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EDITORIAL

The Panacea of Comprehensive Practice Groups

Dental school clinics continue to be under tremendous pressure to reduce costs while increasing productivity without decreasing the quality of care for patients and education for students. With treatment fees already established as high as is practical, schools are looking at how much available clinic time is actually being utilized by students. Surprisingly to some, the results showed that only 40% to 85% of available clinic time was actually utilized. At one school the results were blamed on lazy students. Poppycock! With the kind of tuition charged to attend any dental school, laziness isn't the issue. What is the issue is the *availability* and subsequent *management of patients*. At another institution the cry was for faculty and AEGD (advanced education in general dentistry) students to do the dentistry while undergraduate students watched and assisted. Again, this is an indication that the administrators had lost sight of the fact that students *must* work on patients to become competent dentists. Most recently, the emphasis is being placed on establishing comprehensive dentistry groups as the panacea for solving all problems. I am not aware of any dental school that does not already have the necessary departments to provide total patient care. So why the move towards something that dental schools already have? Administrators supporting these practice groups will fill the air with verbiage about how patients haven't received total comprehensive dental treatment because students only do what is necessary to complete their requirements, then forget the rest. Although these administrators won't admit it, the real reason is that they are convinced that by forming these groups, clinic income will dramatically increase. At one dental school an administrator came up with the idea of paying incentive money to faculty leaders of these comprehensive groups once the income produced by the group exceeded a certain dollar amount! It's clear that the administrator felt that increased clinic income was more important than the quality of clinical treatment provided to patients.

Many dental schools have already gone to the comprehensive group practice concept. Clinic income has increased at some schools, but at many other schools, the effort failed or is failing. Why? It doesn't take a rocket scientist to figure out that multiple groups of students require multiple support personnel and record-keeping centers. In other words, small comprehensive practice groups require *more* support, not less, if the concept is to succeed. Schools that have tried to form these practice groups fail because of the lack of insight into what is actually needed for the plan to succeed. For example, to assign a faculty director to a group of 15 students, each with 20 patients, on a part-time basis with one support staff person is pure folly. To even have a chance of success, the director's full-time duty must be the practice group, and he/she needs to be supported by at least two staff personnel assigned solely to the group and to have a cadre of supporting faculty from various departments ready, willing, and able to support the program. Another factor often overlooked by administrations is that to succeed with this plan, it is *imperative* that the faculty responsible for it as well as supporting departments are an integral part of the planning process. Dental school administrations tend to form committees of supportive faculty to approve administrative plans. Yet the majority of these committee members are often not the ones needed to make the plan work. Those dental schools that have come to the realization that to have a successful program requires that faculty most intimately involved *must* be the planners as well as the initiators are far ahead of those who are still floundering with the concept that everyone will eagerly support programs developed by administrators who plan but do not execute programs.

Dental school administrators may dream on about increasing clinic income by forming comprehensive group practices while decreasing clinic personnel, but departments within these schools become extremely resistant to these changes when it is obvious that adequate support is not part of the plan. Once dental school administrations are willing to provide comprehensive practice groups with the necessary additional support and agree to include the responsible clinical faculty in the planning process, then the results obtained by these groups have an excellent chance of becoming a successful reality. However, dental schools must be on guard against making income the dominant factor in developing clinic protocol, for if that happens, the quality of patient care and the education provided the students will surely suffer.

RICHARD B McCOY
Editor

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ORIGINAL ARTICLES

An in Vitro Shear Bond Strength Study of Enamel/Dentin Bonding Systems on Enamel

P E REIFEIS • M A COCHRAN • B K MOORE

Clinical Relevance
Bond strengths achieved by utilizing bonding systems with maleic, citric, or nitric acid as conditioners were not significantly different from those achieved when using conventional phosphoric acid etching.

SUMMARY

The purpose of this study was to compare the enamel shear bond strengths achieved with four acid conditioners employed by current enamel/dentin bonding systems (maleic acid, citric acid, nitric acid, oxalic acid) with a 37% phosphoric acid etching technique. The study also compared enamel shear bond strengths between the manufacturers' enamel/dentin conditioner used with an unfilled enamel bonding resin.

The facial surfaces of 135 bovine incisors were ground flat and divided into nine test groups of n = 15. Conditioning and bonding procedures were carried out following manufacturers' instructions. The phosphoric acid groups were etched for 15 seconds, rinsed for 30 seconds, and dried for 20 seconds with compressed air. All bonding was accomplished at a constant temperature of 21 °C and a relative humidity of 60%. A single composite restorative resin (Z-100) was used with all specimens to eliminate variables between composite materials. All specimens were thermocycled 2500 times (5 to 45 °C) and had a total storage time of 21 days prior to shear testing on an Instron at a crosshead speed of 1.0 mm/minute. Shear strengths were calculated by dividing load at failure by specimen area. A light microscope was used to determine failure mode. The data were subjected to Bartlett's test for homogeneity of variance and were found not to be homogeneous. The Welch Test was applied and indicated that the treatments used had influence on bond strength at $P < 0.05$. There was no significant difference in bond strength values between traditional phosphoric acid/enamel bonding resin and Mirage Bond Dentin and Enamel Adhesive, Clearfil Liner Bond System, and Scotchbond Multi-Purpose Dental Adhesive System.

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INTRODUCTION

Since the concept of modifying the enamel structure of teeth with acid was first introduced by Michael Buonocore in 1955, the acid-etch technique has become a standard procedure for surface preparation of enamel prior to composite resin restoration. Many types of acids were initially studied as possible etchants, but phosphoric acid systems displayed better bonding strengths and ease of use (Gwinnett & Buonocore, 1965). Low-viscosity enamel bonding agents composed of unfilled dimethacrylate or BIS-GMA readily flow into the

irregularities of etched enamel (Buonocore, Matsui & Gwinnett, 1968). Shear bond strengths of composite resins bonded to etched enamel surfaces are regularly reported in the range of 20 to 25 MPa (Legler & others, 1989).

Bonding to dentin has not been as easy to achieve. A loosely held smear layer exists that must be modified to accept resin attachment mechanisms or removed to allow adhesion directly to dentin (Joynt & others, 1991). Early dentin bonding systems have required many precise clinical steps to clean, condition, and prime the dentin to accept the adhesive resin. The enamel was then etched separately with 37% phosphoric acid, which was theoretically kept from the dentin due to the concerns regarding potential pulpal reactions. These early systems were clinically difficult and time consuming.

Most new dentin bonding systems effectively remove the smear layer and demineralize the surface of dentin. The acceptance of this procedure resulted from investigations revealing that limited acid exposure to dentin does not cause a significant pulpal response when subsequently treated with a compatible adhesive system (Cox, 1992). Recent dentin acid conditioners have included phosphoric acid, nitric acid, oxalic acid, maleic acid, and citric acid.

In an effort to simplify the dentin/enamel bonding procedures, manufacturers have combined the dentin conditioning and priming steps and most recently have begun directing that the dentin conditioner be used as an enamel etchant. The dentin bonding agent is applied to both dentin and enamel, thus eliminating the separate treatment of enamel and easing the demands at chairside. There is, however, some concern that the manufacturers are sacrificing enamel bond strength in their effort to simplify clinical application.

The purpose of this study was to determine the shear bond strength to enamel of four bonding systems now available to the marketplace that incorporate a conditioner that is recommended for both enamel and dentin. The study compared shear enamel bond strengths between the manufacturer's enamel/dentin conditioner and complete bonding system versus the manufacturer's enamel/dentin conditioner and an unfilled enamel bonding resin.

METHODS AND MATERIALS

A total of 135 bovine incisor teeth with roots removed were used in this study. The specimens were stored in deionized water except for preparation and testing. The facial surfaces were ground flat with 400-grit carbide paper mounted on a grinding wheel. The flattened surfaces of each specimen were centered flush horizontally in a cylindrical ring and embedded in a cold cure acrylic (Jet Acrylic, Long Dental, Wheeling, IL 60090). After curing, the specimens were cleaned and returned to the deionized water. Before the bonding procedure, the specimens were again ground slightly to assure a clean and fresh surface for bonding and to remove any acrylic from the enamel smear layer.

Fifteen specimens were randomly assigned to each of nine groups. The test groups are listed in Table 1. In Table 1, "system" indicates that the manufacturer provided all of the materials used for bonding. All systems except Gluma 2000 required a primer before application of the bonding agent. Mirage Bond had a primer supplied but allowed a bonding agent of choice. In the group labeled "enamel bond," the specimens were etched with the supplied conditioner, and then an unfilled resin bonding agent (Scotchbond Multi-Purpose, 3M Dental Products, St Paul, MN 55144) was applied and cured.

Bonding to the specimens of all groups was accomplished at a constant temperature of 21 °C and a constant relative humidity of 60%. The 37% phosphoric acid etchant (Ultra-Etch, Ultradent Products, Inc, South Jordan, UT 84065) in Group 1 was applied for 15 seconds, rinsed with water for 30 seconds, and dried for 20 seconds with compressed air. In all other groups, the application of the conditioner was accomplished according to the

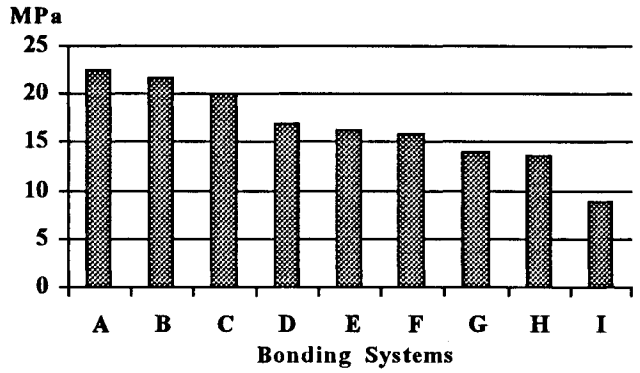
Table 1. Test Groups

Group	Etchant/Conditioner	Manufacturer	Bonding Agent
1	Ultra-etch (phosphoric acid)	Ultradent Products, South Jordan, UT 84065	enamel bond
2	Scotchbond Multi-Purpose (maleic acid)	3M Dental Products, St Paul, MN 55144	system
3	Clearfil Liner Bond System (citric acid)	Kuraray, Osaka, Japan	system
4	Mirage Bond System (nitric acid)	Chameleon Dental Products, Kansas City, KS 66101	
5	Gluma 2000 (oxalic acid)	Bayer Dental, Leverkusen, Germany	system
6	Scotchbond Multi-Purpose	3M	enamel bond
7	Liner Bond System	Kuraray	enamel bond
8	Mirage Bond	Chameleon	enamel bond
9	Gluma 2000	Bayer	enamel bond

Table 2. Newman-Keuls Multiple Comparisons

	Means	Std Dev
Liner Bond system	22.52	3.19
Mirage Bond system	21.66	3.87
phosphoric acid	19.98	5.24
Scotchbond Multi-Purpose enamel bond	16.93	3.61
Scotchbond Multi-Purpose system	16.34	4.93
Gluma 2000 enamel bond	15.92	4.37
Liner Bond enamel bond	14.04	3.98
Gluma 2000 system	13.64	2.97
Mirage Bond enamel bond	8.81	1.76

Means connected by vertical lines are not statistically different ($P < 0.05$).



Mean shear bond strengths. A = Liner Bond system; B = Mirage Bond system; C = PO_4 control; D = Scotchbond Multi-Purpose enamel bond; E = Scotchbond Multi-Purpose system; F = Gluma 2000 enamel bond; G = Liner Bond enamel bond; H = Gluma 2000 system; I = Mirage Bond enamel bond.

manufacturer's directions. After conditioning, each group received either the system agents supplied or the enamel bonding agent. The enamel bonding agent was light cured for 20 seconds. A Delrin ring mold 5 mm in diameter and 4 mm in height was placed against the specimen to receive the composite filling material (Restorative Z-100, 3M).

The composite material was placed and cured in three separate increments with 40 seconds of light exposure for each increment. The Delrin mold was then removed. After the curing procedure the specimens were placed in a humidor for 1 hour and then transferred to 37 °C deionized water. The specimens were then thermocycled 2500 times between 5 and 45 °C with a dwell time of 30 seconds and a transfer time of 10 seconds. After thermocycling the specimens were returned to the deionized water until testing. The total storage period before testing was 21 days.

Each specimen was attached to the stationary portion of an Instron Testing Machine (Instron Corp, Canton, MA 02021) and aligned so that the bonding surface was parallel to the line of travel of the machine. A knife-edge steel ring was placed over the specimen so that the shear force was directed at the bond surface. The specimens were loaded to failure at a crosshead speed of 1.0 mm per minute. Shear strengths were calculated by dividing load at failure by the specimen area. Using a light microscope, the site of failure was determined. The Newman-Keuls multiple comparisons are shown in Table 2.

RESULTS

The mean shear strengths for all groups are shown in Table 3 and illustrated graphically in the figure above. The data were subjected to Bartlett's test for homogeneity of variance, and the variances were found not to be homogeneous at the 0.10 level of significance. The Welch Test was applied to the data and indicated that the treatments used had influence on bond strength at $P < 0.05$.

As can be seen, Liner Bond System, Mirage Bond System, and phosphoric acid etch with enamel

Table 3. Mean Shear Strengths

	PO_4— control	SB MP system	LB system	MB system	Gluma system	SB MP enamel bond	LB enamel bond	MB enamel bond	Gluma enamel bond
Mean	19.98	16.34	22.52	21.66	13.64	16.93	14.04	8.81	15.92
Min	11.33	7.51	16.69	15.77	8.78	11.51	7.99	6.42	9.03
Max	32.16	23.51	29.15	27.90	19.30	23.80	19.61	13.54	24.67
Std Dev	5.24	4.93	3.19	3.87	2.97	3.61	3.98	1.76	4.37
%Cov	26.24	30.18	14.15	17.87	21.80	21.33	28.33	20.01	27.42

Mean, min, and max values are in MPa. Std Dev denotes Standard Deviation. %Cov denotes percent convergence of the data. PO_4 = phosphoric acid; SB MP = Scotchbond Multi-Purpose; LB = Liner Bond; MB = Mirage Bond.

Table 4. Manner of Specimen Failure

Group	Cohesive in Resin	Failure at Interface*	Cohesive in Enamel
1	0	15	0
2	0	15	0
3	0	12	3
4	0	15	0
5	0	15	0
6	0	14	1
7	0	15	0
8	0	15	0
9	0	15	0

*Failure at Interface" indicates that failure occurred cohesively in the bonding resin between composite and enamel.

bonding resin had the highest bond strengths, which were not statistically different from each other. On the other hand, Mirage Bond using conditioner only and enamel bonding resin had the lowest bond strength and was significantly different from the other eight groups tested.

Comparing the system with the same conditioners and primers used with enamel bonding resin, Liner Bond and Mirage Bond systems were significantly stronger than when used with enamel bonding resin only. The values for Scotch Bond Multi-Purpose were essentially the same, and Gluma 2000 exhibited a lower bond strength when used as a system compared with its use with enamel bonding resin. However, this difference was not statistically significant.

The manner of specimen failure is shown in Table 4.

DISCUSSION

The 37% phosphoric acid control group was found to have bond strengths (19.98 MPa) similiar to the results of other research (Legler & others, 1989).

The Gluma Bonding System (Bayer Dental, Leverkusen, Germany) was developed by Munksgaard and Asmussen in 1984. Their most recent formulation of etchant/conditioner (Gluma 2000) consists of oxalic acid and aluminum nitrate buffered with the amino acid glycine.

Gluma 2000 was the only system in this study to exhibit significantly lower bond strength values than the phosphoric acid control group. de Araujo and Asmussen (1989), who used Gluma, reported similar enamel shear bond strengths between 12 and 15 MPa and phosphoric acid-etched bond strengths close to 20 MPa. When an enamel bonding agent was substituted for Solution 2 in the Gluma 2000 system, the mean bond strength compared to the system increased, although not significantly. This increase in bond strength with enamel bond was not significantly different from the phosphoric acid control.

Scotchbond Multi-Purpose (3M) employs maleic acid in the conditioner. Recently, Duke, Conn, and Lane (1992) concluded that shear bond strengths after etching enamel with maleic acid were comparable across a range of 8% to 15% acid concentrations. However, these results were 5 MPa less than those obtained using a phosphoric acid control. Some researchers have been concerned about lower enamel bond strengths when 10% maleic acid is used as an etchant/conditioner (Swift & Cloe, 1993; Triolo, Mudgil & Levine, 1993). Other investigators have found that a maleic acid system provides bonding equivalent to a phosphoric acid system (Aasen & Ario, 1993). Although lower in mean strength, the Scotchbond Multi-Purpose system bond strength in this research was found not to be significantly different from that obtained with phosphoric acid. In Group 6, the Scotchbond Primer was omitted, but strength values were nearly identical to those with the Multi-Purpose system. The manufacturer states in the instructions that the primer is not necessary if bonding is solely to enamel. This study supports the manufacturer's claim that the primer does not impact the enamel bond strength in any significant way. The HEMA-containing primer increases the wetting ability of the bonding agent on the tooth surface. This action is apparently unimportant when bonding to maleic acid-etched enamel.

The Mirage Bond System utilizes a solution of nitric acid and NPG (n-phenylglycine) to etch both the enamel and dentin. A primer of pyromellitic diethylmethacrylate (PMGDM) copolymerizes with the resin composite. Berry and others (1990) and Saunders, Strang, and Ahmad (1991) independently concluded that shear bond strengths to enamel using the 2.5% HN03-NPG etchant were not significantly different from bond strengths obtained using phosphoric acid.

Similarly, in this study, Mirage Bond system bond strengths to enamel were found to be comparable to bond strengths obtained from phosphoric acid-etched enamel. However, after conditioning the enamel with the system HNO_3-NPG etchant and applying only enamel bonding resin, bond strengths dropped dramatically. This result is probably due to the chemical components of the Mirage Bond conditioner and Part 2 resin (PMGDM). The conditioner (2.5% HNO_3 and 4% NPG) is agitated on the tooth surface for 60 seconds and then dried with air to produce a frosty appearance. The surface is not rinsed with water as in other systems. The manufacturer states that the NPG component of the conditioner is a surface-activating agent that initiates the polymerization of the Part 2 PMGDM

resin. The PMGDM polymerizes when placed in contact with the NPG surface as its acetone carrier evaporates. When the PMGDM resin is eliminated in Group 8, the enamel bonding resin probably does not bond adequately to the NPG enamel surface, and the result is lower bond strength values. It is not known whether this inadequate bond is due to an actual interference of the NPG with the enamel bond adhesion or due to a more thorough polymerization reaction between the NPG surface and the PMGDM resin. In either case, the decrease in bond strength is very significant in the absence of the system resin. The manufacturer indicates that 37% phosphoric acid should be used if the conditioner does not cause a slight frosted appearance. It is important to note that the Mirage Bond conditioner must then be reapplied for 15 seconds and dried in order to re-establish the NPG surface.

Citric acid has been introduced as an enamel/dentin conditioner by Kuraray in its Clearfil Liner Bond System. The conditioner is a combination of 10% citric acid and 20% calcium chloride. Citric acid has previously been studied as an etchant for enamel, but bond strengths were reported significantly lower than those obtained with phosphoric acid. Retief and others (1986) stated that citric acid is not a viable alternative to phosphoric acid, because they observed the etching pattern to be milder than that obtained with phosphoric acid. The primer contains a salicylic derivative monomer (5-NMSA) that combines with the conditioner to enhance the bond strength of the bonding agent. Liner Bond tensile bond strengths of approximately 16 MPa have been reported (Fujitani, Hosoda & Yamauchi, 1991). In this study, enamel bond strengths using the Clearfil Liner Bond System were not significantly different than those obtained using phosphoric acid etch and enamel bond adhesive. As in the case of Mirage Bond, however, the bond strength values declined when the Liner Bond etchant/conditioner was followed by enamel bonding resin only. There has been some concern about the high calcium concentration in Liner Bond. The calcium component may stabilize collagen during dentin etching but may also decrease the demineralization effect of hydroxyapatite by a common ion effect (Pashley, Horner & Brewer, 1992). However, the primer probably neutralizes this effect of the calcium and allows the bonding agent, an adhesive phosphate monomer, to penetrate deeper into the etched surface. The result is an adequate bond to the etched enamel.

CONCLUSIONS

The following conclusions may be drawn from the data obtained in this study:

1. When using Liner Bond System and Mirage Bond, the manufacturer's materials and directions should be strictly applied in order to obtain the best bonding strength. Substitution or omission of part of the system will likely result in significantly decreased bond strengths.
2. Scotchbond Multi-Purpose system primer may be safely omitted when bonding only to enamel.
3. Gluma system bond strengths were found to be significantly lower in value than phosphoric acid-etched enamel followed by enamel bonding resin. The oxalic acid-based system appears to sacrifice enamel bond strength in an attempt to increase dentin bond strength and ease of delivery.
4. There is no significant difference in bond strength values between traditional phosphoric acid/enamel bonding resin and each of the following systems: Mirage Bond Dentin and Enamel Adhesive, Clearfil Liner Bond System, and Scotchbond Multi-Purpose Dental Adhesive System.

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References

AASEN SM & ARIO PD (1993) Bonding systems: a comparison of maleic and phosphoric acids *Journal of Dental Research* **72** *Abstracts of Papers* p 137 Abstract 269.

BERRY TG, BARGHI N, KNIGHT GT & CONN LJ (1990) Effectiveness of nitric-NPG as a conditioning agent for enamel *American Journal of Dentistry* **3** 59-62.

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

BUONOCORE MG, MATSUI A & GWINNETT AJ (1968) Penetration of resin dental materials into enamel surfaces with reference to bonding *Archives of Oral Biology* **13** 61-70.

COX CF (1992) Effects of adhesive resins and various dental cements on the pulp *Operative Dentistry* **Supplement 5** 165-176.

de ARAUJO PA & ASMUSSEN E (1989) Aluminum oxalate/glycine solutions as pretreatment in the Gluma bonding system *Scandinavian Journal of Dental Research* **97** 552-558.

DUKE ES, CONN LJ & LANE LD (1992) Maleic acid conditioning of enamel for resin adhesive *Journal of Dental Research* **71** 655 (Abstract).

FUJITANI M, HOSODA H & YAMAUCHI J (1992) Advanced bonding system using salicylic acid derivative and phosphate monomers *Journal of Dental Research* **71** *Abstracts of Papers* p 667 Abstract 1211.

GWINNETT AJ & BUONOCORE MG (1965) Adhesives and caries prevention *British Dental Journal* **119** 77-80.

JOYNT RB, DAVIS EL, WIECZKOWSKI G Jr & YU XY (1991) Dentin bonding agents and the smear layer *Operative Dentistry* **16** 186-191.

LEGLER LR, RETIEF DH, BRADLEY EL, DENYS FR & SADOWSKY PL (1989) Effects of phosphoric acid concentration and etch duration on the shear bond strength of an orthodontic bonding resin to enamel: an in vitro study *American Journal of Orthodontics and Dentofacial Orthopedics* **96** 485-492.

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.

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

RETIEF DH, BUSSCHER HJ, de BOER P, JONGEBLOED WL & ARENDS JA (1986) A laboratory evaluation of three etching solutions *Dental Materials* **2** 202-206.

SAUNDERS WP, STRANG R & AHMAD I (1991) Shear bond strength of Mirage Bond to enamel and dentin *American Journal of Dentistry* **4** 265-267.

SWIFT EJ Jr & CLOE BC (1993) Shear bond strengths of new enamel etchants *American Journal of Dentistry* **6** 162-164.

TRIOLO P, MUDGIL A & LEVINE A (1993) A comparison of bond strengths of Scotchbond Multi-Purpose with alternative etchants *Journal of Dental Research* **72** *Abstracts of Papers* p 134 Abstract 242.

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The Effect of Amalgam Surface Preparation on the Shear Bond Strength between Composite and Amalgam

N D RUSE • R T SEKIMOTO • D FEDUIK

Clinical Relevance
Shear bond strength was enhanced by sandblasting the amalgam surface prior to bonding.

SUMMARY

The aim of this study was to investigate the effect of amalgam surface preparation on the short- and long-term in vitro shear bond strength between a dental amalgam (Valiant) and two dental composites (Herculite, Z100) mediated by three universal bonding agents (All-Bond 2, Amalgambond, and Scotchbond Multi-Purpose). Cylinders of dental composite resin were formed on, and bonded to, flat amalgam surfaces. Prior to bonding, the amalgam surfaces were: a) ground flat, with the grinding lines oriented parallel to the direction of the shear stress; b) ground flat, with the grinding lines oriented perpendicular to the direction of the shear stress; or c) ground flat and then sandblasted using 50 μm Al_2O_3. A computerized Universal Testing Machine was used to determine the 1-, 7-, and 30-day shear bond strength of 162 samples (six per group) that were stored in distilled water at 37 °C. The results, which were statistically analyzed by performing a three-way analysis of variance (ANOVA) and 27 one-way ANOVA followed by modified (Bonferroni) *t*-tests for between-group comparisons ($\alpha = 0.05$), have shown that: 1) sandblasting resulted in higher shear bond strength than grinding, except for 1-day All-Bond 2, where no differences were identified; 2) there was no difference in the shear bond strength between samples with parallel or perpendicular ground surfaces for a given bonding system and storage time; 3) for All-Bond 2, the 7-day shear bond strength of parallel and perpendicular ground samples dropped to half of the 1-day values, while the sandblasted samples showed a constant, high shear bond strength over 30 days, 4) for Amalgambond, the shear bond strength of parallel, perpendicular, and sandblasted samples was constant over 30 days; and 5) for Scotchbond Multi-Purpose, a sharp drop in the 7-day shear bond strength was recorded for all the samples, irrespective of amalgam surface preparation.

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INTRODUCTION

Combined amalgam-composite resin restorations have been advocated to mask the unaesthetic appearance of amalgam restorations and to overcome difficulties associated with the composite restorations of large posterior class 2 cavities (Durnan, 1971; Barkmeier & Cooley, 1979; Zalkind & others,

1981; Anglis & Fine, 1982). Reducing the surface area of exposed amalgam may also result in a decrease in the mercury released into the oral cavity.

Grooves and undercuts (Anglis & Fine, 1982; Pollack & Blitzer, 1983) associated with pins (Gordon, Laufer & Metzger, 1985; Lambert, Scrabeck & Robinson, 1983) have been used to provide mechanical retention for composite resin veneers. Enamel/dentin bonding agents have also been used to mediate the bond between composite resins and amalgams (Zalkind & others, 1981; Cardash & others, 1990). Today there are several bonding systems on the market that claim to provide a strong and long-lasting attachment between composite resins and set amalgams. Their effectiveness has been assessed by in vitro shear bond strength tests (Cooley, McCourt & Train, 1989; Cooley, Burger & Chain, 1991a; Cooley, Tseng & Barkmeier, 1991b; Hadavi & others, 1991c; Hadavi, Hey & Ambrose, 1991b; Chang & others, 1992; Watts, Devlin & Fletcher, 1992) and microleakage studies (Kossa, 1987; Maroney & others, 1988; Cardash & others, 1990; Cooley & others, 1991b; Hadavi, Hey & Ambrose, 1991a; Hadavi & others, 1993). Several reports of short- and long-term clinical results have also been published (Gordon & others, 1985; Roda & Zwicker, 1992; Plasmans & Reukers, 1993). It has been postulated that both chemical and mechanical interaction mechanisms play important roles in producing an adequate attachment and, consequently, the amalgam surface morphology and chemistry would greatly influence the attachment of composites. Increased bond strength due to a diamond stone finishing of the amalgam surface prior to the application of the bonding agent has been reported (Cooley & others, 1989). The aim of this study was to assess the effect of amalgam surface preparation on the 1-, 7-, and 30-day in vitro shear bond strength between amalgam and composite resins mediated by three universal bonding agents.

METHODS AND MATERIALS

A spherical, high-copper dental amalgam, Valiant (L D Caulk/Dentsply, Milford, DE 19963), two composite resins, Herculite XR (Sybron/Kerr, Romulus, MI 48174), Z100 (3M Dental Products, St Paul, MN 55144), and three bonding agents, All-Bond 2 (Bisco, Inc, Itasca, IL 60143), Amalgambond (Parkell, Farmingdale, NY 11735), and Scotchbond Multi-Purpose (3M) were used in this study. A total of 162 samples, divided into 27 groups according to the experimental design summarized in Table 1, were made.

The amalgam was triturated, according to the manufacturer's recommendations regarding speed and time, and then condensed with a hand condenser into a round (5 mm in diameter) undercut cavity prepared in a plexiglass block. Condensed amalgams were allowed to age 24 hours under room environment conditions. Three surface preparation procedures were used to prepare amalgam surfaces for bonding: a) grinding flat with 600-grit silicon carbide (SiC) grinding paper on a water-irrigated grinding wheel (Buehler Ltd, Evanston, IL 60204) to produce grooves aligned parallel to the direction of the shearing stress; b) grinding flat with 600-grit SiC grinding paper on a water-irrigated grinding wheel to produce grooves aligned perpendicular to the direction of the shearing stress; and c) grinding flat with 600-grit SiC grinding paper on a water-irrigated grinding wheel, rinsing, drying, and sandblasting (Micro Etcher Model er/erc, Danville Engineering, Inc, San Ramon, CA 94583) with 50 μm Al_2O_3 for 10 seconds at an air pressure of 0.6 MPa. The sandblasting procedure closely reproduced the one recommended for intraoral usage. Prepared surfaces were then rinsed with distilled water and dried with compressed air. Amalgam surfaces were prepared one at a time immediately before the bonding procedure. The manufacturer's instructions for each bonding system were followed to attach composites to prepared amalgam surfaces. The protocols are summarized below.

All-Bond 2/Herculite XR: Primers A and B were mixed, the mixture was applied in two thin coats, and dried for 5-6 seconds. The sample was placed in a mounting jig, and the lid, carrying a polyvinyl siloxane diaphragm lined with a gelatin cylinder, cut from a #4 gelatin capsule (internal diameter 4.22 mm), was placed over the flattened area of the

Table 1. Experimental Design

Composite	Bonding Agent	Amalgam Surface Preparation								
		parallel			perpendicular			sandblasted		
	Days	1	7	30	1	7	30	1	7	30
Herculite XR	All-Bond 2	6	6	6	6	6	6	6	6	6
Herculite XR	Amalgambond	6	6	6	6	6	6	6	6	6
Z100	Scotchbond Multi-Purpose	6	6	6	6	6	6	6	6	6

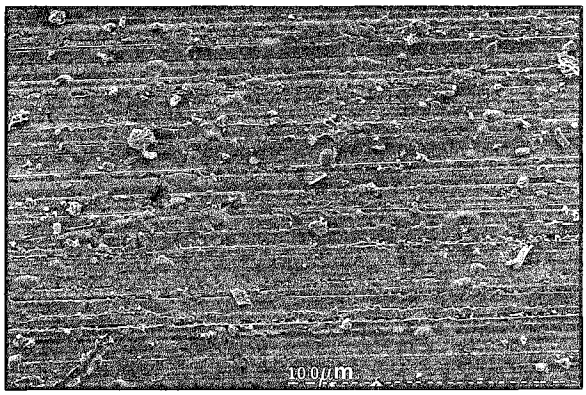

Figure 1. *Ground amalgam surface using 600-grit SiC paper: grinding grooves, which were oriented either parallel or perpendicular to the shearing stress, are evident.*

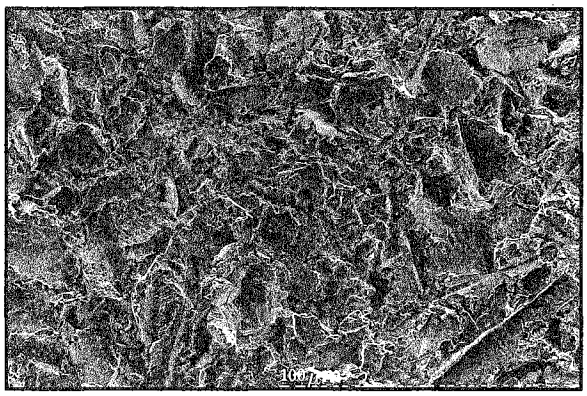

Figure 2. *Sandblasted amalgam surface showing a rough, increased surface area*

amalgam surface. All-Bond Dual Cure Opaquer Base and Catalyst were mixed and applied in a thin layer onto the primed amalgam surface. The opaquer was light cured for 10 seconds. A thin layer of Dentin/Enamel Bonding Resin was brushed over the opaquer and light cured for 20 seconds. Herculite XR composite was packed into the lined diaphragm and light cured for 30 seconds, in accordance with the manufacturer's instructions for the approximately 2 mm-thick composite used. The lid and the diaphragm were carefully removed and the composite was light cured for an additional 50 seconds.

Amalgambond/Herculite XR: A thin film of adhesive agent was brushed onto the amalgam surface and left undisturbed for 30 seconds before being thinned with a gentle stream of air; the sample was then placed in a mounting jig (as for All-Bond, see above). Two drops Amalgambond Base and one drop Amalgambond Catalyst were mixed, brushed in a thin layer over the primed amalgam, and thinned with a gentle stream of air. Herculite XR composite was packed and double light cured, as for All-Bond 2.

Scotchbond Multi-Purpose/Z100: The amalgam surface was etched for 15 seconds with the Scotchbond Multi-Purpose etchant gel. The surface was rinsed and dried; Scotchbond Multi-Purpose Primer was applied to the etched amalgam surface and dried with a gentle stream of air. The sample was placed in a mounting jig (as for All-Bond, see above). A thin layer of Scotchbond Multi-Purpose Adhesive was applied and light cured for 10 seconds; Z100 composite was packed and double light cured, as for All-Bond 2.

Composite cylinders with a constant contact area of 14 mm^2 between the composite and the amalgam were thus obtained. Samples were stored in distilled water at 37 °C for 1, 7, and 30 days prior to being tested.

For the shear bond strength tests, the samples were placed in the brass jig so that the composite cylinder was always aligned at 90° to the vertical plane. The jig was placed on the platen of a Universal Testing Machine (Instron, Model 4301, Canton, MA 02021) and positioned so that the shearing blade contacted the composite cylinder at the amalgam-composite interface. A 500 kg reversible load cell was used with a crosshead speed of 5 mm/min. The specimens were tested to failure and the results recorded in MPa. A three-way analysis of variance (ANOVA) and 27 one-way ANOVA followed by modified (Bonferroni) *t*-tests for between-group comparisons ($\alpha = 0.05$) were performed to analyze the results of the shear bond strength tests.

Ground (Figure 1) and sandblasted (Figure 2) amalgam surfaces, as well as selected fractured surfaces, were obtained using a scanning electron microscope (SEM), and representative low- and high-magnification micrographs were made of these surfaces.

RESULTS

The three-way ANOVA has identified significant effects ($P < 0.05$) for the three main categories investigated, i e, bonding system, surface, and time. The results of the shear bond strength tests and the statistical analysis are summarized in Table 2. Horizontal and vertical brackets join results that are not significantly different ($P < 0.05$). Horizontal brackets summarize the results of statistical analyses between samples of the same age with different surface preparations; vertical brackets on the left-hand side of the columns summarize the results of within-group statistical analyses for the same amalgam surface preparation; vertical brackets on the right-hand side of the columns summarize the results of between-groups statistical analyses for similar time intervals. The statistical analysis of the results showed that:

(1) There was no significant difference between the shear bond strength of parallel and perpendicular

*Table 2. Shear Bond Strength (in MPa +- SD)**

Bonding System	Age	Parallel	Perpendicular	Sandblasted
All-Bond 2/Herculite XR	1 day	5.61 ± 1.59	5.65 ± 1.54	8.06 ± 3.13
	7 days	2.38 ± 1.48	2.50 ± 0.81	10.41 ± 1.71
	30 days	2.55 ± 0.85	3.65 ± 0.80	8.91 ± 2.47
Amalgambond/Herculite XR	1 day	1.02 ± 0.84	2.26 ± 0.73	7.62 ± 2.43
	7 days	2.80 ± 1.32	3.15 ± 0.43	9.22 ± 1.41
	30 days	2.52 ± 0.66	3.15 ± 0.46	7.83 ± 1.35
Scotchbond Multi-Purpose/ Z100	1 day	4.13 ± 2.23	6.20 ± 1.50	13.37 ± 2.68
	7 days	1.28 ± 0.43	1.04 ± 0.47	5.64 ± 0.62
	30 days	0.31 ± 0.18	0.32 ± 0.21	5.47 ± 1.10

*Horizontal and vertical brackets join results that are not statistically significantly different. Horizontal brackets summarize the results of statistical analysis between samples with different surface preparations; vertical brackets on the left-hand side of the columns summarize the results of within-group statistical analyses; vertical brackets on the right-hand side of the columns summarize the results of between-groups statistical analyses.

ground surfaces at any given storage time (Table 2, horizontal brackets);

(2) For the All-Bond 2 group, there was no significant difference between the 1-day shear bond strength, irrespective of surface preparation; at 7 and 30 days, however, the sandblasted samples showed significantly higher shear bond strength than the parallel and perpendicular ground samples (Table 2, horizontal brackets);

(3) For the Amalgambond and Scotchbond Multi-Purpose groups, the sandblasted samples showed significantly higher shear bond strength than the parallel and perpendicular ground samples at all storage times;

(4) For the parallel ground samples, the 1-day shear bond strengths were significantly different (higher for All-Bond and Scotchbond Multi-Purpose, and lower for Amalgambond) than the 7- and 30-day shear bond strengths, which were not different from one another (Table 2, parallel, left vertical brackets);

(5) For the All-Bond and Scotchbond Multi-Purpose perpendicular ground samples, the 1-day shear bond strengths were significantly higher than the 7- and 30-day shear bond strengths, which were not different from one another; no differences were identified in the Amalgambond samples (Table 2, perpendicular, left vertical brackets);

(6) For the All-Bond 2 and Amalgambond sandblasted samples, there was no significant difference between the 1-, 7-, and 30-day shear bond strengths; for the Scotchbond Multi-Purpose sandblasted samples, the 1-day shear bond strength was significantly higher than the 7- and 30-day shear bond strengths, which were not different from one another (Table 2, sandblasted, left vertical brackets); and

(7) The 1-day shear bond strength of the sandblasted Scotchbond Multi-Purpose was significantly higher than that of the sandblasted All-Bond and Amalgambond; however, at 7 days, the shear bond strength of sandblasted Scotchbond Multi-Purpose was significantly lower than that of All-Bond and Amalgambond (Table 2, sandblasted, right vertical brackets).

DISCUSSION

The shear bond strength results between composite and set amalgam obtained in this study, ranging between 6 and 13 MPa, compare well with those reported by Cooley and others (1989, 4 to 7 MPa), Hadavi and others (1991b, 4 MPa), and Watts and others (1992, 5 to 16 MPa). They are similar in magnitude with the shear bond strengths of repaired amalgam with Amalgambond (11 MPa, Chang & others, 1992; 7 MPa, Hadavi & others 1991c).

The success of many dental procedures that involve the attachment between dental materials and hard tooth tissues or between different dental materials is dictated by the performance of the adhesive used and the adhesive interfaces created. The surface

properties of the adherent, i e, its surface chemical composition and morphology, are critical to the success of the adhesive interface. Surface chemistry is responsible for the initial interaction and for the long-term performance via possible chemical bonding. Surface morphology can affect attachment by improving the initial interaction, by offering an increased surface area, and by facilitating mechanical interlocking of the adhesive. The results of this study showed that sandblasting of amalgam surfaces prior to composite bonding leads to an improved attachment as compared with parallel or perpendicular grinding. Sandblasted amalgam surfaces (Figure 2) have a higher surface area than ground surfaces (Figure 1), which could be responsible for the higher shear bond strengths but cannot explain the different long-term behaviors. The results showed that, with the exception of Scotchbond Multi-Purpose, the sandblasted samples retained their original, high 1-day bond strengths. The sandblasted Scotchbond Multi-Purpose samples showed a halving in their shear bond strength after 7 days' storage in water. This might indicate a higher susceptibility of the Scotchbond Multi-Purpose adhesive system to water exposure, a possibility supported by the dramatic decrease in shear bond strength for all three Scotchbond Multi-Purpose groups at 7 days. The results suggest that sandblasting facilitates an interlocking attachment and impedes, or at least postpones significantly, the penetration of water to the adhesive interface. It is also possible that, as postulated by Roeder, DeSchepper, and Powers (1991), based on the findings of Eliades, Tzoutzas, and Vougiouklakis (1991), changes in the surface chemistry of amalgam as a result of sandblasting (loss of Cu_6Sn_5—the η phase) could have affected its interaction with the bonding systems investigated.

In the case of parallel and perpendicular ground All-Bond 2 and Scotchbond Multi-Purpose samples, a decrease in shear bond strength was detected after 7 days' storage in water, a decrease which suggests a degradation of the adhesive and/or of the adhesive interface as a result of exposure to water.

With the exception of the parallel ground 1-day value, which was significantly lower, no other differences were detected in the corresponding Amalgambond samples. The results obtained for the ground amalgam samples, probably due to differences in the amalgam surface preparation for bonding and the type of amalgam used, are slightly higher that those reported by Chang and others (1992) for Dispersalloy (1.6 MPa). The bond strengths of the Amalgambond samples, as determined in this study, did not decrease over the 30 days' exposure to water, suggesting the presence of a hydrolytically stable bond between amalgam and Amalgambond. The increase in microleakage in class 5 cavities restored with Amalgambond-bonded amalgam reported by Saiku, St Germain, and Meiers (1993), suggests that the tooth-Amalgambond interaction is sensitive to hydrolysis. The postulated interaction mechanism of Amalgambond, and of 4-META-based bonding agents in general, involves the attachment to the substrate via hydrophilic carboxylate groups and the exposure of a hydrophobic moiety able to interact with the composite. Thermocycling may have been responsible for the hydrolytic degradation of the tooth-Amalgambond bond and the increased microleakage detected by Saiku and others (1993).

Although 30 days is a relatively short period of time, the magnitude and the constancy of the shear bond strengths determined for the sandblasted samples for two of the bonding systems suggest that combined amalgam-composite restorations may be a viable clinical procedure. However, longer-term studies on the effect of thermocycling and cyclic loading should be conducted before full clinical recommendations could be safely made.

CONCLUSIONS

Under the conditions of this investigation, the shear bond strength between composite resins and a spherical, high-copper dental amalgam was significantly enhanced by a 10-second sandblasting of the amalgam surface with 50 μm Al_2O_3 and an air pressure of 0.6 MPa prior to bonding.

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References

ANGLIS LF & FINE L (1982) The amalgam-composite resin restoration *Journal of Prosthetic Dentistry* **47** 685.

BARKMEIER WW & COOLEY RL (1979) Amalgam restoration with a composite resin window *Quintessence International* **10** 31-34.

CARDASH HS, BICHACHO N, IMBER S & LIBERMAN R (1990) A combined amalgam and composite resin restoration *Journal of Prosthetic Dentistry* **63** 502-505.

CHANG J, SCHERER W, TAUK A & MARTINI R (1992) Shear bond strength of a 4-META adhesive system *Journal of Prosthetic Dentistry* **67** 42-45.

COOLEY RL, BURGER KM & CHAIN MC (1991a) Evaluation of a 4-META adhesive cement *Journal of Esthetic Dentistry* **3** 7-10.

COOLEY RL, McCOURT JW & TRAIN TE (1989) Bond strength of resin to amalgam as affected by surface finish *Quintessence International* **20** 237-239.

COOLEY RL, TSENG EY & BARKMEIER WW (1991b) Dentinal bond strengths and microleakage of a 4-META adhesive to amalgam and composite resin *Quintessence International* **22** 979-983.

DURNAN JR (1971) Esthetic dental amalgam-composite resin restorations for posterior teeth *Journal of Prosthetic Dentistry* **25** 175-176.

ELIADES GC, TZOUTZAS JG & VOUGIOUKLAKIS GJ (1991) Surface alterations on dental restorative materials subjected to an air-powder abrasive instrument *Journal of Prosthetic Dentistry* **65** 27-33.

GORDON M, LAUFER B-Z & METZGER Z (1985) Composite-veneered amalgam restorations *Journal of Prosthetic Dentistry* **54** 759-762.

HADAVI F, HEY JH & AMBROSE ER (1991a) Assessing microleakage at the junction between amalgam and composite resin: a new method in vitro *Operative Dentistry* **16** 6-12.

HADAVI F, HEY JH & AMBROSE ER (1991b) Shear bond strength of composite resin to amalgam: an experiment in vitro using different bonding systems *Operative Dentistry* **16** 2-5.

HADAVI F, HEY JH, AMBROSE ER & ELBADRAWY HE (1991c) The influence of an adhesive system on shear bond strength of repaired high-copper amalgams *Operative Dentistry* **16** 175-180.

HADAVI F, HEY JH, AMBROSE ER & ELBADRAWY HE (1993) Effect of different adhesive systems on microleakage at the amalgam/composite resin interface *Operative Dentistry* **18** 2-7.

KOSSA AP (1987) Microleakage in a hybrid amalgam-composite restoration *General Dentistry* **35** 289-291.

LAMBERT RL, SCRABECK JG & ROBINSON FB (1983) Esthetic composite resin facings for amalgam restorations *General Dentistry* **31** 222-224.

MARONEY WF, BLANK LW, HARGRAVE JW & PELLEU GB Jr (1988) Microleakage at the etched-amalgam/composite resin interface of etched-metal resin-bonded retainers *General Dentistry* **36** 18-19.

PLASMANS PJJM & REUKERS EAJ (1993) Esthetic veneering of amalgam restorations with composite resin—combining the best of both worlds? *Operative Dentistry* **18** 66-71.

POLLACK BF & BLITZER MH (1983) Esthetic veneering: Materials and techniques *General Dentistry* **31** 483-488.

RODA RS & ZWICKER PF (1992) The combined composite resin and amalgam restoration for posterior teeth: a clinical report *Quintessence International* **23** 9-13.

ROEDER LB, DeSCHEPPER EJ & POWERS JM (1991) *In vitro* bond strength of repaired amalgam with adhesive bonding systems *Journal of Esthetic Dentistry* **3** 126-132.

SAIKU JM, ST GERMAIN HA Jr & MEIERS JC (1993) Microleakage of a dental amalgam alloy bonding agent *Operative Dentistry* **18** 172-178.

WATTS DC, DEVLIN H & FLETCHER JF (1992) Bonding characteristics of a phosphonated anaerobic adhesive to amalgam *Journal of Dentistry* **20** 245-249.

ZALKIND M, REHANY A, REVAH A & STERN N (1981) A composite resin bonded to dental materials *Journal of Prosthetic Dentistry* **46** 300-303.

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Bond Strength of Composite to Air-abraded Enamel and Dentin

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C YOU • J M POWERS

Clinical Relevance
Air abrasion does not eliminate the need for acid etching enamel and priming dentin.

SUMMARY

Human enamel and dentin were prepared with an air abrasion unit (KCP-2000), using two particle sizes (27 μm and 50 μm) of aluminum oxide. In vitro tensile bond strengths of a composite resin were determined after three enamel and three dentin surface treatments. Enamel treatments were: air abraded only, E-1; air abraded + adhesive, E-2; air abraded + acid etch + adhesive, E-3. Dentin surface treatments were air abraded only, D-1; air abraded + adhesive/no primer, D-2; air abraded + primer + adhesive, D-3. Etched enamel and dentin prepared with 600-grit SiC paper and adhesive served as controls. There were 10 replications for each condition. A dentin bonding system (Optibond) and a composite resin (Herculite XRV) were bonded to treated surfaces by light curing in an inverted, truncated cone die with a bond diameter of 3 mm. Samples were stored at 37 °C and 100% relative humidity for 24 hours and debonded in tension using a Universal Testing Machine at a 0.05 cm/min crosshead speed. Based on analysis of variance, there was no statistical difference between 27 μm and 50 μm aluminum oxide abrasive for both enamel and dentin. For enamel bond strengths, E-2 was significantly higher than E-1, and E-3 was significantly higher than E-1 and E-2. E-1 and E-2 were significantly lower than the control, while E-3 was not significantly different from the control ($P \leq 0.05$).

For dentin bond strengths, D-2 was significantly higher than D-1, and D-3 was significantly higher than D-1 and D-2. All treatments except D-3 were significantly lower than the control ($P \leq 0.05$). Air-abrasion treatment of enamel and dentin alone resulted in reduced in vitro bond strengths as compared to etched enamel and dentin prepared with dentin adhesive and dentin primer.

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INTRODUCTION

Dr Robert B Black (1945) reported on the airbrasive technique for nonmechanical cavity preparation. Kinetic energy, generated by a high-velocity stream of aluminum oxide particles, was utilized to prepare hard tissue (dentin and enamel) while having little effect on softer materials like gingival tissues.

The airbrasive technique was developed in response to the need to increase patient comfort by reducing pressure, heat, vibration, and noise during the mechanical preparation of teeth with a rotating bur. Restorative materials at that time were limited to amalgam, direct and indirect gold, and silicate cement. Cavity preparation designs required sharp line angles, flat floors, and smooth cavity walls, and airbrasive preparations had to be finished with rotary and hand instrumentation. Although only 50 to 80% of the cutting on a given preparation could be accomplished with the airbrasive unit, patient acceptance was high. In 1954, Dr Black (Black, 1955) re-evaluated the airbrasive technique for cavity preparation and tested the Airdent unit, introduced in 1951. Over 2000 dentists had, by that time, acquired experience in the airbrasive technique. It had proven a valuable adjunct for cavity preparation and prophylaxis, but still required supplementary mechanical instrumentation. Goldberg (1952) reported that of 1141 patients surveyed, 92% preferred the airbrasive technique to conventional mechanical preparation. Myers (1954) observed that although the abrasive would cut silicate restorations, dull metallic restorations, and etch mouth mirrors, it was still a valuable adjunct in cavity preparation.

Despite the initial enthusiasm, the Airdent unit and airbrasive cavity preparation had disappeared from the scene within a decade. The cost of the Airdent unit, the difficulty of learning the airbrasive technique, and the introduction of the much less costly high-speed air rotor contributed to its demise. Air-abrasion technology survived but was limited to prophylaxes. The Prophy-Jet was developed to remove stain and plaque using sodium bicarbonate as the abrasive. It proved to be superior to conventional rubber cup polishing techniques, especially in areas of difficult access, such as areas around orthodontic appliances (Horning, 1987). However, care was required in its use, as a significant increase in surface roughness was observed on seven of 10 restorative materials investigated (Lubow & Cooley, 1986). Surface roughness of three composite resins increased significantly after a 5-second exposure to the sodium bicarbonate abrasive stream. After the initial roughening, longer periods of exposure did not significantly increase the surface roughness (Cooley, Lubow & Patrissi, 1986). However, numerous advantages of the Prophy-Jet system were observed:

Air-abrasion prophylaxis has been widely accepted. In clinical practice, it effectively and rapidly removed stain with little effect on the treated tooth or soft tissues if used according to directions (Clinical Research Associates, 1981). In addition, in a study that compared Prophy-Jet prophylaxis, rubber cup prophylaxis, and no prophylaxis with and without acid etching of enamel, the highest bond strengths of pit and fissure sealants to enamel were obtained when air-abrasive prophylaxis was combined with acid etching (Brockman, Scott & Eick, 1989).

New air-abrasion cavity preparation systems, similar to the SS White Airdent, have been introduced. They utilize aluminum oxide and compressed air and cut enamel and dentin effectively. This technology has re-emerged at a time when restorative materials and techniques are available that can restore small preparations cut only with air abrasion. Today, ultraconservative restorations can be placed with enamel and dentin bonding agents and strong, wear-resistant composite resins. Fissure sealants and preventive resin and hybrid ionomer restorations can be placed with minimal removal of tooth structure. These modern restorative materials may make air abrasion a viable and desirable alternative to preparation with high-speed, mechanical instrumentation.

It has been suggested that acid etching of enamel and priming of dentin are not necessary when cavity preparations are completed with air abrasion (Clinical Research Associates Newsletter, 1994). Laurell, Lord, and Beck (1993) reported that use of a dentin primer did not enhance the resin bond to air-abraded dentin, and that acid etching of enamel was unnecessary only when the enamel surface was prepared at 160 psi. Studies investigating the effect of air abrasion on the bond of a hybrid ionomer to enamel and dentin showed significantly lower bond strengths to both enamel and dentin when surface conditioning with 10% polyacrylic acid was eliminated (Berry, Rainey & Powers, 1993; Berry, Berry & Powers, 1994).

Table 1. Experimental Groups for Enamel and Dentin Study

ENAMEL STUDY

Group	Surface Finish	Acid Etch	Adhesive
Control	600-grit SiC	Yes	Yes
E-1	27-μm Al_2O_3	No	No
	50-μm Al_2O_3	No	No
E-2	27-μm Al_2O_3	No	Yes
	50-μm Al_2O_3	No	Yes
E-3	27-μm Al_2O_3	Yes	Yes
	50-μm Al_2O_3	Yes	Yes

DENTIN STUDY

Group	Surface Finish	Primer	Adhesive
Control	600-grit SiC	Yes	Yes
D-1	27-μm Al_2O_3	No	No
	50-μm Al_2O_3	No	No
D-2	27-μm Al_2O_3	No	Yes
	50-μm Al_2O_3	No	Yes
D-3	27-μm Al_2O_3	Yes	Yes
	50-μm Al_2O_3	Yes	Yes

Table 2. Tensile Bond Strengths

		E-1		E-2		E-3	
ENAMEL	Control	27 μm	50 μm	27 μm	50 μm	27 μm	50 μm
MPa	21.6 [6]	5.4 [2]	6.6 [1]	14.5 [6]	16.3 [4]	23.3 [8]	23.3 [6]
		D-1		D-2		D-3	
DENTIN	Control	27 μm	50 μm	27 μm	50 μm	27 μm	50 μm
MPa	24.1 [8]	0.6 [0.4]	1.0 [0.5]	11.8 [4]	10.3 [4]	21.8 [7]	20.2 [3]

Mean of 10 replications with standard deviations in brackets. Tukey-Kramer intervals at the 0.05 significance level for comparisons of means among enamel groups and among dentin groups were 3.9 and 2.9 MPa.

The purpose of this study was to determine the effect of air abrasion using two particle sizes of abrasive on the in vitro tensile bond strength of a composite resin to enamel and dentin.

METHODS AND MATERIALS

Noncarious human third molars were selected from a pool of extracted teeth stored in 0.25% solution of sodium azide in water. Teeth were embedded in resin blocks so that one approximal surface would be exposed and parallel to the surface. Half of the samples were randomly assigned to the enamel study and half to the dentin study, and further randomly assigned to seven experimental groups each for enamel and dentin as shown in Table 1.

All teeth were prepared on a metallographic polisher with 600-grit silicon carbide paper. The enamel groups were ground until a minimum 3 mm-in-diameter bonding area was exposed. The dentin groups were further ground until enamel was removed and a 3 mm-in-diameter dentin surface was exposed for bonding.

Surfaces prepared with 600-grit SiC paper served as controls. The other surfaces were abraded with 27 μm or 50 μm aluminum oxide at 120 psi delivered with a KCP-2000 (American Dental Technologies, Troy, MI 48084) cavity preparation system. Some enamel samples were then etched with 37% phosphoric acid (Onyx L/G, #310055, Centrix Inc, Shelton, CT 06484) for 30 seconds, rinsed, and dried. Herculite XRV (#3604, Sybron/Kerr Dental Specialties, Glendora, CA 91740) and Optibond (primer #750684, adhesive #750663, Sybron/Kerr) were bonded to both enamel and dentin (Table 1).

All samples were stored at 37 °C and 100% relative humidity for 24 hours. All samples were tested to failure in tension in a Universal Testing Machine (Model 8501, Instron Corp, Canton, MA 02021).

Means and standard deviations were recorded. The data analyzed by two-way analysis of variance (SuperANOVA, Abacus Concepts Inc, Berkeley, CA 94704) and differences located with the Tukey-Kramer (SuperANOVA) test at a 0.05 significance level.

RESULTS

Means and standard deviations for 10 replications for each condition are shown in Table 2. There was no significant difference between 27 μm and 50 μm aluminum oxide abrasive under any conditions in either the enamel or the dentin study. The Tukey-Kramer interval among experimental groups in the enamel study was 3.9 MPa. Bond strengths to enamel surfaces that were air abraded only were significantly lower than all other groups. When adhesive was added to the air-abraded surface, the bond strength was significantly higher than the air-abraded-only surface, but lower than both the control and the enamel surfaces that were air abraded, acid etched, and bonded with adhesive. Maximum bond strengths were obtained when enamel surfaces were

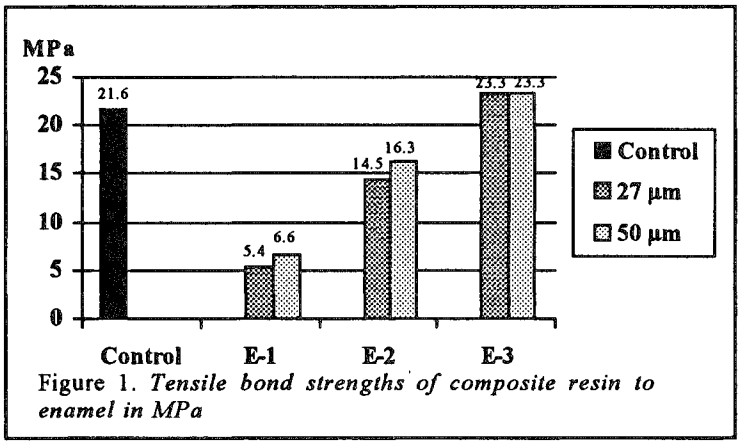

Figure 1. *Tensile bond strengths of composite resin to enamel in MPa*

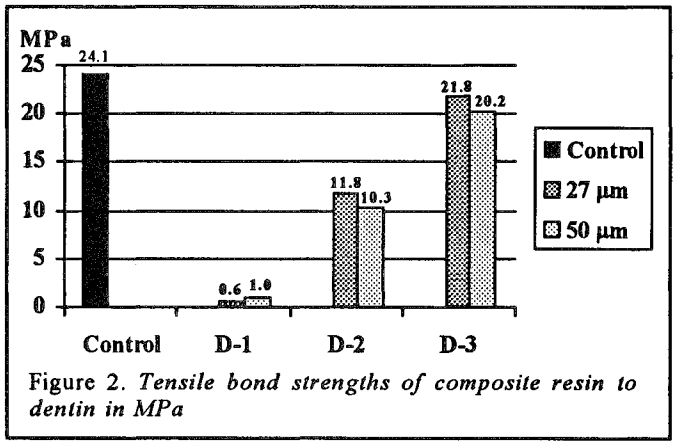

Figure 2. *Tensile bond strengths of composite resin to dentin in MPa*

air abraded, acid etched, and bonded with adhesive, although these values were not significantly different from the control. Comparison of enamel bond strengths is shown in Figure 1.

In the dentin study, the Tukey-Kramer interval among experimental groups was 29 MPa. Bond strengths to dentin surfaces that were air abraded only were significantly lower than all other groups. When the adhesive was added to the air-abraded surface, the bond strength was significantly higher than the air-abraded-only surface, but lower than both the control and the dentin surfaces that were air abraded, primed, and bonded with adhesive. Bond strengths obtained when dentin surfaces were air abraded, primed, and bonded with adhesive were significantly higher than the air-abraded-only and air-abraded and adhesive groups, but the same as the control group. Comparison of dentin bond strengths is shown in Figure 2.

DISCUSSION

This study showed that maximum bond strengths of composite to enamel were achieved with air abrasion, acid etching, and bonding with an adhesive and were significantly higher than all other groups except the control group. This finding is consistent with the results of Brockman, Scott, and Eick (1989). They found the highest bond strengths of fissure sealants were obtained only when air abrasion and acid etching were combined. Although bond strengths were significantly increased over the use of air abrasion alone by the addition of the adhesive, bond strengths were significantly lower than those achieved when the enamel was also acid etched. It is not clear why this is the case. It may be that air abrasion increases the wettability of enamel and enhances the effectiveness of the acid etch.

In vitro studies are conducted under rigidly controlled conditions that are not possible clinically. Results are obtained under the "best-case" scenario, while clinical conditions cannot be optimized in every case. A technique that produces enamel bond strengths of 23 MPa provides room for error, and clinical success should be routine. A technique that produces bond enamel bond strengths of only 14 to 16 MPa must be executed perfectly each time and may have a low tolerance for less than ideal clinical conditions. The mean polymerization shrinkage of composite resins causes a stress of about 7 MPa. Bond strength values must always exceed this value for predictable clinical success. The coefficient of variation of the enamel experimental group mean of 14.5 MPa is 43%, and therefore some clinical failures are inevitable at this bond strength level.

Laurell, Lord, and Beck (1993) reported that dentin primer did not enhance the resin bond to air-abraded dentin. The current study failed to confirm that conclusion. The control was significantly higher than all air-abraded groups except D-3. However, dentin surfaces that were air abraded, primed, and adhesively bonded yielded mean bond strengths in excess of 20 MPa. Munksgaard, Hansen, and Asmussen (1984) suggested that a dentin bonding agent should have a tensile or shear bond strength of at least 17.6 MPa to eliminate gap formation at the margin of a 4 mm restoration. As in the enamel study, bonds 20 MPa or greater give the clinician room for error and clinical failures should be few.

While enamel bonding is clearly micromechanical and dependent on the quality of resin tags penetrating the spaces left by acid etching, dentin bonding is more complex. Heymann and Bayne (1993) noted that three factors play significant roles in dentin bonding: smear layer; dentinal tubule density, size, and length; and dentin sclerosis. A smear layer is a mixture of cutting debris that may consist of enamel, dentin, cementum, saliva, blood, and bacteria. The quality of the smear layer may change if high shear stresses or temperatures occur during cutting. The character of the smear layer affects bonds to dentin with resin bonding agents (Tao, Pashley & Boyd, 1988). The new generation of dentin bonding agents is dependent on smear layer removal and formation of the "hybrid layer" (Nakabayashi, Nakamura & Yasuda, 1991; Van Meerbeek & others, 1992). Air-abraded dentin is quite different in appearance from mechanically prepared dentin. Dentinal tubules are occluded, but the surface does not have the familiar "smeared" appearance. This study indicates that this layer, whatever its nature, must be removed for maximum dentin bond strengths.

This study investigated the effect of the particle size of aluminum oxide abrasive on the bond strength of composite to both enamel and dentin. The particle size had no significant effect on bond strength to either surface. The air pressure was held constant in this study. Changes in air pressure with different particle sizes might demonstrate a difference.

CONCLUSIONS

Under the conditions of this in vitro study,

1. Aluminum oxide abrasive particle size had no influence on the bond strength of composite resin to enamel or dentin;
2. Maximum composite resin bond strengths to enamel are achieved with a combination of air abrasion, acid etching, and adhesive bonding; and
3. Maximum composite resin bond strengths to dentin are achieved with a combination of air abrasion, application of a dentin primer, and adhesive bonding.

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References

BERRY EA, BERRY LL & POWERS JM (1994) Bonding of hybrid ionomers to air-abraded enamel and dentin *Journal of Dental Research* **73** 183.

BERRY EA, RAINEY JT & POWERS JM (1993) Bond strength of hybrid ionomer to enamel treated by KCP-2000 *Transactions of Second International Congress of Dental Materials* 302.

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

BLACK RB (1955) Application and reevaluation of air abrasive technique *Journal of the American Dental Assocation* **50** 408-414.

BROCKMANN SL, SCOTT RL & EICK JD (1989) The effect of an air-polishing device on tensile bond strength of a dental sealant *Quintessence International* **20** 211-217.

CLINICAL RESEARCH ASSOCIATES (1981) Subject: Oral prophylaxis prophy-jet *Clinical Research Associates Newsletter* **5** 1.

CLINICAL RESEARCH ASSOCIATES (1994) Subject: Air microabrasive for etching and cavity preparation *Clinical Research Associates Newsletter* **18** 3.

COOLEY RL, LUBOW RM & PATRISSI GA (1986) The effect of an air-powder abrasive instrument on composite resin *Journal of the American Dental Association* **112** 362-364.

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

HEYMANN HO & BAYNE SC (1993) Current concepts in dentin bonding: focusing on dentinal adhesion factors *Journal of the American Dental Assocation* **124** 26-36.

HORNING G (1987) Clinical use of an air-powder abrasive *Compendium of Continuing Education in Dentistry* **8** 652-658.

LAURELL K, LORD W & BECK M (1993) Kinetic cavity preparation effects on bonding to enamel and dentin *Journal of Dental Research* **72** *Abstracts of Papers* p 283 Abstract 1437.

LUBOW RM & COOLEY RL (1986) Effect of air-powder abrasive instrument on restorative materials *Journal of Prosthetic Dentistry* **55** 462-465.

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.

MYERS GE (1954) The airbrasive technique *British Dental Journal* **XCVII** 291-295.

NAKABAYASHI H, NAKAMURA M & YASUDA N (1991) Hybrid layer as a dentin-bonding mechanism *Journal of Esthetic Dentistry* **3** 133-138.

TAO L, PASHLEY DH & BOYD L (1988) Effect of different types of smear layers on dentin and enamel bond strengths *Dental Materials* **4** 208-216.

VAN MEERBEEK B, INOKOSHI S, BRAEM M, LAMBRECHTS P & VANHERLE G (1992) Morphological aspects of the resin-dentin interdiffusion zone with different dentin adhesive systems *Journal of Dental Research* **71** 1530-1540.

OPERATIVE DENTISTRY, 1995, 20, 191-196

Repairability of a Polyacid-modified Composite Resin

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Clinical Relevance
Bonding of a polyacid-modified composite resin to previously placed material can be achieved.

SUMMARY

The purpose of this study was to evaluate the effect of time and surface treatment on the resulting shear bond strength of a repaired polyacid-modified composite resin restorative material (VariGlass VLC). Seventy-two specimens of VariGlass were prepared in cavities (2 mm x 7 mm) cut into acrylic resin cylinders. The specimens were then divided into three groups of 24. For each of the three groups, 12 of the specimens were repaired 5 minutes after the cavities were initially filled, while 12 specimens were repaired 1 week after the initial fill. The VariGlass surfaces were treated in one of the following ways: no treatment; primer (30 seconds) and adhesive (light activated for 10 seconds); or 37% phosphoric acid etchant (30 seconds), primer (30 seconds), and adhesive (light activated for 10 seconds). Repairs were made using a split polytetrafluoroethylene mold (3 mm x 5 mm) mounted over the exposed VariGlass surface. After bonding a cylinder of VariGlass to the treated surfaces, the specimens were thermocycled 500 times (5 °C and 55 °C water baths), stored in distilled water for 1 week, and loaded to failure in shear at 0.5 mm/min. Data were analyzed using two-way ANOVA and a Student-Newman-Keuls multiple comparison test. Results indicated that the bond strength of specimens repaired at 5 minutes was significantly higher when no surface treatment was used prior to repair. Bond strength of specimens repaired at 1 week was unaffected by surface treatment. Time of repair significantly affected the no-treatment and the primer-adhesive groups.

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INTRODUCTION

As with other direct restorative materials, it is sometimes necessary to repair light-activated hybrid resin/glass-ionomer materials after initial placement of the restoration because of overfinishing, fracture, lack of contour, erosion, or voids. Several in vitro studies (Parra & Kopel, 1992; Charlton, Murchison & Moore, 1991; Robbins & others, 1989; Scherer & others, 1989; Pearson & others, 1989; Brackett & Johnston, 1989) have examined the repairability of chemically set glass ionomers and the effect of time of repair and surface treatment on their shear bond strengths. In general, these studies have found that delayed repairs have resulted in significantly lower bond strengths (Parra & Kopel, 1992; Charlton & others, 1991; Robbins

& others, 1989; Scherer & others, 1989; Pearson & others, 1989). Surface treatment of the initially placed material, however, has produced variable results (Parra & Kopel, 1992; Charlton & others, 1991; Scherer & others, 1989; Brackett & Johnston, 1989). No research has been published on the repairability of the polyacid-modified composite resin, VariGlass VLC. There is a need for research to determine if this and similar materials can be repaired and what effect time of repair and surface treatment have on the resulting shear bond strength.

The purpose of this study was to evaluate the effect of time and surface treatment on the resulting shear bond strength of a repaired polyacid-modified composite resin restorative material.

METHODS AND MATERIALS

Seventy-two 25 mm-long, 15 mm-in-diameter acrylic resin cylinders were made using a split polytetrafluoroethylene mold. A 2 mm-deep by 7 mm-in-diameter cavity was cut into one end of each cylinder using a steel drill bit and drill press. Undercuts were placed in the walls of the cavity using a dental high-speed handpiece and #1/2 round bur.

VariGlass VLC (Shade D2, L D Caulk/Dentsply, Milford, DE 19963) was prepared according to the manufacturer's recommendations for use as a restorative material by mixing one level scoopful of powder with two drops of liquid. The mixed material was placed into the cavity in 1 mm increments using a placement syringe. Each increment was polymerized by exposure for 40 seconds to a visible-light unit (Optilux 400, Demetron Research, Danbury, CT 06810). A radiometer (Demetron Research) was used to verify the light intensity of the unit immediately prior to use. The last increment was light activated in contact with a plastic strip to ensure that the exposed VariGlass surface was smooth and parallel to the end of the cylinder.

The 72 specimens were then divided into three groups of 24 with each group receiving a different surface treatment. For each of the three groups, 12 of the specimens were repaired 5 minutes after the cavities were initially filled with VariGlass, and 12 specimens were repaired 1 week after the cavities were filled. The experimental design is summarized in Figure 1.

Group I: The exposed VariGlass received no additional surface treatment. A 3 mm-thick split polytetrafluoroethylene mold with a 5 mm circular opening was placed over the VariGlass surface and stabilized using an alignment tube (Figures 2 and 3). A second mix of VariGlass (shade A3) was prepared according to the manufacturer's recommendations by mixing one level scoopful of powder with two drops of liquid. A shade was chosen for this mix (A3) that was distinctly different from the shade of the VariGlass used to fill the original cavities in order to make it easier to distinguish cohesive from adhesive failures after bond strength testing. The mixed

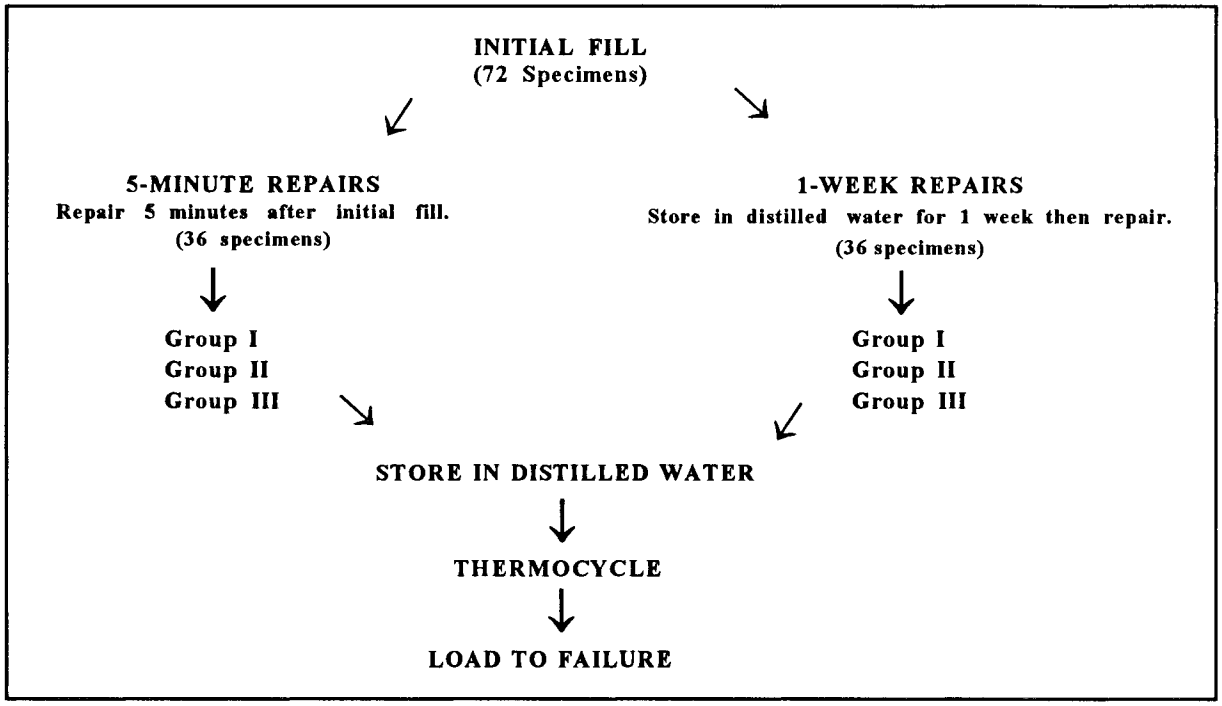

Figure 1. *Experimental design*

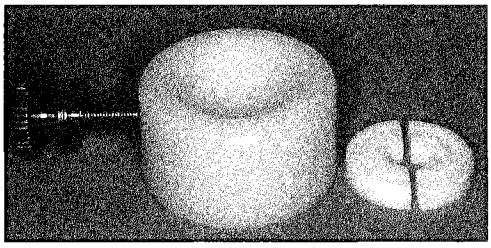

Figure 2. *Alignment tube and mold*

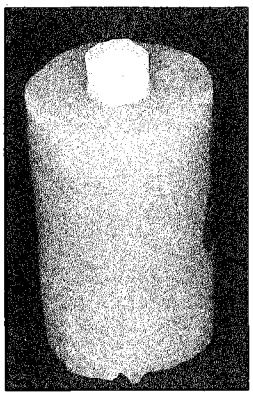

Figure 4. *Bonded specimen*

material was placed into the mold in 1 mm increments using a placement syringe, and each increment was light activated for 40 seconds. The mold was removed and the specimen placed in 37 °C distilled water (Figure 4).

Group II: Prisma Universal Bond 3 Primer was applied to the exposed VariGlass VLC surface of each specimen using a small brush. After being allowed to remain undisturbed for 30 seconds, the Primer was gently dried for 10 seconds with oil-free, compressed air. Prisma Universal Bond 3 Adhesive was applied with a brush, lightly air thinned, and light activated for 10 seconds. VariGlass VLC was placed on the treated surface as described for Group I.

Table 1. Mean Shear Bond Strengh (MPa) of Repaired VariGlass VLC

	Time of Repair	
Surface Treatment	**5 Minutes**	**1 Week**
Group I: No Treatment	14.02 ± 1.96	7.91 ± 1.64
Group II: Primer, Adhesive	9.60 ± 3.31	7.13 ± 1.08
Group III: Etch, Primer, Adhesive	7.53 ± 2.31	7.18 ± 1.16

Vertical lines connect nonsignificant differences at the 0.05 level; n = 12. Mean ± standard deviation.

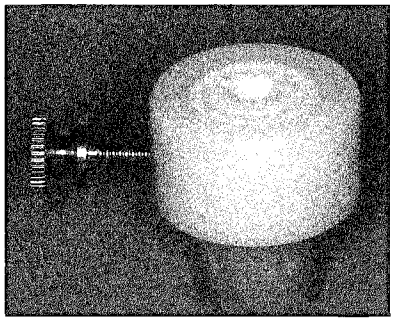

Figure 3. *Alignment tube and mold on specimens*

Group III: A 37% phosphoric acid etchant (Tooth Conditioner Gel, L D Caulk/Dentsply) was applied to the exposed VariGlass VLC surface of each specimen and was allowed to remain for 30 seconds. The etchant was removed by rinsing for 20 seconds with tap water, and the etched surface was dried for 10 seconds with oil-free, compressed air. Prisma Universal Bond 3 Primer was applied to the treated surface with a small brush and was allowed to remain undisturbed for 30 seconds. The Primer was gently dried with oil-free, compressed air for 10 seconds. Prisma Universal Bond 3 Adhesive was applied with a brush, lightly air thinned, and light activated for 10 seconds. VariGlass VLC was bonded to the treated surface as described for Group I. The specimens repaired at 1 week were stored prior to repair in 37 °C distilled water and dried for 10 seconds with oil-free, compressed air immediately before being repaired.

Following repair, all specimens were stored in 37 °C distilled water for 72 hours. The specimens were then thermocycled for 500 cycles between a 5 °C water bath and a 55 °C water bath (dwell time of 40 seconds). After thermocycling, all specimens were stored in 37 °C distilled water. One week after repair, the specimens were tested in shear using a steel ring engaging the VariGlass VLC cylinders and attached to a testing machine (Tinius Olsen, Series 1000, Willow Grove, PA 19090). The specimens were loaded to failure at a crosshead speed of 0.5 mm/min.

Following shear bond strength testing, all specimens were examined using a stereomicroscope at X8 magnification to determine the mode of failure. Failures were recorded as cohesive (those which occurred within the VariGlass), adhesive (those which occurred between VariGlass surfaces), or mixed (a combination of cohesive and adhesive failures).

RESULTS

Data were analyzed using a two-way ANOVA (surface treatment and time of repair) and a Student-Newman-Keuls multiple comparison test at the 0.05

Table 2. Modes of Failure

Fracture Type	5 Minutes Group I No Treatment	5 Minutes Group II Primer, Bond	5 Minutes Group III Etch, Primer, Bond	1 Week Group I No Treatment	1 Week Group II Primer, Bond	1 Week Group III Etch, Primer, Bond
Adhesive	1	0	0	2	0	0
Cohesive	11	7	6	8	12	12
Mixed	0	5	6	2	0	0

Adhesive: failures occurring between VariGlass surfaces; Cohesive: failures occurring within the VariGlass; Mixed: a combination of adhesive and cohesive failures

significance level. Mean shear bond strength values and standard deviations in MPa are presented in Table 1. For the 5-minute repairs, bond strength was significantly higher when no additional surface treatment was used immediately prior to repair. For the 1-week repairs, there was no significant difference between any of the surface treatment groups. Time had a significant effect on the no-treatment group and primer-adhesive group.

Modes of failure are presented in Table 2. For the majority of the specimens (56/72), the mode of failure was cohesive. Only three adhesive failures were noted, and all of these occurred in groups receiving no surface treatment.

DISCUSSION

It has recently been suggested that researchers make a determined effort to use appropriate terminology when referring to glass-ionomer cements and related materials (McLean, Nicholson & Wilson, 1994). The term "glass-ionomer cement" should be reserved for those materials that consist of an acid-decomposable glass and a water-soluble acid that set via an acid-base reaction. This reaction should be fully capable of occurring in the dark. The term "resin-modified glass ionomer" refers to materials that set by way of an acid-base reaction and photochemical polymerization. Finally, "polyacid-modified composite resin" is used to identify materials that contain glass-ionomer ingredients but do not exhibit an acid-base reaction in the dark. The term "polyacid-modified composite resin" has been used in this study to describe VariGlass, because the product appears to meet the requirements for this term. It is a resin-based material that has been compositionally altered through the addition of certain glass-ionomer ingredients such as polyacrylic acid and aluminum fluorosilicate glass powder. In addition, the glass-ionomer ingredients are present in amounts insufficient to cause a glass-ionomer acid-base reaction in the dark.

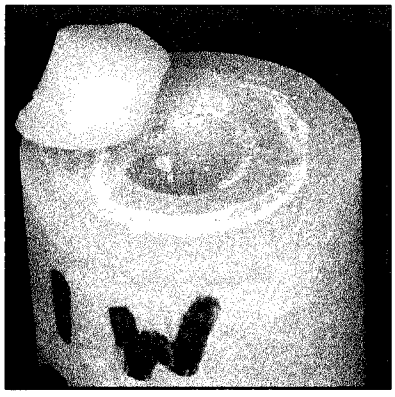

Figure 5. *Sample of cohesive failure*

Although VariGlass differs substantially from true glass ionomers, comparing the findings of this study with those evaluating the repairability of glass-ionomer restorative materials yields interesting results. The finding that shear bond strengths for the delayed (1-week) repairs were lower than those for the early (5-minute) repairs is consistent with the results of other researchers. Parra and Kopel (1992) found that the shear bond strength of repaired Ketac-Fil was lower when repaired at 24 hours or 6 days than when repaired at 15 minutes. Fuji II, when repaired at 24 hours, had a bond strength that was lower than when repaired at 15 minutes. Charlton and others (1991) found that the tensile bond strengths of repaired Ketac-Fil and Fuji II were lower at 24 hours than when repaired at 20 minutes. Robbins and others (1989) found that the shear bond strength of repaired Ketac-Fil was lower when repaired at 24 hours than when repaired at 30 minutes. Fuji II, when repaired at 24 hours, had a bond strength that was lower than when repaired at 30 minutes. Scherer and others (1989) found that the shear bond strength of Ketac-Fil was lower when repaired at 24 hours than when repaired at either 5 minutes or 15 minutes. Pearson and others (1989)

measured the flexure strength of three glass-ionomer cements when repaired at 1 hour and 7 days and found that the 7-day flexure strength values were lower than the 1-hour values. In addition, surface treatment had an effect on bond strength of early repairs but not on late repairs (Charlton & others, 1991). Finally, for early repairs, the strongest bond was on untreated surfaces, while the weakest was on etched surfaces (Charlton & others, 1991).

For two of the three surface treatment groups, mean bond strengths for the specimens repaired at 1 week were significantly lower than those repaired at 5 minutes. Storage in water may have contributed to this finding. Studies evaluating glass-ionomer cements have reported that depending on the type of polyacid used in their formulation, the strength of these materials can deteriorate as a result of storage in water (Williams & Billington, 1991; Pearson & others, 1989). More recent studies have reported a significant reduction in compressive strength of resin-modified ionomers stored in water and suggest that these materials may be sensitive to moisture (Nicholson & McLean, 1992; Anstice & Nicholson, 1992). These studies have reported that after photochemical activation, resin-modified glass-ionomer cements contain a high proportion of hydrophilic functional groups. The resulting structure resembles that of a synthetic hydrogel, which by its design is intended to absorb moisture. By virtue of their high degree of hydration, hydrogels generally have low mechanical strengths. In these studies (Nicholson & McLean, 1992; Anstice & Nicholson, 1992), the authors concluded that resin-modified glass-ionomer cements exhibited behavior similar to that of hydrogels. It is conceivable that in the present study, water storage adversely affected the cohesive strength of the stored specimens and caused the significantly lower mean bond strengths. Additional evidence that this occurred is the large number of cohesive failures exhibited by these specimens (Figure 5).

Adverse effects of water storage on repair strengths have also been found for composite resin restorative materials (Kao, Pryor & Johnston, 1988; Swift, Cloe & Boyer, 1994). Because of its resin content, VariGlass may suffer similar adverse effects from water storage.

It is interesting to note that no significant reduction in bond strength was found between the 5-minute group and the 1-week group that were surface treated with etchant prior to bonding. It is possible that acid etching, which has been shown to adversely affect the matrix of glass ionomers (Smith, 1988; Taggart & Pearson, 1991), significantly weakened the structure of the 5-minute repair specimens. This reduction in cohesive strength may account for the similarity in mean bond strengths measured for the 5-minute and 1-week specimens that were surface treated with acid.

It should be noted that the great majority of failures seen in this study were cohesive within the VariGlass. No difficulty was encountered in distinguishing cohesive from adhesive failures because of the distinctly different shades of VariGlass used for the original specimen preparation and the repair.The large number of cohesive failures indicates that the mean bond strength reported here represents only the cohesive strength of the restorative material. The actual adhesive bond strength of repaired VariGlass VLC is greater than the values reported.

CONCLUSIONS

The results of this study indicate that for at least one polyacid-modified composite resin restorative material, bonding of new material to previously placed material can be achieved. For VariGlass, bond strength of early repairs is maximized when no surface treatment is used immediately prior to repair. Bond strength of delayed repairs is unaffected by surface treatment. For two of the three surface treatment groups studied (no-treatment group and primer-adhesive group), time of repair significantly affected the bond strength.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Defense or other Departments of the United States Government.

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References

ANSTICE HM & NICHOLSON JW (1992) Studies on the structure of light-cured glass-ionomer cements *Journal of Materials Science: Materials in Medicine* **3** 447-451.

BRACKETT WW & JOHNSTON WM (1989) Repair of glass ionomer restorative materials: Flexure strength of specimens repaired by two methods *Journal of Prosthetic Dentistry* **62** 261-264.

CHARLTON DG, MURCHISON DF & MOORE BK (1991) Repairability of type II glass polyalkenoate (ionomer) cements *Journal of Dentistry* **19** 249-254.

KAO EC, PRYOR HG & JOHNSTON WM (1988) Strength of composites repaired by laminating with dissimilar composites *Journal of Prosthetic Dentistry* **60** 328-333.

McLEAN JW, NICHOLSON JW & WILSON AD (1994) Proposed nomenclature for glass-ionomer dental cements and related materials *Quintessence International* **25** 587-589.

NICHOLSON JW & McLEAN JW (1992) A preliminary report on the effect of storage in water on the properties of commercial light-cured glass-ionomer cements *British Dental Journal* **173** 98-101.

PARRA M & KOPEL HM (1992) Shear bond strength of repaired glass ionomers *American Journal of Dentistry* **5** 133-136.

PEARSON GJ, BOWEN G, JACOBSEN P & ATKINSON AS (1989) The flexural strength of repaired glass-ionomer cements *Dental Materials* **5** 10-12.

ROBBINS JW, COOLEY RL, DUKE ES & BERRONG JM (1989) Repair bond strength of glass-ionomer restoratives *Operative Dentistry* **14** 129-132.

SCHERER W, VAIDYANATHAN J, KAIM JM & HAMBURG M (1989) Evaluation of the ability of glass-ionomer cement to bond to glass-ionomer cement *Operative Dentistry* **14** 82-86.

SMITH GE (1988) Surface deterioration of glass-ionomer cement during acid etching: An SEM evaluation *Operative Dentistry* **13** 3-7.

SWIFT EJ Jr, CLOE BC & BOYER DB (1994) Effect of a silane coupling agent on composite repair strengths *American Journal of Dentistry* **7** 200-202.

TAGGART SE & PEARSON GJ (1991) The effect of etching on glass polyalkenoate cements *Journal of Oral Rehabilitation* **18** 31-42.

WILLIAMS JA & BILLINGTON RW (1991) Changes in compressive strength of glass ionomer restorative materials with respect to time periods of 24 h to 4 m *Journal of Oral Rehabilitation* **18** 163-168.

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Microleakage of Gold Casting Repairs with Different Materials as Quantified by a Helium Gas System

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Clinical Relevance
Among the materials studied, amalgam allowed the least microleakage, Ketac Silver the greatest.

SUMMARY

Inadequate adaptation of a filling material to a gold crown can promote the passage of bacteria; thus, recontamination of sound dentin and/or the pulp canal space is feasible. The aim of this study was to determine the marginal microleakage between two different amalgams (Tytin and Valiant PhD-XT), three different composites (Tetric, Charisma, and Polofil Molar), and one glass-ionomer cement (Ketac Silver) and gold cast crowns using a helium gas microleakage method.

In order to standardize the research parameters, gold washers with standardized dimensions were used as study models together with a helium leakage testing device. Standardized cavities were punched into the gold washers. The cavities were filled according to the manufacturers' recommendations with the different materials. The amount of helium passing the marginal interface between the fillings and cavities was measured with a mass spectrometer 48 hours after the fillings were placed and after 100, 1000, and 2000 thermocycles (5 °C-55 °C). The results showed that amalgam allowed the least microleakage. Ketac Silver showed the greatest microleakage. Statistically significant differences were found between the composites and both amalgams and Ketac Silver between the 48-hour and 100-thermocycling groups. Yet, Ketac Silver showed a significant ascending tendency when compared to the composites and amalgams after 100, 1000, and 2000 thermocycles.

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INTRODUCTION

Cavities must often be prepared in gold cast crowns to determine tooth vitality or to facilitate access for endodontic therapy. Subsequent microleakage at the marginal interface between gold crowns and restorative materials can encourage the appearance of carious lesions in the remaining tooth structure and/or recontamination of the root canal system in the case of previous endodontic treatment. The renewal of a crown with a prepared cavity is advisable; yet, due to functional and/or financial considerations, this is not always practicable. This confronts the operator with the question of the most adequate restorative material for such cases.

Several researchers have reported on leakage into the root canal system when using temporary filling materials (Blaney & others, 1981; Chohayeb & Bassiouny, 1985; Deveaux & others, 1992; Lim, 1990;

Krakow, deStoppelaar & Grøn, 1977; Tamse, Ben-Amar & Gover, 1982; Teplitsky & Meimaris, 1988). To the best of our knowledge, little research has been carried out trying to elucidate the marginal interface between restorative filling materials and cast gold (Carlson, Cochran & Lund, 1986; Carlson & others, 1990).

Microleakage studies have been conducted with different research models, perhaps the most popular being dye penetration with different solutions. However, visual measurements and their difficulty of three-dimensionally quantifying the dye hinder the acquisition of objective results (Delivanis & Chapman, 1982). Scanning electron microscopy studies are vulnerable due to the possibility of artifact inclusion and probe deformation during SEM preparation and lack of objective quantification (Al-Hamadani & Crabb, 1975; Going, 1972). Quantification of autoradiography methods also represent an uncontrollable variable (Going, Massler & Dute, 1960). Radioisotope methods are quantifiable; yet long-term studies are cumbersome (Going, Myers & Prussin, 1968), as are research conduction and the necessary equipment (Crisp & Wilson, 1980). Quantification in bacterial studies also represents a variable that is difficult to control. An undetermined number of bacteria can succumb during marginal migration, or rapid bacterial development can make proper colony differentiation difficult (Crisp & Wilson, 1980; Granath, 1967). Moreover, accumulation of toxins at the interface passages cannot be detected (Taylor & Lynch, 1992). Leinfelder, O'Neal, and Mueninghoff (1986) claim that the use of calcium hydroxide as an agent for determining microleakage offers in vivo testing possibilities, is less toxic, and has a methodology that is reliable, simple to carry out, and which can be conducted in a short period of time. Yet quantitative microleakage cannot be measured readily with this method (Leinfelder & others, 1986). To the best of our knowledge, electrochemical microleakage studies have been widely used to determine microleakage of root canal fillings (Lim, 1990). This type of study allows a more accurate quantification in comparison to dye penetration; however, variables such as control of the buffering and pH of the solution used can lead to inaccurate interpretations. Air pressure and fluid filtration techniques, however, allow quantification of results (Granath & Svensson, 1970). Presently, these methods probably represent the most adequate research methodology.

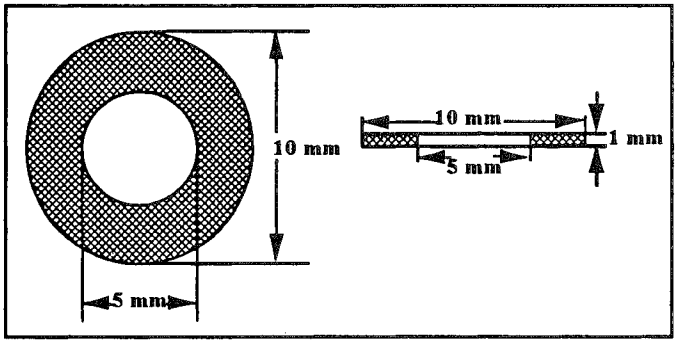

Figure 1. *Dimensions of the gold washers used as probes to simulate occlusal cavities in cast gold crowns. The hole punched at the middle represents a 15.7 mm cavity margin circumference.*

The aim of this study was to evaluate microleakage at the interface between gold cast restorations and different restorative materials by means of a helium microleakage testing method.

METHODS AND MATERIALS

Gold washers (n=160) were manufactured (10 mm in diameter/1 mm thick) out of laminated Degulor M-type gold (Degussa AG, Frankfurt, Germany) to simulate the clinical conditions of cast crowns. A hole (5 mm in diameter) was punched into the middle of the washers to simulate occlusal cavities (Figure 1). This produced a 15.7 mm cavity circumference. The dimension of the cavities in the gold washers was pre-established to approximate clinical conditions.

The gold washers were randomly divided into six groups (n=25), marked for light identification, roughened at the cavity circumference, and fixed with two pliers under constant pressure on a glass plate. This provided a one-sided smooth filling surface. The cavities were filled according to the manufacturers' recommendations with three different composites (n=25): Charisma (Kulzer & Co GmbH, Wehrheim, Germany), Polofil Molar (Voco Chemie GmbH, Cuxhaven, Germany) and Tetric (Vivadent, Schaan, Liechtenstein); two amalgams (n=25): Tytin (Kerr, Romulus, MI 48174) and Valiant PhD-XT (De Trey, Konstanz, Germany) and one glass-ionomer cement (n=25): Ketac Silver (ESPE, Seefeld, Germany). The composites were autopolymerized with a Translux CL (Kulzer & Co GmbH, Friedrichsdorf, Germany) light curing unit. The amalgams were triturated (Silamat; Vivadent) for 5 seconds. The cavities for the glass-ionomer cement were lightly moistened with a cotton pellet and filled after vibrating (Silamat; Vivadent) the cement capsules for 7 seconds.

The samples were placed in distilled water containers immediately after light curing (composites), 5 minutes after having filled the cavities (amalgams) and 10 minutes after water rinsing (glass ionomer). The fillings were polished 24 hours afterward, according to the manufacturers' recommendations. The fillings were not coated with varnish or liners at any time. Ten gold washers without punched cavities were used as the negative control.

An HLT 100 (Balzers AG, Liechtenstein) helium testing device was used to quantify microleakage

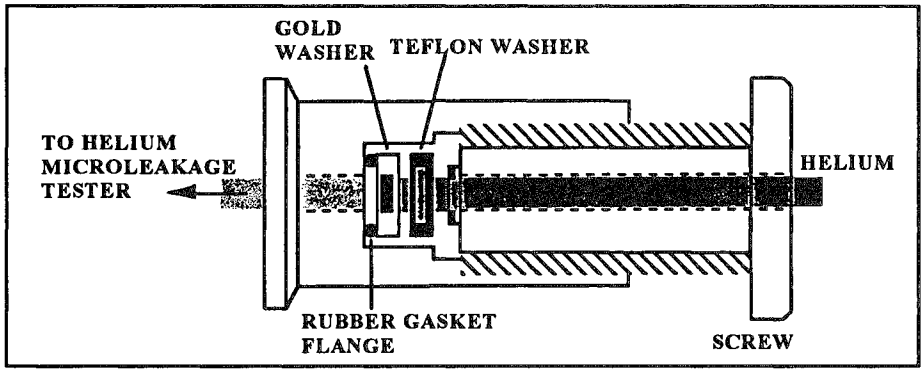

Figure 2. *Flange designed to fix the gold washers in the helium microleakage testing device. An absolute hermetic seal was systematically demonstrated using washers without a "cavity."*

(2×10^{-2} mbar l/s) between the cavities' margins and the different filling materials. The gold washer/sample system was fixed in a flange (Figure 2) specially manufactured for this purpose. Helium gas was introduced as shown. The rubber gasket in the flange was changed every 25 measurements. An absolute hermetic seal of the rubber gasket was proven immediately after being changed with one of the indiscriminately picked negative controls. A vacuum produced by a revolving pump facilitated the streaming of helium gas through the interface between the fillings and the gold washers. The helium atoms were then evacuated through vacuum valves into a high vacuum, which was produced with a turbo molecular pump (Figure 3). The amount of helium atoms could then be quantified by a mass spectrometer reading display.

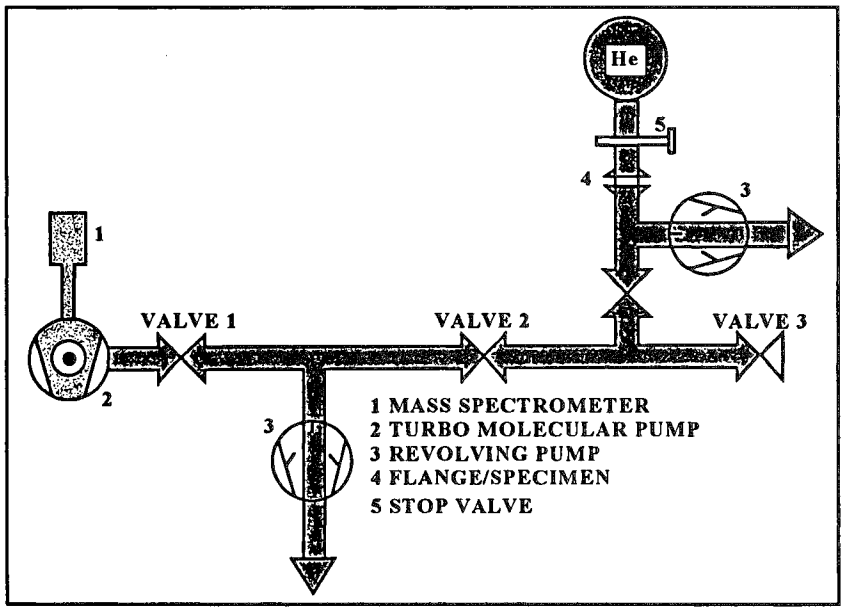

Figure 3. *Helium microleakage testing device*

Leakage measurements were made after 48 hours and 100, 1000, and 2000 thermocycles. A thermocycling machine (Kulzer) was used for this purpose. The device consisted of two thermostats (MGW Lauda; types RKT-RK 20 and KS.K 20) and a computer (Commodore C64) to regulate the thermocycling parameters. The samples were placed into 5 and 55 °C (± 0.5 °C) baths for 60 seconds respectively. The time between both baths was 10 seconds.

Statistical analyses were conducted for every group. Analyses of Variance were made after ensuring normal distributions (Kolmogrov-Smirnov-test; $P \leq 0.05$) and variance homogeneity (Bartlett's test; $P = 0.05$). The Kruskal-Wallis test was used in cases of nonnormal distribution. Significant differences between the 48-hour and 100-, 1000-, and 2000-thermocycling trials, within the same material, were analyzed with the *t*-test for paired groups. Significant increasing differences of the median values between the 100-, 1000- and 2000-thermocycling trials, also within the same material, were analyzed with the trend test.

RESULTS

Statistical analyses are shown in Tables 1 to 4. A summary of the average microleakage tendencies is shown in Figure 4. Ketac Silver and all composite filling materials showed significant higher and lower (respectively) differences between the 48-hours and 100-thermocycling groups (Table 5). Composites displayed the highest leakage rates in the 48-hour group (Figure 4). Their microleakage decreased significantly after 100 thermocycles (Table 5 and Figure 5); however, a significant ascending tendency of the median values was obtained between the 100-2000 thermocycles (Table 5). Both amalgams and Ketac Silver showed lower microleakage rates after 48 hours in comparison to the composites (Figures 4-6). A slight, nonsignificant, ascending microleakage tendency was observed with the two different amalgams between the 100-2000 thermocycles (Figure 6). It was noticeable that Tytin proved a constant higher leakage rate of at least 10 times in comparison to Valiant PhD-XT (Figure 6). Ketac Silver showed a low microleakage rate after 48 hours (Figures 4-5). Yet a significant ascending tendency was observed among all thermocycling groups (Table 5 and Figure 5).

Table 1. Statistical Analyses of Helium Microleakage Rate (10^{-7} mbar l/s) 48 hours after the Different Filling Materials (n=25) Were Placed into Gold Washers

	Charisma	Polofil Molar	Tetric	Tytin	Valiant PhD-XT	Ketac Silver
Mean	21.96	16.92	37.08	2.22	0.16	2.65
SD	7.86	8.79	10.73	1.33	0.12	1.22
Minimum	9.00	4.00	16.00	0.80	0.07	0.70
Maximum	36.00	38.00	57.00	5.40	0.48	5.00
Median	22.00	18.00	38.00	2.20	0.11	2.40

Table 2. Statistical Analyses of Helium Microleakage Rate (10^{-7} mbar l/s) 100 Cycles after the Different Filling Materials (n=25) Were Placed into Gold Washers

	Charisma	Polofil Molar	Tetric	Tytin	Valiant PhD-XT	Ketac Silver
Mean	0.20	2.09	0.84	3.29	0.21	7.30
SD	0.11	1.40	0.55	1.75	0.11	4.38
Minimum	0.10	0.40	0.30	1.00	0.07	2.00
Maximum	0.45	4.50	2.00	8.40	0.52	17.80
Median	0.15	1.20	0.60	3.20	0.18	6.10

Table 3. Statistical Analyses of Helium Microleakage Rate (10^{-7} mbar l/s) 1000 Cycles after the Different Filling Materials Were Placed into the Gold Washers

	Charisma	Polofil Molar	Tetric	Tytin	Valiant PhD-XT	Ketac Silver
Mean	0.47	3.79	2.32	3.63	0.23	41.04
SD	0.25	2.04	0.96	1.56	0.11	11.71
Minimum	0.13	1.00	0.50	1.50	0.11	24.00
Maximum	0.91	8.20	4.40	8.20	0.45	67.00
Median	0.40	3.30	2.20	3.40	0.19	38.00

Table 4. Statistical Analyses of Helium Microleakage Rate (10^{-7} mbar l/s) 2000 Cycles after the Different Filling Materials (n=23) Were Placed into the Gold Washers

	Charisma	Polofil Molar	Tetric	Tytin	Valiant PhD-XT	Ketac Silver
Mean	0.72	5.65	2.77	3.95	0.30	64.91
SD	0.46	2.99	0.97	1.52	0.17	22.23
Minimum	0.25	2.10	1.10	1.80	0.11	37.00
Maximum	1.80	13.10	4.70	8.40	0.77	112.00
Median	0.50	4.80	2.70	3.70	0.24	61.00

DISCUSSION

Quantification of microleakage is a subject that concerns the methodology. The use of dye does not allow an objective leakage quantification. Neither do scanning electron microscopy and radioisotope methods. Electrochemical methods allow the conduction of quantitative studies; however, different variables can affect the solutions. Thus, possible misinterpretation during a long-term study can substantially distort the results. Due to the small size of the helium atom (21.9 nm at 0 °C and 1013 mbar) and its ease of detection in a mass spectrometer, the method presented in this study is also used to test leakproof objects that demand an absolute hermetic seal, like in nuclear physics. It facilitates the reduction of variables and the standardization of research parameters. Thus, reproducibility is increased and the results can be more dependably analyzed. A problem with this methodology is its applicability to a clinical situation. The gas pressure to which the probes were submitted with this method does not occur clinically, and the molecules of helium are significantly smaller in comparison to bacteria (He atom ~ 21.9 nm; radioisotopes ~ 40 nm/Cocci ~ 0.5-1.2 µm = 500-1200 nm). Therefore, studies that clarify which levels of helium microleakage have clinical significance are necessary. Regardless of this fact, materials that show less helium microleakage should be preferred. It can be assumed that they offer, proportionally, clinically superior marginal adaptation to cast gold in comparison to those materials that show higher helium leakage.

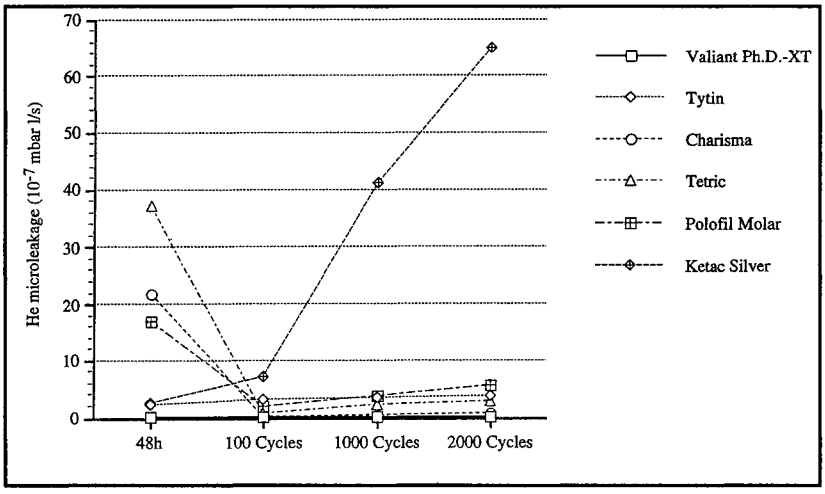

Figure 4. *Line graph representing the average microleakage measurements of all materials determined at the different trials*

The aim of this first report was to give an overview of the marginal microleakage tendencies of different commonly used filling materials and, as expressed before, to establish the validity of the research method. The materials studied in this research were selected according to a financial/statistically feasible gold probe number (160 washers = 195.50 grams), grouping characteristics and availability. A series of studies in which specific groups of different restorative materials, such as wider range of amalgam alloys, different types of composites, or glass ionomer and hybrid ionomers, are being undertaken. The use of direct gold or cast gold inlays was not considered in this study due to the

Table 5. Significant (P < 0.05) Increasing (+) and Decreasing (-) Differences between the 48-Hour and 100-, 100- and 1000-, 100- and 2000-, and 1000- and 2000-Thermocycling Groups, within the Same Material (ns = nonsignificant)

	48/100	100/1000	100/2000	1000/2000
Charisma	-	ns	+	ns
Tetric	-	ns	+	ns
Polofil Molar	-	ns	+	ns
Tytin	ns	ns	ns	ns
Valiant PhD-XT	ns	ns	ns	ns
Ketac Silver	+	+	+	+

fact that, at least in Germany, it represents few financial advantages in comparison to a newly cast restoration. Yet, the validity of these types of restorative materials should be given consideration.

CONCLUSION

According to the results obtained with the materials presented in this study, amalgam could be considered the best restorative material for cavities prepared in cast crowns in molars and premolars. Although no clinical significance has been demonstrated, the probability of corrosion products (Dewald, Arcoria & Marker, 1992; Fusayama, Katayori & Nomoto, 1963; Marek & Hochman, 1976; Moberg, 1985; Moberg & Odén, 1985; Odén & Tullberg, 1985) and galvanic electrochemical interactions (Holland, 1980; Johansson, 1986; Johansson & Lagerlöf, 1992; Johansson & Moberg, 1991; Momoi & others, 1986) resulting from the contact between amalgam and gold should be considered before implementation. In contrast, other authors' (Holland, 1980; Leistner, 1986) findings report favorable results between gold and a nongamma 2-phase amalgam. Perhaps due to

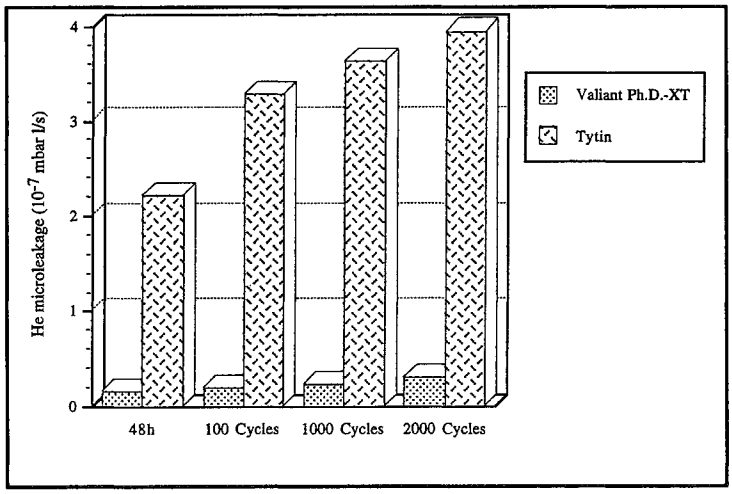

Figure 6. *Bar graph representing the average microleakage measurements of the amalgams determined at the different trials*

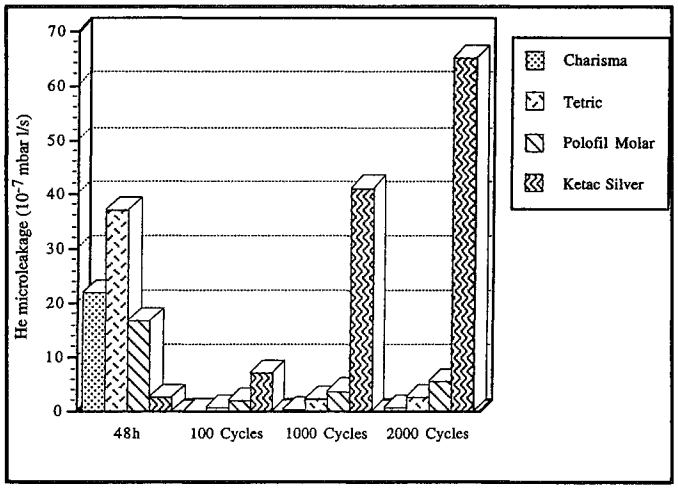

Figure 5. *Bar graph representing the average microleakage measurements of the composites and glass-ionomer cement determined at the different trials*

the lack of a consensus concerning the attributes of amalgam, its use as a restorative material for cast crowns should be carefully considered. The differences obtained between both amalgams can be explained through their different particle form. These results are in agreement with the ones of Mahler and Nelson (1984, 1994) and Leinfelder and others (1986), who found that the marginal leakage of spherical amalgam was greater in comparison to that of lathe-cut or irregularly shaped particle amalgam. In cases where amalgam has been selected as the restorative material of choice, the use of lathe-cut or irregularly shaped particle amalgam should be considered instead of spherical amalgam when restoring cavities prepared in gold cast restorations. Ketac Silver showed a poor seal of cavities prepared in casting fillings. This result is in disagreement with that obtained by Carlson and others (1986, 1990). In our study, no replicas were used, and the fillings were not protected with varnish that could have had an influence on the polymerization of the glass-ionomer cement and would not mimic standard clinical situations with all materials. Additionally, glass-ionomer cements can wash out with time and are therefore generally not recommended as definitive filling materials (Kullmann, 1986, 1989). Interpretation of the results presented in this study suggests that, concerning microleakage, composites presently do not represent the material of choice for restoration of endodontic-access cavities in cast crowns. The different microleakage results obtained with the composites used in this study are probably due to different monomer formulations. In the 48-hour group Tetric (fine-particle) showed a higher microleakage rate than a different fine-particle (Charisma) and a hybrid (Polofil Molar) composite. This can probably be explained through the initial volume

reactions of the different composites. Studies to test this supposition are currently being undertaken. The leakage reduction observed with all composites between the 48-hour and 1000-thermocycles groups can be explained through the incorporation of water into the composites. This phenomenon compensates for their initial shrinkage. Yet, it was noted that microleakage of composites increased as the number of thermocycles increased. This suggests that composites should be renewed at regular intervals in order to prevent marginal passage of bacteria from the occlusal into sound dentin and/or the root canal system. In the 100- through the 2000-thermocycling groups only slight microleakage differences were found between the composites and Tytin. This might suggest that composites could represent the material of choice instead of spherical amalgams. However, Polofil Molar, a hybrid composite, showed a linear ascending tendency that might indicate possible significant differences after 2000 thermocycles. Thus, microleakage studies of different composite formulations and spherical amalgams over longer thermocycling periods are desirable.

Sound scientific research should consider result reproducibility. The use of gold washers facilitates the reproduction of cavities and fillings of constant dimensions. The methodology and probe model used in this study allow the reproduction of results, objective quantification, and simplification of research parameters.

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References

AL-HAMADANI KK & CRABB HSM (1975) Marginal adaptation of composite resins *Journal of Oral Rehabilitation* **2** 21-33.

BLANEY TD, PETERS DD, SETTERSTROM J & BERNIER WE (1981) Marginal sealing quality of IRM and Cavit as assessed by microbial penetration *Journal of Endodontics* **7** 453-457.

CARLSON T, COCHRAN M & LUND M (1986) Effectiveness of direct restorative materials in repairing cast restorations *Operative Dentistry* **11** 143-146.

CARLSON TJ, NAGUIB EA, COCHRAN MA & LUND MR (1990) Comparison of glass-ionomer cements used to repair cast restorations *Operative Dentistry* **15** 162-166.

CHOHAYEB AA & BASSIOUNY MA (1985) Sealing ability of intermediate restoratives used in endodontics *Journal of Endodontics* **11** 241-244.

CRISP S & WILSON AD (1980) Radioactive tracer technique for monitoring of microleakage: An interim report *Journal of Biomedical Materials Research* **14** 373-382.

DELIVANIS PD & CHAPMAN KA (1982) Comparison and reliability of techniques for measuring leakage and marginal penetration *Oral Surgery, Oral Medicine & Oral Pathology* **53** 410-416.

DEVEAUX E, HILDELBERT P, NEUT C, BONIFACE B & ROMOND C (1992) Bacterial microleakage of Cavit, IRM, and TERM *Oral Surgery, Oral Medicine & Oral Pathology* **74** 634-643.

DEWALD JP, ARCORIA CJ & MARKER VA (1992) Evaluation of the interactions between amalgam, cement and gold castings *Journal of Dentistry* **20** 121-127.

FUSAYAMA F, KATAYORI T & NOMOTO S (1963) Corrosion of gold and amalgam placed in contact with each other *Journal of Dental Research* **42** 1183-1197.

GOING RE (1972) Microleakage around dental restorations: a summarizing review *Journal of the American Dental Association* **84** 1349-1357.

GOING RE, MASSLER M & DUTE HL (1960) Marginal penetrations of dental restorations as studied by crystal violet dye and I131 *Journal of the American Dental Association* **61** 285-300.

GOING RE, MYERS HM & PRUSSIN SG (1968) Quantitative method for studying microleakage in vivo and in vitro *Journal of Dental Research* **47** 1128-1132.

GRANATH L-E (1967) Studies on microleakage with restorative materials I: introductory experiments on amalgam *Journal of Dental Research* **46** 1331-1336.

GRANATH L-E & SVENSSON A (1970) Studies of microleakage with restorative materials. A new air pressure method *Scandinavian Journal of Dental Research* **78** 353-366.

HOLLAND RI (1980) Galvanic currents between gold and amalgam *Scandinavian Journal of Dental Research* **88** 269-272.

JOHANSSON BI (1986) An in vitro study of galvanic currents between amalgam and gold alloy electrodes in saliva and in saline solutions *Scandinavian Journal of Dental Research* **94** 562-568.

JOHANSSON BI & LAGERLÖF F (1992) Integrated currents between amalgams and a gold alloy in saline solutions and natural saliva with different chloride content *Scandinavian Journal of Dental Research* **100** 240-243.

JOHANSSON C & MOBERG L-E (1991) Area ratio effects on metal ion release from amalgam in contact with gold *Scandinavian Journal of Dental Research* **99** 246-253.

KRAKOW AA, deSTOPPELAAR JD & GRØN P (1977) In vivo study of temporary filling materials used in endodontics in anterior teeth *Oral Surgery, Oral Medicine & Oral Pathology* **43** 615-620.

KULLMANN W (1986) Glas-Ionomer-Zemente—Entwicklung, Eigenschaften und Verarbeitung In *Deutsche Zahnärztekalender* ed Ketterl W p 119 München: Hanser.

KULLMAN W (1989) Zemente, Adhäsive und Komposit-Kunstoffe In *Fortschritte der Zahnärtztlichen Prothetik und Werkstoffkunde* 4th edition, eds Voß R & Meiners H p 391 München: Hanser.

LEINFELDER KF, O'NEAL SJ & MUENINGHOFF LA (1986) Use of $Ca(OH)^2$ for measuring microleakage *Dental Materials* **2** 121-124.

LEISTNER M (1986) Korrodiert die zervikale Amalgamfüllung an der Goldkrone? *Deutsche Zahnärtliche Zeitschrift* **41** 761-764.

LIM KC (1990) Microleakage of intermediate restorative materials *Journal of Endodontics* **16** 116-118.

MAHLER DB & NELSON LW (1984) Factors affecting the marginal leakage of amalgam *Journal of the American Dental Association* **108** 51-54.

MAHLER DB & NELSON LW (1994) Sensitivity answers sought in amalgam alloy microleakage study *Journal of the American Dental Association* **125** 782-788.

MAREK M & HOCHMAN RF (1976) *In vitro* corrosion of dental amalgam phases *Journal of Biomedical Materials Research* **10** 789-804.

MOBERG L-E (1985) Long-term corrosion studies in vitro of amalgams and casting alloys in contact *Acta Odontologica Scandinavica* **43** 163-177.

MOBERG L-E & ODÉN A (1985) The microstructure of corroded amalgams *Acta Odontologica Scandinavica* **43** 179-190.

MOMOI Y, ASANUMA A, KOHNO A & YANAGISAWA K (1986) A measurement of galvanic current and electrical potential in extracted human teeth *Journal of Dental Research* **65** 1441-1444.

ODÉN A & TULLBERG M (1985) Cracks in gold crowns cemented on amalgam restorations *Acta Odontologica Scandinavica* **43** 15-17.

TAMSE A, BEN-AMAR A & GOVER A (1982) Sealing properties of temporary filling materials used in endodontics *Journal of Endodontics* **8** 322-325.

TAYLOR MJ & LYNCH E (1992) Microleakage *Journal of Dentistry* **20** 3-10.

TEPLITSKY PE & MEIMARIS IT (1988) Sealing ability of Cavit and TERM as intermediate restorative materials *Journal of Endodontics* **14** 278-282.

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In Vivo Adhesive Interface between Resin and Dentin

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S INOKOSHI • M F BURROW • T TAKATSU

Clinical Relevance
Adhesion to deep dentin by resin might be compromised by the presence of dentinal fluid.

SUMMARY

V-shaped cervical cavities prepared in monkey teeth were restored with several dentin bonding systems, and the in vivo resin-dentin interfacial structures were observed under the scanning electron microscope using an argon-ion etching technique. The hybrid layer could be clearly observed; its depth was dependent on the conditioner/primer used and tended to be thinner at the deep part of the cavity. Resin tags were also clearly observed, and their structure at the inner part was noted to be rougher than that closer to the tubule orifices. When 37% phosphoric acid gel was used, the tags in the deeper parts of the cavity were much rougher. Hemispherical and spherical roughened structures were observed directly above the tubule orifices, which were thought to be a mixture of dentinal fluid and bonding resin that had flowed out from the tubules. The acidic primer containing maleic acid and HEMA could not remove the smear plugs, and undissolved smear particles were observed in the tubules.

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INTRODUCTION

The essential mechanism of adhesion for current dentin bonding systems to the dentin substrate has been suggested as being the formation of a hybrid layer that is made up of resin that has impregnated the superficial demineralized dentin surface (Nakabayashi, 1982, 1984). Morphological analysis of the adhesive interface has been performed using the scanning electron microscope (SEM), transmission electron microscope (Nakabayashi, 1984; Abe, 1986; Sugizaki, 1991; Eick & others, 1989, 1991, 1992; Van Meerbeek & others, 1992), and confocal optical microscope (Watson, 1989). The SEM is a commonly used method among these observation instruments. However, a technique is necessary to enhance the structural differences at the resin-dentin interface. An argon-ion beam etching technique has been reported to be useful to disclose the morphological variation of the hybrid layer in several current dentin bonding systems using an SEM (Inokoshi & others, 1990, 1993; Sugizaki, 1991; Harnirattisai & others, 1992, 1993; Van Meerbeek & others, 1992; Tagami & others, 1993). However, all of these morphological studies have been performed using extracted teeth where no dynamic physiological

effects take place (Coffy, Ingram & Bjorndal, 1970; Kim & others, 1984; Kim, 1986; Meryon, Tobias & Jakeman, 1987; Gwinnett & Kanca, 1992). Many researchers have reported that removal of the smear layer and dentinal plugs with acidic conditioners will allow outflow of dentinal fluid onto the dentinal floor (Pashley & others, 1983; Pashley, 1990; Tagami, Sugizaki & Hosoda, 1990). Outward tissue fluid flow due to physiological intrapulpal pressure wets the dentin surface and can inhibit adhesion of resin to the dentin (Brännström & Nordenvall, 1978; Pashley & others, 1983; Pashley, 1990; Meryon & others, 1987; Jacobsen & Finger, 1993; Nikaido & others, 1994).

This in vivo study was designed to observe the interfacial structure between an adhesive resin and vital dentin of monkey teeth treated with several pretreatment agents that create different degrees of demineralization using an argon-ion beam etching technique (Inokoshi & others, 1990, 1993) in conjunction with an SEM.

METHODS AND MATERIALS

Two monkeys were anesthetized by intramuscular injection of 2 mg/kg ketamine (Ketaral, Sankyo Co, Tokyo, Japan) and intravenous injection of 2 mg/kg pentobarbital sodium (Nembutal Sodium Solution, Abbott Laboratories, Abbott Park, IL 60064). In order to compare resin-dentin interfaces of superficial and deep dentin with perpendicularly cut dentinal tubules, 20 standardized V-shaped cervical cavities (Figure 1) were prepared in the teeth using inverted cone-shaped diamond stones (#1421ss, Shofu Inc, Kyoto, Japan) at high speed under water spray coolant. An effort was made to prepare the cavities as deep as possible without pulp exposure.

Twenty teeth were divided into four groups of different dentin surface conditioning. The conditioning agents, adhesive resins, and the resin composites employed are listed in Table 1. Cavities were treated with 37% phosphoric acid gel, 10% citric acid with 20% $CaCl_2$ (10-20 Ca), and 0.3M EDTA-2Na + 0.2M EDTA-Fe-Na (EDTA 3-2) respectively for 60 seconds, followed by 10 seconds of air-water spray washing and 15 seconds air drying. In the fourth group, an acidic primer (Scotchprep, 55% HEMA/2.5% maleic acid in water) was applied to the cavity surfaces and continuously agitated with a small sponge pellet for 60 seconds. The surfaces were air dried without washing.

Table 1. Dentin Conditioners, Primer, and Resins Used

Materials	Composition	Batch #	Manufacturer
K-etchant	37% phosphoric acid gel	EG014	Kuraray Co Ltd, Osaka, Japan
10-20 Ca	10% citric acid + 20% $CaCl_2$		prepared by the authors
Scotchprep	2.5% maleic acid + 55% HEMA	9CK	3M Dental Products, St Paul, MN 55144
EDTA 3-2	0.3M EDTA 2Na +0.2M EDTA FeNa		courtesy of Dr Nakabayashi
Clearfil Photobond	Dual-cure bonding resin with 10-methacryloxydecyl dihydrogen phosphate	U:206 C:102	Kuraray
Protect Liner	Low-viscosity resin composite BIS-GMA-based microfilled resin filler weight 42 w/w%	0015	Kuraray

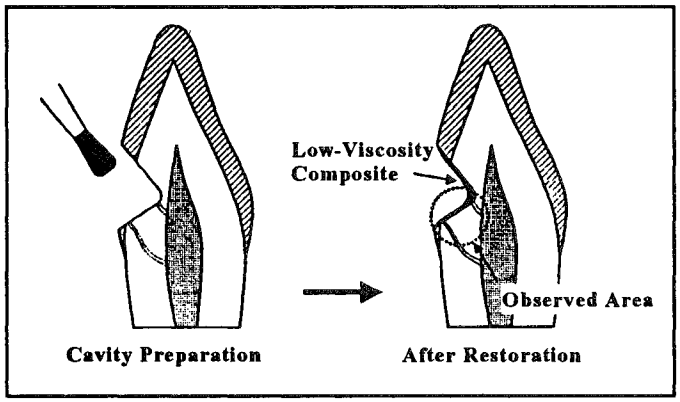

Figure 1. *A schematic illustration of the V-shaped cervical cavity*

The conditioned or primed cavity surfaces were then coated with a dual-cure adhesive resin (Clearfil Photo Bond, Kuraray Co Ltd, Osaka, Japan), which was light-cured for 30 seconds. A visible-light-cured low-viscosity resin composite (Protect Liner, Kuraray) was applied in a thin layer to cover the cavity surface and light cured for 60 seconds. No further placement of a resin composite was made so as to prevent separation of the bonding resin from the dentin surface due to curing contraction forces of the resin composite (Van Meerbeek & others, 1992).

After 3 days, the teeth were removed from the jaws

and fixed with 10% neutral buffered formalin solution for 24 hours. The teeth were then washed under running tap water, and longitudinally sectioned through the center of the cavities with a diamond saw microtome (Leitz 1600 saw microtome, Leica Instruments GmbH, Nussloch, Germany) under copious water lavage. The sectioned surfaces were ground and polished using wet silicon carbide papers and diamond pastes. The polished surfaces were subjected to argon-ion beam etching (EIS-1E, Elionix Ltd, Tokyo, Japan) for 10 minutes, under operating conditions of an accelerating voltage of 1kV and an ion current density of 0.2mA/cm^2, with the ion beam directed perpendicular to the polished surface (Inokoshi & others, 1990, 1993). The surfaces were then sputter coated with gold and observed under an SEM (JXA840, JEOL Ltd, Tokyo, Japan).

The depth of the hybrid layer at different parts of the cavity walls was measured from the SEM photographs. Statistical analysis of the results was performed using parametric one-way ANOVA and Fisher's protected least significant difference test for the difference among conditioners, and Student's *t*-test for the difference between deep and superficial dentin.

RESULTS

The hybrid layer and resin tags could be clearly observed at the interface between the resin and vital dentin treated with the three conditioners and primer. The mean depth of the hybrid layers and length of resin tags and undissolved smear plugs are represented in Table 2.

In Vivo Hybrid Layer

The depth of the hybrid layer was dependent on the conditioner/primer used, ranging in thickness throughout the cavity from 2 to 8 μm for 37% phosphoric acid gel (Figures 2 and 3), 1 to 6 μm for 10% citric acid containing 20% $CaCl_2$ (Figure 4), 1 to 5 μm for Scotchprep (Figure 5), and 0.1 to 2 μm for EDTA 3-2 (Figure 6). Hybrid layer depth was also dependent on the depth of the cavity, appearing to be thinner at the deep parts when compared with the middle and superficial parts (Figures 2 and 3). This tendency was more evident when 37% phosphoric acid gel, 10% citric acid with 20% $CaCl_2$, and EDTA 3-2 were used, but was less so for Scotchprep.

Statistical analysis of the depth of the hybrid layer revealed significant differences between deep and superficial dentin (t = -3.8 to -2.5; df = 8; $P < 0.05$) except for Scotchprep (t = -0.34 ; df = 8; $P = 0.74$). At the deep part of the dentin, the depth of hybrid layer was comparable among 37% phosphoric acid gel, Scotchprep, and 10% citric acid containing 20% $CaCl_2$, while EDTA was significantly thinner than the rest ($F = 7.1$; df = 3, 16; $P < 0.05$). At the superficial part of the dentin, 37% phosphoric acid gel and EDTA were significantly thicker and thinner than the rest respectively ($F = 10.9$; df = 3, 16; $P < 0.05$).

In Vivo Resin Tags

Thirty-seven percent phosphoric acid gel, and 10% citric acid with 20% $CaCl_2$ completely removed the smear plugs, and resin was observed to have penetrated into the open tubules forming tags. The resin tags were approximately 20 μm long and showed little difference between the deep parts of the cavity compared with the superficial region (Figures 2 and 4). After argon-ion beam etching, the surface of the resin tags that had penetrated deep into the dentin became much rougher than those close to the tubule apertures in all specimens. Especially at the inner third of the dentin, the tags were much rougher than those of the outer third. Also, hemispherical and spherical structures were observed in the bonding resin layer directly above the tubule orifices (Figures 2, 7, and 8). The ion-etched surfaces of these structures were as rough as those of the resin tags penetrating deep into the tubules.

With EDTA 3-2, although the hybrid layer at the intertubular dentin was thin, smear plugs were rarely observed at the tubule orifices, and resin was noted to have penetrated into the tubules. The length of these tags was about 20 μm (Figure 6).

The acidic primer containing maleic acid and HEMA failed to completely remove the smear plugs in most tubules. Undissolved dentinal plugs were fixed by infiltration of bonding

Table 2. Approximate Depth of Hybrid Layer, Length of Resin Tags and of Remaining Smear Plugs (μm)

Material	Mean Depth of Hybrid Layer* Inner Third		Outer Third		Length of Resin Tag	Length of Smear Plug
Phosphoric acid	3	(2-4)	6	(4-8)	20	-**
10-20 Ca	2	(1-3)	4	(2-6)	20	-
Scotchprep	3	(1-5)	3	(2-5)	20	15
EDTA 3-2	0.5	(0.1-1)	1.5	(0.5-2)	20	-

*Maximum and minimum values are in parentheses.
**- stands for absence of smear plugs.
Numbers of sample are five in each material.

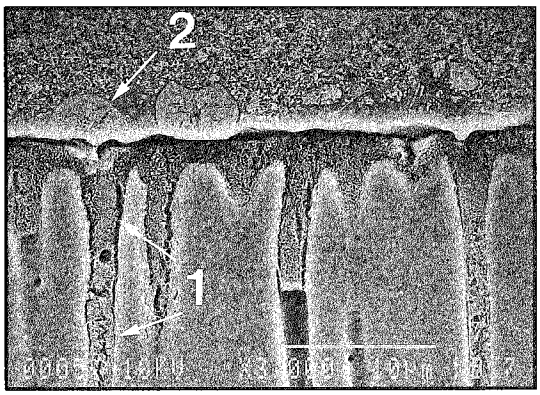

Figure 2. *SEM image of the inner third of the dentin treated with 37% phosphoric acid gel. The depth of the hybrid layer was about 2.5 μm. Resin tags were about 20 μm long, and the deeper parts became rougher compared with the superficial part (arrow 1). Spherical structures could be observed directly above tubule orifices (arrow 2). (magnification X1500)*

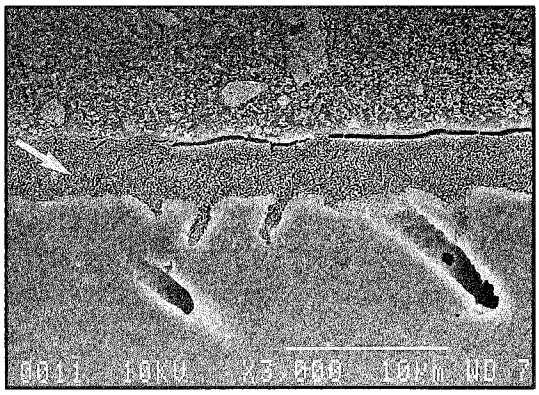

Figure 3. *SEM image of the outer third of the dentin treated with 37% phosphoric acid gel. Same tooth as Figure 2. The depth of the hybrid layer (arrow) was about 5 μm. (magnification X1500)*

resin and were clearly observed in longitudinally cut tubules, especially in the deeper part of the cavity. The length of the smear plugs was approximately 10 μm, and resin tags about 20 μm (Figure 5).

DISCUSSION

The greatest difference between vital and extracted teeth is the presence of living odontoblastic processes and fluid in the dentinal tubules. Although there has been much argument about how far the living processes extend into the tubules, during cavity preparation with diamond stones, grinding debris is forced into the tubules to form smear plugs (Pashley & others, 1983; Pashley, 1990), which may push the processes deep into the tubules away from the cavity surface. Therefore, the living processes do not seem to prevent the bonding resin from penetrating into the tubules to form resin tags.

Dentinal fluid is similar to extracellular fluid (Coffey & others, 1970) containing minerals and proteins. Once the tubules are cut open, the fluid tends to flow outwards because of the physiological intrapulpal pressure. Due to the fan-shaped radiation of dentinal tubules and tubule diameter that increases towards the inner part of the dentin, the inner dentin contains a greater area occupied by the tubules (Pashley & others, 1983; Pashley, 1990). Dentin permeability increases exponentially as the pulp chamber is approached (Tagami & others, 1990; Pashley, 1990). Meryon and others (1987) compared several smear removal agents using in vivo/vital and in vitro/nonvital dentin by SEM observations of treated cavity floors. They found a reduced etching effect of acids on in vivo samples in comparison with in vitro results. In the present study, demineralization of the intertubular dentin was determined on a longitudinal sectional view by measuring the depth of the hybrid layer. Demineralizing effects of the agents used are ranked in order of increasing severity, from EDTA 3-2 < Scotchprep < 10% citric acid with 20% $CaCl_2$ < 37% phosphoric

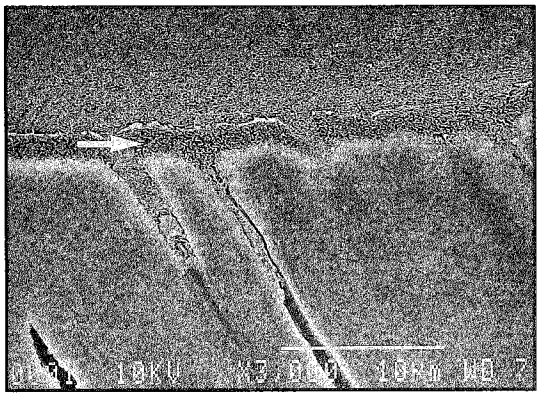

Figure 4. *SEM image of the inner third of the dentin treated with 10-20 Ca. The hybrid layer (arrow) was about 2 μm deep. (magnification X1500)*

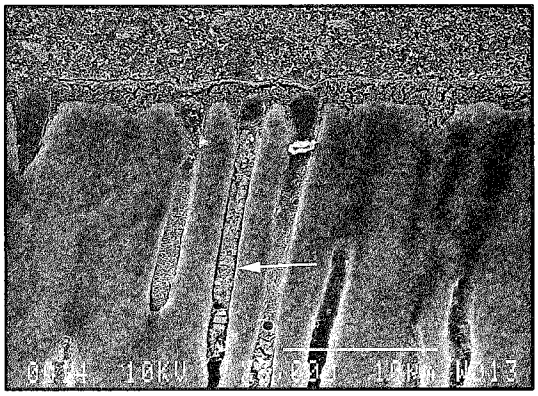

Figure 5. *SEM image of inner third of the dentin treated with Scotchprep. Undissolved smear plugs were about 10 μm long and were fixed by the infiltration of the bonding resin (arrow). The hybrid layer was about 2 μm deep. (magnification X1500)*

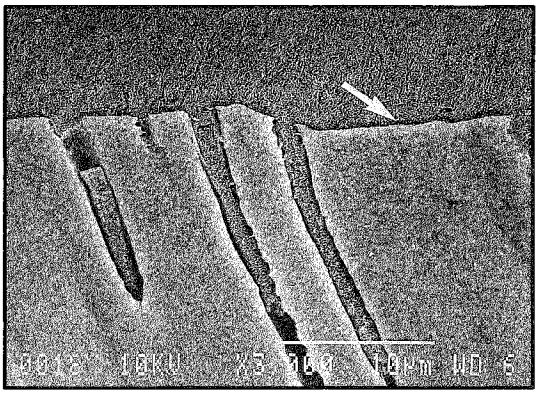

Figure 6. *SEM image of the inner third of the dentin treated with EDTA 3-2. The hybrid layer (arrow) was about 0.5 μm deep, and smear plugs could not be detected. (magnification X1500)*

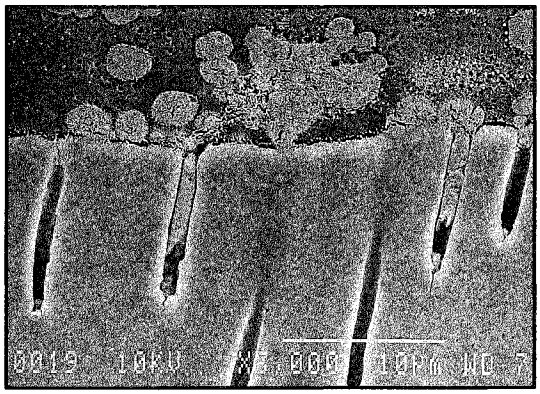

Figure 8. *SEM image of the interface identical to Figure 7. Bubble-like structures as observed under the light microscope were noted to be small, nonhomogeneous spherical structures in close apposition to tubule orifices. These structures are thought to be a mixture of dentinal fluid and the bonding resin. (magnification X1500)*

acid. Although the depth of the hybrid layers seems to be less than those produced in extracted teeth in vitro (Inokoshi & others, 1990, 1993), the order is the same. Reduced demineralizing effects in vivo seem to be due to dilution and buffering effects of the dentinal fluid.

In this study, experimental cavities were prepared at the cervical area in a V-shaped form, which enabled us to observe the resin-dentin interface with perpendicularly cut dentinal tubules. From this, easy comparison of the thickness of the hybrid layer at different depths of the cavity within one tooth could be performed, and it was found to be dependent upon not only the conditioners used, but also cavity depth. The reason for a thin hybrid layer near the pulp was probably due to the presence of dentinal fluid in the dentinal tubules that caused a dilution effect of the conditioners, and also the fluid may have acted as a buffer because of its mineral and protein content. In contrast, the thickness of the hybrid layer of

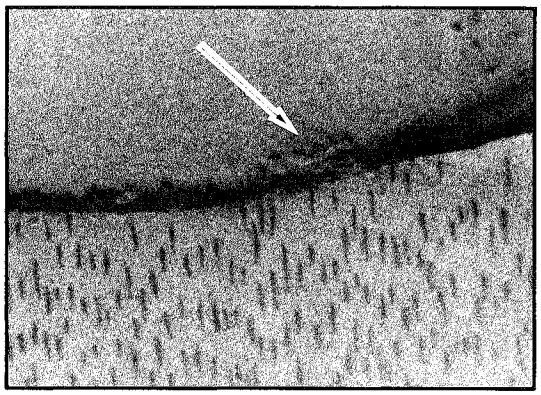

Figure 7. *Light microscopic image of the inner fifth of the dentin (remaining dentin thickness was about 0.5 mm) treated with 10-20 Ca. Numerous bubbles were observed in the bonding resin along the dentinal wall (arrow). (magnification X125)*

Scotchprep seemed to be independent of depth. Scotchprep has been reported to cause coagulation of bovine serum prepared at a similar protein concentration to dentinal fluid (Tagami & others, 1993). Coagulation of dentinal fluid in the dentinal tubules might suppress the dilution and buffering effects of the fluid. Another possibility was that HEMA might have provided support to the collagen fibers during the priming process. Inokoshi and others (1990), observing argon-ion etched human dentin by SEM, reported that the remaining collagen fibers after decalcification of the dentin tended to shrink or collapse. However, after priming it was observed that these collapsed fibers were restored close to the original height (Sugizaki, 1991). It is thought that HEMA may have had a similar effect on the decalcified dentin.

Argon-ion etching clearly disclosed structural differences in the resin tags, which became much rougher than the bonding resin over the dentin surface as previously reported using extracted teeth (Inokoshi & others, 1990,1993; Harnirattisai & others, 1992, 1993). Especially in the inner third of the dentin, the tags were much rougher than those of the outer third of the dentin (Figure 2), suggesting that polymerization may have been inhibited. Iwaku and others (1981) observed the inner surface of adhesive resin restorations placed in vital human teeth with the SEM by dissolving tooth substance with HCl and NaOCl. They reported that the length of the resin tags was relatively short, only reaching about 10 μm in length. However, Gwinnett and Kanca (1992) reported that occasionally resin tags penetrated into dentinal tubules to at least 150 μm in their in vivo study using human teeth. In this study, the length of the resin tags observed on longitudinal sections of dentinal tubules was as long as 20 μm, even at the inner third of the dentin. Since the inner structure of the resin tags appeared not

homogeneous, especially in the deep dentin, the shorter resin tags might be long tags that fractured during specimen preparation.

For Scotchprep, the smear plugs were embedded in the infiltrated bonding resin. The embedded plugs were as deep as 15 μm, even at the inner third of the dentin. This finding might also suggest that the particles of debris that form the smear plugs are tightly packed at the tubule orifices and are less tightly packed deeper in the tubules. The uppermost part of the smear plugs that tightly fill the tubule orifice might be loosened by the acidic primer, thus permitting the penetration of resin into the tubules through spaces between loosely packed plug particles. It is also surprising that the length of the remaining smear plugs was as long as 10 μm, even in the deeper parts of the vital intact dentin (Figure 5). On the other hand, resin-infiltrated smear plugs were rarely observed at the superficial part of the dentin. This might be caused by the difference of the tubule diameter. In the outer part, the tubule orifices are much narrower, which may not permit entry of smear particles deeper into the tubules.

When 37% phosphoric acid gel or 10-20 Ca were used, spherical and hemispherical structures could be observed in the bonding resin layer directly above the tubule orifices (Figures 2, 7, and 8). These are thought to be a mixture of the dentinal fluid leaking out from the open tubules and the bonding resin containing MDP and HEMA that had penetrated into the tooth structure. These findings suggest that polymerization of the dentin adhesive resin that penetrated into the dentinal tubules was inhibited not only by the presence of oxygen and water in the dentin, but also by fluid leaking out from the dental pulp. However, not all of the tubules in the deep dentin showed these structures. The permeability of dentinal tubules seems not to be uniform from one tubule to another.

Cavity preparation and restoration were performed under general anesthesia without local anesthesia in this study. However, local anesthesia is mandatory for preparation of normal intact dentin. Since local anesthesia suppresses intrapulpal blood circulation (Kim & others, 1984; Kim, 1986), the effect of dentinal fluid flow on the formation of the adhesive interface might be less pronounced. Long tag formation seen in human teeth (Gwinnett & Kanca, 1992) might be due to the effects of local anesthesia. Further study should be performed to clarify the effect of local anesthesia on adhesion of resin to dentin in vivo.

CONCLUSIONS

In this study, the in vivo interfacial structures between an adhesive bonding resin and vital dentin treated with three conditioners and a primer for 60 seconds were investigated using monkey teeth.

1. The depth of the hybrid layer varied depending on the conditioners. The demineralizing effects in vivo are ranked in order of increasing severity, from EDTA 3-2 < Scotchprep <10% citric acid with 20%$CaCl_2$ < 37% phosphoric acid.
2. The hybrid layer appeared to be thinner at the deeper part of the dentin compared with the middle and superficial parts. This tendency was clear for the three conditioners, but not for the acidic primer.
3. Three conditioners removed smear plugs, permitting penetration of resin into the tubules even at the inner third of the dentin. The inner structure of the resin tags seemed to be loose, and spherical, roughened structures were observed in the bonding resin layer directly above the tubule orifices, believed to be produced by a mixture of bonding resin and pulpal fluid.
4. The acidic primer did not remove the smear plugs, which were subsequently infiltrated by the bonding resin.

Further study is needed to confirm the structure of the resin-dentin adhesive interface in vivo.

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References

ABE Y (1986) Relation between interpenetration and bond strength to dentin with 4-META, Phenyl-P, HNPM, and 4-META/MMA-TBB resins *Journal of the Japanese Society for Dental Materials and Devices* **5** 839-851.

BRÄNNSTRÖM M & NORDENVALL KJ (1978) Bacterial penetration, pulpal reaction and the inner surface of Concise Enamel Bond Composite fillings in etched and unetched cavities *Journal of Dental Research* **57** 3-10.

COFFY CT, INGRAM MJ & BJORNDAL AM (1970) Analysis of human dentinal fluid *Oral Surgery, Oral Medicine & Oral Pathology* **30** 835-837.

EICK JD, COBB CM, CHAPPEL RP, SPENCER P & ROBINSON SJ (1991) The dentinal surface: its influence on dentinal adhesion. Part I *Quintessence International* **22** 967-977.

EICK JD, ROBINSON SJ, COBB CM, CHAPPEL RP & SPENCER P (1992) The dentinal surface: its influence on dentinal adhesion. Part II *Quintessence International* **23** 43-51.

EICK J, SPENCER P, CHAPPEL R, COBB C, ROBINSON S & SACKUVICH D (1989) Further SEM/TEM of the smear layer and dentin-adhesive interface *Journal of Dental Research* **68** *Abstracts of Papers* p 321 Abstract 1116.

GWINNETT AJ & KANCA J III (1992) Micromorphological relationship between resin and dentin in vivo and in vitro *American Journal of Dentistry* **5** 19-23.

HARNIRATTISAI C, INOKOSHI S, SHIMADA Y & HOSODA H (1992) Interfacial morphology of an adhesive composite resin and etched caries-affected dentin *Operative Dentistry* **17** 222-228.

HARNIRATTISAI C, INOKOSHI S, SHIMADA Y & HOSODA H (1993) Adhesive interface between resin and etched dentin of cervical erosion/abrasion lesions *Operative Dentistry* **18** 138-143.

INOKOSHI S, HOSODA H, HARNIRATTISAI C, SHIMADA Y & TATSUMI T (1990) A study on the resin-impregnated layer of dentin. Part I. A comparative study on the decalcified and undecalcified sections and the application of argon ion beam etching to disclose the resin-impregnated layer of dentin *Japanese Journal of Conservative Dentistry* **33** 427-442.

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.

IWAKU M, NAKAMICHI I, NAKAMURA K, HORIE K, SUIZU S & FUSAYAMA T (1981) Tags penetrating dentin of a new adhesive resin *Bulletin of Tokyo Medical and Dental University* **28** 45-51.

JACOBSEN T & FINGER W J (1993) Morphology of coupling sites between bonding agents and dentin in vivo and in vitro *Journal of Dentistry* **21** 150-157.

KIM S (1986) Ligamental injection: A physiological explanation of its efficacy *Journal of Endodontics* **12** 486-491.

KIM S, EDWALL L, TROWBRIDGE H & CHIEN S (1984) Effects of local anesthetics on pulpal blood flow in dogs *Journal of Dental Research* **63** 650-652.

MERYON SD, TOBIAS RS & JAKEMAN KJ (1987) Smear removal agents: a quantitative study in vivo and in vitro *Journal of Prosthetic Dentistry* **57** 174-179.

NAKABAYASHI N (1982) Resin-reinforced dentin due to infiltration of monomers into the dentin at the adhesive interface *Journal of the Japanese Society for Dental Materials and Devices* **1** 78-81.

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

NIKAIDO T, BURROW MF, TAGAMI J & TAKATSU T (1994) Effect of pulpal pressure on adhesion of resin composite to dentin-bovine serum vs saline *Quintessence International* (In press).

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

PASHLEY DH, KEPLER EE, WILLIAMS EC & OKABE A (1983) The effects of acid etching on the in-vivo permeability of dentine in the dog *Archives of Oral Biology* **28** 555-559.

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.

TAGAMI J, SUGIZAKI J & HOSODA H (1990) Effect of various pretreatments for dentin bonding on dentin permeability *Journal of the Japanese Society for Dental Materials and Devices* **9** 240-246.

TAGAMI J, SUGIZAKI J, NAKAJIMA M, SHONO T, TAKATSU T & HOSODA H (1993) Effect of SA-primer on dentin bonding of adhesive resin material *Journal of Hard Tissue Biology* **2** 6-12.

VAN MEERBEEK B, INOKOSHI S, BRAEM M, LAMBRECHTS P & VANHERLE G (1992) Morphological aspects of the resin-dentin interdiffusion zone with different dentin adhesive systems *Journal of Dental Research* **71** 1530-1540.

WATSON TF (1989) A confocal optical microscope study of the morphology of the tooth/restoration interface using Scotchbond 2 dentin adhesive *Journal of Dental Research* **68** 1124-1131.

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BOOK REVIEWS

FUNDAMENTALS OF PEDIATRIC DENTISTRY
Third Edition

Richard J Mathewson and Robert E Primosch

Published by Quintessence Publishing Co, Inc, Chicago, 1995. 400 pages, 661 illustrations. $58.00, softbound.

In the third edition of this practical text the authors set out to present "step-by-step guidelines for all phases of pediatric dentistry." Dr Mathewson is a professor and chairman of the Department of Pediatric Dentistry at the University of Oklahoma, and Dr Primosch is a professor in the Department of Pediatric Dentistry at the University of Florida. They are both well known as clinicians and educators and lecture widely in the specialty of pediatric dentistry. This text is written in a style that should appeal to students and practitioners who are looking for concise information with immediate clinical application. Each chapter begins with a list of objectives that the reader should accomplish in reading the chapter. Additionally, there are questions related to these objectives at the end of each chapter. This unique format allows the reader to self-assess the retention of important points in each chapter.

The book is divided into the major categories of "Diagnosis," "Child Management," and "Clinical Procedures," and the authors have done an admirable job of covering the spectrum of pediatric dentistry within the confines of a rather small text. Each section is divided into multiple chapters, which to a varying degree review one aspect of the section. Within this format there is always a difficulty in assigning appropriate weight to the various chapters. The authors have generally maintained a good sense of balance, but there are some exceptions, such as the chapter on hospital dentistry in the "Child Management" section. This chapter is overly detailed, since any reader who is going to work in a hospital will have to undergo direct hands-on training in the policies and procedures of that institution. The majority of readers of this text would wish to merely understand where care under general anesthesia fits within the spectrum of child management. The text is generously illustrated, but unfortunately the quality of the reproduction at times detracts from the impact of the material. This is especially evident in the chapter on radiology, which has very unclear reproduction of many of the radiographs and line diagrams which, although illustrative of the point, appear amateurish and out of sync with the general quality of the book. As in any text there is always a problem of developments that occur during or shortly after publication. Chapter 7 is a good review of fluoride therapy, but the dosage recommendations for fluoride supplementation were changed earlier this year, likely when the book was in press.

The three chapters on restorative procedures are "Restorative Procedures for Primary Molars," "Stainless Steel Crown Procedures for Primary Molars," and "Restorative Procedures for Primary Incisors." Any reader will find these chapters well worth the price of the book. The text is clear and thorough, the illustrations are good, and the information is timely and current. The authors cover the most current techniques using glass ionomers, hybrid composite resins, and composite resins. They also well illustrate the traditional procedures used for restoration of the primary dentition.

This book would be a valuable addition to the library of any clinician who treats children. It not only provides an excellent overview of pediatric dentistry but also would be a superb chairside reference book.

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IMPLANTOLOGY

Hubertus Spiekermann, MD, DDS, PhD

Published by Thieme Medical Publishers, Inc, New York, 1995. 388 pages, 1537 illustrations. $189.00.

It is well accepted that implants have become an integral part of dental therapy today. *Implantology* is part of the *Color Atlas of Dental Medicine* series published by Thieme. This atlas is timely and the most complete of its kind to date. It is an English translation of the original German edition and is written for the dentist and the student, both graduate

and undergraduate, who practice or are learning the application of dental implantology. It stresses the knowledge that is required in the biologic, biomechanical, surgical, and restorative aspects before one seriously engages in implant therapy. The author is well qualified as a scientist, teacher, and clinician and utilizes the help of distinguished individuals as editors and contributors. Practical information abounds in this publication. The clinical and technical parts of the atlas are excellent as references for the technologist as well, for the fabrication of implant-supported restorations.

The book is divided into 18 sections that cover implant dentistry, including the prerequisites, materials, systems, histopathology and biomechanicals, diagnostic methods, surgical and prosthetic procedures. While the scope of the atlas does not attempt to provide a comprehensive review of the scientific studies on the subject, it does nonetheless cover it sufficiently. It contains over 700 references as current as 1993. The style and overall design of the atlas are attractive, well organized, and readable. The clinical and technical photographic illustrations are in color. They are especially clear, precisely showing what the author describes.

The atlas includes sections on all currently accepted modalities of implant treatment from the totally endentulous to the partially dentate and the single-tooth replacement. It does not neglect the basic requirements of occlusion nor the follow-up care that is so necessary in implant therapy.

If there are any valid criticisms of this atlas it is in the lack of discussion of the cementable versus screw-retained techniques that are currently both widely accepted. For the most part the author emphasizes the screw-retained prosthesis except for a brief inclusion of the UCLA abutment. Currently the profession is offered a confusing array of abutment choices other than those designed for screw retention of the superstructure. It would be welcomed by the reader to have an expression of the author's view of the advantages and disadvantages of both techniques. The sections on Peri-Implant Pathology, other surgical and prosthetic complications, and guided bone regeneration are useful but not as complete as they could be.

To summarize, this atlas is certainly one of the best on the topic and is one that deserves careful consideration by all who are involved in providing implant therapy.

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COLOR ATLAS OF ORAL DISEASES
Second Edition

George Laskaris

Published by Thieme Medical Publishers, Inc, New York, 1994. 386 pages, 555 illustrations. $99.00.

Color Atlas of Oral Diseases by Laskaris is an example of perfection in illustration quality and knowledge of medicine and dentistry. This is not a surprise, knowing that the author is one of the most respected, highly published, experienced, and knowledgeable clinicians in the field of oral medicine and oral pathology.

The main goal of this atlas is to provide readers, mainly medical and dental practitioners, both generalists and specialists, with a collection of outstanding illustrations of oral diseases juxtaposed with concise and yet very informative descriptions of the diseases accompanied by proper diagnostic testing (where applicable) and differential diagnosis and treatment. The latter includes the most current treatment modalities combined with the author's extensive experience in this field. It is my opinion that this atlas has met and exceeded the author's goal. Also offered are selective references for the readers who are interested in further research in a specific disease.

The atlas is 386 pages, 35 chapters, with 555 color illustrations. The illustrations are chosen from a collection of 25,000 color slides. The main emphasis is on soft tissue diseases with no reference to bone pathology. The 35 chapters include common genetic disorders; mechanical, chemical, and radiation injuries; periodontal diseases; oral manifestations of systemic disease; allergy and drug-induced oral diseases; viral, bacterial, and fungal infections; AIDS and other infectious diseases. This atlas also has chapters on specific oral disease sites such as the tongue and lips, oral soft tissue cysts, endocrine and metabolic diseases and many benign and malignant epithelial, salivary gland, soft tissue, and hematopoietic neoplasms. One chapter is dedicated to the effects of tobacco use on oral mucosa.

It is encouraging to see the chapter specifically dedicated to effects of tobacco carcinogens on oral mucosa. There is no question that the practitioner will learn more about tobacco effects by reviewing this chapter.

The second edition is revised and expanded. New chapters have been added on HIV infection and AIDS and a chapter on renal diseases, with many new and high-quality color illustrations. In addition to the new chapters, the text in many other chapters has been revised and provided with more representative illustrations.

When comparing this atlas with others, there is no question that the organization, differential diagnosis, treatment, and high-quality illustrations of oral mucosa and soft tissue diseases are the

best in the field. In my opinion, this is the best atlas of oral mucosal lesions available, especially in the areas of vesiculo-bullous diseases, genetic diseases, smoking-related lesions, and infectious diseases.

I strongly recommend this atlas for general dental practitioners, oral pathologists, and oral medicine specialists, as well as for dermatologists and ENT surgeons.

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DENTAL IMPLANTS: ARE THEY FOR ME?

Thomas D Taylor and William R Laney

Published by Quintessence Publishing Co, Inc, Chicago, 1993. 60 pages, 48 illustrations. $26.00, softbound.

This paperback booklet is for the patient who is considering dental implants for the replacement of missing teeth. The booklet answers the following questions for the patient: What are dental implants? Are they for you? How are they placed in your mouth? What is the best way for you to take care of them?

The authors have systematically explained to the patient the steps to be considered for dental implants. Subjects covered very well are: indications and contraindications, risks, types of implants, definition of osseointegration, cost, and the typical course of implant treatment.

The language and illustrations are very clear and concise and are presented so a patient will easily understand the terminology. The course of treatment follows primarily total edentulism; there could be a better balance between total and partial edentulism.

As the field of dental implantology continues to grow, patients have increased questions about dental implants. This booklet gives an excellent foundation for patients who are considering dental implants as part of their dental treatment. It would be a good booklet to have available in the dental office.

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LASERS IN DENTISTRY

Leo J Miserendino and Robert M Pick

Published by Quintessence Publishing Co, Inc, Chicago, 1995. 344 pages, 349 illustrations. $98.00.

This text is the first comprehensive publication about lasers in dentistry. Its stated goal is to help clinicians understand the relationship between different types of lasers and their respective tissue reactions. It is designed to act as a guide to laser physics and tissue interaction, laser safety, and current status in dental practice. Miserendino and Pick achieve their goals in an outstanding manner. The book is written for an international audience and employs contributors from many parts of the United States and five foreign countries.

The book is divided into four parts: 1) "Scientific Basis," 2) "Practical Considerations," 3) "Current Applications," and 4) "Current Technology and Future Directions." This arrangement makes finding information easy, aided by a clear table of contents and fairly comprehensive index. The appendices include a glossary, units of measurement, laser precautions, and curriculum guidelines and standards; these are valuable to clinicians and educators alike. Each chapter is followed by a list of references. The illustrations are of high quality, well placed within the text, and include many color plates.

The most clinically useful part of the book is the section on current applications. Clinical uses are divided by type of laser (six are listed), and procedures are described in detail. Laser processing of dental materials is included, as is biostimulation and photodynamic therapy. The latter is interesting but probably not practical for most dental practitioners. The other three sections of the book are also informative; however, the chapters on modern optics and laser physics may be a little difficult for some readers to understand. There is a fair amount of repetition in many of the chapters and, if a second edition is printed, the book would be greatly improved if this problem were addressed. One aspect of the approach taken by Miserendino and Pick disturbed this reviewer. On page 133, the following is stated: "The purpose of this material is not to argue the indications and contraindications based on the published literature but to provide the practitioner with an adequate description of the technique for this application." The profession would be well served if authors with the depth of knowledge of those who contributed to this text were a little more critical of the laser and spent more time on possible problems and relative indications and contraindications for each clinically useful wavelength of light.

If practitioners are interested in a comprehensive description of lasers in dentistry today, this text will fully satisfy the needs of the novice and experienced laser dentist.

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ANNOUNCEMENTS

Notice of the
ANNUAL MEETING of the
AMERICAN ACADEMY OF GOLD FOIL OPERATORS

1-4 November 1995
Cottages Conference Center,
Hilton Head Island, South Carolina

The meeting this year will have a different format from those in the past. In addition to a clinical presentation by 20 to 24 operators at the Naval Dental Clinic at the Marine Base at Parris Island, there will be three half-day sessions with presentations by various people on a variety of subjects, including Dr Frank Spear ("Communications in Esthetic Crown and Bridge Cases"), Drs Richard V and Richard D Tucker ("What is Quality Dentistry Today?"), Dr Steve Duke ("Adhesive Restorative Materials: Expectations vs Realizations"), Dr Alan Osborn ("The Class 3 Gold Foil: Design, Preparation, and Filling"), Dr Peter Miller ("Healthful Living through Reduced Stress"), and Dr Darryl Farley ("Critique of Clinical Operations").

In addition to scheduled social activities, including an afternoon cruise of the Hilton Head Bay area, there will be golf, tennis, and beach walks—something for everyone.

For further details regarding registration costs and accommodations, please contact:

Dr Ronald K Harris, Secretary-Treasurer
17922 Tallgrass Court
Noblesville, IN 46060
(317) 867-3011

BASES, LINERS, AND VARNISHES UPDATE

Operative Dentistry published an excellent letter in 1994 (volume 19, number 1, page 35), submitted by Dr James Summitt, that outlined definitions for bases, liners, and varnishes. Feedback from several *Operative Dentistry* readers resulted in changes to the original definitions and structure. The following groups are segregated into categories based on an increase in thickness and viscosity proceeding from sealers to bases. The revision is as follows:

1. Cavity Sealers provide a protective coating for freshly cut tooth structure of the prepared cavity.
   a. **Varnish**: A natural gum, such as copal rosin, or a synthetic resin dissolved in an organic solvent, such as acetone, chloroform, or ether. Examples include Copalite, Plastodent Varnish, and Barrier.
   b. **Resin Bonding Agents**: Includes the primers and adhesives of dentinal and all-purpose bonding agents. Examples include All-Bond 2, Scotchbond MP+, Optibond, ProBond, Amalgambond, etc.
2. Cavity Liners: Resin or cement coating of minimal thickness (usually less than 0.5 mm) to achieve a physical barrier and/or therapeutic effect (a chemical effect that in some way benefits the health of the tooth pulp). Examples include Dycal, Life, Cavitec, Hydroxyline, Vitrebond, and Fuji Lining LC.
3. Cavity Bases: A replacement material for missing dentinal tooth structure, used for bulk buildup and/or for blocking out undercuts.

Thanks to Dr Summitt for his continual concern for providing a definitive classification structure for these materials and for sharing it with readers of *Operative Dentistry*.

RICHARD B McCOY
Editor

BOUND ISSUES OF *OPERATIVE DENTISTRY* AVAILABLE

Volume 19 of *Operative Dentistry* (1994, six issues) has been bound and is available for purchase from the Editorial Office in Seattle. Individual volumes sell for $30.00 each, while the entire set of 19 volumes sells for $350.00. Checks or money orders should be made payable to Operative Dentistry and sent to:

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INSTRUCTIONS TO CONTRIBUTORS

Correspondence

Send manuscripts and correspondence about 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 of the source or manufacturer. The editor reserves the right to make literary corrections.

Authors who prepare their manuscripts on a word processor are encouraged to submit an IBM-compatible computer disk of manuscript (3½ - or 5¼-inch) in addition to original typed manuscript; authors need to identify the word processing program used.

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

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References

Arrange references in alphabetical order of the authors' names at the end of the article, the date 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, thus: Smith (1975) found ...; or, by placing both name and date in parentheses, thus: 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); 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.

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EDITORIAL

ORIGINAL ARTICLES

DEPARTMENTS

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Second Class