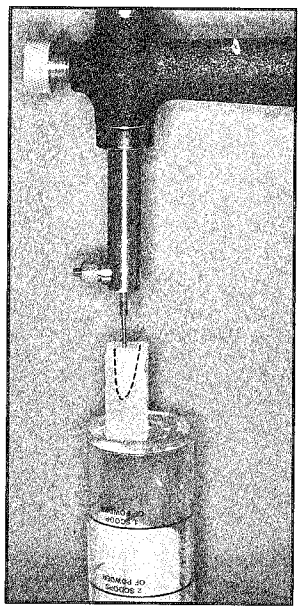


Figure 4. *Apparatus used for embedding roots in resin block along the long axis*

Figure 5. *Tooth in resin block with cemented post*

8.96 to 13.46 kg. The serrated 10 mm Standard ParaPost was the least retentive system, with a mean retentive force of 46.4 ± 8.96, followed by the 7 mm active ParaPost XT-7 with a mean of 52.1 ± 13.46, then the 10 mm combined active/passive ParaPost XT-10 with a mean force of 68.2 ± 13.15. The 10 mm active Flexi-Post was the most retentive group, with a mean retentive force of 79.2 ± 9.2. Statistically there was no difference in retention between the ParaPost XT-7 and the Standard ParaPost. The ParaPost XT-10 was statistically more retentive then the Standard ParaPost and the ParaPost XT-7. Finally, the Flexi-Post was statistically more retentive than all the other systems (Figure 7).

DISCUSSION

A shorter-length threaded post benefits by engaging dentin. However, to avoid dentinal crazing and root fracture, passive posts are often preferred over active post designs (Nicholls, 1988; Henry, 1977). The two experimental designs, by engaging only the thicker coronal root portion, have the potential to enhance retention with less risk of root fracture.

In the present study, length and surface characteristics of each post system clearly played a role in retention. The 10 mm active FP was more retentive than the 10 mm combined active/passive XT post (XT-10). This combined XT post was more retentive than the 10 mm passive SP, and finally there was no difference between the SP and the 7 mm active XT post. Similar results between the FP and SP systems

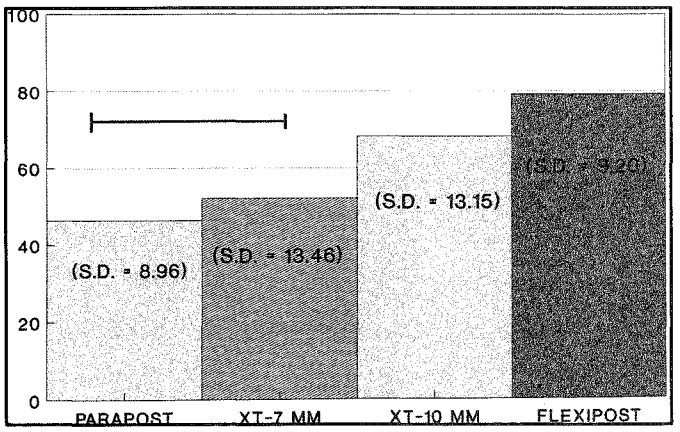


Figure 7. *ANOVA results for tensile dislodgment*

were demonstrated by Keyf and Sahin (1994). The additional retention of the XT-10 compared to the SP may be advantageous in circumstances where more retention is needed (for example short roots, curved roots, and bridge abutments). Although the XT-10 has a 7 mm screw design in the coronal end of the shank, it still offers a passive serrated apical end design.

All teeth used in this study were single-canal teeth with round canals. Although the canals were similar in cross-sectional geometry, there most likely were slight differences in diameter and amount of apico-gingival flare. These differences can affect retention when an intimate adaptation of the post to the canal is not accomplished, and may be sufficient to justify a larger-diameter post. This study used the most similar twist drill diameters available between the systems. This may be the reason why there were higher standard deviation values for the two experimental posts, which only engage the coronal root portion. The FP system that is threaded throughout its entire length has a better chance of engaging dentin even if there is a slight flare to the canal. However, the clinical perception of the operator was that much less insertion force was needed during delivery of the two experimental designs than the FP. Other studies using photoelastic and finite element analysis during delivery and function are necessary to evaluate stress concentration.

CONCLUSIONS

For the four systems evaluated in this study the following was observed:

1. This study demonstrated that the active Flexi-Post system is statistically more retentive than the combined active/passive ParaPost XT system, and that both of these designs are more retentive than the passive Standard ParaPost system.

2. This study also demonstrated that a 7 mm active post can be as retentive as a 10 mm passive post.

Acknowledgment

This study was supported by Coltène/Whaledent Inc.

Received 28 June 1995

References

BURNS DR, DOUGLAS HB & MOON PC (1993) Comparison of the retention of endodontic posts after preparation with EDTA *Journal of Prosthetic Dentistry* **69** 262-266.

HANSON EC & CAPUTO AA (1974) Cementing mediums and retentive characteristics of dowels *Journal of Prosthetic Dentistry* **32** 551-557.

HENRY PJ (1977) Photoelastic analysis of post core restorations *Australian Dental Journal* **22** 157-159.

JOHNSON JK & SAKAMURA JS (1978) Dowel form and tensile force *Journal of Prosthetic Dentistry* **40** 645-649.

KEYF F & SAHIN E (1994) Retentive properties of three post-core systems *Australian Dental Journal* **39** 20-24.

KRUPP JD, CAPUTO AA, TRABERT KC & STANDLEE JP (1979) Dowel retention with glass-ionomer cement *Journal of Prosthetic Dentistry* **41** 163-166.

NICHOLLS JI (1988) Rebuilding the treated tooth *Journal of the California Dental Association* **Nov** 34-38.

ROSENSTIEL SF, LAND MF & FUJIMOTO J (1994) *Contemporary Fixed Prosthodontics* 2nd edition St Louis: C V Mosby pp 250-255.

RUEMPING DR, LUND MR & SCHNELL RJ (1979) Retention of dowels subjected to tensile and torsional forces *Journal of Prosthetic Dentistry* **41** 159-162.

STANDLEE JP, CAPUTO AA, COLLARD EW & POLLACK MH (1972) Analysis of stress distribution by endodontic posts *Oral Surgery, Oral Medicine, Oral Pathology* **33** 952-960.

STANDLEE JP, CAPUTO AA & HANSON EC (1978) Retention of endodontic dowels: effects of cement, dowel length, diameter, and design *Journal of Prosthetic Dentistry* **39** 400-405.

STANDLEE JP, CAPUTO AA & HOLCOMB JP (1982) The Dentatus screw: comparative stress analysis with other endodontic dowel designs *Journal of Oral Rehabilitation* **9** 23-33.

TJAN AHL, TJAN AH & GREIVE JH (1987) Effects of various cementation methods on the retention of prefabricated posts *Journal of Prosthetic Dentistry* **58** 309-313.

©OPERATIVE DENTISTRY, 1996, 21, 213-217

The Difference in Degree of Conversion between Light-cured and Additional Heat-cured Composites

S-H PARK • C-S LEE

Clinical Relevance
When composite resins were heated in an inlay oven, there were significant increases in the degree of conversion.

SUMMARY

This study was designed to determine the changes in the degree of conversion throughout composite resins of varying thicknesses after heat curing and to evaluate whether or not the thin wafer technique that was applied in this study was sensitive to changes in distance from the light source. A 5 mm-in-diameter hole was made in a 4 mm-thick Teflon plate, and composite resin was placed in the hole and light cured from the top for 60 seconds. Twenty samples were prepared; 10 of these were additionally heat cured in an inlay oven. After light curing or light and heat curing, the samples were sectioned into four parts and assigned to groups A, B, C, or D according to their distance from the light source. These sections were then thinned to 50-70 μm, and analyzed by use of a standard baseline technique with a Fourier Transform Infrared Spectrometer (FT-IR) to determine the degree of conversion.

The degree of conversion diminished as the distance from the light source increased; however, once the samples were heat cured, significant increases in the degree of conversion were noted throughout the samples. In the heat-cured composites, the degree of conversion in the outer portion of the sample was higher than in the inner portion. The thin wafer technique with FT-IR is considered to be a reliable method for measuring the degree of conversion in a composite resin, because changes between groups were clearly noted.

Yonsei University, College of Dentistry, Department of Conservative Dentistry, Seoul, Korea 120-752

Seong-Ho Park, DDS, PhD, instructor

Chung-Suck Lee, DDS, PhD, professor

INTRODUCTION

Hardness and strength of restorative resins depend upon the catalytic system involved in the polymerization (Asmussen, 1982). One important physical property of this system is the Degree of Conversion (DC) of the double bonds (C=C to C-C) in the restorative resin during the setting reaction. To evaluate the DC of unfilled sealants, IR-spectrometry has been applied. The results show that 15-35% of the monomer remains unreacted (Ruyter & Györösi, 1976). For composite resins that contain inorganic fillers, the multiple internal reflection technique with IR-spectrometry has been used (Ruyter & Svendsen, 1978; Ruyter & Øysaed, 1981). Using this method, the reported DC of three light-cured posterior composites, at a depth of 0.5 mm, ranged from 55% to 70% (Ruyter, 1985).

However, it has been pointed out that the results can vary with IR-spectrometry; thus, use of a Fourier Transform Infrared (FT-IR) Spectrometer using the thin film method has been recommended for determining the DC in unfilled BIS-GMA-based resin (Ferracane & Greener, 1984). To measure the conversion of light-activated composites with FT-IR,

a thin unfilled bonding agent is applied under the plastic matrix, and a composite resin of a constant thickness is placed over the matrix. After illumination of the composite, this bonding agent is used to measure the DC (Ferracane & others, 1986). This method is thought to be more sensitive than the Knoop hardness test, the optical test, or the scraping method in representing the changes caused by distance from the light source (Dewald & Ferracane, 1987). However, with this technique, the thin unfilled bonding agent, not the composite resin itself, is used to measure the DC. Since bonding agents have more diluent monomer in their composition than composite resins, it is unreasonable to assume that the DC of a bonding agent will be the same as that of a composite resin. In addition, this technique cannot be used to measure the DC of a heat-cured composite, because a heat-cured unfilled bonding agent cannot represent a heat-cured composite. Chung and Greener (1988) used a similar method to determine the DC of a composite resin. In their study, the composite resin was pressed into a thin circular film, and this film was used to determine the DC. However, this method cannot be used to determine the changes in the DC throughout a composite resin sample. Thus a new method was needed to determine the changes in DC after heat curing and to evaluate the changes in the conversion rate throughout a composite resin restoration.

The increases in the DC after heat curing vary widely: 1-3% (Reinhardt, 1991); 3-18% (Ferracane & Condon, 1992); 10-20% (Cook & Johannson, 1987); and 25-30% (Eliades, Vougiouklakis & Caputo, 1987). These differences may be due not only to the composition of the monomer and the applied temperature, but also to the sensitivity of the technique applied.

The purpose of this study was to determine the changes in DC after additional heat curing throughout the varying thicknesses of a restoration and to evaluate whether or not the thin wafer technique that was developed in this study was sensitive to changes in distance from the light source.

METHODS AND MATERIALS

The following steps are illustrated in the schematic diagram of Figure 1. A 5 mm-in-diameter hole was made in a 4 mm-thick Teflon plate and a Mylar strip (Hawe Striproll, Hawe Neos Dental, Gentilino, Switzerland) was positioned along the lower side of the hole using adhesive tape. Titanium-coated instruments (Composite Instrument, Coltène, Altstätten, Switzerland) were used to place the composite resin (Brilliant enamel, shade D3, Coltène) in the Teflon mold. A cover glass was placed over the top of the mold. The samples were light cured for 60 seconds from the top. A Max curing light unit (L D Caulk, Milford, DE 19963), the light intensity of which was 411 mW as measured by a Cure Rite light intensity meter (Efos Inc, Mississawga, Ontario, Canada), was used. The tip touched the cover glass. When light curing was completed, the composite resin was removed from the Teflon mold. Three lines were drawn on the surface of the composite to divide it into four sections. The resulting pieces were assigned to groups A, B, C, and D according to their distance from the light source during curing. Twenty samples were prepared. Ten of these samples were then heat cured in a DI-500 (Coltene) oven for 7 minutes at a temperature of 120 °C. This process was performed within 5 minutes of light curing. After these procedures, samples were stored under dark, dry conditions for 3 days. The samples were then sectioned into four parts with a diamond disk along

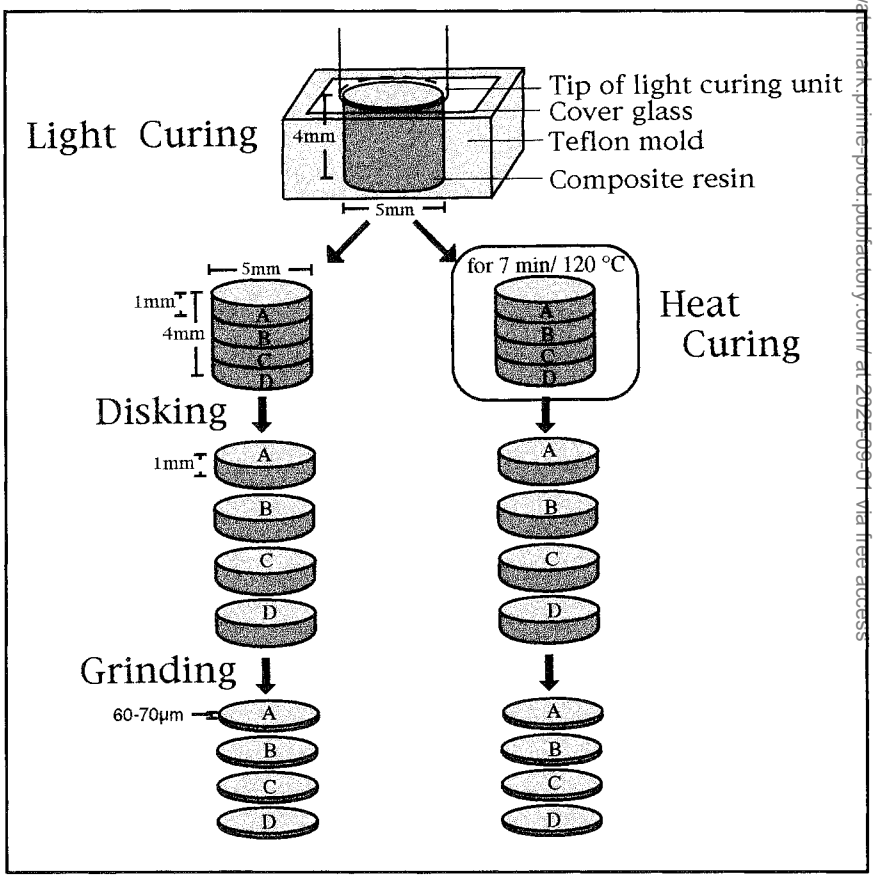


Figure 1. *Schematic diagram of the light-curing method and flow of this study. Inclusion in groups A, B, C, and D was based on distance from the light source.*

the lines drawn previously and thinned to 50-70 μm with SiC paper. Grinding was carried out equally on the upper and lower side of the sample, and the samples were irrigated with water during this procedure to prevent heat build-up. The edges of the samples were cut away to eliminate the influence of oxygen inhibition. Samples were stored in a dry environment.

To determine the DC of the prepolymerized paste, a thin layer of the composite resin was placed on a sodium chloride disk, which was then positioned in a minicell in the FT-IR spectrometer (IFS 120 HR, Bruker, Karlsruhe, Germany). By contrast, the polymerized samples were positioned directly in a sample holder. The range from 400 cm^{-1} to 4000 cm^{-1} was scanned first, and then the range from 1560 cm^{-1} to 1670 cm^{-1} was expanded. All procedures were carried out with nitrogen gas purging to produce a clean background spectrum. The spectra, recorded initially as the transmission mode, were converted to the absorbence mode. The DC was calculated by using the baseline method (Heigel, Bell & White, 1974). That is, the intensities of the aliphatic C=C absorbance peak at 1637 cm^{-1} and the aromatic C=C reference peak at 1609 cm^{-1} were measured using the baseline technique, and the ratio of the absorbance intensities of aliphatic C=C/aromatic C=C was compared before and after polymerization to determine the unreacted percentage of the aliphatic C=C bond. The DC was calculated by subtracting this ratio from 100%:

$$(\%C{=}C) = \frac{[Abs(C{=}C)/Abs(C\text{-}C)]polymer}{[Abs(C{=}C)/Abs(C\text{-}C)]monomer}$$

Degree of conversion = 100% - (% C=C).

The changes in DC caused by the distance from the light source and by heat curing were analyzed and compared by two-way ANOVA with Tukey HSD pairwise comparison at the 95% level of confidence. Differences between DC means larger than the Tukey interval were considered statistically significant.

Table 1. Two-Way ANOVA between Distances from the Light Source and Curing Methods

Source	Sum of Square	df	Mean Square	F
Distance (D)	586.785	3	195.595	1884.75*
Curing Method (C)	2538.005	1	2538.005	24456.15*
Interaction (D)(C)	571.437	3	190.479	1835.45*
Error	7.472	72	0.104	
Total	3703.698	79		

*F-value was significant at the 95% level of confidence.

Table 2. Degree of Conversion [DC] in Composite Resin

	Group A	Group B	Group C	Group D
LC	70.2[0.6]	63.4[0.4]	59.6[0.2]	55.7[0.1]
LC+HC	74.2[0.3]	72.7[0.2]	72.7[0.2]	74.4[0.3]

LC = light cure; HC = heat cure. DC in % with standard deviation in brackets.

RESULTS

Significant differences in DC were observed for both the distance from the light source and the different curing methods by two-way ANOVA. A significant interaction also existed between the curing method and the distance from the light source (Table 1).

The means and standard deviations for each group are listed in Table 2 and a summary of the Tukey contrast is presented in Table 3. The Tukey intervals at the 95% level were 0.2679% for groups A, B, C, and D and 0.1426% for the difference between the light-cured and light- and heat-cured groups.

When light cured, the DCs in groups A, B, C, and D were 70.2%, 63.4%, 59.6%, and 55.7% respectively; the differences in the DCs between groups were significant, and the DC decreased as the distance from the light source increased (Table 3).

When the samples were heat cured in an inlay oven, the DCs for groups A, B, C, and D were 74.2%, 72.7%, 72.7%, and 74.4% respectively. Statistical analysis revealed that the DCs for groups A and D were significantly higher than the DCs for groups B and C (Table 3).

The differences in the DCs between the light-cured and heat-cured composite in groups A, B, C, and D were 4%, 9.3%,

Table 3. Summary of Comparisons between Groups

Curing Method (Light Curing vs Heat Curing)	
Group 1	*
Group 2	*
Group 3	*
Group 4	*
Curing Depth	
Light Cure	
Group 1 vs 2	*
Group 2 vs 3	*
Group 3 vs 4	*
Heat Cure	
Group 1 vs 2	*
Group 2 vs 3	
Group 3 vs 4	*
Group 1 vs 4	

*Significant difference at 95% level of confidence

13.1%, and 18.7% respectively; the change in the DC with heat was significant in each group (Table 3). The difference in the DC between the light-cured and heat-cured composite was relatively small in group A, but became larger as the distance from the light source increased (Figure 2).

DISCUSSION

Since the resin inlay technique was developed, it has been reported that tensile strength, hardness, and color stability are improved when additional heat is applied after heat curing (Wendt, 1987a,b). Other physical properties have also been studied and increases reported (Wendt, 1989; Asmussen & Peutzfeldt, 1990; Ferracance & Condon, 1992). Considering the results of this paper, the increased physical properties noted with the resin inlay technique are related to the overall increase in DC.

The DC of the light-cured composite in this study was well within the range of other studies (Ruyter, 1985; Chung & Greener, 1988); similarly, the heat-induced increase in DC of this study was consistent with a previous study that reported a 3% heat-induced conversion in Brilliant dentin (Reinhardt, 1991). When we consider that the difference in the DC in group A between the light-cured and additionally heat-cured samples was significant but relatively small, we can conclude that a high and signficant level of DC can be accomplished with the layering technique if the light source is placed close to the resin surface. However, the annealing effect (de Gee & others, 1990) may enhance the physical properties of heat-cured composites even though the heat-induced conversion is relatively small.

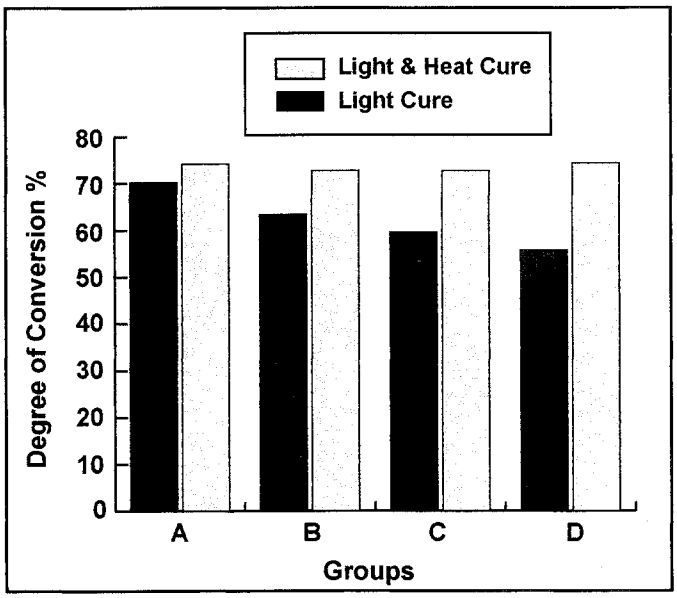


Figure 2. *Changes in degree of conversion*

In some brands, much higher levels of heat-induced conversion have been reported. For Herculite (Kerr Mfg Co, Romulus, MI 48174), a 15% increase in DC (from 62% to 77%) was reported when it was heat cured at 125 °C for 2.5 minutes (Reinhardt, 1991). Ferracane and Condon (1992) reported a 9.4% increase in DC (from 52.8% to 62.2%) for Herculite and an 18.4% increase (from 46% to 64.4%) for Heliomolar (Vivadent, Schaan, Liechtenstein) after a 10-minute heat treatment at 120 °C. We should note that these composites had a lower DC with light curing compared to Brilliant composite. The DC does not indicate degree of polymerization of BIS-GMA itself, but rather indicates the conversion rate of the aliphatic C=C bond in the methyl methacrylate group into a C-C bond. Since BIS-GMA has two methyl methacrylate groups in its composition, we can assume that most of the BIS-GMA molecules are cross-linked with each other if the conversion rate is over 70%. Thus, the DC in a BIS-GMA-based composite resin will not exceed 80% even after additional heat curing. If the DC approaches 70% in a composite with light curing, the increase in DC after heat curing will be relatively small. A previous study supports this (Ferracane & Condon, 1992).

The DCs of the heat-cured composites were higher in groups A and D than in groups B and C. This means that more heat was applied in the outer portions of the samples than in the inner portions.

There was a significant interaction between the curing method and distance from the light source (Table 1). This is felt to be related to the experimental design in this study; the light-curing process was undertaken from one direction, and the heat-curing process was within 5 minutes of light curing. The increased time interval between light-curing and the heat-curing process might affect the results, due to rapid decay of free radicals as they become tied up through reactions with oxygen (Ferracane & Condon, 1992). This phenomenon may be more definite in the outer portions of composite samples such as groups A and D.

The thin wafer technique used in this study differs from the thin film technique (Dewald & Ferracane, 1987). In addition to the problems with the thin film technique mentioned in the introduction, it was found in a preliminary pilot study that the thin bonding agent could be affected by oxygen, even though the bonding agent was covered by a matrix.

In some studies, the composite resins have been cured in a polyethylene bag filled with argon gas to prevent an oxygen-inhibition zone from developing (Ruyter, 1981). However, in this study, this procedure was omitted, because the samples were thinned from 1 mm to 50-70 μm to remove the oxygen-inhibition zone.

Ruyter and Svendsen (1978) indicated that the presence of fillers in a composite resin makes it

difficult to measure the DC by the transmission or absorption mode with IR spectroscopy; thus, they used the MIR technique. The effects of fillers were so reduced in the present study that it was possible to measure the degree of conversion. This was accomplished by thinning the samples to 50-70 μm.

This study showed that the thin wafer method with FT-IR is a reliable method for measuring the DC in a composite resin; distinct changes between groups were clearly noted. However, due to the grinding process, this method is more time consuming than other methods. Care must also be taken to prevent heat build-up during the grinding process.

CONCLUSION

1. In light-cured composite, the degree of conversion diminished as the distance from the light source increased.
2. When the composite resins were heat cured in an inlay oven, there were significant increases in the degree of conversion throughout the sample, and the degree of conversion in the outer portion of the sample was higher than in the inner portion.
3. The thin wafer technique with FT-IR is considered to be a reliable method for measuring the degree of conversion in a composite resin.

Acknowledgment

The authors most gratefully acknowledge the help of Dr Kang-Bond Lee of the Korea Institute of Science and Technology.

(Received 7 July 1995)

References

ASMUSSEN E (1982) Restorative resins: hardness and strength vs quantity of remaining double bonds *Scandinavian Journal of Dental Research* **90** 484-489.

ASMUSSEN E & PEUTZFELDT A (1990) Mechanical properties of heat treated restorative resins for the inlay/onlay technique *Scandinavian Journal of Dental Research* **98** 564-567.

CHUNG K & GREENER EH (1988) Degree of conversion of seven visible light-cured posterior composites *Journal of Oral Rehabilitation* **15** 555-560.

COOK WD & JOHANNSON M (1987) The influence of postcuring on the fracture properties of photo-cured dimethacrylate based dental composite resin *Journal of Biomedical Material Research* **21** 979-989.

de GEE AJ, PALLAV P, WERNER A & DAVIDSON CL (1990) Annealing as a mechanism of increasing wear resistance of composites *Dental Materials* **6** 266-270.

DEWALD JP & FERRACANE JL (1987) A comparison of four modes of evaluating depth of cure of light-activated composites *Journal of Dental Research* **66** 727-730.

ELIADES GC, VOUGIOUKLAKIS GJ & CAPUTO AA (1987) Degree of double bond conversion in light-cured composites *Dental Materials* **3** 19-25.

FERRACANE JL, ADAY P, MATSUMOTO H & MARKER VA (1986) Relationship between shade and depth of cure for light-activated dental composite resins *Dental Materials* **2** 80-84.

FERRACANE JL & CONDON JR (1992) Post-cure heat treatments for composites: properties and fractography *Dental Materials* **8** 290-295.

FERRACANE JL & GREENER EH (1984) Fourier transform infrared analysis of degree of polymerization in unfilled resins--methods comparison *Journal of Dental Research* **63** 1093-1095.

HEIGEL JJ, BELL MF & WHITE JN (1947) Application of infrared spectroscopy to the analysis of liquid hydrocarbons *Analytical Chemistry* **19** 293-298.

REINHARDT K-J (1991) Die extraorale vertgutung von Komposite-inlays *Deutsche Zahnarztliche Zeitschrift* **46** 342-345.

RUYTER IE (1981) Unpolymerized surface layers on sealants *Acta Odontologica Scandinavica* **39** 27-32.

RUYTER IE (1985) Monomer system and polymerization In *International Symposium on Posterior Composite Resin Dental Restorative Materials* Vanherle G, Smith DC, eds, Utrecht, The Netherlands: Peter Szulc Publishing Co, pp 109-135.

RUYTER IE & GYÖRÖSI P-P (1976) An infrared spectroscopic study of sealants *Scandinavian Journal of Dental Research* **84** 396-400.

RUYTER IE & ØYSAED H (1981) Conversion in different depths of ultraviolet and visible light activated composite materials *Acta Odontologica Scandinavica* **40** 179-192.

RUYTER IE & SVENDSEN SA (1978) Remaining methacrylate groups in composite restorative materials *Acta Odontologica Scandinavica* **36** 75-82.

WENDT SL Jr (1987a) The effect of heat used as secondary cure upon the physical properties of three composite resins. I. Diametral tensile strength, compressive strength and marginal dimensional stability *Quintessence International* **18** 265-271.

WENDT SL Jr (1987b) The effect of heat used as secondary cure upon the physical properties of three composite resins. II. Wear, hardness, and color stability *Quintessence International* **18** 351-356.

WENDT SL Jr (1989) Time as a factor in the heat curing of composite *Quintessence International* **20** 259-263.

©OPERATIVE DENTISTRY, 1996, 21, 218-224

Bond Strengths of Resin to Enamel and Dentin Treated with Low-Pressure Air Abrasion

T NIKAIDO • M KATAUMI • M F BURROW
S INOKOSHI • T YAMADA • T TAKATSU

Clinical Relevance
Air abrasion with alumina and glass beads did not enhance the bond strength of a bonding resin to enamel and dentin.

SUMMARY

The effect of low-pressure (41.8 psi) air abrasion with alumina and glass beads on bonding to tooth substrates was evaluated. Tensile bond strengths of a bonding resin to air-abraded bovine enamel and dentin were measured. Scanning electron microscopy was used to observe (1) air-abraded surfaces, (2) fractured surfaces after the tensile bond test, and (3) interfaces of bonded specimens. Air abrasion with glass beads significantly decreased the bond strengths to enamel and dentin, whereas air abrasion with alumina decreased adhesion to enamel but not to dentin. The air-abraded enamel and dentin surfaces were irregularly roughened, and smear layers were created by air abrasion. Hybrid layers were observed at the interface between the bonding resin and the air-abraded dentin. The SEM photographs suggested that air abrasion may weaken the tooth surfaces, which could account for the decrease of the bond strengths.

Tokyo Medical and Dental University, Faculty of Dentistry, Department of Operative Dentistry, 5-45, Yushima 1-chome, Bunkyo-ku, Tokyo 113, Japan

Toru Nikaido, DDS, PhD, instructor

Masaaki Kataumi, DDS, graduate student

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

Shigehisa Inokoshi, DDS, PhD, lecturer

Toshimoto Yamada, DDS, PhD, lecturer

Toshio Takatsu, DDS, PhD, professor, Ohu University, Faculty of Dentistry, Department of Periodontics and Restorative Dentistry, Koriyama, Japan

INTRODUCTION

Air-abrasion technology was introduced to dentistry by R B Black in 1945. The air-abrasive device for cavity preparation (Airdent, S S White Co, Lakewood, NJ 08710) was developed, and several clinical and scientific investigations were reported in the 1950s (Epstein, 1951; Goldberg, 1952; Myers, 1954; Peyton & Henry, 1954). Air-abrasion technology appeared to eliminate the vibration, pressure, heat, and bone-conducted noise associated with rotary cutting instruments. However, the cavity prepared with the air-abrasive instrument was not accepted at that time, because gold and amalgam restorations were the primary methods of tooth restoration. In the 1980s, with the advance of bonding systems, the use of resin composite became widely accepted in restorative dentistry (Nakabayashi, Kojima &

Masuhara, 1982a; Munksgaard & Asmussen, 1984; Bowen, 1985). Cavity preparation for bonded restorations has been changed from the box form to the conservative (minimal) form. Furthermore, several new air-abrasion instruments for cavity preparation (KCP-2000, American Dental Technologies Co, Troy, MI 48084; MicroPrep, Sunrise Technologies Co, Fremont, CA 94538) have been developed in the 1990s. In view of these developments, air-abrasive technology has been re-examined as a means of cavity preparation for current resin composite restorations (Goldstein & Parkins, 1994).

The purpose of this study was to evaluate the influence of air abrasion on bonding to bovine enamel and dentin using tensile bond testing and scanning electron microscopy.

METHODS AND MATERIALS

Tensile Bond Measurement

Freshly extracted bovine teeth, stored frozen, were used for the tensile bond measurement tests. Bovine teeth that were ground with 600-grit silicon carbide paper under a stream of running water to form flat enamel or dentin surfaces composed a control group. For the experimental groups, exposed enamel or dentin surfaces, initially finished with 600-grit paper, were then air abraded with a Micro Blaster (Panaheraus Dental, Osaka, Japan) for 15 seconds at an air pressure of 3 kgf/cm^2 (41.8 psi), by means of powder of either 50 μm alumina or 50 μm glass beads. The air was taken from the compressed air available in the hospital facilities.

After the surfaces were rinsed and dried, each bonding area was demarcated with a vinyl masking tape in which a 4 mm-in-diameter hole was cut, then Superbond D-Liner Plus (Sun Medical Co, Kyoto, Japan) was placed according to the manufacturer's instructions (see the bonding protocol below). A photocured resin composite, Photoclearfil Bright (Kuraray Co, Osaka, Japan), was then applied, covered with a plastic matrix strip, pressed flat with a glass slide, and light cured for 40 seconds. A stainless steel rod, used for the tensile bond test, was cemented perpendicularly to the surface of the cured composite using a resin cement (Panavia EX, Kuraray) as illustrated in Figure 1.

The specimens were stored in water at 37 °C for 1 day. After this, the tensile bond strengths were measured using a Universal Testing Machine (Autograph GA-500B, Shimadzu Co, Kyoto, Japan) at a crosshead speed of 2 mm/min. Ten specimens were tested for each test group. The data were statistically analyzed using one-way ANOVA and Duncan's Multiple Range Test at the 5% level of significance ($P < 0.05$).

Bonding protocol of Superbond D-Liner Plus: (1) 10-3 solution (3% ferric chloride in 10% citric acid) was applied to enamel or dentin surfaces for 30 seconds or 10 seconds respectively, then rinsed and gently dried with air, (2) 35% aqueous HEMA (2-hydroxyethyl methacrylate) was applied to the surface and dried gently, (3) 4-META (4-[2-(methacryloxyethoxy)carbonyl] phthalic acid anhydride) in MMA (methyl methacrylate) and unknown dimethacrylates, with a catalyst of TBB (tri-n-butyl borane) and PMMA (polymethyl methacrylate) powder, were mixed and the thin paste applied to the surface.

SEM Observation

The air-abraded bovine enamel and dentin surfaces were trimmed with a diamond disk (3 mm x 3 mm x 1 mm), then gold sputter coated to examine their surface morphologies with a scanning electron microscope (JXA-840, Jeol, Tokyo, Japan). The fractured surfaces on the enamel or dentin side, after the tensile bond test, were also trimmed by the same procedure to observe the fracture mode of the bonded samples by SEM.

In order to observe the enamel or dentin/adhesive interfaces, bonded specimens, which were prepared the same as the tensile test specimens, were cut vertically and embedded in epoxy resin (Epon 815, Nisshin EM, Tokyo, Japan). After curing of the epoxy resin, the specimens were ground and polished with diamond pastes down to 1 μm. The specimens were subsequently etched with an argon-ion beam for 10 minutes with an EIS-1E (Elionix Ltd, Tokyo, Japan) prior to SEM examination using the technique described by Inokoshi and others (1993).

Three specimens were observed for each group to confirm any morphologic differences.

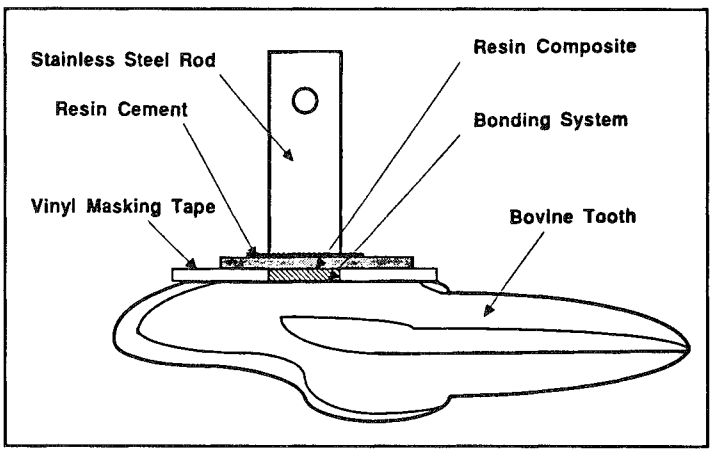


Figure 1. *Specimen for the tensile test*

Mean Tensile Strengths to Air-abraded Enamel and Dentin (MPa)

	Control	Alumina	Glass Beads
Enamel	18.7 ± 4.0	11.4 ± 2.5	8.5 ± 1.6
Dentin	17.3 ± 4.2	18.7 ± 4.4	10.9 ± 3.4

Horizontal bar indicates no significant difference ($P > 0.05$). ± standard deviation; number of specimens (n = 10).

RESULTS

Tensile Bond Strength

The tensile bond strengths to air-abraded enamel and dentin are summarized in the table. The tensile bond strengths statistically decreased for the enamel air abraded with either alumina or glass beads. The bond strength to glass bead-abraded enamel was significantly lower than that of the alumina-treated enamel ($P < 0.05$). For dentin, no significant differences were detected between the control and dentin air abraded with alumina. However, the bond strength to glass bead-abraded dentin was significantly weaker ($P < 0.05$).

SEM Observation

The morphological characteristics of the enamel and dentin surfaces following exposure to air abrasion with alumina or glass beads are illustrated in Figures 2 and 3. In enamel abraded with alumina, the uniformly ground enamel surface from the 600-grit paper (Figure 2A) was observed to have been removed, resulting in a surface that was rough in appearance (Figure 2B). The enamel surface treated with glass beads was smoother (Figure 2C). In dentin, a smear layer was created on dentin ground with 600-grit paper (Figure 3A). After air abrasion with alumina, the surface seemed to be irregularly roughened (Figure 3B). After abrasion with glass beads, however, the surface was somewhat irregular and appeared to have a crust-like surface layer (Figure 3C). There was some artifact crack formation created during desiccation for SEM evaluation. Dentinal tubules were not observed after either the alumina or glass bead treatments, indicating that a smear layer was formed.

The SEM views of the fractured surfaces after tensile bond measurement of the bonded specimens are illustrated in Figures 4 and 5. Cohesive failure within the bonding resin and/or the resin composite was observed in specimens bonded to ground enamel. Cohesive fractures of enamel were observed after

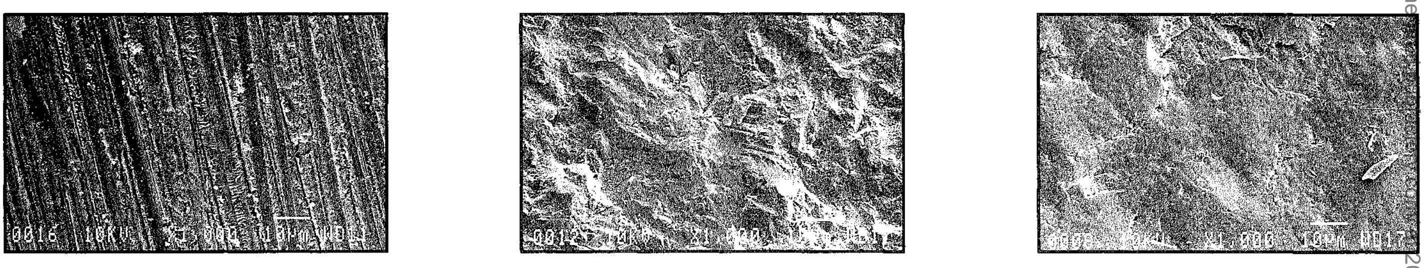


Figure 2. *SEM photographs of ground and air-abraded enamel surfaces (original magnification X500)* **2A**. *A uniformly ground enamel surface from the 600-grit paper was observed.* **2B**. *The surface air abraded with alumina was somewhat roughened in appearance and not uniform.* **2C**. *The enamel surface treated with glass beads seems to be smoother; however, the superficial enamel surface was partially peeled away.*

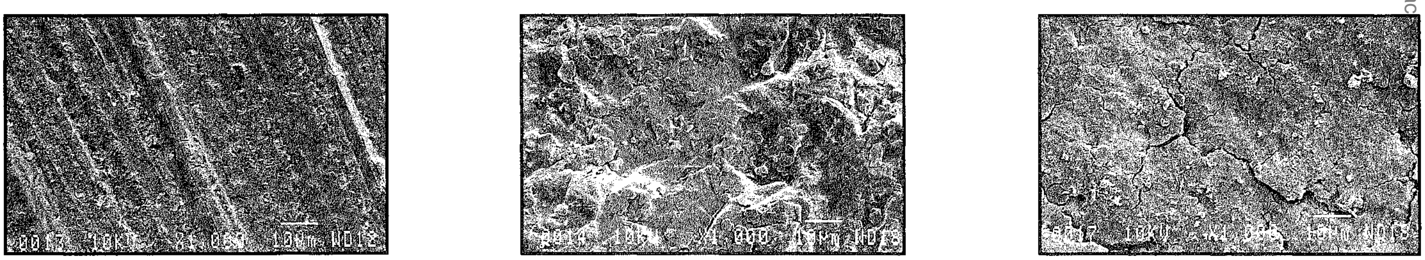


Figure 3. *SEM photographs of ground and air-abraded dentin surfaces (original magnification X500)* **3A**. *A smear layer was created on dentin ground with 600-grit SiC paper.* **3B**. *The dentin surface air abraded with alumina seemed to be irregular or roughened in nature.* **3C**. *After abrasion with glass beads, the surface seemed somewhat irregular and a crust appears to have been formed by abrasion from the glass beads. There was some crack formation during the desiccation for sample preparation. Dentinal tubules were not observed after both the alumina and glass bead treatments.*

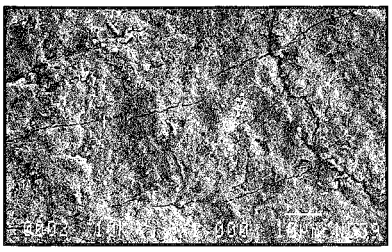
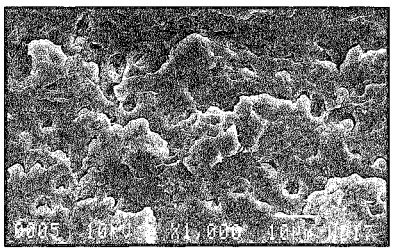


Figure 4. *SEM photograph of fractured alumina air-abraded specimen after the tensile bond test. Cohesive fractures of enamel were observed on the enamel side (original magnification X500)*



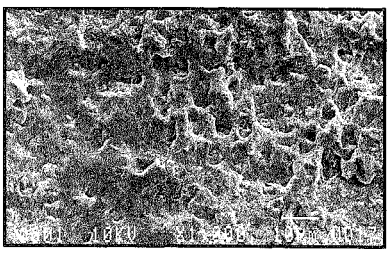


Figure 5. *SEM photographs of fractured surfaces on the dentin side after the tensile bond test (original magnification X500)* **5A**. *Cohesive failure of the bonding resin was observed in most areas; however, opened dentinal tubules remained on the surface in the abraded sample with alumina.* **5B**. *Cohesive failure of dentin occurred after abrasion with glass beads.*

abrasion with either alumina or glass beads (Figure 4). In dentin, cohesive failure within the bonding resin was observed in most areas; however, open dentinal tubules remained on the surface in the control and in the sample abraded with alumina (Figure 5A). Cohesive failure within dentin occurred after abrasion with glass beads in most of the specimens (Figure 5B).

The SEM view of the interface between the resin and enamel air abraded with alumina is shown in Figure 6. The enamel surface was roughened, and resin tags were formed in the air-abraded and 10-3-etched surface. However, cracks in the subsurface of enamel (arrows) were observed. The SEM observation of the interface of resin/dentin treated with alumina is shown in Figure 7. The surface roughness of the dentin increased with air abrasion using alumina. However, the interfaces between the bonding resin (R) and dentin (D) indicate close apposition. An irregular hybrid layer (H) could be detected at the interface below the bonding resin ranging from 2 μm to 3 μm in thickness.

DISCUSSION

Bovine teeth were used in this study as a substitute for human teeth because a large number of teeth were required for this study, and human teeth are now scarce. Additionally, the size of bovine teeth facilitates elimination of some factors that may influence testing for bond strengths (Suzuki & Finger, 1988; Tagami & others, 1993), as well as simplifying the experimental procedure. Previous studies have shown little or no difference for tensile bond strength tests comparing human and bovine teeth (Nakamichi, Iwaku & Fusayama, 1983; Fowler & others, 1992).

Phosphoric acid etching of enamel has been widely accepted in restorative and orthodontic procedures (Buonocore, 1955). The adhesion of resin to etched enamel was shown to be due to micromechanical retention caused by resin tag formation (Gwinnett & Matsui, 1987). Dentin bonding results from the formation of a hybrid layer due to monomer infiltration and polymerization in the subsurface of

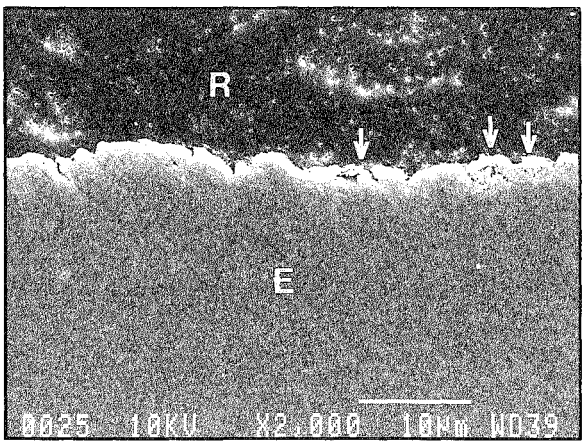


Figure 6. *SEM observation of the interface between Superbond D-Liner Plus and air-abraded enamel with alumina. The enamel surface was roughened and resin tags were formed on the enamel surface. Some cracks were observed in the subsurface on the enamel (arrow). R = bonding resin; E = enamel. (original magnification X1500)*

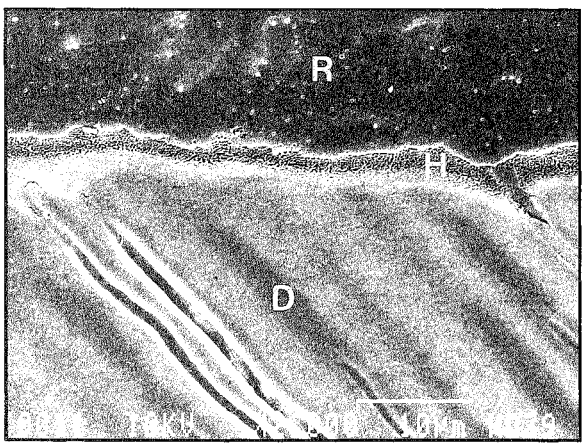


Figure 7. *SEM observation of the interface between Superbond D-Liner Plus and dentin air abraded with alumina. The dentin surface became irregular and the depth of the hybrid layer (H) ranged from 2 μm to 3 μm. R = bonding resin; D = dentin (original magnification X1500).*

the demineralized dentin (Nakabayashi, 1984).

The 10-3 solution removes the smear layer, demineralizes the underlying dentin, and has been reported to promote bonding not only to dentin, but also to enamel in self-curing (Nakabayashi & others, 1982b) or photocuring bonding systems (Nikaido & others, 1990). The ferric chloride in the 10-3 solution is believed to act as a stabilizer of collagen during the demineralization process (Nakabayashi, 1984), while the primer (HEMA) appears to restore the strength of the demineralized collagen fiber network to near its original level (Sugizaki, 1991; Pashley & others, 1993; Van Meerbeek & others, 1993). The surface-active monomer, 4-META (Takeyama & others, 1978), has been reported to improve the bond strength of resins to tooth structure because 4-META promotes the penetration of monomers into tooth structure.

Air-abrasion using alumina has been commonly used to increase the adhesion of resin to metal surfaces (Tanaka & others, 1986; Swift, 1989). It was also reported to be used for mechanical etching or modifying the surface of enamel as a substitute for acid etching (Katora, Jubach & Polimus, 1981). However, the effectiveness of this technique is controversial, with some researchers supporting the etching ability of air abrasion to enamel and/or dentin (Keen, Von Fraunhofer & Parkins, 1994; Dotty & others, 1994), while other researchers deny its efficacy (Eakle, Wong & Huang, 1995; Horgesheimer & others, 1995).

The SEM observations of the air-abraded enamel and dentin surfaces (Figures 2 and 3) showed that the surface roughness increased with the air-abrasive treatment; however, the characteristics of the air-abraded enamel or dentin surfaces were much different from those treated chemically with acid etching. The air-abraded enamel surfaces were irregular but not similar to the honeycomb-like structure seen after etching with phosphoric acid (Hotta & others, 1992). In the case of dentin, the dentinal tubules could not be observed on the air-abraded dentin surfaces, which suggests that a smear layer was created by the air-abrasive process. Los and Barkmeier (1994) also pointed out the formation of a smear layer on the air-abraded dentin. The morphological appearance of the air-abraded dentin smear layer was much different from that produced with the 600-grit paper. The alumina air-abraded surface appeared very rough, with pitting of the surface. However, glass bead air abrasion created a smear layer that was smooth in appearance. After dessication for the SEM observations, crack formation occurred, causing the smear layer to appear crust-like in nature. The use of an acidic conditioner prior to application of resin is necessary to remove the smear layer created by the air abrasion to obtain good bonding, because the smear layer can prevent the diffusion of monomers into the superficial dentin structure (Bowen, 1978). Thus air abrasion as a mechanical etching technique appears ineffective. Roeder and others (1994) reported that preparation of tooth structure by air abrasion does not alleviate the need for chemical conditioning of the tooth before bonding.

The bond strengths to enamel air abraded with either alumina or glass beads indicated that the air-abrasion treatment adversely affected bond strengths to enamel (table). The SEM observations of the fractured samples showed that cohesive failure within enamel occurred in the air-abraded samples (Figure 4). Furthermore, the SEM view of the interface between enamel and air-abraded enamel (Figure 6) indicated that some microcracks occurred in the subsurface of enamel using the air-abrasive treatment. These observations suggest that the enamel structure was weakened by air abrasion and thus, cohesive failure within enamel occurred with lower loads during the tensile bond test. The adverse action of air abrasion may be that the force of impact of the abrasive particles produced microcracks in the surface of the enamel, which could not be completely eliminated by etching with the 10-3 solution. To overcome this problem, it is believed that a stronger acid or increased etching time should be used.

There was no significant influence of air abrasion with alumina on bonding to dentin (table). The hybrid layer (H) was irregular, but the interface indicated close apposition of resin with dentin air abraded with alumina (Figure 7). However, air abrasion with glass beads decreased the bond strength to dentin, and cohesive failure in dentin was observed (Figure 5b). The cause of the decrease of the strength of dentin air abraded with glass beads may be due to a weakened or flawed structure, analogous to the condition of air-abraded enamel.

Los and Barkmeier (1994) reported that air abrasion did not increase the bond strength to dentin, but increased cohesive failures in dentin. Eakle and others (1994) reported that the bond strength of a resin to dentin was higher for high-speed (160 psi) than for low-speed air abrasion (80 psi). The even lower air pressure of 41.8 psi used in this study could have contributed to the decreased bond strengths. Further study is needed to analyze the complex effects of air abrasion on bonding.

CONCLUSIONS

Air abrasion decreased the bond strengths of a bonding resin to enamel and dentin except for dentin air abraded with alumina. The air-abraded enamel and dentin surfaces were roughened, and a smear layer

was observed on the air-abraded dentin. The SEM views of the fractured and the cross-sectional bonded specimens indicated that air-abrasive treatment of the enamel and dentin surfaces caused decreased bond strengths.

(Received 13 July 1995)

References

BLACK RB (1945) Technic for nonmechanical preparation of cavities and prophylaxis *Journal of the American Dental Association* **32** 955-965.

BOWEN RL (1978) Adhesive bonding of various materials to hard tooth tissues—Solubility of dentinal smear layer in diluted acid buffers *International Dental Journal* **28** 97-107.

BOWEN RL (1985) Bonding of restorative materials to dentine: the present status in the United States *International Dental Journal* **35** 155-159.

BUONOCORE MG (1955) A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces *Journal of Dental Research* **34** 849-853.

DOTTY WD, PETTEY D, HOLDER R & PHILLIPS S (1994) KCP 2000 enamel etching abilities tested *Journal of Dental Research* **73** *Abstracts of Papers* p 411 Abstract 2474.

EAKLE WS, GOODIS HE, WHITE JM & DO HK (1994) Effect of microabrasion on dentin permeability and bond strength *Journal of Dental Research* **73** *Abstracts of Papers* p 131 Abstract 239.

EAKLE WS, WONG J & HUANG H (1995) Microleakage with microabrasion versus acid etched enamel and dentin *Journal of Dental Research* **74** *Abstracts of Papers* p 31 Abstract 160.

EPSTEIN S (1951) Analysis of airbrasive procedures in dental practice *Journal of the American Dental Association* **43** 578-582.

FOWLER CS, SWARTZ ML, MOORE BK & RHODES BF (1992) Influence of selected variables on adhesion testing *Dental Materials* **8** 265-269.

GOLDBERG MA (1952) Airbrasive: Patient reactions *Journal of Dental Research* **31** 504-505.

GOLDSTEIN RE & PARKINS FM (1994) Air-abrasive technology: its new role in restorative dentistry *Journal of the American Dental Association* **125** 551-557.

GWINNETT AJ & MATSUI A (1987) A study of enamel adhesives. The physical relationship between enamel and adhesive *Archives of Oral Biology* **12** 1615-1620.

HORGESHEIMER JJ, HAWS SM, KANELLIS MJ & VARGAS MA (1995) Composite shear bond strength to air-abraded enamel *Journal of Dental Research* **74** *Abstracts of Papers* p 32 Abstract 162.

HOTTA K, MOGI M, MIURA F & NAKABAYASHI N (1992) Effect of 4-MET on bond strength and penetration of monomers into enamel *Dental Materials* **8** 173-175.

INOKOSHI S, HOSODA H, HARNIRATTISAI C & SHIMADA Y (1993) Interfacial structure between dentin and seven dentin bonding systems revealed using argon ion beam etching *Operative Dentistry* **18** 8-16.

KATORA ME, JUBACH T & POLIMUS MM (1981) Airbrasive etching of the enamel surface *Quintessence International* **12** 967-968.

KEEN DS, VON FRAUNHOFER JA & PARKINS FM (1994) Air-abrasive "etching": composite bond strengths *Journal of Dental Research* **73** *Abstracts of Papers* p 131 Abstract 238.

LOS SA & BARKMEIER WW (1994) Effects of dentin air abrasion with aluminum oxide and hydroxyapatite on adhesive bond strength *Operative Dentistry* **19** 169-175.

MUNKSGAARD EC & ASMUSSEN E (1984) Bond strength between dentin and restorative resins mediated by mixtures of HEMA and glutaraldehyde *Journal of Dental Research* **63** 1087-1089.

MYERS GE (1954) The airbrasive technique: a report *British Dental Journal* **91** 291-295.

NAKABAYASHI N (1984) Biocompatibility and promotion of adhesion to tooth substrates *CRC Critical Review Biocompatibility* **1** 25-52.

NAKABAYASHI N, KOJIMA K & MASUHARA E (1982a) The promotion of adhesion by the infiltration of monomers into tooth substrates *Journal of Biomedical Materials Research* **16** 265-273.

NAKABAYASHI N, TAKEYAMA M, KOJIMA K & MASUHARA E (1982b) Studies on dental self-curing resins, XIX Adhesion of 4-META/MMA-TBB resin to pretreated dentine *The Journal of the Japanese Society for Dental Materials and Devices* **23** 29-33.

NAKAMICHI J, IWAKU M & FUSAYAMA T (1983) Bovine teeth as possible substitutes in the adhesion test *Journal of Dental Research* **62** 1076-1081.

NIKAIDO T, PODSZUN W, MULLER M & NAKABAYASHI N (1990) Effect of sulfonamides and 4-MET on adhesion to tooth substrates *Dental Materials* **6** 78-82.

PASHLEY DH, CIUCCHI B, SANO H & HORNER JA (1993) Permeability of dentin to adhesive agents *Quintessence International* **24** 618-631.

PEYTON FA & HENRY EE (1954) The effect of high speed burs, diamond instruments and air abrasive in cutting tooth tissue *Journal of the American Dental Association* **49** 426-435.

ROEDER LB, BERRY EA, YOU C & POWERS JM (1994) Bond strength of composite to air-abraded enamel and dentin *Journal of Dental Research* **73** *Abstracts of Papers* p 131 Abstract 237.

SUGIZAKI J (1991) The effect of the various primers on the dentin adhesion of resin composites—SEM and TEM observations of the resin-impregnated layer and adhesion promoting effect of the primers *Japanese Journal of Conservative Dentistry* **34** 228-265.

SUZUKI T & FINGER WJ (1988) Dentin adhesives: site of dentin vs bonding of composite resins *Dental Materials* **4** 379-383.

SWIFT EJ Jr (1989) New adhesive resins. A status report for the American Journal of Dentistry *American Journal of Dentistry* **2** 258-260.

TAGAMI J, NAKAJIMA M, SHONO T, TAKATSU T & HOSODA H (1993) Effect of aging on dentin bonding *American Journal of Dentistry* **6** 145-147.

TAKEYAMA M, KASHIBUCHI N, NAKABAYASHI N & MASUHARA E (1978) Studies on dental self-curing resins (17). Adhesion of PMMA with bovine enamel or dental alloys *The Journal of Japanese Society for Dental Materials and Devices* **19** 179-185.

TANAKA T, FUJIYAMA E, SHIMIZU H, TAKAKI A & ATSUTA M (1986) Surface treatment of nonprecious alloys for adhesion-fixed partial dentures *Journal of Prosthetic Dentistry* **55** 456-462.

VAN MEERBEEK B, DHEM A, GORET-NICAISE M, BRAEM M, LAMBRECHTS P & VAN HERLE G (1993) Comparative SEM and TEM examination of the ultrastructure of the resin-dentin interdiffusion zone *Journal of Dental Research* **72** 495-501.

©OPERATIVE DENTISTRY, 1996, 21, 225-226

STUDENT AWARDS

RECIPIENTS OF 1996 STUDENT ACHIEVEMENT AWARDS

American Academy of Gold Foil Operators

Loma Linda University, CA	Paul Hoang Dole
University of California, Los Angeles	Lorese Gerlone Vandemark
University of California, San Francisco	Arthur Lowe
University of Southern California	Gregg K Johnson
Université de Montréal, Québec,Canada	Josée LaFontaine
Université Laval, Québec, Canada	Marco Couturier
University of Alberta, Canada	Jason Pan
Howard University, DC	Dexter A Woods
University of Illinois	Jeffrey A Herman
Indiana University	James E Duncan
University of Maryland	Eric A Van Venrooy
University of Minnesota	Alan F Schneider
University of Missouri-Kansas City	Michelle L Dearinger
University of Nebraska	David G Merritt
University of Medicine and Dentistry of New Jersey	Raul C González
Columbia University, NY	Thomas Mulvey
State University of New York at Buffalo	Robert J LaCarrubba
Case Western Reserve University, OH	Philip J Znidarsic
Temple University, PA	Bill Vasile S Bucur
University of Pennsylvania	Kianoush Mohammadi Tari
Medical University of South Carolina	Bradley J Engle
University of Texas at Houston	Behrooz Niknam
University of Washington	Eric C Ellingsen
West Virginia University	Shadrouz Kianouri
Marquette University, WI	Mark W Stivers

Academy of Operative Dentistry

University of Alabama	Jay Eugene Hypes
University of Argentina at Buenos Aires	Federico Blotta
University of Sydney, New South Wales, Australia	Wymin Yuen
Loma Linda University, CA	Vivian Ok Hee Kwon
University of California, Los Angeles	Tracy Noel Blakely
University of California, San Francisco	Marjan Mirshemirani
University of the Pacific, CA	William Lee Willis
University of Southern California	Chi Chan Leung
Université de Montréal, Québec, Canada	Helene Levesque

Université Laval, Québec, Canada
University of Alberta, Canada
University of British Columbia, Canada
University of Manitoba, Canada
University of Saskatchewan, Canada
University of Western Ontario, Canada
University of Colorado
University of Connecticut
University Dental Hospital of Manchester, England
University of Florida
Medical College of Georgia
Northwestern University, IL
Southern Illinois University
University of Illinois at Chicago
Indiana University
University of Iowa
University of Kentucky
University of Louisville, KY
Louisiana State University
University of Maryland
Boston University, MA
Harvard School of Dental Medicine, MA
Tufts University, MA
University of Detroit Mercy, MI
University of Michigan
University of Minnesota
University of Mississippi
University of Missouri-Kansas City
Creighton University, NE
University of Nebraska
Katholieke Universiteit Nijmegen, The Netherlands
University of Medicine and Dentistry of New Jersey
Columbia University, NY
New York University
State University of New York at Buffalo
State University of New York at Stony Brook
University of North Carolina at Chapel Hill
Case Western Reserve University, OH
Ohio State University
University of Oklahoma
Oregon Health Sciences University
Temple University, PA
University of Pennsylvania
University of Puerto Rico
Medical University of South Carolina
Meharry Medical College, TN
University of Tennesse, Memphis
Baylor College of Dentistry, TX
University of Texas at Houston
University of Texas at San Antonio
Virginia Commonwealth University
University of Washington
West Virginia University
Marquette University, WI

Isabella Su Ming Wang
Charles Stewart
Shehin Amirali Jessa
Darrell Pilat
Blayne Thibodeau
Julie L Michalko
Jodie Keimi Nishimura
Donna Zabaneh

Connie Choi
Eddie Cha Orobitg
Julia Kinnett Howard
Robert P Bradley
Heidi M Butts
Terry R Joiner
Oluseyi A Ayangade
Gregory D Evans
Clyde Blair
Rodney Cordell Johns
Kay Daniel
John Michael Tilghman
Marianna Goziker
José Manuel Marchena
Bich-Ha Thi Nguyen
Stephanie Huang
Rebecca Louise Byl
Henry D Watzl
Joey E Rogers
Sheri Kay Miller
Mark A Lloyd
Michael Craig Smith

Miss J M ten Dolle

Theresa T Heidel
Thomas Sherlock
Jeffrey Karlin
Andrew P Privitera
Debra Ann Oreste
Virginia Wilson
Judith R Kiss-Benke
Mark Patrick Vogley
Carol Margret Blossfeld
Gregory Atack
Frank R Eutsey
Blair Adam Schachtel
Jaime Castro
Sonya L Windham
Teri Diane Forster
Craig T Davis, Jr
David Christopher Henson
Frank Edmund Bonner, IV
John S Mahaney
Gregory Bath
Gil Furman
Shadrouz Kianouri
Mark W Stivers

DEPARTMENTS

NOTICE: "WHAT WORKS" TIPS NEEDED

At the February 1996 meeting of the Journal's Editorial Board, it was decided to include a **What Works** section for practitioners. This would be totally different from a Clinical Article, which goes into detail about a certain technique.

I would envision this section to be comprised of short paragraphs, each of which would present a helpful hint for providing quality dental treatment for patients. The hint would NOT have to be exotic, only useful. For example, one member mentioned that he routinely places a drop of anesthetic on his retraction cord before placement to decrease sensitivity and crevicular fluid flow. Some tips may require an illustration or two for clarification. Most will probably not. In any event, if any clarification is needed, the editor will get back to you. Unless specifically requested otherwise, all submissions will be credited to the submitter by indicating his/her name at the end of the tip.

The key to having a successful **What Works** section in our Journal is to have adequate participation from our readers. Therefore, I would greatly appreciate hearing from you concerning initiation of this concept as well as passing on your many little aids for performing quality dentistry.

If I can generate enough enthusiasm from you to obtain a significant number of these clinical tips, I plan to keep them all in a notebook, which would be available for new and old members upon demand.

Our readership comprises the most elite and talented dentists in the world. I would sincerely hope that you would all be willing to share "what works" with other readers of *Operative Dentistry.*

RICHARD B McCOY, Editor
Telephone: 206-543-5948; Fax: 206-543-7783;
E-mail: rmccoy@u.washington.edu

CLASSIFIEDS: FACULTY POSITIONS

The *Journal* accepts appropriate classified advertisements from institutions and individuals. Advertisements are run at the following rate: $45.00 for 30 or fewer words, plus $0.75 for each additional word. Consecutively repeated ads are run at a flat rate of $50.00. The *Journal* neither investigates the offers being made, nor assumes any responsibility concerning them. The *Journal* reserves the right to edit copy and to accept, delete, or withdraw classified advertisements at its discretion. To ensure publication in a given issue, copy must be received by the first day of the month preceding the month of publication. In other words, copy should be received by the first of February, April, June, August, October, or December. Send advertisements to the editorial office identified inside the back cover.

INDIANA - Professor of Restorative Dentistry - Endowed Chair

Indiana University School of Dentistry is conducting a search for a faculty member to serve in a full-time, tenure-track position as the Indiana Dental Association Chair in Restorative Dentistry. This position is not that of the departmental administrative chair, but is instead a newly established honorary position endowed by, and named for, the Indiana Dental Association. The endowed chair connotes a level of funding and stature commensurate with excellence in teaching, clinical practice, and research. The Department of Restorative Dentistry includes the disciplines of Operative Dentistry, Fixed and Removable Prosthodontics, Endodontics, and Dental Materials. Qualifications for this position include a DDS/DMD degree from an ADA-accredited institution or equivalent. Advanced training in an area of Restorative Dentistry and/or a PhD degree in a related area would also be desirable. Candidates must be licensed to practice dentistry in the state of Indiana or eligible for such licensure. The successful candidate must have a national/international reputation as an exceptional clinician and/or researcher. Minimum of 10 years of clinical and/or research experience is required. 1 January 1997 is the deadline for application. Applicants should submit a letter of intent, curriculum vitae, and names of references to Dr George P Willis, Chair, Department of Restorative Dentistry, Indiana University School of Dentistry, 1121 West Michigan Street, Indianapolis, IN 46202. Indiana University is an Equal Opportunity/Affirmative Action employer.

WASHINGTON - Assistant Professor

University of Washington, Department of Restorative Dentistry seeks applicants for an assistant professor, tenure-track position. Responsibilities include research and undergraduate teaching in restorative dentistry, occlusion, and fixed prosthodontics. Applicants must have DDS or DMD and postgraduate training in prosthodontics or restorative dentistry. Send curriculum vitae with letters by 30 November 1996 to Virginia Powell, DMD, University of Washington, School of Dentistry, Department of Restorative Dentistry, Box 357456, Seattle, WA 98195-7456. The University of Washington is an Equal Opportunity/Affirmative Action employer.

Interested in Academy Information?

Check for information packet:
____Academy of Operative Dentistry (AOD)
____American Academy of Gold Foil Operators (AAGFO)

Moving Soon?

Please notify us promptly of any change in address.
Complete the form below and send it to: Operative Dentistry, University of Washington School of Dentistry, Box 357457, Seattle, WA 98195-7457 USA

NAME_____ EFFECTIVE DATE?_____

NEW ADDRESS_____ OLD ADDRESS_____

_____ _____

(CITY, STATE, ZIP)_____ (CITY, STATE, ZIP)_____

Interested in Subscribing to OPERATIVE DENTISTRY?

Please enter my subscription to OPERATIVE DENTISTRY at $55.00 per year (USA and Canada); $70.00 all other countries, in US funds only (international money orders accepted). Full remittance must accompany order. Make checks payable to Operative Dentistry.

Complete the form below and send it to: Operative Dentistry, University of Washington School of Dentistry, Box 357457, Seattle, WA 98195-7457 USA.

NAME_____

ADDRESS_____

_____

(CITY, STATE, ZIP)_____

INSTRUCTIONS TO CONTRIBUTORS

Correspondence

Send manuscripts and correspondence regarding manuscripts to the Editor, Richard B McCoy, at the editorial office: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

Exclusive Publication

It is assumed that all material submitted for publication is submitted exclusively to *Operative Dentistry*.

Manuscripts

Submit the original manuscript and one copy; authors should keep another copy for reference. Type double spaced, including references, and leave margins of at least 3 cm (1 inch). Supply a short title for running headlines and a FAX number for the corresponding author. Spelling should conform to *American Heritage Dictionary of the English Language*, 3rd ed, 1992. Nomenclature used in descriptive human anatomy should conform to *Nomina Anatomica*, 6th ed, 1989. The terms *canine* and *premolar* are preferred; the terms *vestibular*, *buccal*, *facial*, and *lingual* are all acceptable. SI (Système International) units are preferred for scientific measurement, but traditional units are acceptable. **Proprietary names of equipment, instruments, and materials should be followed in parentheses by the name and address, including ZIP code, of the source or manufacturer.** The editor reserves the right to make literary corrections. Research (original) papers must include a one-sentence **Clinical Relevance** statement, as well as **Summary**, **Introduction**, **Methods and Materials**, **Results**, **Discussion**, and **Conclusion** sections. Clinical papers should contain at least the following: **Purpose**, **Description of Technique** or **Solution** along with materials and potential problems, and a **Brief Summary** outlining advantages and disadvantages.

Authors who prepare their manuscripts on a word processor are to submit a computer disk of the manuscript (3½ - or 5¼-inch) in addition to the original typed manuscript. Identification of the operating system (Macintosh or IBM-compatible) and the word processing program used is necessary. Authors should also retain an additional manuscript copy on disk to facilitate altering the paper in response to comments by referees.

Illustrations

Submit four copies of each illustration. **Line drawings** should be in india ink or its equivalent on heavy white paper, card, or tracing vellum. All lettering must be of professional quality, be legible against its background, and remain proportionally legible if reduced. Type legends on separate sheets. **Graphs** are to be submitted with any lettering proportional to their size as indicated for illustrations, and with their horizontal and vertical axes values **as well as all values used to create the graphs**. **Photographs** should be on glossy paper with a maximum size of 15x20 cm (6x8 inches). For best reproduction a print should be one-third larger than its reproduced size. Only black-and-white photographs will normally be accepted. On the back of each illustration, near the edge, indicate lightly in pencil the top, the author's name, and the number of the figure. Where relevant, state staining technique(s) and the magnification of prints. Obtain written consent from holders of copyright to republish any illustrations published elsewhere.

Tables

Submit two copies of tables typed on sheets separate from the text. Number the tables with arabic numerals.

References

Arrange references in alphabetical order of the authors' names at the end of the article, the year of publication being placed in parentheses immediately after the author's name. Do not abbreviate titles of journals; write them out in full. Give full subject titles and first and last pages. In the text cite references by giving the author, and, in parentheses, the date: Smith (1975) found ...; or, by placing both name and date in parentheses: It was found ... (Smith & Brown, 1975; Jones, 1974). When an article cited has three authors, include the names of all of the authors the first time the article is cited; subsequently, use the form (Brown & others, 1975). Four or more authors should always be cited in the text thus: (Jones & others, 1975), but in the list of references list all the authors. If reference is made to more than one article by the same author and published in the same year, the articles should be identified by a letter (a, b) following the date, both in the text and in the list of references. Titles of books should be followed by the name of the place of publication and the name of the publisher.

Reprints

Reprints of any article, report, or letter can be ordered through the Seattle office.

SEPTEMBER-OCTOBER • VOLUME 21 • NUMBER 5 • 181-228

EDITORIAL

CLINICAL ARTICLE

ORIGINAL ARTICLES

DEPARTMENTS

10-9385
University of Washington
OPERATIVE DENTISTRY
Box 357457
Seattle, WA 98195-7457 USA

Periodicals