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Aim and Scope

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

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EDITORIAL

The Three *D*'s: the Dream, the Determination, the Delivery

In the early 1970s, a group of conscientious dentists met to develop a plan of action for beginning a new journal to be called *Operative Dentistry*, the purpose of which would be to advance the practice of operative dentistry. The format was presented to the Academy of Operative Dentistry and the American Academy of Gold Foil Operators. These academies, dedicated to quality restorative dentistry, voted to sponsor this new venture. Dr Ian Hamilton volunteered to become the first editor, and the initial issue was published in the winter of 1976. Dr Hamilton, along with the 27 referees comprising his Editorial Board, painstakingly set about obtaining, reviewing, and editing articles to be published in the journal. To assist him in this awesome task were his associate editors, Drs David Grainger and Clifford Miller, as well as his managing editor, Dr Marty Anderson, who was responsible for the subscriptions, finances, and production of the journal. Assistant managing editors were Drs Lyle Ostlund and Ralph Werner. Joan Manzer served as editorial assistant and later as editorial associate for the first 12 years of the journal's existence. From the third through the seventh year Roberta Merryman served as editorial secretary and then as editorial assistant. Dr Anderson solicited the help of one of his dental assistants, Judy Valela, to serve as subscription manager. Her salary came from Dr Anderson, for the journal had no funds with which to pay her. This continued for many years as Dr Anderson not only gave of his own time and energy but also supported Judy's salary and dedicated one of the operatories in his private practice for journal support. The years went by and *Operative Dentistry* grew in prestige and subscribers. Lou-Ann Loew (1983-84) and Nancy Neyens (1985-86) took their turns as editorial assistant during these years. Those of us who had been subscribers since its inception were proud of our journal and marveled at the quality and relevance of published articles.

In 1986 Dr Hamilton passed the baton to Dr David Bales, who had been recruited as chairman of the Department of Restorative Dentistry at the University of Washington. Dr Bales aggressively pursued time- and cost-effective improvements by introducing computer technology to journal production. He also introduced two new "stars" to journal support—his wife Darlyne, who assumed the duties as editorial assistant in 1987, and Kate Flynn Connolly, who became editorial associate in 1988. The dedication and endless energy he devoted to the journal were as monumental as they had been for Dr Hamilton. Since the financial picture was still quite bleak, Darlyne worked without pay for many months. The voluminous correspondence, manuscript control, and coordination of journal activities were consolidated into her position.

Dave passed the baton to Dr Max Anderson in January of 1993. Advances in the computer world had been skyrocketing, and Max incorporated these improvements, dedicating himself to streamlining our journal's operation. He recognized that Kate Connolly had a tremendous untapped ability in the computer field and began grooming her to take over the pagesetting and other duties required by the publisher. At this point, *Operative Dentistry* finally reached the level where income exceeded expenses. With a brighter financial picture, vast improvements in computer technology, and the creative genius of Dr Max, *Operative Dentistry* continued its rise to fame from the stimulation and efforts of the editors before him.

Your journal remains on a solid foundation with the same staunch support staff (Darlyne Bales, Judy Valela, Marty Anderson, and Kate Connolly) as well as loyal referees on the Editorial Board and supportive editorial advisors. The importance and reputation of *Operative Dentistry* has noticeably continued its upward momentum. More and more articles are using *Operative Dentistry* for references. The recognition for all the hard work that so many dedicated professionals and Academy members have expended was paid to *Operative Dentistry* in the January, 1994, issue of *Dental Materials*. The article "Review of the 1993 Dental Materials Literature" by Stephen Bayne and Edward Swift included our journal as one of the 17 **primary journals** for dental materials scientific literature during 1993. There were also 101 secondary journals referred to in this article.

Those of us who have so richly benefitted from reading *Operative Dentistry* sincerely thank all of you who have contributed so much in making our journal one of the very best.

R B McCOY
Editor

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ORIGINAL ARTICLES

Increases in Cavity Volume Associated with the Removal of Class 2 Amalgam and Composite Restorations

A R HUNTER • E T TREASURE • A J HUNTER

Clinical Relevance
Removal of class 2 composites results in significantly larger cavity volumes when compared to amalgams.

SUMMARY

Removal of amalgam restorations from class 2 cavities has been shown to cause increases in cavity volume. The aim of this study was to test whether the removal of composite resin from class 2 cavities was associated with greater increases in cavity volume compared to that produced during removal of amalgam. Class 2 cavities were prepared in previously extracted human molar teeth and the cavity volumes calculated. The teeth were restored with either amalgam or a composite resin and appropriate dentin bonding agent (APH/Optibond). Two dentists removed the restorations, and the resultant cavity volumes were calculated. The results were analyzed using a standard *t*-test, ANOVA, and a Scheffé F-test. Removal of composite from class 2 cavities resulted in significantly increased cavity volumes compared to that when amalgam was removed. While there was significant interoperator difference in cavity volumes following removal of amalgam from class 2 cavities, there was no significant interoperator difference in cavity volumes following the removal of composite. These differences were related to the methods used to eliminate the restorations from the cavities.

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INTRODUCTION

Composite resins are often preferred to amalgam for the restoration of class 2 cavities. This is probably due to their ability to bond to tooth tissue; the increasing reluctance of the public to have mercury-containing restorations; their ability to develop early strength, thereby reducing the likelihood of early fracture; and their superior aesthetics. Posterior composite materials, however, still suffer from problems of microleakage, excessive wear, and reduced strength compared with amalgam (Lambrechts, Braem & VanHerle, 1987; Burgess, Summitt & Laswell, 1987; Ferracane, 1992), and it has been shown that their longevity in posterior cavities is less than that of amalgam (Qvist, Qvist & Mjör, 1990; Mjör, Jokstad & Qvist, 1990).

The ability of composite to bond directly to tooth structure has led to the suggestion that cavity shapes can be more conservative in their design. Once adequate access has been established, then only the diseased tooth tissue requires removal (Hosoda & Fusayama, 1984; Simonsen, 1991; Nordbo, Leirskar & von der Fehr, 1993). The resultant reduction in cavity size may have major implications, as it has been demonstrated that increases in cavity size cause reductions in tooth strength (Mondelli & others, 1980; Stampalia & others, 1986; Hood, 1991). With the introduction of the third-generation dentin bonding agents, it would appear that the bond strengths obtained when joining composite to dentin are close to those obtained when bonding to enamel (Triolo & Swift, 1992; Barkmeier & Cooley, 1992; Leinfelder, 1993).

The ability to bond strongly to tooth tissue and the improved aesthetics of composite resins may make it more difficult to remove them adequately from class 2 cavities when replacement is indicated. The difficulty in distinguishing between resin and tooth and its adherence to the cavity wall may lead to excessive enlargement of cavity volume during its removal. The aim of this experiment was to test whether removal of composite from class 2 cavities was associated with increased amounts of tooth tissue being removed compared to that experienced when a class 2 amalgam was replaced.

METHODS AND MATERIALS

Conservative class 2 cavities were prepared on extracted third molar teeth previously stored in distilled water. These teeth were then "boxed" in polyethyl methacrylate resin (Trim, H J Bosworth Co, Skokie, IL 60076) and an occlusal template fabricated in Duralay resin (Reliance Dental, Worth, IL 60402). The resins were allowed to polymerize for at least 48 hours to reduce the amount of dimensional change. Minimal class 2 cavities were prepared in each tooth using an ultra-high-speed turbine and a 541 diamond bur. The prepared teeth were located in their boxing and the volume of the cavities determined by making an impression in regular body addition silicone (Exaflex, G-C International, Tokyo, Japan), and replacing the occlusal template (figure). Once the silicone impression material had set, the teeth were removed from their boxing and excess impression material dissected, with a sharp scalpel, back to the margins of the cavity. This was done under magnification. Two impressions of each cavity were made and the impressions were then weighed on an electronic balance (Sartorius GmbH, Göttingen, Germany).

After cavity preparation the teeth to be restored in amalgam (Permite C, Southern Dental Industries Ltd, Victoria, Australia) were washed and air dried for 30 seconds. No cavity varnish was used, and they were restored using a combination of mechanical and manual compaction.

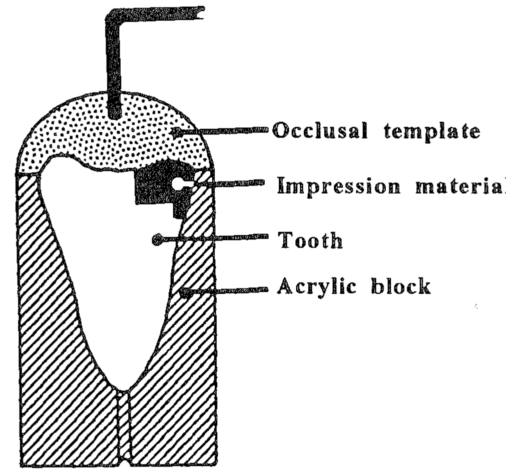

Diagram of the experimental method

The teeth to be restored in composite (APH Prisma, L D Caulk, Milford, DE 19963) were washed for 30 seconds and air dried for 30 seconds. An enamel and dentin bonding agent, Optibond (Kerr Mfg Co, Romulus, MI 48174), was applied according to the manufacturer's instructions, and the composites were placed and cured in three increments using a commercially available curing light (ESPE GmbH, Seefeld/Oberbay, Germany).

The restored teeth were then stored in distilled water for at least 48 hours before being attached to a Columbia plastic dentoform arch (Columbia Dental Corporation, Long Island City, NY 11101-4803) and mounted in a Kavo phantom head (Kaltenbach and Voigt GmbH and Co, D-88396 Biberach, Bismarckring 39, Germany) in an attempt to simulate clinical conditions. Two dentists removed the restorations from the cavities using ultra-high-speed burs of a standard size (541 diamonds) and fiber-optic illumination but without magnification. Each dentist was given a combination of amalgam and composite restorations and asked to remove all visible restorative material. The time taken, in minutes, was recorded. The teeth were replaced in their previously fabricated boxing and further impressions of the new cavity volume made. The volume of the resultant cavity was

Table 1. Number and Types of Restorations Removed by Each Operator

Operator	Composite	Amalgam	Total
A	11	11	22
B	11	11	22
Total	22	22	

determined using the equation:

Volume (V) = weight (W) / density (D), where the density of the impression material was calculated previously from:

D = W / V.

Each tooth was placed under a stereomicroscope (Nikon 100306, Tokyo, Japan) to assess whether all of the restorative material had been removed from the cavity.

Table 2. Volume Increase in Cavity Size following Amalgam and Composite Removal

	mean cm³	increase %	standard deviation	minimum increase cm³	minimum increase %	maximum increase cm³	maximum increase %
amalgam removal n = 22	0.006	2.23	0.004	0.001	0.22	0.168	8.76
composite removal n = 22	0.012	3.31	0.006	0.001	0.25	0.029	7.83
	$t = 3.57$ $P < 0.01$						

RESULTS

Each operator removed 11 amalgam restorations and 11 composite restorations (Table 1). Clinically it took three times longer to remove composite than amalgam from class 2 cavities. Incomplete elimination of all composite from the cavities, especially from the gingival floors of approximal boxes, was frequently observed.

Regression analysis of the weights of duplicate impressions taken for each cavity showed that the weights recorded were consistent at r = 0.99. The pooled results showed that removal of either material produced a statistically significant increase in cavity volume ($P < 0.01$). The increase in cavity volumes produced after composite was removed were significantly greater than that for amalgam (Table 2).

The cavity volume increases when amalgam or composite was removed by operator A were not statistically different (Table 4). Removal of composite by operator B resulted in significantly greater increases in cavity volume compared to when he removed amalgam (Table 4). The amount the cavity volume increased when amalgam was removed was significantly different between operators. Operator A removed significantly more tooth when removing amalgam than operator B (Tables 3 & 4). The increase in cavity volumes associated with composite removal was not significantly different between operators (Table 4).

Table 3. Volume Increase in Cavity Size following Amalgam and Composite Removal—Comparison of Two Operators

	mean increase cm³	mean increase %	standard deviation	minimum increase cm³	minimum increase %	maximum increase cm³	maximum increase %
amalgam removal							
Operator A n = 11	0.009	3.71	0.004	0.003	1.24	0.017	8.76
Operator B n = 11	0.004	0.75	0.002	0.001	0.22	0.007	1.05
composite removal							
Operator A n = 11	0.012	3.79	0.005	0.0001	0.03	0.021	7.83
Operator B n = 11	0.012	2.83	0.008	0.004	0.85	0.029	6.57

Table 4. Statistical Differences between Removal of Types of Materials and between Operators Using Scheffé F-Test after an ANOVA

Operator A amalgam compared to composite	NS
Operator B amalgam compared to composite	$P < 0.01$
Operator A amalgam compared to Operator B amalgam	$P < 0.01$
Operator B composite compared to Operator A composite	NS

DISCUSSION

Under ideal conditions, the percentage increases in cavity volume when amalgam restorations were replaced has been reported to be less than 2% (Whitehead & Wilson, 1988). Elderton (1977) reported that cavities became "... substantially larger when amalgam restorations were replaced." The results of this study are consistent with these previous reports, with increases in cavity volume following amalgam removal of around 2%. It is possible that the overall increase in cavity volume following removal of a restoration may not continue to be as great as a percentage of the total volume of the original cavity when the class 2 cavities are larger.

The significant increases in cavity volumes associated with composite removal, compared with amalgam removal, were expected, as the interface between composite and tooth tissue was extremely difficult to locate. The use of an intermediate liner, such as glass-ionomer cement, may have allowed better demarcation between tooth and composite resin. With the increasing use of third-generation bonding agents, the excessive enlargement of cavities restored with composite resin may become more common. However, of equal importance was the difference between the operators in the amount the cavity volumes increased when materials were replaced. When removing amalgam, operator A removed significantly more tooth than operator B. Operator A used the high-speed turbine to drill out all of the material. In comparison, operator B used the turbine to eliminate only the retentive features of the amalgam and then used a plastic instrument to fracture out the remaining bulk. This latter technique did not take a longer time to eliminate amalgam from the cavity and produced significantly smaller increases in cavity volume, a conclusion also reached by Elderton (1977). As operator A drilled out both amalgam and composite, it was to be expected that the subsequent increases in cavity volume for these materials were similar for this operator. In contrast, operator B produced significantly greater increases in cavity volume when removing composite, compared to when amalgam was removed. This was because the composite was unable to be fractured out of the cavity, due to its strong dentin bond, and therefore had to be drilled out in a manner similar to that adopted by operator A. That there was no significant difference in the cavity volume size following composite removal between the operators tends to confirm this explanation.

It can be concluded that the method employed to remove the restorative material from a cavity has a significant effect on the degree of subsequent cavity enlargement. The removal of only the retentive features of an amalgam with a handpiece and then fracturing out the remaining material is associated with significantly smaller increases in cavity volume. Whether using amalgam-dentin bonding agents, as suggested by some authors (Lacy & Staninec, 1989), may make the elimination of amalgam from cavities by fracturing more difficult and lead to greater enlargments in cavity volume during amalgam replacement needs further investigation.

Even with the increased time associated with composite removal, incomplete elimination of composite, especially along the gingival floors of the approximal boxes, was observed. This is an area where the bond of composite to the tooth is least predictable, due to problems in achieving adequate moisture control and the poor quality of the enamel in this area (Martin & Bryant, 1984). The consequences of incomplete removal of pre-existing composite from the gingival floor of the approximal box are unclear. Whether the polymerization shrinkage associated with the placement of a new composite restoration over a fragment of remaining composite could lead to increased amounts of microleakage, sensitivity, and ultimately decay is open to debate. However, it is unlikely to improve the success of a new restoration.

The extra time involved in the removal and placement of posterior composites suggests that posterior composites are a relatively expensive treatment option, especially if the longevity of class 2 composite restorations is less than that of amalgam (Qvist & others, 1990). The increased frequency of replacement and the increase in cavity volume associated with replacement make it possible that, rather than preserving tooth tissue, the replacement of posterior composite restorations may be associated with significantly greater amounts of tooth destruction. This may be related to both the difficulty of distinguishing between the composite resin and tooth and the method of composite removal from the cavity. While there is some debate in the literature as to whether posterior composite resin bonded restorations reinforce teeth, there is no dispute that teeth are significantly weakened when cavity volumes increase (Hood, 1991).

CONCLUSIONS

1. Removal of composite resin from class 2 cavities produced significantly greater increases in cavity volume compared to removal of amalgam.
2. There were significant interoperator differences in cavity volume increase following removal of amalgam from class 2 cavities.
3. Fracturing of amalgam from class 2 cavities resulted in smaller increases in cavity volume.
4. There were no statistically significant interoperator differences in cavity volume increase following removal of composite from class 2 cavities.

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References

BARKMEIER WW & COOLEY RL (1992) Laboratory evaluation of adhesive systems *Operative Dentistry* **Supplement** 5 50-61.

BURGESS JO, SUMMITT JB & LASWELL H (1987) Posterior composite resins: a status report for the Academy of Operative Dentistry *Operative Dentistry* **12** 173-178.

ELDERTON RJ (1977) A method for relating subjective judgments of the quality of amalgam restorations to objective measurements of their morphology In *A Series of Monographs on the Assessment of the Quality of Dental Care* ed Allred H pp 53-74 London: University of London.

FERRACANE JL (1992) Using posterior composites appropriately *Journal of the American Dental Association* **123(7)** 53-58.

HOOD JAA (1991) Biomechanics of the intact, prepared and restored tooth: some clinical implications *International Dental Journal* **41** 25-32.

HOSODA H & FUSAYAMA T (1984) A tooth substance saving restorative technique *International Dental Journal* **34** 1-12.

LACY AM & STANINEC MA (1989) The bonded amalgam restoration *Quintessence International* **20** 521-524.

LAMBRECHTS P, BRAEM M & VANHERLE G (1987) Evaluation of clinical performance for posterior composite resins and dentin adhesives *Operative Dentistry* **12** 53-78.

LEINFELDER KJ (1993) Current developments in dentin bonding systems: major progress found in today's products *Journal of the American Dental Association* **124** 40-42.

MARTIN FE & BRYANT RW (1984) Acid-etching of enamel cavity walls *Australian Dental Journal* **29** 308-314.

MJÖR IA, JOKSTAD A & QVIST V (1990) Longevity of posterior restorations *International Dental Journal* **40** 11-17.

MONDELLI J, STEAGALL L, ISHIKIRIAMA A, NAVARRO MF de L & SOARES FB (1980) Fracture strength of human teeth with cavity preparations *Journal of Prosthetic Dentistry* **43** 419-422.

NORDBO H, LEIRSKAR J & von der FEHR FR (1993) Saucer-shaped cavity preparation for composite resin restorations in class II carious lesions: three-year results *Journal of Prosthetic Dentistry* **69** 155-159.

QVIST V, QVIST J & MJÖR I (1990) Placement and longevity of tooth-colored restorations in Denmark *Acta Odontologica Scandinavica* **48** 305-311.

SIMONSEN RJ (1991) New materials on the horizon *Journal of the American Dental Association* **122(7)** 25-31.

STAMPALIA LL, NICHOLLS JI, BRUDVIK JS & JONES DW (1986) Fracture resistance of teeth with resin-bonded restorations *Journal of Prosthetic Dentistry* **55** 694-698.

TRIOLO PT Jr & SWIFT EJ Jr (1992) Shear bond strengths of ten dentin adhesive systems *Dental Materials* **8** 370-374.

WHITEHEAD SA & WILSON NHF (1988) Changes in cavity size following the removal of existing amalgam restorations *Journal of Dental Research* **67** *Divisional Abstracts* p 674 Abstract 278.

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Factors Associated with Clinical Success of Cervical Abrasion/Erosion Restorations

L V POWELL • G H JOHNSON • G E GORDON

Clinical Relevance
Glass-ionomer restorations and restorations lined with a dentin bonding agent and glass-ionomer liner placed in cervical abrasions/erosions demonstrated acceptable clinical performance after 3 years.

SUMMARY

The purpose of this study was to evaluate the clinical performance of class 5 restorations according to USPHS criteria. Twenty-five patients and 116 abrasion/erosion lesions were restored with either a glass-ionomer cement restoration (Ketac-Fil), a composite resin restoration with a dentin bonding agent (Silux Plus, Scotchbond 2), or a composite resin restoration with a dentin bonding agent and a glass-ionomer liner (Silux Plus, Scotchbond 2, Vitrebond). At 3 years, 24 patients and 110 teeth were evaluated. All restorations were rated clinically acceptable for color match, cavosurface discoloration, surface texture, and caries development. Glass-ionomer cement restorations demonstrated a slightly rougher surface texture than the composite restorations (Friedman Two-way ANOVA, $P = 0.000$). Significant differences were found with retention (Cochran Q test, $P = 0.012$). Percentages retained were: glass ionomer, 97.3% (36/37); composite/dentin bonding agent, 75.7% (28/37); composite/dentin bonding agent/glass-ionomer liner, 100% (36/36). At 3 years class 5 restorations of glass-ionomer cement or composite with a dentin bonding agent and a glass-ionomer liner demonstrated significantly better retention than restorations of composite with a dentin bonding agent. Increased occlusal function, mobility, and mandibular arch were associated with a decrease in retention rate.

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INTRODUCTION

Currently several different restorative techniques are recommended for the cervical abrasion/erosion lesion: the glass-ionomer cement restoration, the composite resin applied with a dentin bonding agent, and the composite resin applied with a glass-ionomer liner and a dentin bonding agent.

Some laboratory studies have concluded that the "sandwich" technique, the layering of composite over a glass-ionomer cement liner, reduces microleakage when compared to glass-ionomer restorations or composite resin restorations, especially when the gingival margin of cervical restorations is examined (Smith & Martin, 1992; Schwartz, Anderson & Pelleu, 1990). Other studies have found that glass-ionomer cement restorations, dentin bonding systems, and glass-ionomer cement liners used with dentin bonding systems all result in similar microleakage patterns (Prati, Nucci & Montanari, 1989; Chohayeb, 1992).

Clinical studies are few in number and usually test individual materials rather than compare techniques. Complicating matters further is the fact that glass-ionomer cement and composite resin formulations are frequently changed, making meaningful clinical interpretation of current techniques difficult.

Recently investigators have determined that factors other than the restorative material may significantly influence the clinical performance of cervical restorations (Heymann & others, 1991). Factors such as occlusal stress and patient age were determined to affect the retention of cervical restorations.

The present study compares the clinical performance of three restorative techniques for restoring cervical abrasions/erosion lesions. The techniques include: a glass-ionomer restorative material, a composite resin with a dentin bonding agent, and a composite resin with a dentin bonding agent and a glass-ionomer liner. The purpose is to determine if one system demonstrates superior clinical performance. Clinical parameters of color match, marginal staining, surface texture, and caries development will be compared. The outcome measure for clinical success will be retention. In addition, certain factors such as tooth location, patient age, and occlusal function will be analyzed to determine what effect they may have on restoration success.

METHODS AND MATERIALS

Twenty-five patients with at least three noncarious abrasion/erosion lesions were selected for the study. All lesions were at least 1 mm in axial depth. A total of 116 lesions were restored with one of the following treatments: glass-ionomer restorative material (Ketac-Fil, ESPE/Premier, Norristown, PA 19404), composite with a dentin bonding agent (Silux Plus with Scotchbond 2, 3M Dental Products, St Paul, MN 55144), and composite with a dentin bonding agent and a glass-ionomer liner (Silux Plus with Scotchbond 2 and Vitrebond, 3M). Each patient received at least one of each treatment. Restorations were inserted during the summer of 1988 and were followed through the summer of 1991. All lesions were cleaned with flour of pumice prior to shade selection; no preparation was done. Isolation was achieved by gingival displacement with braided surgical silk. Lesions restored with glass-ionomer restorative material were first treated with 25% polyacrylic acid (Ketac Conditioner, ESPE/Premier) for 10 seconds, rinsed, and dried prior to material placement, leaving the tooth surface moist. The restorative material was mixed according to the manufacturer's directions and applied to the lesion. A cervical matrix was placed, and the extruded material was covered with an unfilled resin (Visiobond, ESPE/Premier). After 5 minutes, the gross excess was removed with hand instruments, and after 15 minutes final polishing was completed with Sof-Lex disks (3M) and water. The restoration was given a final coat of resin (Visiobond) that was cured for 30 seconds. For lesions restored with composite, the enamel margins were first beveled 1 mm and etched for 15 seconds. Dentin primer (Scotchprep, 3M) was applied for 60 seconds and allowed to dry. Dentin adhesive (Scotchbond 2, 3M) was applied without air thinning and cured. Composite (Silux Plus, 3M) was applied incrementally and cured. Finishing and polishing were completed with hand instruments, Sof-Lex disks, and 12-fluted carbide burs. For those lesions that were restored with the addition of a glass-ionomer liner, the liner (Vitrebond, 3M) was placed prior to the enamel bevel and etch; however, care was taken not to etch the liner. The dentin was not conditioned with polyacrylic acid. The

Table 1. Distribution of Restorative Materials

	Glass Ionomer	Composite/ Dentin Adhesive	Composite/ Dentin Adhesive/ Glass Ionomer
N	39	39	38
Shape			
notch	25	24	24
saucer	14	15	14
Arch			
maxillary	25	24	23
mandibular	14	15	15
Position			
anterior	13	20	17
posterior	26	19	21
Axial Depth (mm)			
(mean)	1.3	1.2	1.3
Age (years)			
(mean)	66.5	67.8	66.6
(mode)	70.0	70.0	70.0
Cold Sensitivity (%)			
at 1 week	2/27(7)	2/27(7)	8/30(27)
at 6 months	5/27(19)	8/27(30)	3/29(10)
Occlusion			
centric	34	29	29
eccentric	28	31	30
wear	26	28	27
mobility	14	11	11

liner was placed in a thin coat and light cured.

One week after placement, baseline records were taken that included color photographs, quadrant polyvinylsiloxane impressions (President, Coltene, Altstätten, Switzerland), and clinical evaluation by two calibrated examiners. Clinical evaluation included assessment of color match, cavosurface discoloration, surface texture, and caries according to modified USPHS criteria (Cvar & Ryge, 1971). Restorations were observed for retention and note was made if restorations were partially retained. Disagreements between examiners were resolved by forced consensus. These procedures were repeated at 6 months, 1 year, 2 years, and 3 years. At examinations, evaluators were blinded as to the type of restoration; however, they may have been able to deduce the glass-ionomer restorations due to the rougher surface texture.

Data were analyzed using nonparametric tests for related samples, since each patient received all three treatments. Data for color, stain, and texture were analyzed using the Friedman two-way analysis, since these measures were ordinal. Data for caries and retention were analyzed using the Cochran Q test, since these measures were nominal. All hypothesis testing was conducted at the 95% level of confidence.

To assess the effect of factors other than technique on the retention of restorations, variables that may have potentially affected retention were identified. The distribution of these factors is presented in Table 1. Logistic regression analysis was used to analyze the simultaneous effects of technique and the other factors on retention rates. This analysis provides an estimate of the differences between techniques that is adjusted for possible imbalances on various tooth-level factors. In addition, the effects of these risk factors themselves can be determined. The intrapatient correlation was estimated to be only 0.03, allowing the application of logistic regression with the tooth as the unit of analysis. All hypothesis tests performed were two-sided.

Table 2. Teeth Examined at Recall

	Baseline	1 Year	2 Years	3 Years
Glass Ionomer	39	34	39	37
Dentin Bonding Agent/Composite	39	35	38	37
Glass Ionomer/ Dentin Bonding Agent/Composite	38	34	38	36
Total	116	103	115	110

RESULTS

The number of teeth available for evaluation at each recall is presented in Table 2. At the 1-year recall, one patient had moved. At the 2-year recall, all patients were again available; however, one tooth could not be evaluated because it had been crowned for reasons unrelated to the cervical restoration. At the 3-year recall, one patient had moved and two teeth had been crowned for reasons unrelated to the cervical restoration. Data for color match, marginal staining, surface texture, caries development, and retention are presented in Tables 3-6 and the figure.

All three techniques resulted in restorations that were clinically acceptable for color match, marginal staining, surface texture, and caries development when evaluated at 3 years. There were no statistically significant differences when recall data were compared to baseline data for any technique, nor were there statistically significant differences among the techniques for these clinical parameters, with the exception of the glass-ionomer cement restoration; it had a slightly rougher texture than the two composite resin restorations (Friedman Two-way ANOVA, $P < 0.001$).

Differences were found among the materials with regard to retention. At the 3-year recall, restorations of glass-ionomer cement or composite resin applied with a glass-ionomer cement liner and a dentin bonding agent demonstrated significantly better retention than restorations of composite with a dentin bonding agent (Cochran Q Test, $P = 0.012$).

Logistic regression analysis of 3-year retention results showed that the composite/ dentin bond system had higher

Table 3. Percentage of Restorations with Clinically Acceptable Color Match at 3-Year Recall

	Baseline	1 Year	2 Years	3 Years
Glass Ionomer	97	94	100	97
Dentin Bonding Agent/Composite	97	91	94	97
Glass Ionomer/ Dentin Bonding Agent/Composite	97	100	100	100

Table 4. Percentage of Restorations with Clinically Acceptable Cavosurface Discoloration at 3-Year Recall

	Baseline	1 Year	2 Years	3 Years
Glass Ionomer	100	100	100	97
Dentin Bonding Agent/Composite	100	97	97	86
Glass Ionomer/ Dentin Bonding Agent/Composite	100	100	100	97

failure rates ($P = 0.004$), confirming the result of the unadjusted comparison based on Cochran's Q Test. The odds ratio for retention of the composite resin/dentin bond restorations compared to the other restorations was 33.4 (95% CI = 3.1 to 356). The logistic regression analysis also suggested the presence of effects on retention rates due to arch

Table 5. Percentage of Restorations with Clinically Acceptable Surface Texture at 3-Year Recall

	Baseline	1 Year	2 Years	3 Years
Glass Ionomer	97	100	100	97
Dentin Bonding Agent/Composite	97	100	100	100
Glass Ionomer/ Dentin Bonding Agent/Composite	100	100	100	100

(mandibular/maxillary) ($P = 0.06$) and the presence of eccentric and/or centric occlusal contacts and/or wear facets ($P = 0.20$), and the presence of mobility ($P = 0.11$). Although these effects were quite large (see discussion), they were estimated with poor precision due to the small number of failures in this study, and could not be conclusively established.

DISCUSSION

Comparison of Materials

The retention rate for the glass-ionomer cement restorations compares well with previously reported clinical results (Matis & others, 1988; Tyas & others, 1989). The current study found 97% of these restorations were retained after 3 years. Other studies found 90 to 100% retained restorations.

Table 7 compares the retention rates for the composite/dentin bonding agent system (Scotchbond 2) (Jordon, Suzuki & MacLean, 1989; van Dijken, 1992; Bastos, Teixeira & Leinfelder, 1991). The current study found retention rates that more resembled the retention rates for nonetched lesions found in other studies, even though the lesions in this study were etched. One explanation for the lower retention rates of this study may be that the age of the patient was older, mean 70 years of age,

Table 7. Percentage of Retained Composite Restorations Applied with Scotchbond 2

	Powell	Duke (1991)		van Dijken (1992)	Bastos (1991)	Jordan (1989)
	Etch	No Etch	Etch	No Etch	No Etch	No Etch
6 Months	97	91	100	95	93	98
1 Year	94	88	100	91	91	
2 Years	87	86	94	85	85	
3 Years	76	80	93		70	

and the treated dentin was sclerotic. Scanning electron micrographs of sclerotic dentin, perhaps secondary to aging and attrition, found more than 70% of the dentinal tubules obturated by intraluminal crystals (Yoshiyama & others, 1989). Duke and Lindemuth (1991) found sclerotic dentin to be resistant to the alteration by the primer solution, and

Table 6. Percentage of Restorations with No Caries Development at 3-Year Recall

	Baseline	1 Year	2 Years	3 Years
Glass Ionomer	100	97	97	97
Dentin Bonding Agent/Composite	100	100	88	90
Glass Ionomer/ Dentin Bonding Agent/Composite	100	97	97	97

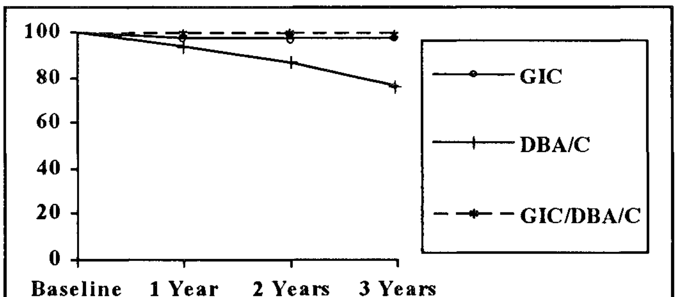
resinous tag penetration into the tubules was not created. If the dentin in the current study was sclerosed, then it was not affected by the primer and it then follows that the retention data would resemble the nonetched treatments of other trials. Some studies found improved adhesion with older teeth when the dentin bonding system (Tenure) contained NTG-GMA, which purportedly chemically bonds with calcium, which is in abundance in the sclerosed tooth (Sidhu, Soh & Henderson, 1991).

The glass-ionomer restorations were better retained than the composite restorations applied with dentin bonding agent only. In a related laboratory finding, investigators found less microleakage with glass-ionomer restorations when compared to nonretentive composite restorations (Kaplan & others, 1992). One possible explanation is that the glass-ionomer restorations undergo less stress and gap formation resulting from polymerization shrinkage and from thermal expansion and contraction (Feilzer, DeGee & Davidson, 1988; Bullard, Leinfelder & Russell, 1988).

The composite resin restorations with a dentin bonding agent and a glass-ionomer liner were better retained than the composite resin restorations applied with a dentin bonding agent alone. A recent laboratory study came to a related conclusion that glass-ionomer-lined composites experienced less microleakage than unlined composites (Sidhu & Henderson, 1992). The most likely explanation for this finding is that the liner imparted some flexibility to the total restoration. Kemp-Scholte and Davidson (1990) found in an in vitro study that an intermediate layer reduced the stiffness of the total restoration, allowing it to compensate for stress that exceeded the bond strength. They attributed an increase in flexibility to the "movability" of the clusters of molecules in the early set of the glass-ionomer cement liner, which compensated for polymerization shrinkage of the composite resin. Further stress relief was obtained by water sorption of the lining materials. This theory is further supported by the fact that microfilled composite resins, with their increased flexibility, are better retained than macrofilled composite resins (Johnson, Powell & Gordon, 1991; Heymann & others, 1991; Heymann & others, 1993).

Another hypothesis for why the composite resin restorations placed with a glass-ionomer cement liner performed better is that the glass-ionomer cements rely less on the demineralization of the dentin surface, a step that is essential to the dentin bonding agent used here (Erickson, 1989), and which may have been prevented by the hypermineralized surface characteristic of this study population. The glass-ionomer cement liner may actually benefit from the extra calcium ions found in sclerosed dentin. According to Mitra (1991), in the third step of the setting reaction for Vitrebond, positive ions (CA^{2+}, Al^{3+}, Al^{F2+}, etc) react with the negatively charged polycarboxylate polymer to form a cross-linked network.

A last hypothesis for the poorer performance of the composite resin restoration placed with a dentin bonding agent only may relate to moisture control.



	BASELINE	1 YEAR	2 YEARS	3 YEARS
GIC	100	97	97	97
DBA/C	100	94	87	76
GIC/DBA/C	100	100	100	100

Percentage of retained restorations from baseline to 3-year recall. GIC = glass-ionomer restorative; DBA/C = composite with a dentin bonding agent; GIC/DBA/C = composite with a dentin bonding agent and a glass-ionomer liner. 1 year, P *= 0.369 (Chi-square test); 2 years,* P *= 0.0743 (Cochran Q Test); 3 years,* P *= 0.0019 (Cochran Q Test).*

One study using an earlier version of Scotchbond found improved in vivo bond strengths when a rubber dam was used as opposed to cotton roll isolation (Barghi, Knight & Berry, 1991). Another study using a later version of Scotchbond did not find a statistically significant decrease in in vitro bond strength with saliva-contaminated teeth (Johnson & others, 1993). The current study achieved isolation with cotton rolls and retraction cord to more closely simulate the most adverse clinical situation. Surveys have shown that approximately 40% of practicing dentists never use a rubber dam when placing composite resin restorations, and only 11-17% always use one (Joynt, Davis & Schreier, 1989). The Scotchbond 2 bonding system is sensitive to moisture contamination also, so adhesion may have been adversely affected by poor moisture control (Erickson, 1989; Mitchem & Gronas, 1989; Prati & Pashley, 1992). Glass-ionomer cements are apparently less sensitive to moisture contamination (Mitchem & Gronas, 1989; Prati, Pashley & Montanari, 1991), and the results of this study would support this finding. If moisture contamination were a problem, the glass-ionomer cement restorations and the composite resin restorations placed with a dentin bonding agent and a glass-ionomer cement liner were not adversely affected.

Risk Factors

Certain factors were evaluated to determine what effect, if any, they had on retention of the restorations (Table 1). This study did not conclusively demonstrate significant effects of any factors other than technique. However, the number of retention failures was small and may have been insufficient to demonstrate such effects. The possible effects of age, occlusion, and arch warrant further discussion.

Several clinical studies have found more restoration failures with older patients (Heymann & others, 1991; Duke & Lindemuth, 1991; Smales, 1991). Some attribute the failures to increased flexure (Heymann & others, 1991; Smales, 1991). Another theory is described above, that older teeth are sclerosed and more mineralized, making them more resistant to the priming step in some dentin bonding systems (Duke & Lindemuth, 1991). The current study did not find age to be associated with retention loss, but this could be due to the narrow age range of the patients (42 - 85 years), with 14 of the 25 patients aged 70 or older. Had the study population contained more subjects from younger age groups, the result may have been different. The fact that the retention loss from these subjects was higher than other studies indicates that the age of this population may have been a factor in retention.

Occlusal forces have been found to increase microleakage and gap formation at the cemental margin (Mandras, Retief & Russell, 1991; Rigsby & others, 1991; Jörgensen, Matono & Shimokobe, 1976; Davidson & Abdalla, 1993). Heyman and others (1991) also found occlusal factors to be associated with decreased retention of cervical restorations. If in heavy occlusion a tooth experiences increased flexure, this stress may contribute to loss of adhesion between the dentin and the restoration. Most of the teeth that experienced a loss of restoration in the current study had centric and eccentric occlusal contacts and wear facets. Half of them were mobile. The presence of eccentric or centric occlusal contacts and/or wear facets appeared to be associated with a decrease in retention rates (odds ratio = 3.6, 95% CI = 0.5 - 26.4). There was also a suggestion that the presence of mobility was associated with a lower retention rate (OR = 4.5, 95% CI = 0.7 - 28.7).

In the current study a higher failure rate was observed in the mandibular arch relative to the maxillary arch (OR = 5.6, 95% CI = 0.9 to 33.3). Two other clinical studies found similar results (Heymann & others, 1991; Ziemiecki, Dennison & Charbeneau, 1987). One author suggested that this finding may be due to greater flexure of mandibular teeth or greater difficulty of moisture control (Heymann & others, 1991). Another hypothesis may be that mandibular teeth have dentin that is more sclerosed or that has fewer tubules. Two clinical studies have found that mandibular teeth are significantly less sensitive to cold (Powell, Gordon & Johnson, 1990; Johnson, Gordon & Bales, 1988). An SEM study found that naturally desensitized dentinal areas had only 24% of the tubules open compared to hypersensitive dentin, which had 75% of the tubules open (Yoshiyama & others, 1989). Therefore, one may deduce that this decrease in sensitivity found with mandibular teeth may be due to a decrease in open tubules. If indeed there are fewer open tubules in mandibular dentin available for bonding, then retention loss associated with lesions found in mandibular teeth should be greater than that found in maxillary teeth.

Shape of the lesion did not seem to affect the retention of the restoration, a finding corroborated by other investigations (McEvoy & others, 1993; Kamposiora & others, 1993).

CONCLUSION

All three techniques, the glass-ionomer cement restoration, the composite restorations with a dentin bonding agent, and the composite resin restoration with a dentin bonding agent and a glass-ionomer liner, resulted in restorations that were clinically acceptable for color match, marginal staining, surface texture, and caries development when evaluated at 3 years. Restorations of glass-ionomer cement or composite with a dentin bonding agent and a glass-ionomer liner were significantly more retentive than restorations of composite resin and a dentin bonding agent alone. The factors of increased occlusal function or mobility and mandibular arch were associated with a decrease in the retention rate.

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References

BASTOS P, TEIXEIRA L & LEINFELDER K (1991) Three-year clinical evaluation of Scotchbond 2 as a dentinal adhesive *Journal of Dental Research* **70** *Abstracts of Papers* p 395 Abstract 1031.

BARGHI N, KNIGHT GT & BERRY TG (1991) Comparing two methods of moisture control in bonding to enamel: a clinical study *Operative Dentistry* **16** 130-135.

BULLARD RH, LEINFELDER KF & RUSSELL CM (1988) Effect of coefficient of thermal expansion on microleakage *Journal of the American Dental Association* **116** 871-874.

CHOHAYEB AA (1992) Microleakage comparison of dentin bonding systems with glass ionomer *Dental Materials* **8** 27-30.

CVAR JF & RYGE G (1971) Criterion for the clinical evaluation of dental restorative materials *USPHS Publication* **790** p 244 San Francisco: US Government Printing Office.

DAVIDSON CL & ABDALLA AI (1993) The effect of occlusal load cycling on marginal integrity of adhesive Class V restorations *Journal of Dental Research* **72** *Abstracts of Papers* p 114 Abstract 87.

DUKE ES & LINDEMUTH J (1991) Variability of clinical dentin substrates *American Journal of Dentistry* **4** 241-246.

ERICKSON RL (1989) Mechanism and clinical implications of bond formation for two dentin bonding agents *American Journal of Dentistry* **2** 117-123.

FEILZER AJ, DeGEE AJ & DAVIDSON CL (1988) Curing contraction of composites and glass-ionomer cements *Journal of Prosthetic Dentistry* **59** 297-300.

HEYMANN HO, STURDEVANT JR, BAYNE S, WILDER AD, SLUDER TB & BRUNSON WD (1991) Examining tooth flexure effects on cervical restorations: a two-year clinical study *Journal of the American Dental Association* **122(5)** 41-47.

HEYMANN HO, WILDER AD, BAYNE SC, STURDEVANT JR & LISK M (1993) 5-year clinical study of Class-V adhesive retention factors *Journal of Dental Research* **72** *Abstracts of Papers* p 348 Abstract 1962.

JOHNSON GH, GORDON GE & BALES DJ (1988) Postoperative sensitivity associated with posterior composite and amalgam restorations *Operative Dentistry* **13** 66-73.

JOHNSON GH, POWELL LV & GORDON GE (1991) Dentin bonding systems: a review of current products and techniques *Journal of the American Dental Association* **122(7)** 34-41.

JOHNSON M, BURGESS J, HERMESCH C & BUIKEMA D (1993) Saliva contamination of dentin bonding agents *Journal of Dental Research* **72** *Abstracts of Papers* p 133 Abstract 236.

JORDAN RE, SUZUKI M & MACLEAN DF (1989) Early clinical evaluation of Tenure and Scotchbond 2 for conservative restoration of cervical erosion lesions *Journal of Esthetic Dentistry* **1** 10-13.

JÖRGENSEN KD, MATONO R & SHIMOKOBE H (1976) Deformation of cavities and resin fillings in loaded teeth *Scandinavian Journal of Dental Research* **84** 46-50.

JOYNT RB, DAVIS EL & SCHREIER PJ (1989) Rubber dam usage among practicing dentists *Operative Dentistry* **14** 176-181.

KAMPOSIORA P, BAYNE SC, PAPAVASILIOU G, HEYMANN HO & FELTON DA (1993) 3D-FEA of unrestored and restored cervical defects *Journal of Dental Research* **72** *Abstracts of Papers* p 350 Abstract 1977.

KAPLAN I, MINCER HH, HARRIS EF & CLOYD JS (1992) Microleakage of composite resin and glass ionomer cement restorations in retentive and nonretentive cervical cavity preparations *Journal of Prosthetic Dentistry* **68** 616-623.

KEMP-SCHOLTE CM & DAVIDSON CL (1990) Complete marginal seal of Class V resin composite restorations effected by increased flexibility *Journal of Dental Research* **69** 1240-1243.

MANDRAS RS, RETIEF DH & RUSSELL CM (1991) The effects of thermal and occlusal stresses on the microleakage of the Scotchbond 2 dentinal bonding system *Dental Materials* **7** 63-67.

MATIS BA, COCHRAN M, CARLSON T & PHILLIPS RW (1988) Clinical evaluation and early finishing of glass ionomer restorative materials *Operative Dentistry* **13** 74-80.

McEVOY SSA, RICHARDS ND, McCONNELL TA & MITCHELL RJ (1993) Lesion shape and retention of dentin-bonded restorations *Journal of Dental Research* **72** *Abstracts of Papers* p 349 Abstract 1968.

MITCHEM J & GRONAS D (1989) Adhesion to dentin with and without smear layers under varying degrees of wetness *Journal of Dental Research* **68** *Abstracts of Papers* p 321 Abstract 1115.

MITRA SB (1991) Adhesion to dentin and physical properties of a light-cured glass-ionomer liner/base *Journal of Dental Research* **70** 72-74.

POWELL LV, GORDON GE & JOHNSON GH (1990) Sensitivity restored of Class V abrasion/erosion lesions *Journal of the American Dental Association* **121** 694-696.

PRATI C, NUCCI C & MONTANARI G (1989) Microleakage of mixed Class-V restorations placed with GIC-bases or dentin bonding agents *Schweizer Monatsschrift für Zahnmedizin* **99** 1117-1121.

PRATI C & PASHLEY DH (1992) Dentin wetness, permeability and thickness and bond strength of adhesive systems *American Journal of Dentistry* **5** 33-38.

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

RIGSBY DF, RETIEF DH, BIDEZ MW & RUSSELL CM (1991) Microleakage of Class V restorations subjected to temperature and load cycling *Journal of Dental Research* **70** *Abstracts of Papers* p 388 Abstract 981.

SCHWARTZ JL, ANDERSON MH & PELLEU GB Jr (1990) Reducing microleakage with the glass-ionomer/resin sandwich technique *Operative Dentistry* **15** 186-192.

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

SIDHU SK, SOH G & HENDERSON LJ (1991) Effect of dentin age on effectiveness of dentin bonding agents *Operative Dentistry* **16** 218-222.

SMALES RJ (1991) Effects of enamel-bonding, type of restoration, patient age and operator on the longevity of an anterior composite resin *American Journal of Dentistry* **4** 130-133.

SMITH EDK & MARTIN FE (1992) Microleakage of glass ionomer/composite resin restorations: a laboratory study 1. The influence of glass ionomer cement *Australian Dental Journal* **37** 23-30.

TYAS MJ, BURNS GA, BYRNE PF, CUNNINGHAM PJ, DOBSON BC & WIDDOP FT (1989) Clinical evaluation of Scotchbond™: three-year results *Australian Dental Journal* **34** 277-279.

van DIJKEN JWV (1992) Two-year clinical evaluation of four new dentin bonding agents *Journal of Dental Research* **71** *Abstracts of Papers* p 662 Abstract 1177.

YOSHIYAMA M, MASADA A, UCHIDA A & ISHIDA H (1989) Scanning electron microscopic characterization of sensitive *vs* insensitive human radicular dentin *Journal of Dental Research* **68** 1498-1502.

ZIEMIECKI TL, DENNISON JB & CHARBENEAU GT (1987) Clinical evaluation of cervical composite resin restorations placed without retention *Operative Dentistry* **12** 27-33.

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Alcohol-containing Mouthwashes: Effect on Composite Color

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Clinical Relevance
Rinsing with mouthwashes for 6 months can cause a hybrid resin to undergo color variations.

SUMMARY

This study investigated whether commercially available mouthwashes could affect or change the color of a hybrid composite resin. Twenty-four disks were fabricated and divided into eight equal groups for testing. At baseline, six colorimetric recordings and color parameters (L*, a*, b*) were recorded for each grouping of disks using a Chroma Meter CR-300 in reflectance mode. The groups of disks were immersed in their respective mouthwashes for 2 minutes a day in a vibratory fashion over a 6-month period. At the end of 6 months, color differences, ΔE, were calculated between the base line and test recordings. The results indicate that rinsing with mouthwashes for 6 months can cause a hybrid resin to undergo color variations. Except for one product, the color variations were not clinically significant.

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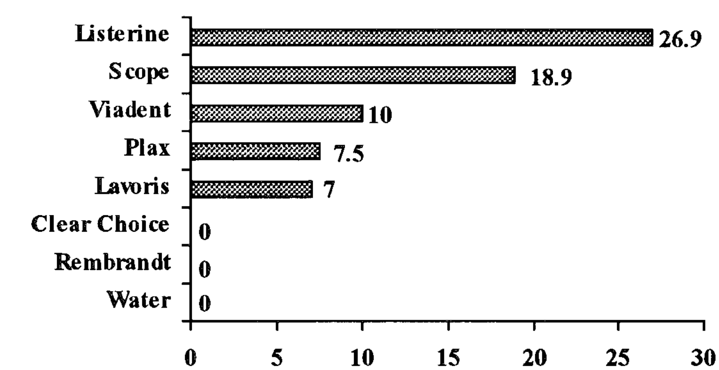
INTRODUCTION

In recent years, over-the-counter and prescription products such as mouthwashes, which often contain alcohol in high-volume percentages, have increased in sales and represent a substantial market share of the at-home oral care products (figure). In addition to alcohol these materials often contain other ingredients such as detergents, emulsifiers, organic acids, and dyes (Otomo-Corgel, 1992). It has been noted that such materials, especially solvents, can produce physical changes in polymers, leading to a deterioration of the polymer surface (Hall, 1990). Concurrently, several investigators have demonstrated that a variety of chemicals may contribute to the degradation of composite resin by causing surface softening and the possible removal of portions of the polymer matrix (Wu & McKinney, 1982; McKinney & Wu, 1985). More recently, it has been shown that the alcohol content found in mouthwashes can directly lead to a softening of a hybrid composite resin (Penugonda & others, 1994). Since oral care products such as mouthwashes are used by patients routinely, the dental profession has a responsibility



Alcohol content of mouthwashes

to determine whether the chemicals within such materials may affect restoratives used daily in dental practice.

The purpose of this study, therefore, was to determine whether alcohol-containing mouthwashes could affect or change the color of a hybrid composite resin.

METHODS AND MATERIALS

A dark yellow shade of the hybrid composite resin APH (LD Caulk Co, Milford, DE 19963) was chosen for use in this study. Twenty-four composite disks were fabricated by injecting this composite resin into preformed rubber ring molds, 20 mm in diameter and 1 mm thick. After the insertion of the composite resin into the molds, the molds were covered by thin glass plates and heavy weights to ensure a smooth surface. The composite resin was then light activated by a curing light through the glass plate for a total of 1 minute on each side. The process was repeated immediately after the glass plates were removed; each disk was stored in an air-tight container at 37 °C for 24 hours before testing. At the end of the 24-hour period, the 24 disks were divided into eight equal groups for testing:

Group I—Listerine (Warner Lambert, Morris Plains, NJ 07950),

Group II—Scope (Procter & Gamble, Cincinatti, OH 45202),

Group III—Viadent (Viadent Inc, Fort Collins, CO 80525),

Group IV—Plax (Pfizer, New York, NY 10017),

Group V—Lavoris (DEP Corporation, Rancho Dominguez, CA 90220),

Group VI—Clear Choice (Bausch and Lomb, Rochester, NY 14604),

Group VII—Rembrandt Mouth Refreshing Rinse (Den-Mat Corp, Santa Maria, CA 93456), and

Group VIII—water (control).

Six colorimetric recordings and color parameters in terms of CIE (1976) tristimulus values (L*, a*, b*) were recorded for each group of disks on a calibration plate using a Chroma Meter CR-300 (Minolta, Ramsey, NJ 07446) in reflectance mode. The L*a*b* color space is presently one of the most popular and uniform color spaces available for measuring object color. It was devised in 1976 to provide more uniform color differences in relation to visual differences. In this color space, L* indicates lightness, and a* and b* are the chromaticity coordinates. Thus, lightness, L*, is rated on a scale of 0-100, with 100 as the lightest value. The a* and b* chromaticity coordinates indicate color directions. As the a* and b* values increase, the saturation of the color increases: +a* is in the red direction, -a* is in the green direction, +b* is in the yellow direction, and -b* is in the blue direction (Minolta, 1993). The mean values were calculated for each group as baseline measurements. The colorimeter was set to produce color parameters based on average daylight (D65) illumination. The groups of disks were placed in laboratory beakers, immersed in their respective mouthwashes, and placed on a laboratory vibrator at a low-speed setting for 2 minutes a day, 5 days per week for a 6-month period. After each session, the specimens were washed off with water, dried with a cellulose tissue, and placed in air-tight containers until the following test session.

At the end of the 6 months, L*a*b* readings were again similarly recorded, and the color differences, ΔE, were calculated between pretest and test disks by means of the following equation:

$$\Delta E = [(L^*_C - L^*_T)^2 + (a^*_C - a^*_T)^2 + (b^*_C - b^*_T)^2]^{1/2},$$

where the C subscript refers to the baseline mean value, and the T subscript refers to the test mean value.

The results of the study were evaluated by a one-way analysis (ANOVA) and a Scheffé comparison between groups.

RESULTS

The mean results and standard deviations of the baseline and test recordings are reported in Tables 1 and 2. The color change, ΔE, between the control and test samples is reported in Table 3. A one-way analysis of variance (ANOVA) revealed that Group V, Lavoris, was significantly different from all of the other mouthwashes ($P < 0.01$, ANOVA). The Scheffé comparison also indicated that both groups VII and VIII, Rembrandt Mouth Refreshing Rinse and water respectively, were different at the 0.05 level of significance compared to Group III (Viadent), Group V (Lavoris), and Group VI (Clear Choice). It should be noted that the L*a*b* values differed between groups at baseline. This is due to the sensitivity of the Chroma Meter CR-300 unit in discerning color differences. Furthermore, there is no evidence that these differences

Table 1. Baseline Mean (SD) Values

Mouthwashes	L*	a*	b*
I--Listerine	68.39 [0.27]	4.19 [0.09]	34.66 [0.35]
II--Scope	67.37 [0.17]	4.67 [0.04]	33.83 [0.11]
III--Viadent	73.08 [0.03]	3.71 [0.04]	35.96 [0.11]
IV--Plax	67.10 [0.40]	4.65 [0.05]	33.54 [0.03]
V--Lavoris	69.01 [0.13]	4.67 [0.11]	35.15 [0.26]
VI--Clear Choice	70.74 [0.35]	4.18 [0.08]	35.34 [0.24]
VII--Rembrandt	67.92 [0.14]	4.79 [0.08]	33.91 [0.48]
VIII--water	71.02 [0.32]	4.07 [0.09]	35.87 [0.45]

affected the outcome of the experiment.

Even though statistically color changes were noted, it was impossible to visually discern any of these differences, except for those disks immersed in Lavoris.

DISCUSSION

The Chroma Meter used in this study, CR-300, uses a diffuse illumination/0° viewing geometry to provide measurements. In this case, the specimen is illuminated from all directions at an almost constant illuminance, and only the light reflected perpendicular to the specimen surface is accepted for measurement. The sensors within this system thus receive the light from an object and transmit the information to the microcomputer, which then determines the numerical values based on the information received from the sensors. Hence, a colorimeter has an advantage over the human eye in indicating numerically slight color differences (Minolta, 1991).

Table 2. Test Mean (SD) Values

Mouthwashes	L*	a*	b*
I--Listerine	68.21 [0.13]	4.40 [0.07]	34.57 [0.69]
II--Scope	67.51 [0.14]	4.77 [0.01]	34.40 [0.22]
III--Viadent	71.71 [0.09]	4.05 [0.02]	36.24 [0.23]
IV--Plax	67.21 [0.08]	4.96 [0.05]	34.07 [0.32]
V--Lavoris	56.12 [0.42]	29.00 [0.46]	29.57 [0.29]
VI--Clear Choice	71.58 [0.06]	4.11 [0.05]	36.23 [0.25]
VII--Rembrandt	67.89 [0.20]	4.86 [0.07]	33.69 [0.37]
VIII--water	71.05 [0.07]	4.14 [0.06]	35.71 [0.08]

Table 3. Color Differences (ΔE) between Baseline and Test Disks

Mouthwashes	ΔE
I--Listerine	0.68
II--Scope	0.59
III--Viadent	1.46
IV--Plax	0.62
V--Lavoris	28.09
VI--Clear Choice	1.23
VII--Rembrandt	0.24
VIII--water	0.19

The results of this study have indicated that all of the liquids caused the composite to undergo changes in color over the 6-month period. However, investigators have determined that shade variations within 2 ΔE units are clinically acceptable, and that a visually close match or mismatch may be observed when ΔE is in the 2-4 range (Johnston & Kao, 1989; O'Brien, Groh & Boenke, 1990). Most of the color differences, with the exception of Lavoris, were under 1 ΔE or in the range of 1 ΔE. As a result, the color differences between the other groups of mouthwashes were clinically imperceptible, even though statistically there were noted differences due to the sensitivity of the Chroma Meter CR-300.

The composite disks in contact with the Lavoris mouthwash stained a reddish color. This color change could be visually observed and was darker around the periphery of the disk than at its center. The large ΔE associated with Lavoris may be due to the fact that this mouthwash contains eugenol, methyl salicylate, and furfural. Eugenol has the ability to soften a composite resin (Paige, Hirsch & Gelb, 1986; Craig, 1989) and decrease surface hardness (Civjan, Huget & DeSimon (1973). In addition it has been demonstrated that eugenol can increase surface discoloration (Lingard, Davies & von Fraunhofer, 1981). It is thus entirely possible that the combination of alcohol and eugenol contained within this mouthwash facilitated the degradation or plasticizing of the composite. This was especially apparent at the periphery of the disks, where there appeared to be increased infiltration of the D+C Red #6 and #33 dyes into the composite to cause the significant color change. This infiltration and color change appeared to occur even though the APH resin is composed of a urethane-modified BIS-GMA with a reduction of TEGDMA to reduce water sorption (Jeffries, Smith & Leinfelder, 1992). It should lastly be noted that Listerine also contains methyl salicylate, an ingredient found in clove oil. However, the disks in contact with this mouthwash did not appear to differ visually from its control determinants.

CONCLUSIONS

1. Rinsing with mouthwashes for 6 months can cause a hybrid composite resin to undergo color variations.
2. These color changes, except for one product, were not clinically significant.

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References

COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE (1976) *Recommendations on uniform color spaces. Color difference equations* CIE Publication 15 (Suppl 2) Paris: Bureau Central de la CIE.

CIVJAN S, HUGET EF & DeSIMON LB (1973) Compatibility of resin composites with varnishes, liners and bases *Journal of Dental Research* **52** *Program and Abstracts of Papers* p 65 Abstract 27.

CRAIG RG (1989) *Restorative Dental Materials* 8th edition p 218 St Louis: C V Mosby.

HALL C (1990) *Polymer Materials—An Introduction for Technologists and Scientists* 2nd edition pp 122-123 New York: John Wiley & Sons.

JEFFRIES SR, SMITH RL & LEINFELDER KF (1992) The evolution of urethane-modified BIS-GMA composite materials with respect to physical properties and wear resistance *Esthetic Dentistry Update* **3** 116-119.

JOHNSTON WM & KAO EC (1989) Assessment of appearance match by visual observation and clinical colorimetry *Journal of Dental Research* **68** 819-822.

LINGARD GL, DAVIES EH & von FRAUNHOFER JA (1981) The interaction between lining materials and composite resin restorative materials *Journal of Oral Rehabilitation* **8** 121-129.

McKINNEY JE & WU W (1985) Chemical softening and wear of dental composites *Journal of Dental Research* **64** 1326-1331.

MINOLTA CHOMRA METERS PRODUCT DESCRIPTION (1991) Minolta Camera Co, Ltd.

MINOLTA PRECISE COLOR COMMUNICATION (1993) pp 15-22 Minolta Camera Co, Ltd.

O'BRIEN WJ, GROH CL & BOENKE KM (1990) A new, small-color-difference equation for dental shades *Journal of Dental Research* **69** 1762-1764.

OTOMO-CORGEL J (1992) Over-the-counter and prescription mouthwashes—an update for the 1990s *Compendium of Continuing Dental Education in Dentistry* **13** 1086-1095.

PAIGE H, HIRSCH SM & GELB MN (1986) Effects of temporary cements on crown-to-composite resin core bond strength *Journal of Prosthetic Dentistry* **55** 49-52.

PENUGONDA B, SETTEMBRINI L, SCHERER W, HITTELMAN E & STRASSLER H (1994) Alcohol-containing mouthwashes: effect on composite hardness *Journal of Dental Research* **73** *Abstracts of Papers* p 327 Abstract 1803.

WU W & McKINNEY JE (1982) Influence of chemicals on wear of dental composites *Journal of Dental Research* **61** 1180-1183.

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Nanoleakage: Leakage within the Hybrid Layer

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Clinical Relevance
Nanoleakage can occur at gingival margins of gap-free composite restorations.

SUMMARY

Most microleakage studies involve quantitating the magnitude of movement of a tracer molecule through a gap between restorative materials and the wall of cavity preparations. The present microscopic study examined the migration of silver nitrate into the interface between dentin and five different dentin bonding agents used to restore class 5 cavities, in the absence of gap formation. Several different leakage patterns were seen, but they all indicated leakage within the hybrid layer when viewed by SEM. The ranking of microleakage from most to least was: All-Bond 2 > Superbond C&B > Scotchbond Multi-Purpose > Clearfil Liner Bond System > Kuraray Experimental System, KB-200. To distinguish this special type of microleakage within the basal, porous region of the hybrid layer in the absence of gap formation, we propose the term *nanoleakage*.

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INTRODUCTION

Most microleakage studies have assumed that tracer molecules diffuse into channels that exist between many restorative materials and cavity walls. The evaluation of microleakage is usually done at a macroscopic, rather than a microscopic level (Wu & others, 1983; García-Godoy & Finger, 1993). A number of investigators have measured marginal gap width and/or length using microscopes (Kemp-Scholte & Davidson, 1990; Wieczkowski & others, 1992; Xin & others, 1992), although the correlation between marginal gaps and the extent of microleakage is not known. In cases of extreme microleakage, dye molecules penetrate between restorative materials and cavity walls far enough to gain access to enough dentin to begin migrating toward the pulp (Youngson, Grey & Glyn Jones, 1990).

Penetration of bacterial products, various acids and bases, and even water at the interface between a restoration and tooth has been regarded as detrimental to the longevity of the restorations (Kiyomura, 1987). The ability of a material to prevent this penetration is evaluated using a number of microleakage techniques that have been published. Many materials have become available that attempt to minimize a tooth/restoration interface gap that is a main microleakage pathway. Most of the newer-generation adhesive systems produce bonds by demineralizing the dentin to a depth of 3-6 μm using acidic conditioners. Resin retention is achieved by infiltrating hydrophilic monomers into the demineralized dentin to form a resin-collagen hybrid (Nakabayashi, 1985; Wang & Nakabayashi, 1991; Sugizaki, 1991; Imai & others, 1991; Gwinnett & Kanca, 1992; Van Meerbeek & others, 1992, 1993; Pashley & others, 1993). Gwinnett and Kanca (1992) reported the absence of gap formation using a current dentin adhesive system that created a hybrid layer between resin and dentin. Another approach to creating gap-free bonds has been the use of an elastic intermediate layer of resin between composite and adhesive resin that may absorb the contraction stress of composite during polymerization (Davidson, DeGee & Feilzer, 1984; Kemp-Scholte & Davidson, 1990; Van Meerbeek & others, 1992, 1993; Nishida & others, 1993).

However, Fukushima and others (1991) demonstrated that the microleakage along the dentinal wall was apparent even when using the new-generation dentin adhesive systems that do not form gaps. García-Godoy and Finger (1993) reported that the traditional method of leakage testing failed to detect the exact location of microleakage. Recently, Sano and others (1994) suggested the existence of a leakage pathway through a porous zone at the hybrid layer-adhesive interface without gap formation. This was shown by exposing restorations to silver nitrate (Wu & others, 1983; Mair, 1989, 1991; Ferracane, Condon & Mitchem, 1992) and then sectioning the specimens and viewing them in the SEM to observe silver that had penetrated into submicron-sized spaces beneath the bonded dentin surface (Sano & others, 1994). This penetration reveals the lack of a perfect seal but is not microleakage in the classical sense. Rather, we hypothesize that it represents permeation laterally, through micron to submicrometer spaces in the base of the hybrid layer that have not been filled with adhesive resin or which were left when poorly polymerized resin was extracted by oral or dentinal fluids. To distinguish this leakage from typical microleakage we suggest the term *nanoleakage*. This small amount of leakage cannot be seen with the naked eye or even with X10-20 magnification. Instead, it requires the use of electron microscopy. The problem is that the leakage patterns of hybrid layers are not well understood.

The purpose of this study was to evaluate the leakage pathway within the hybrid layer of four commercial and one experimental dentin adhesive systems that condition enamel and dentin simultaneously.

Table 1. Adhesive Systems That Condition Both Enamel and Dentin Simultaneously

Product Name (Manufacturer)	Conditioner	Primer	Bonding Resin	Liner
All-Bond 2 (Bisco, Itasca, IL 60143)	10% H_3PO_4	2% NTG-GMA 16% BPDM acetone	BIS-GMA UDMA HEMA	——
Superbond C&B (Sun Medical, Kyoto, Japan)	10% citric acid 3% $FeCl_2$	——	4-META MMA TBB	——
Scotchbond Multi-Purpose (3M, St Paul, MN 55144)	maleic acid	HEMA polyalkenoate copolymer water	BIS-GMA HEMA	——
Clearfil Liner Bond System (Kuraray, Osaka, Japan)	10% citric acid 20% $CaCl_2$	3% NMSA ethanol	BIS-GMA MDP HEMA	microfilled low-viscosity resin
KB-200 (experimental) (Kuraray)	self-etching primer: Phenyl-P, NMSA, HEMA, water		MDP BIS-GMA HEMA microfiller	PMF BIS-GMA microfiller

METHODS AND MATERIALS

Extracted unerupted human third molars stored in isotonic saline containing 0.2% sodium azide were employed in this study. Cervical saucer-shaped class 5 cavities (2.5 mm high, 2.5 mm wide, and 1.5-2 mm deep) were cut with a high-speed diamond bur under water coolant. The cavity form was completed with a #2 round bur in a low-speed handpiece. There were seven teeth in each of five groups. The preparations were treated with one of four commercial and one experimental adhesive systems that condition both enamel and dentin simultaneously, as listed in Tables 1 and 2, and then cavities were restored with a bulk placement technique using Silux composite (3M

Dental Products, St Paul, MN 55144). Previous work (Sano & others, 1994) had shown that bulk placement did not result in gap formation in class 5 cavities using the in vitro technique described in this report. No thermal or incisor loading was done in the hope that one or more of the bonding agents would create gap-free and leak-free bonds. After immersion in water at 37 °C for 24 hours, the restorations were finished with an ultrafine low-speed diamond point under water coolant. Specimen apices were sealed with Silux and entire teeth were coated with nail varnish except for the restoration and a 1 mm circumferential border. Specimens were placed in freshly prepared 3 mol/L silver nitrate solution for 24 hours and kept in darkness. They were then rinsed in tap water for 1 minute and immersed for 8 hours in photodeveloping solution (Wu & others, 1983; Wieczkowski & others, 1992; Xin & others, 1992). Then specimens were rinsed in tap water to remove the photodeveloping solution.

Table 2. Adhesive Procedures

All-Bond 2	Superbond C&B	Scotchbond Multi-Purpose	Clearfil Liner Bond System	KB-200
conditioning (15 seconds)	conditioning (30 seconds)	conditioning (15 seconds)	conditioning (40 seconds)	conditioning/priming (30 seconds)
rinse	rinse	rinse	rinse	gentle dry
blot dry	dry	dry	dry	-----
priming (3-5 times)	-----	priming	priming (30 seconds)	-----
blot dry	-----	gentle dry	gentle dry	-----
bonding (light cure 20 seconds)	bonding (self-cure)	bonding (light cure 10 seconds)	bonding (light cure 10 seconds)	bonding (light cure 20 seconds)
			liner (light cure 20 seconds)	liner (light cure 20 seconds)

Observation of Global Leakage

Sections 0.5 mm thick were cut longitudinally through the center of each of the seven restorations in each group using a low-speed diamond saw, and the cut surfaces were polished with increasingly fine diamond pastes (6, 3, 1 µm; Buehler, Ltd, Lake Bluff, IL 60044-1699). Prior to SEM examination, each specimen was air dried, mounted on an aluminum stub, and coated with gold. Specimens were examined in the SEM by means of both secondary and backscattered electron images. Global leakage scores of each specimen were calculated as the percent of the total cut dentin surface that was penetrated by silver nitrate:

Global leakage score = $p/L \times 100$,

where p = length of silver nitrate penetration along the resin/dentin interface and L = total length of dentinal cavity wall on the cut surface.

Statistics

After obtaining means and standard deviations, a one-way ANOVA was used to search for statistically significant differences. The groups were then ranked and subjected to multiple comparisons using Duncan's multiple range test using $P < 0.05$ as a level of significance. Observation of marginal gap opening was also carried out by using the SEM image.

Evaluation of Leakage Pathway

Two of the restored specimens from each group were used for acid etching of the cut surface to better visualize the hybrid layer. Cut and polished specimen surfaces, as described above, were subjected to 10% phosphoric acid solution for 5 seconds to expose the acid-resistant hybrid layer at the adhesive/dentin interface (Gwinnett & Kanca, 1992). The specimens were air dried, coated with gold, and observed by secondary and backscattered electron imaging.

RESULTS

Table 3 shows the mean values of the global leakage scores and marginal gap opening of each of the bonding systems. No penetration of silver or gap formation was detected at the enamel (occlusal) margin of the restorations (not shown). Thus, only the cemental/dentin (gingival) margins were photographed. Most of the restorative systems tested in this study failed to demonstrate any marginal gap formation, except for Scotchbond Multi-Purpose and Clearfil Liner Bond System (one out of five in each system). Penetration of silver nitrate along the dentinal wall was observed with or without gap formation in all specimens. All-Bond 2 showed a significantly higher leakage score than that of other

Table 3. Numbers of Marginal Gap Openings and Mean Values of Leakage Score

	Marginal Gap number/total	Leakage Score (%) mean ± SD
All-Bond 2	0/5	26.77 ± 7.58
Superbond	0/5	16.12 ± 5.75
Scotchbond	1/5	10.58 ± 3.26
Clearfil Liner Bond System	1/5	4.62 ± 1.22
KB-200	0/5	2.71 ± 2.51

Mean values connected by vertical bars in same plane are not statistically different using Duncan's Multiple Range Test ($P > 0.05$.).

systems ($P < 0.05$). There was no statistically significant difference between the microleakage scores for Superbond C&B and Scotchbond Multi-Purpose. Clearfil Liner Bond System and KB-200 had significantly lower microleakage scores than other adhesive systems ($P < 0.05$).

The leakage patterns revealed by SEM imaging of representative resin/dentin interfaces are shown in Figures 1-5. In all of the micrographs, the abbreviation "a" designates adhesive resin, "h" defines the hybrid layer, and "d" indicates dentin. All-Bond 2 showed a leakage pattern of silver along the adhesive interface (Figure 1A) that gave the appearance of a dashed line. The All-Bond 2 adhesive interface subjected to 37% phosphoric acid solution for 5 seconds revealed that the leakage occurred within the acid-resistant hybrid layer (Figure 1B). Silver accumulated slightly and discontinuously within the hybrid layer (Figure 1C). Figures 2A and 2B show the leakage pattern of silver at the dentin-Superbond C&B interface in secondary versus backscattered electron images respectively. A higher magnification of the interface (Figure 2C) revealed that almost half the depth of the hybrid layer contained silver. Figures 3A and 3B show the interface between resin and dentin of specimens bonded with Scotchbond Multi-Purpose. In this bonding system, a thin white line that contained silver was seen at the top of the hybrid layer. Just beneath this line of silver was the dark appearance of cured resin, below which was an intensive accumulation of silver at the bottom half of the hybrid layer. Using the Liner Bond System, intense silver penetration was seen along the bottom half of the hybrid layer (Figures 4A and 4B). When the KB-200-treated dentin sections were acid etched, the hybrid layer was seen to be only about 1 μm in depth, and few resin tags could be identified (Figure 5A). There was a slight accumulation of silver in the hybrid layer, but it was distributed in a delicate, vertical pattern that was unique to this bonding system and extended over the full thickness of the hybrid layer (Figures 5B and C). No silver was seen in any of the dentinal tubules.

DISCUSSION

Many studies have recommended the removal of the smear layer using acidic solutions followed by primer application in order to obtain better adaptation of the filling material to the dentinal wall. This concept has provided strong adhesion of resins to dentin and excellent adaptation to the cavity wall. However, in order to obtain ideal adhesive performance with many of the bonding systems, a number of separate sequential steps are required in the adhesive procedure. Many dentists have complained about these complicated operative procedures.

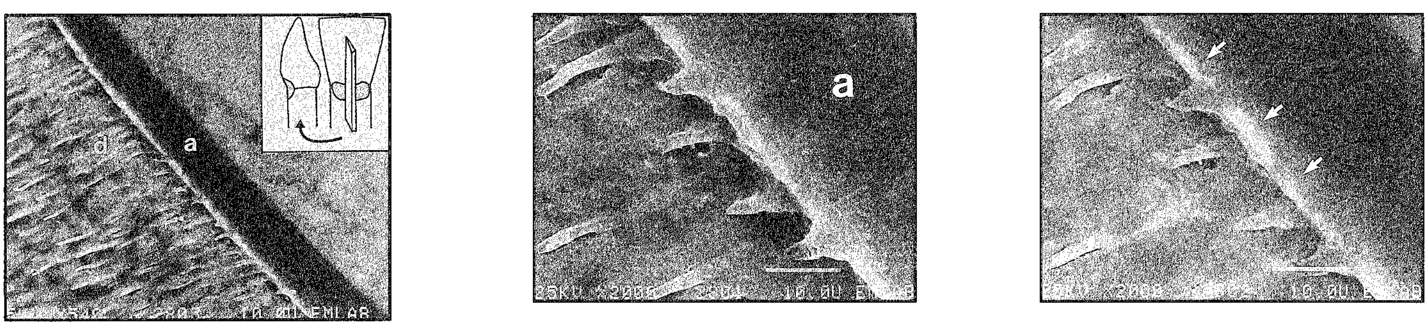

Figure 1. **A**: *SEM of the interface between dentin (d) and All-Bond 2-bonded specimen. The insert shows the position of the cavity and the plane of section viewed by SEM. In this and all following SEM's, only the gingival margin of the restoration is shown. The dark diagonal band is the adhesive layer (a). Above the adhesive layer is the composite. The cavosurface margins of the class 5 cavity were exposed to 3 mol/L silver nitrate for 24 hours, rinsed, the tooth sectioned, polished, lightly etched, and then viewed using backscatter electrons to better demonstrate the distribution of metallic silver seen as white material along the dentin-adhesive interface and in the dentinal tubules. (magnification X248.4)* **B**: *Secondary electron image of 1A at higher magnification (X1000). The adhesive layer (a) has wet the dentin surface well. Resin-unprotected dentin has been removed by brief acid etching to reveal funnel-shaped resin tags and intermittent deposits of silver.* **C**: *Backscatter electron image. Little silver was able to enter tubules due to the seal afforded by the resin tags. White arrowheads indicate the top of the hybrid layer (magnification X1000).*

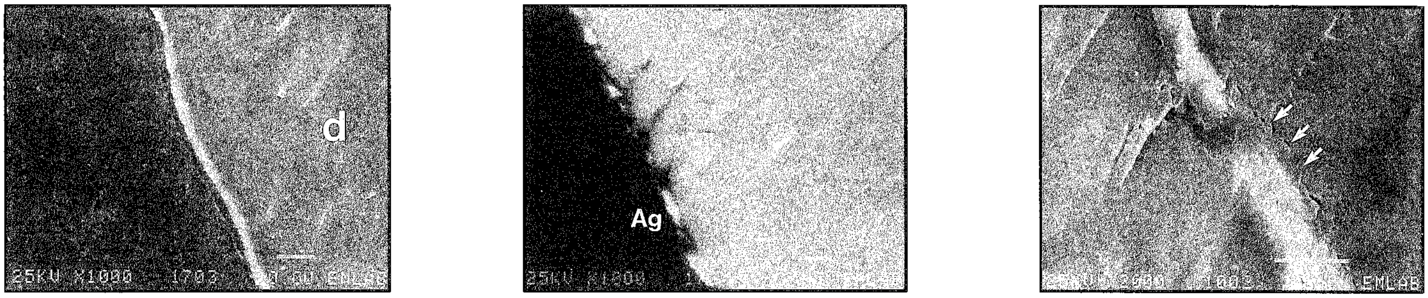

Figure 2. *Interface between dentin (d) and Superbond C&B-bonded composite in nonetched specimen. In A (X500) the image was obtained using secondary electrons, while B (X500) was obtained on the same specimen with backscattered electrons. Note the intermittent deposits of silver within the hybrid layer (Ag) and in the tubules. In C another specimen is viewed at a higher magnification (X1000) to show the thickness of the hybrid layer (~ 6-8 µ) and the large amount of silver within that layer. White arrowheads indicate the top of the hybrid layer.*

Figure 3. *Interface between dentin and Scotchbond Multi-Purpose-bonded composite. In A (X1000) there is a sharp distinction between the adhesive layer (a) and the top of the hybrid layer (arrows). A great deal of silver appeared in the bottom half of the hybrid layer and into the tubules. The contrast between the dentin, hybrid layer resin, and silver is seen more clearly in the backscatter electron image (B, X1000). This also revealed a thin deposit of silver along the top of the hybrid layer.*

Figure 4. *Interface between dentin (d) and Clearfil Liner Bond System at low (A, X500) and higher (B, X2700) magnification. This specimen was not acid etched. Micrograph A reveals a large amount of silver in the bottom two-thirds of the hybrid layer. The silver grains can be seen even more clearly at higher magnification (arrows, B).*

According to the results of this study, Clearfil Liner Bond System and KB-200 showed the lowest leakage scores (Table 3). Many steps are essential to create strong adhesion using the Clearfil Liner Bond System, compared to KB-200, which needs only a few steps to obtain proper adhesion. The simplicity of KB-200 is due to the fact that the acidic conditioner and primer and one of the bonding agents are mixed together in a single solution, thereby minimizing the number of steps required for bonding (Table 2). Further, no rinsing is done that might dilute the primer.

Although gap formation is believed to be a main leakage pathway, such gaps were rarely observed in this study, even after air drying the specimens. Using conventional SEM techniques, all specimens showed silver nitrate leakage without gap formation. This result confirms a previous study (Sano & others, 1994) that suggested the presence of a porous subsurface below the adhesive interface. In the currently evaluated dentin adhesive systems, several factors contributed to the absence of gap formation even in the high vacuum of the SEM. This was due,

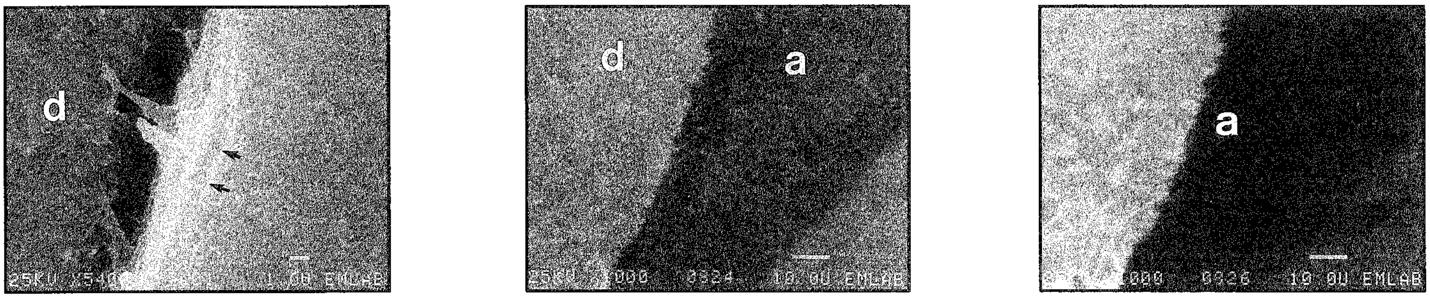

Figure 5. *Interface between dentin (d) and composite bonded with KB-200, an experimental bonding system. After longitudinal sections were made and polished, the section was briefly acid etched to permit examination of resin tags. At high magnification (A, X2700) only a few resin tags were seen extending below a thin (ca 1 μ) hybrid layer. The interface between the hybrid layer and adhesive layer is shown by arrows. B: Lower magnification (X500) of a nonetched interface between dentin (d), adhesive layer (a), and composite shows traces of silver within the hybrid layer at the dentin/adhesive interface. Backscattered electron image (C, X500) shows the silver in better contrast to the adhesive resin (a) that gives a few backscatter electrons compared to the high atomic weight silver.*

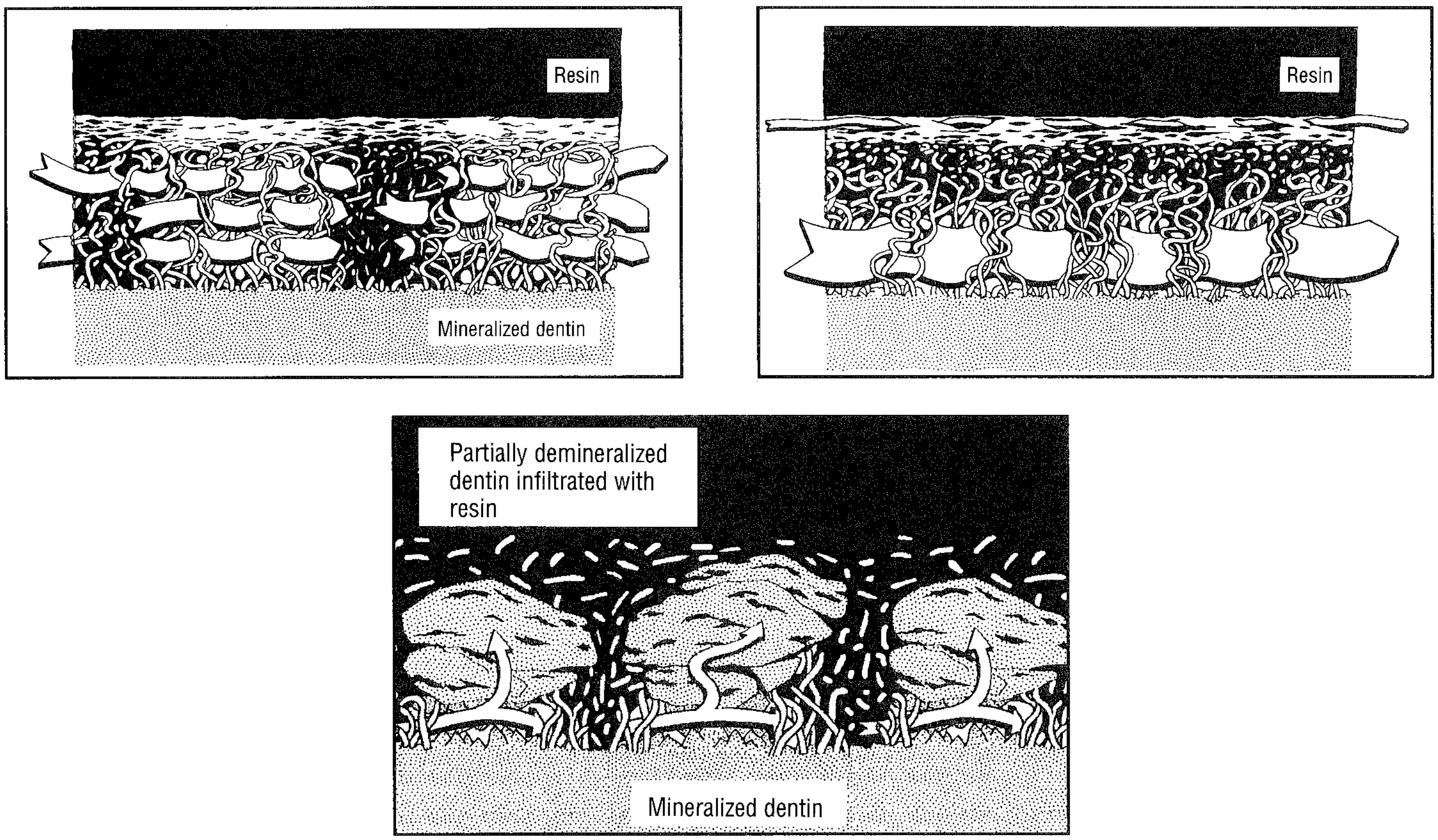

Figure 6. *Schematics of leakage patterns within hybrid layers. In all schematics, the black material depicts resin, the noodle-like structures denote demineralized collagen fibers, and the ribbon-like arrows signify narrow nanometer-sized channels through which silver could penetrate to account for the SEM's seen in Figures 1-5. A: Both All-Bond 2 and Superbond C&B revealed an intermittent distribution of silver throughout the entire depth of the hybrid layer, which alternated with regions of the hybrid layer that were free of silver and presumably occupied by resin. The broad arrows indicate how silver nitrate may have permeated around columns of resin. B: Scotchbond Multi-Purpose seemed to infiltrate resin into the demineralized dentin in a uniform front, but did not infiltrate the entire depth of the demineralized zone, leaving a porous basal region that was filled with silver. There was also a small amount of silver at the top of the hybrid layer between the adhesive resin and the dentin. The Clearfil Liner Bond system gave a very similar appearance, except there was no silver at the interface between the adhesive and the top of the hybrid layer. C: Using Kuraray's experimental adhesive, KB-200, allowed very little silver to penetrate into the dentin. The distribution of silver was in fine vertical striations that may represent localized regions in the smear layer through which the acidic adhesive etched preferential channels of resin.*

in part, to the elasticity of the adhesive layer, reduction of polymerization shrinkage of composite, and utilization of an intermediate low-viscosity resin. However, this study suggests that these current adhesive systems may leave a porous layer beneath the resin/dentin interface, and this layer may allow dentinal or oral fluid to slowly permeate the interface, which is believed to degrade the adhesive resin.

All-Bond 2 and Superbond C&B showed a similar leakage pattern. The intermittent or discontinuous penetration of silver observed within the hybrid layer on the cut dentin surface indicates that the hybrid layer produced by these bonding systems is not uniform (Figure 6). Presumably, local regions of excellent adhesion between resin and collagen are adjacent to areas where little bonding occurred. Silver must have penetrated the adhesive interface by diffusing around the solid resin portions of the hybrid layer. The slight staining of the hybrid layers by silver in the All-Bond 2 and Superbond C&B systems may leave less room for accumulation of silver than those of Scotchbond Multi-Purpose and Clearfil Liner Bond System, which showed much more penetration of silver within the bottom half of the hybrid layer. It is interesting that Scotchbond Multi-Purpose and Clearfil Liner Bond System demonstrated more intense accumulation of silver than All-Bond 2 and Superbond C&B, whereas All-Bond 2 showed a higher global leakage score. This may mean that Scotchbond Multi-Purpose and Clearfil Liner Bond System have much more porosity within the hybrid than other systems. Silver ions are easily reduced to metallic silver by organic material, especially the presence of collagen fibers (Hayet, 1975). We speculate that the intense silver penetration along the base of the hybrid layers formed by Scotchbond Multi-Purpose and Clearfil Liner Bond System may have filled collagen-rich and resin-poor spaces at the bottom half of the demineralized dentin. As silver ions encountered exposed collagen fibers (Pashley & others, 1993), they may have precipitated as metallic silver grains even in the absence of light, which then occluded these spaces and prevented further silver ion penetration within the porous layer. It was not clear why Scotchbond Multi-Purpose showed a thin silver-stained layer at the top of the hybrid layer. Recently, Pashley and others (1993) proposed that residual collagen from acid-etched smear layers may accumulate on the dentin surface following etching. This thin layer (0.2-0.3 μm) might interfere with adhesive resin infiltration. Silver ions may have been absorbed within this collagen smear layer. The experimental dentin bonding system KB-200 showed minimum global leakage and less intensity of silver staining. This suggests that the KB-200 system created minimum porosity within the hybrid layer. This may be due, in part, to its limited depth of demineralization of dentin (about 1 μm), enabling better resin infiltration. The least amount of silver penetration was obtained with the KB-200 bonding system.

It is generally believed that the penetration of bonding monomers into the demineralized surface and subsequent polymerization into large-molecular-weight resin polymers are indispensable in creating an ideal hybrid layer. However, this study showed that currently marketed dentin adhesive systems failed to create a uniform high-quality hybrid layer that sealed dentin completely. Many studies have demonstrated the presence of a hybrid layer using SEM and/or TEM technique. Hybrid layers observed in SEM are usually exposed by sectioning the specimens, which can inadvertently occlude porosities within the hybrid layer with grinding debris. Little information is available about the quality of these hybrid layers. In TEM studies, specimens are usually embedded in epoxy resin before cutting ultrathin sections. If there were porous structures at the adhesive interface, the embedding resin might penetrate into the porosity and create an embedding resin-dentin hybrid. When viewing such ultrathin sections by TEM, it is quite likely that any original porosities would no longer be apparent due to being filled with embedding resin.

The silver staining technique is useful in disclosing any porous structures at interfaces. The metallic silver grains seen in our specimens were not due to surface adsorption, because they were far from the original dentin restoration margin. The silver in our specimens diffused up to a millimeter into a porous zone at the base of the hybrid layer. This study confirmed the presence of submicron spaces at the base of most hybrid layers that might allow water penetration.

As these spaces are of the order of 20-100 nm in width, we propose that this type of leakage that occurs within the hybrid layer in the absence of gap formation be called *nanoleakage*. The diffusion and curing of adhesive resins through demineralized dentin are of crucial importance to create strong adhesion. However, it might be difficult to diffuse adhesive resin through demineralized dentin because of the presence of water around collagen fibers, the depth of the demineralized zone, and nonuniform distribution of monomers. Further studies are needed to develop adhesive systems utilizing minimum thickness of demineralized dentin, and monomers with high affinity to collagen and hydroxyapatite, which give uniform penetration and complete polymerization.

CONCLUSIONS

1. All of the latest-generation adhesive resin bonding systems can create gap-free margins in class

5 cavity preparations.

2. Even in the absence of marginal gaps, the gingival margins of all five tested bonding systems permitted varying amounts of penetration of silver ions through demineralized dentin (hybrid layer) into the underlying tubules.

3. As this leakage occurs via nanometer-sized channels in the absence of marginal gaps, it has been termed *nanoleakage* to distinguish it from conventional microleakage that requires gaps.

4. The ranking of nanoleakage from most to least was: All-Bond 2 > Superbond C&B > Scotchbond Multi-Purpose > Clearfil Liner Bond System > Kuraray's KB-200 (experimental product).

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References

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

FERRACANE JL, CONDON JR & MITCHEM JC (1992) Evaluation of subsurface defects created during the finishing of composites *Journal of Dental Research* **71** 1628-1632.

FUKUSHIMA M, NAKAMATA T, OKABE T, YAMAGA M, SUNADA S & IWAKU M (1991) Microleakage of various dentin adhesive systems on root surface caries *Adhesive Dentistry* **9** 9-23.

GARCÍA-GODOY F & FINGER WJ (1993) Reliability of microleakage evaluation using dentin bonding agents *Journal of Dental Research* **72** *Abstracts of Papers* p 308 Abstract 1636.

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

HAYET MA (1975) *Positive Staining for Electron Microscopy* New York: Nostrand Reinhold Co, p 37.

IMAI Y, KADOMA Y, KOJIMA K, AKIMOTO T, IKAKURA K & OHTA T (1991) Importance of polymerization initiator systems and interfacial initiation of polymerization in adhesive bonding or resin to dentin *Journal of Dental Research* **70** 1088-1091.

KEMP-SCHOLTE CM & DAVIDSON CL (1990) Complete marginal seal of Class V resin composite restorations effected by increased flexibility *Journal of Dental Research* **69** 1240-1243.

KIYOMURA M (1987) Bonding strength to bovine dentin with 4META/MMA-TBB resin—Long term stability and influence of water *The Journal of the Japanese Society for Dental Materials and Devices* **6** 860-872.

MAIR LH (1989) An investigation into the permeability of composite materials using silver nitrate *Dental Materials* **5** 109-114.

MAIR LH (1991) Staining of *in vivo* subsurface degradation in dental composites with silver nitrate *Journal of Dental Research* **70** 215-220.

NAKABAYASHI N (1985) Bonding of restorative materials to dentine: The present status in Japan *International Dental Journal* **35** 145-154.

NISHIDA K, YAMAGUCHI J, WADA T & HOSODA H (1993) Development of a new bonding system *Journal of Dental Research* **72** *Abstracts of Papers* p 137 Abstract 267.

PASHLEY DH, CIUCCHI B, SANO H & HORNER JA (1993) Permeability of dentin to adhesive agents *Quintessence International* **24(9)** 618-631.

SANO H, SHONO T, TAKATSU T & HOSODA H (1994) Microporous dentin zone beneath resin-impregnated layer *Operative Dentistry* **19** 59-64.

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 *The Japanese Journal of Conservative Dentistry* **34** 228-265.

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

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

WANG T & NAKABAYASHI N (1991) Effect of 2-(Methacryloxy)ethyl Phenyl hydrogen phosphate on adhesion to dentin *Journal of Dental Research* **70** 59-66.

WIECZKOWSKI G Jr, XIN YY, DAVIS EL & JOYNT RB (1992) Microleakage in various dentin bonding agent/composite resin systems *Operative Dentistry* **Supplement 5** 62-67.

WU W, COBB E, DERMANN K & RUPP NW (1983) Detecting margin leakage of dental composite restorations *Journal of Biomedical Materials Research* **17** 37-43.

XIN YY, DAVIS EL, JOYNT RB & WIECZKOWSKI G (1992) Origination and progression of microleakage in a restoration with a smear layer-mediated dentinal bonding agent *Quintessence International* **23** 551-555.

YOUNGSON CC, GREY NJA & GLYN JONES J (1990) *In vitro* marginal microleakage: examination of measurements used in assessment *Journal of Dentistry* **18** 142- 146.

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The Effect of Setting Time on the Clinical Performance of a High-Copper Amalgam Alloy

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Clinical Relevance
Changes in setting rate and working time of a high-copper amalgam alloy did not significantly influence its clinical performance.

SUMMARY

The purpose of this clinical study was to evaluate the factor of the setting rate/Eames working time on fracture at the margins of amalgams. One batch of a high-copper amalgam was modified to obtain two setting rates, one fast and one slow setting.

Two dentists originally placed 134 amalgam restorations in 23 patients. Both dentists used a rubber dam throughout the restorative procedure and prepared cavities as conservatively as possible. The amalgams were condensed by hand and carved with sharp instruments. At 1 year 124 restorations and at 2 years 115 restorations were evaluated for fracture at the margins. Results indicated that there was no significant clinical difference between a slow- and fast-setting alloy, nor was there a difference between the operators.

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INTRODUCTION

The clinical performance of dental amalgam has been studied extensively over the past 25 years. These studies have shown that a number of factors affect the rate of fracture at the margins. These factors include operator variables (Osborne & Gale, 1974a; Mahler & Marantz, 1979), cavity design and size (Berry & others, 1981; Osborne & Gale, 1990), patient's oral hygiene (Goldberg & others, 1981), use of a varnish (Borgmeyer & others, 1981), trituration time (Osborne & Gale, 1974b), moisture control (Eames, Tharp & Hibbard, 1973), burnishing (Leinfelder & others, 1978; May, Wilder & Leinfelder, 1983), and content of zinc (Watson & others, 1973; Osborne & Berry, 1992), copper (Letzel & others, 1989; Osborne & Berry, 1992), and palladium (Mahler, Engle & Adey, 1990) in the dental alloy.

Variations in the setting rate of amalgam alloys have been thought to influence the clinical rate of fracture at the margins (Osborne, 1990) and the rating given to an alloy (*Dental Advisor*, 1991). The standard for defining working time was given in 1965 when Eames and Skinner published the technique for determining working time of amalgam. This procedure has been extensively utilized by manufacturers to give practitioners an idea of the time they have to work with an alloy after trituration. The Eames procedure consists of removing the pestle after trituration of an amalgam, then mulling for 1 second every 30 seconds until the amalgam is no longer cohesive. That time when cohesion is lost is called the "Eames working time."

Dental Advisor (1991) has strongly suggested that a faster setting alloy is more desirable. The publication's recommendation for alloy selection is based on mechanical properties, handling characteristics, and clinical data. The setting rate influences both mechanical properties and handling. Faster-setting alloys are clearly rated better than a slower-setting alloy. These factors influence selection of an alloy more than the clinical performance itself; therefore, fast-setting alloys are given a higher rating. In contrast, data from a clinical study (Osborne, 1990) of 14 alloys 5 years after placement might suggest that the slower-setting alloys give better clinical performance as measured by marginal fracture. This study is, however, complicated by variations in multiple factors such as zinc content, copper content, trituration times, and the mercury alloy ratio among the 14 alloys. Therefore, it is difficult to positively draw the conclusion from this study that a slow-setting alloy gives better clinical performance.

Because no conclusive information could be found on the effect of setting rate on clinical performance, this study was designed to assess the fracture at the margins of two alloys to determine if the setting time/Eames working time affected the clinical performance.

METHODS AND MATERIALS

To isolate the effect of the setting time on the alloy's performance, only one alloy was chosen. The alloy, Zenith Premium Dispersed Phase Amalgam (Foremost Dental Mfg Inc, Englewood, NJ 07631), was selected from a batch that was divided into two groups. By varying the heat treatment and acid conditioning of the Zenith alloy particles, two different setting times were produced. Group A had a slower setting rate and an Eames working time of 5 1/2 minutes. Group B had a fast setting rate and an Eames working time of 2 1/2 minutes. The setting rates were evaluated by determining the compressive strength as described by ADA Specification Test #1 at 15 minutes, 1 hour, 24 hours, and 7 days on a Universal Testing Machine (Instron Corp, Canton, MA 02021) with a crosshead speed of 0.5 mm/mn. In addition, creep rate was assessed for both alloys as described by Mahler and others (1970). For the four compressive strength tests and the creep tests, five samples were tested for each group.

All patients selected for the study needed multiple posterior restorations. The patients signed a consent form as required by the University of Texas Health Science Center Institutional Review Board. A total of 134 restorations were placed in 23 patients by two operators at the Clinical Research facility at the University of Texas Health Science Center Dental School. One operator placed 58 restorations and the other placed 76 amalgams. Both operators placed restorations in 14 of the 23 original patients. The other nine patients had only one operator placing restorations. Moisture control for the preparation and restoration of the teeth was achieved by use of a rubber dam. The preparations were as conservative as the carious lesion and/or the restoration being replaced permitted and has been described by Summitt and Osborne (1992). Selection of the alloy to be placed in each preparation was made on a random basis after completion of the preparation. The alloys were triturated according to the manufacturer's directions using a Varimix III (L D Caulk, Milford, DE 19963) amalgamator. Condensation was done by hand, and the alloys were carved with sharp instruments, but they were not polished.

Black-and-white photographs were taken of each restoration at baseline, 1 year, and 2 years using a 200 mm Medical Nikor lens (Nikon, Tokyo, Japan) using a film image size of X1.5. Prints were made on a 4 x 5-inch format that produced a picture approximately X6 the original tooth size. The prints were then cropped to show only the restored tooth. The cropped print was identified on the back with the patient's name, tooth, date, and the alloy group.

Evaluation of the restorations as recorded in the photographs was independently performed by two evaluators using two methods, ridit analysis and rank ordering. First, the photographs of the restorations were placed into categories reflecting increasing amounts of fracture at the margins. This was done using a standard set of four photographs to compare each restoration. The data were analyzed by ridit analysis as described by Mahler and others (1970). These data, however, were not used to determine statistical difference between the alloys, but to show relative position. The second method of evaluation compares one group of restorations with the second group by serial ranking (Osborne & others, 1976). In this technique, the photograph of the restoration with the least fracture at the margins is placed in the #1 position. The photograph with the next amount of fracture is placed in the #2 position and so forth until all photographs have been ranked. In the last position is the amalgam with the greatest amount of fracture at the margins. The data from rank ordering were analyzed by a Mann-Whitney U Test (Siegel, 1956) and were used to determine significant differences. The level of significance was set at $P < 0.05$.

RESULTS

The laboratory data on the two groups of alloy are summarized in Table 1. The slower-setting alloy (longer Eames working time) had higher creep and gained compressive strength more slowly, but was equal in compressive strength to the fast-setting alloy by the seventh day.

Table 1. Compressive Strength, Creep, and Eames Working Time of Two Alloys

	Group A Slower-setting Alloy	Group B Faster-setting Alloy
Eames Working Time	5.5 minutes	2.5 minutes
Creep	0.17 ± 0.02%	0.12 ± 0.02%
Compressive Strength (MPa)		
15 minutes	47 ± 5	52 ± 4
1 hour	162 ± 11	171 ± 8
24 hours	331 ± 20	377 ± 27
7 days	401 ± 28	400 ± 19

Results for the 1- and 2-year clinical evaluations are summarized in Table 2. At the end of the 1-year evaluation, 124 restorations were evaluated, and at the end of 2 years, 115 restorations were evaluated. Two patients were not available at the 2-year evaluation, and one tooth on another patient had the restoration replaced due to fracture. The ridit analysis indicated that the faster-setting alloy had less fracture at the margins at both 1 year and 2 years. The ranking order, however, showed that there were no significant differences between the two groups of setting rates/Eames working times. An examination of the data also indicates that there was no difference found between the two operators.

To examine the reliability of the evaluations, a comparison was made between the evaluators. For the ridit categorization data, the two evaluators independently ranked the restorations in the same category 87.7% of the time. In addition, no restorations were ranked more than two categories apart. The correlation of the two evaluators for the rank ordering test was r = 0.93. Both indicate high reliability.

DISCUSSION

This study evaluated the clinical performance of the two groups of an amalgam alloy after 2 years. Clinical research (Osborne, Norman & Gale, 1991; Letzel & others, 1989) has demonstrated that evaluating the rate of fracture at the margins is a predictable way to assess the long-term clinical success of different amalgam alloys. The results of this study indicate that the setting rate/working time does not seem to influence the clinical performance of the tested amalgam.

This one clinical study of an admix alloy does not prove that other alloys would not show an effect of varying the setting rate. Interestingly, spherical high-copper alloys seem to be less susceptible to manipulative variables, and one would not expect them to be influenced by setting rate. In this study, the Eames working times were exaggerated, the number of restorations studied was large, and yet the statistical data never approached a significant level. It is, therefore, a good assumption that setting rate and the Eames working time do not influence the clinical performance of amalgam. Other factors, such as preparation size (Osborne & Gale, 1990), are far more influential on the success of the restoration.

Promotion of an alloy as superior because it sets faster and, therefore, may be better handling and have greater early strength characteristics is not warranted. Alloy selection may be based on many factors, but setting time is not critical. It is perhaps advisable to have an appropriate alloy supplied with a faster and a slower time to accommodate the different clinical situations encountered.

CONCLUSION

After assessing 115 restorations 2 years postinsertion, it is concluded that the setting rate/working times of the alloy, as used in this study, do not a significantly influence the clinical performance of the alloy. Dentists should select their high-copper amalgam alloy on the basis of their desired handling characteristics and with close attention to the results of clinical tests rather than setting rate/working times.

Acknowledgment

A special thanks to Tim Wolf for his time and effort in providing the same batch of alloy in two different Eames working times.

Table 2. Ridit Analysis of 1- and 2-Year Restorations

	Categories 1	2	3	4	Ridit Means	Variance	Rank Ordering*
1-Year							
Fast-setting alloy	54	54	6	0	0.4414	0.0607	|
Slow-setting alloy	51	67	16	0	0.5028	0.0687	|
2-Year							
Fast-setting alloy	37	56	15	0	0.5256	0.0687	|
Slow-setting alloy	42	62	15	3	0.529	0.0714	|

*($P < 0.05$); Vertical bars = NS.

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References

BERRY TG, LASWELL HR, OSBORNE JW & GALE EN (1981) Width of isthmus and marginal failure of restorations of amalgam *Operative Dentistry* **6** 55-58.

BORGMEYER PJ, ADVOKAAT JGA, AKERBOOM HBM & VAN REENEN GJ (1981) The influence of the use of copalite on the marginal-breakdown of amalgam-restorations. Results after two years *Journal of Dental Research* **60** *Program & Abstracts of Papers* p 1283 Abstract 1285.

DENTAL ADVISOR (1991) **Vol 8** Dental amalgam.

EAMES WB & SKINNER EW (1965) A possible test for working time of dental amalgam *Program and Abstracts of Papers* p 60 Abstract 94.

EAMES WB, THARP LG & HIBBARD ED (1973) The effects of saliva contamination on dental amalgam *Journal of the American Dental Association* **86** 652-656.

GOLDBERG J, TANZER J, MUNSTER E, AMARA J, THAL F & BIRKHED D (1981) Cross-sectional clinical evaluation of recurrent enamel caries, restoration of marginal integrity, and oral hygiene status *Journal of the American Dental Association* **102** 635-641.

LEINFELDER KF, STRICKLAND WD, WALL JT & TAYLOR DR (1978) Burnished amalgam restorations: a two-year clinical evaluation *Operative Dentistry* **3** 2-8.

LETZEL H, van't HOF MA, VRIJHOEF MMA, MARSHALL GW Jr & MARSHALL SJ (1989) A controlled clinical study of amalgam restorations: survival, failures, and cause of failure *Dental Materials* **5** 115-121.

MAHLER DB, ENGLE JH & ADEY JD (1990) Effect of Pd on the clinical peformance of amalgam *Journal of Dental Research* **69** 1759-1761.

MAHLER DB & MARANTZ R (1979) The effect of the operator on the clinical performance of amalgam *Journal of the American Dental Association* **99** 38-41.

MAHLER DB, TERKLA LG, VAN EYSDEN J & REISBICK MH (1970) Marginal fracture vs mechanical properties of amalgam *Journal of Dental Research* **49** 1452-1457.

MAY KN Jr, WILDER AD Jr & LEINFELDER KF (1983) Burnished amalgam restorations: a two-year clinical evaluation *Journal of Prosthetic Dentistry* **49** 193-197.

OSBORNE JW (1990) Five-year clinical assessment of 14 amalgam alloys *Operative Dentistry* **15** 202-206.

OSBORNE JW & BERRY TG (1992) Zinc-containing high copper amalgams: a 3-year clinical evaluation *American Journal of Dentistry* **5** 43-45.

OSBORNE JW & GALE EN (1974a) A two-, three-, and four-year follow-up of a clinical study of the effect of trituration on amalgam restorations *Journal of the American Dental Association* **88** 795-797.

OSBORNE JW & GALE EN (1974b) Long term follow-up of clinical evaluations of lathe-cut versus spherical amalgam *Journal of Dental Research* **53** 1204-1207.

OSBORNE JW & GALE EN (1990) Relationship of restoration width, tooth position, and alloy to fracture at the margins of 13- to 14-year-old amalgams *Journal of Dental Research* **69** 1599-1601.

OSBORNE JW, NORMAN RD & GALE EN (1991) A 14-year clinical assessment of 12 amalgam alloys *Quintessence International* **22** 857-864.

OSBORNE JW, PHILLIPS RW, GALE EN & BINON PP (1976) Three-year clinical comparison of three amalgam alloy types emphasizing an appraisal of the evaluation methods used *Journal of the American Dental Association* **93** 784-789.

SIEGEL S (1956) *Nonparametric Statistics for the Behavioral Sciences* p 116 New York: McGraw-Hill.

SUMMITT JB & OSBORNE JW (1992) Initial preparations for amalgam restorations: extending the longevity of the tooth-restoration unit *Journal of the American Dental Association* **123(11)** 67-73.

WATSON PA, PHILLIPS RW, SWARTZ ML & GILMORE HW (1973) A comparison of zinc-containing and zinc-free amalgam restorations *Journal of Prosthetic Dentistry* **29** 536-541.

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Influence of Irradiation Sequence on Dentin Bond of Resin Inlays

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Clinical Relevance
Premix light activation of dual-cured cements significantly improved dentin bond strengths.

SUMMARY

The relationship between the order in which a dual-cured resin cement is light activated and the bond strength of resin inlay materials to dentin was examined. Also evaluated was the setting time with various irradiation sequences. Lite-Fil CR/Imperva Bond (Shofu) and Clearfil CR/CR Cement (Kuraray) were employed. Ten specimens, 4 mm in diameter by 4 mm deep, were made with each material for each condition and bonded to bovine dentin with the respective bonding agent and cement. Order of light activation was: 1) no light activation; 2) premix activation of only the liquid prior to mix, 3 seconds for Lite-Fil and 25 seconds for Clearfil; 3) postplacement activation, 30 seconds for Lite-Fil and 40 seconds for Clearfil; and 4) premix and postplacement activation, 3 seconds and 30 seconds for Lite-Fil and 25 seconds and 40 seconds for Clearfil. Samples were stored in water for 24 hours and shear strength tested. The setting time with no activation and premix activation was measured according to the ISO #7489 standards. Bond strengths (MPa) were 1) 4.41, 2) 13.07, 3) 6.34, and 4) 14.81 for Lite-Fil, and 1) 0.37, 2) 2.44, 3) 0.52, and 4)2.51 for Clearfil. No light activation or only postplacement activation resulted in lower bond strengths with a 4.0 mm-thick specimen. The setting time of the cement mix with premix activation was shorter than with no activation. Light activation of these dual-cure cements is essential. Premix activation of only the liquid resulted in bond strengths similar to those obtained with combined pre- and postplacement activating.

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INTRODUCTION

The problem of posterior composite restoration wear has been considerably reduced with improved resin formulations, but difficulties still exist in high-stress situations, related to inherent problems with both mechanical and chemical degradation of composite resins (Fukushima & others, 1988). In addition, it has been reported that light-cured composite resins have 2-3% volumetric shrinkages during curing (Masutani & others, 1989). The introduction of composite resin inlay systems that are more completely polymerized outside the oral environment and then luted to the tooth with a compatible resin cement is an attempt to overcome some of the limitations of direct filling posterior composite resin restorations. As a result, composite resin inlays should have improved mechanical properties (Wendt, 1987) and reduced gap formation at the tooth-resin interface (Robinson, Moore & Swartz, 1987).

However, Eguchi (1991) reported that the bond strength of the indirect composite resin inlay is lower than that of the direct composite resin filling. Most of the luting cements for resin inlays are dual-cured resin cements. The bulk and shape of a composite inlay may result in inadequate curing light exposure for the dual-cure cement, which might result in decreased bond strength. This study examines the new light-curing technique of premix activation of the dual-cured resin cement. The relationship between the order in which a dual-cured resin cement is light activated and the bond strength of resin inlay materials to dentin was examined.

METHODS AND MATERIALS

The following composite resin inlay systems were tested: Lite-Fil CR Inlay/Imperva Bond (Shofu Dental Corp, Kyoto, Japan) and Clearfil CR Inlay/CR Inlay Cement (Kuraray, Kurashiki, Japan). The resin inlay and each dual-cured resin cement were cured by exposure to a Day Light Lamp II (Shofu) for Lite-Fil CR and a Quick Light (Kuraray) for Clearfil CR.

The pulpal floor of a large inlay preparation is likely to be located entirely in dentin. In addition, the pulpal surface of a composite inlay is the cement area most likely to be inadequately light cured. In order to isolate the bond strength of this portion of a resin inlay and to eliminate the larger variations associated with actual inlay preparations, the following experiment was designed.

The incisal surfaces of bovine incisors were wet ground until approximately 2 mm remained coronal to the nearest pulp horns. Each tooth was then mounted in cold-curing acrylic resin so that the flattened area was exposed. Final finish was accomplished by grinding on wet 600-grit SiC paper until a 4-mm-in-diameter area of dentin was exposed. These surfaces were treated according to the manufacturer's directions.

Resin inlays were condensed into a mold 4 mm in diameter by 4 mm deep. Then the resin inlay specimens were irradiated and heat cured following manufacturer's instructions. Each specimen was bonded to dentin with its bond agent and cement.

The influence of the following factors on bond strength to dentin were examined: (1) no light activation, only chemically activated curing of the resin cement; (2) activation of only the liquid cement component prior to mixing, 3 seconds for Lite-Fil and 25 seconds for Clearfil. No irradiation was done to the mixed cement or the inlay restoration after placement; (3) postplacement activation, 30 seconds for Lite-Fil and 40 seconds for Clearfil, at 2, 5, and 30 minutes after mixing (manufacturer's instruction); (4) both premix light activation and postplacement light activation, 3 seconds and 30 seconds for Lite-Fil and 25 seconds and 40 seconds for Clearfil respectively.

A sample size of 10 specimens for each material for each test was used. The specimens were stored in 37 °C distilled water. After 24 hours, the shear bond strengths were measured using an Instron Testing Machine (Instron Corp, Canton, MA 02021) at a crosshead speed of 1 mm/minute.

The results were analyzed by calculating the mean bond strength and standard deviation for each group. The means and standard deviations for each cement were tested for homogeneity of variance using Bartlett's test. Since the variances were found to be homogeneous, the data for each cement were subjected to a one-way ANOVA. The ANOVA indicated that the light-curing sequence had a highly significant effect on the bond strength for each cement system. Tukey's procedure was then applied to make multiple comparisons among the groups for each cement.

The setting time with no activation and premix light activation of cement specimens was measured according to the ISO #7489 standards. Two minutes after the start of mixing, the cement was placed into a mold 10 mm in diameter by 3 mm thick. Two and a half minutes after the start of mixing, the indentor (400 ± 5 g load) was lowered vertically onto the surface of the cement and allowed to remain there for 5 seconds. A trial run to determine the approximate setting time was conducted, repeating the indentations at 30-second intervals until the needle failed to make a complete circular indentation in the cement when viewed using a hand lens of low magnification. The process was then repeated, starting the indentations 30 seconds before the approximate setting time, making indentations at 10-second intervals. The sample size was 10 and the mean setting time was rounded to the nearest 20 seconds.

RESULTS

The results of various bond tests are presented in the table. The highest bond strength for Lite-Fil was 14.81 MPa for combined light activation of the liquid prior to mix and irradiation after placement. That for Clearfil was 2.51 MPa for combined premix and postplacement light activation. There were no statistically significant differences between the bond strengths of premix light activation only and those of combined premix and postplacement light activation for either resin. No light activation or only postplacement activation resulted in significantly lower bond strengths when compared to premix or combined light activation.

The setting time of Lite-Fil was 1050 seconds without light activation and was reduced to 840 seconds with premix activation. For Clearfil the setting times were 630 and 310 seconds respectively. For both cements, premix activation significantly decreased setting time ($P > 0.05$).

DISCUSSION

The highest bond strength of Lite-Fil was obtained from 3 seconds of activation of the liquid prior to mix combined with 30 seconds of irradiation after placement. For Clearfil the highest bond strength obtained was with 25 seconds premix and 40 seconds postplacement activation. However, there were no significant differences between the bond strength of premix activation of only the liquid and that of combined premix and postplacement activation. Light activation is one of the most important factors for bonding whether using the pre- or postmix activation. The pre-irradiation of the liquid before cement mixing is effective even without irradiation of the cement after placement. Camphoroquinone in the liquid is made reactive by activation. This condition apparently generates free radicals, and this continues during the handling time. This reactive condition makes the premixed bond strength significantly higher than the postmixed irradiated strength without irradiation after placement.

*Shear Bond Strengths to Dentin, MPa [SD]**

	Lite-Fil	Clearfil
No light activation	4.47 [1.53]	0.37 [0.41]
Only postplacement activation	6.34 [1.50]	0.52 [0.49]
Only premix activation	13.07 [1.77]	2.44 [0.51]
Combined premix and postplacement activation	14.81 [2.14]	2.51 [0.42]

*Group means connected by vertical lines are not statistically different ($P > 0.05$, Tukey's Procedure).

The bond strength created by following the manufacturers' instructions is relatively lower than other reported values. These lower data might be explained by considering the specimen's thickness. The employed thickness in this study was 4 mm. The light transmittance of a 4 mm thickness is around 2%, and the much lower light intensity could result in the relatively lower bond strength. Bond strength studies on composite filling materials are normally conducted by curing increments less than 2 mm thick.

It was interesting to note that the setting time of cement mix with premix activation was shorter than that with no activation, as would be expected. However, it was judged that the reduction was not so great as to cause handling problems associated with too short a working time.

No light activation resulted in significantly lower bond strengths that were not significantly different than those for only postplacement activation. Failure to light cure a dual-cured material places total reliance on the chemical activator system. For the two materials studied, the chemical activation alone did not produce an optimal degree of cure.

Hinoura and others (1991) reported that premix activation of Fuji Lining LC (light-cured glass-ionomer cement) influenced the setting time and the compressive strength. This material has also the camphoroquinone curing system. Further studies are needed to define the kinetics and mechanisms of the camphoroquinone curing system.

CONCLUSION

Premix light activation of dual-cured cements used to bond 4 mm-thick resin inlay specimens significantly improved dentin bond strengths compared to the recommended postcementation light activation from the top surface. Adequate light activation of these dual-cured cements is essential for bonding of a composite resin inlay material, whether done before mixing or after placement. Setting times decreased with premix activation to the liquid; however, this would not appear to cause clinical handling problems related to short working times. Premix activation might be advantageous in cases where shape or thickness of resin inlays limits adequate light curing.

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References

EGUCHI J (1991) Study on composite resin inlays. Effect of bonding agent application on the bond strength to bovine teeth *Japanese Journal of Conservative Dentistry* **34** 1511-1518.

FUKUSHIMA M, OKAMOTO A, NAKAMATA T, HIRATA N, FUJITA K, KOTA K & IWAKU M (1988) Five-year clinical evaluation of chemically cured posterior composite resin restorations *Japanese Journal of Conservative Dentistry* **31** 1540-1549.

HINOURA K, MIYAZAKI M, AKIYAMA Y, AOKI F, AOSHIMA Y & ONOSE H (1991) Influence of irradiation sequence on physical properties of light-cured glass ionomer cement *Japanese Journal of Conservative Dentistry* **34** *Abstracts of Papers* p 148 Abstract B-54.

MASUTANI S, MATSUZAKI T, AKIYAMA Y, ASANO Y, EGUCHI J, ANDO S & ONOSE H (1989) Study on light cured composite resins. Consideration of the continuous volumetric shrinkage of resin during light irradiation *Japanese Journal of Conservative Dentistry* **32** 1606-1611.

ROBINSON PB, MOORE BK & SWARTZ ML (1987) Comparison of microleakage in direct and indirect composite resin restorations in vitro *Operative Dentistry* **12** 113-116.

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

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Placement and Replacement of Composite Restorations in Germany

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Clinical Relevance
Secondary caries was the most frequent reason for replacement in permanent teeth and in restorations with less than four surfaces, whereas fracture caused most failures in primary teeth and in fillings with four surfaces.

SUMMARY

From 15 September to 15 October 1991, 102 dentists practicing in a rural area of Germany provided information on 3375 composite resin fillings. The purpose of this cross-sectional study was to record the reasons for placement and replacement of composite resin restorations, including any change of material when replacing a filling, and to register the age of any failed restoration. First placements because of primary caries were made in 50.6% of all cases; 49.4% were replacements of failed restorations. Composite resins were used as a material for the first placement of a restoration in 19.2% of primary teeth and in 47.8% of permanent teeth. More amalgams were replaced by composites than vice versa. Secondary caries was the most frequent reason for replacement in permanent teeth and in restorations with less than four surfaces, whereas fracture caused most failures in primary teeth and in fillings with four surfaces. The median age of the replaced restorations was 43.5 months. Failed restorations with four surfaces had the lowest median age.

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INTRODUCTION

An increased use of tooth-colored dental materials, especially composite resins, has occurred during the past two decades (Qvist, Qvist & Mjör, 1990; Qvist, Thylstrup & Mjör, 1986). Depending on the clinical conditions, e g, whether esthetics or strength is indicated, different resin-based materials are available, such as microfillers, macrofillers, and hybrids. Silicate cement has been completely replaced by composite resins for use in anterior teeth (Qvist & others, 1990). Better materials and new restorative techniques, including the acid-etch technique, have led away from the classic principles of cavity preparation to a more tissue-saving way of treatment. The new techniques also increased the possibilities for the use of composite resins, e g, for class 4 restorations (Qvist & others, 1990). New dentin bonding systems (Hansen, 1989; Krejci, Picco & Lutz, 1990) should also lead to a wider use of composite resins and other tooth-colored restorations in the future. Even in posterior stress-bearing teeth specially designed composite resins are accepted as an alternative to amalgams in some situations (Hendriks & Letzel, 1988; Swijnenburg & others, 1988).

Rapid developments in the area of dental materials often cause a change in filling materials and restorative techniques without knowledge of the reasons for success or failure in daily practice over a longer period of time (Qvist & others, 1990).

In many cases the failure of a restoration is not dependent on the material itself, but on other reasons, e g, improper handling of the material, refusal of many dentists to use a rubber dam, or bad oral hygiene of the patients (Allan, 1969; Allander, Birkhed & Bratthall, 1990; Dahl & Eriksen, 1978; Mjör, Jokstad & Qvist, 1990; Pieper & Simaitis, 1989).

The aim of this cross-sectional study was to provide information on the use of composite resins in daily practice, including the reasons for failure and the median age of the failed fillings in a rural area of Southern Germany.

METHODS AND MATERIALS

In August 1991 a questionnaire was sent to all 481 dentists practicing in a rural area of Southern Germany (Oberpfalz). They were asked to record information from 15 September to 15 October 1991 on whether a filling was made because of primary caries, which will be referred to as "first placement," or as a replacement of an old filling. The following reasons for replacement were provided on the questionnaire: primary caries, secondary caries, marginal gap without caries, fracture (tooth, isthmus, other), pain, discoloration, loss of contour, and lost filling. The clinicians were also asked to indicate the number of surfaces, the material of the old and new filling, and, if known, the age of the old filling. The dentists were allowed to mark several reasons for replacement.

In order to distinguish the reasons for placement and replacement in primary and permanent teeth among the young and adult patients and to have the possibility of comparing our results with other studies, the patients were divided according to Qvist and others (1990) into three groups:

PRT Group: primary teeth and the patient is 16 years old or younger,

PET 1 Group: permanent teeth and the patient is 16 years old or younger, and

PET 2 Group: permanent teeth and the patient is older than 16 years.

Median ages of failed restorations according to the number of surfaces were compared using the Median Test (Siegel, 1956) at $P < 0.01$.

RESULTS

Information on 8794 fillings was provided by 102 dentists (21.2%) taking part in our study; a total of 3375 composite fillings was placed during the given period, 90.0% of them in the PET 2 group. Figure 1 shows the distribution of all composite fillings according to age, dentition, and number of surfaces of the restoration.

Primary caries was the reason for filling 1707 teeth for the first time; 65.7% of them were anterior teeth. The percentage of the first placements with one or two surfaces in the PET 2 group was 74.8% (Figure 2). Composite was used as the material for the first placement of a restoration in the PRT group in 19.2%, in the PET 1 group in 23.4%, and in the PET 2 group in 47.8%. Composite was used in 10.9% for replacement of amalgam fillings.

Altogether, 1358 composite fillings were replaced: 91.4% of them were replaced by composites, 6.5% were replaced by amalgams, and 2.1% were replaced by other materials. The most frequently recorded reasons for replacement in the PRT group were fracture, secondary caries, and marginal gap without caries. In the PET 1 and in the PET 2 groups they were secondary caries, discoloration, and fracture (Figure 3). Primary caries as the only reason for replacement was recorded in 2.9% of all cases.

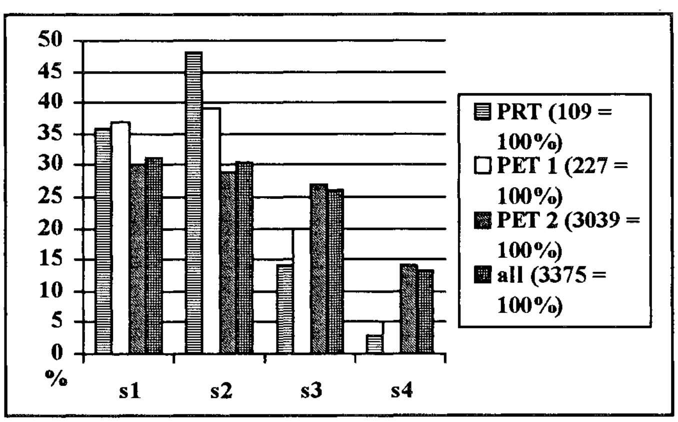

Figure 1. *Distribution of all composite resin restorations (%) according to age of the patient, dentition, and number of restoration surfaces (s); PRT = primary teeth; PET 1 = permanent teeth and patient is 16 years old or younger; PET 2 = permanent teeth and patient is older than 16 years.*

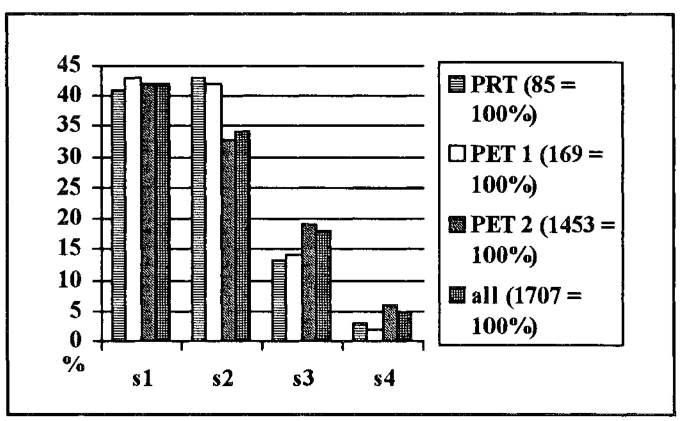

Figure 2. *First placement with composite resins (%) according to age of the patient, dentition, and number of restoration surfaces (s); PRT = primary teeth; PET 1 = permanent teeth and patient is 16 years old or younger; PET 2 = permanent teeth and patient is older than 16 years.*

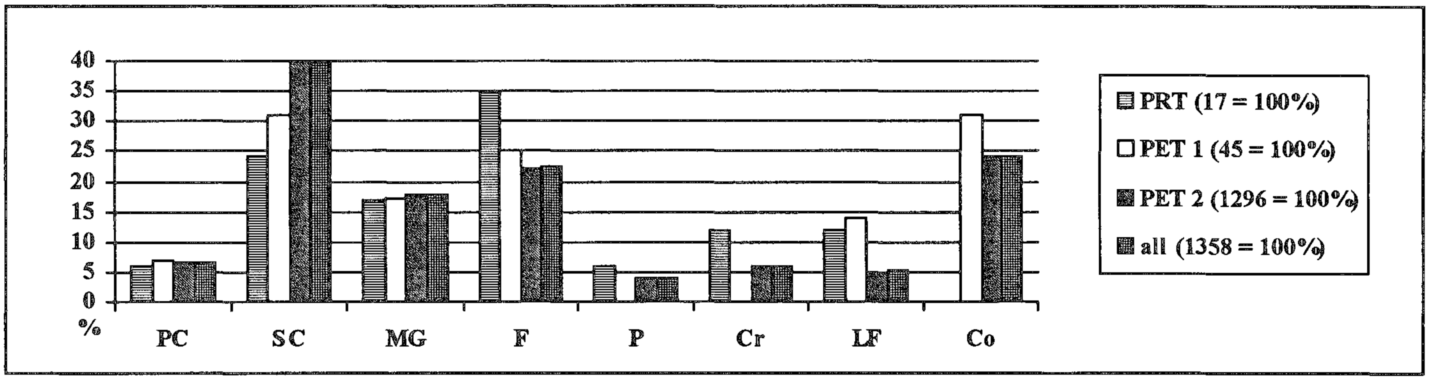

Figure 3. *Reasons for replacement (%) of failed composite resin restorations according to age of the patient and dentition; PRT = primary teeth; PET 1 = permanent teeth and patient is 16 years old or younger; PET 2 = permanent teeth and patient is older than 16 years; PC = primary caries; SC = secondary caries; MG = marginal gap; F = fracture; P = pain; Cr = contour; LF = lost filling; Co = color.*

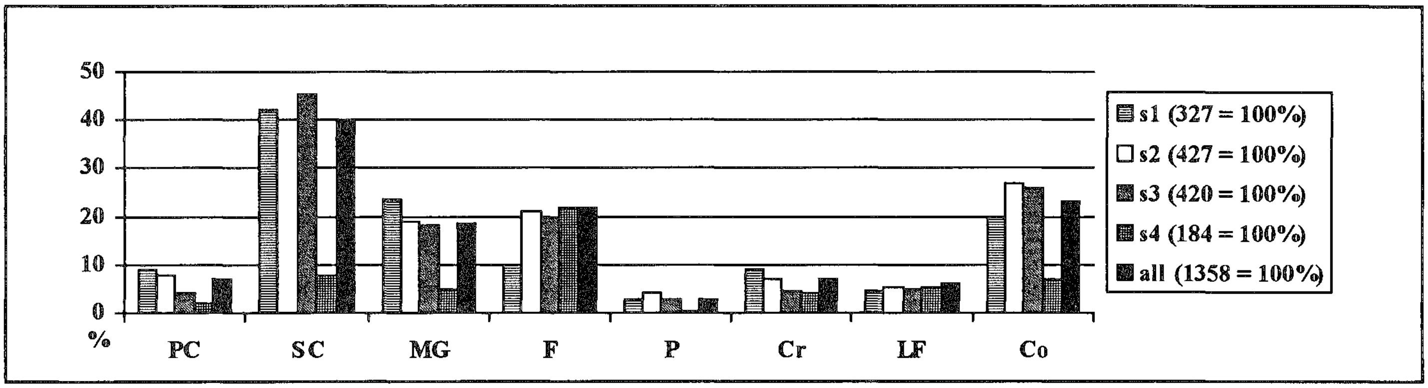

Figure 4. *Reasons for replacement (%) of failed composite resin restorations according to the number of restoration surfaces (s); PC = primary caries; SC = secondary caries; MG = marginal gap; F = fracture; P = pain; Cr = contour; LF = lost filling; Co = color.*

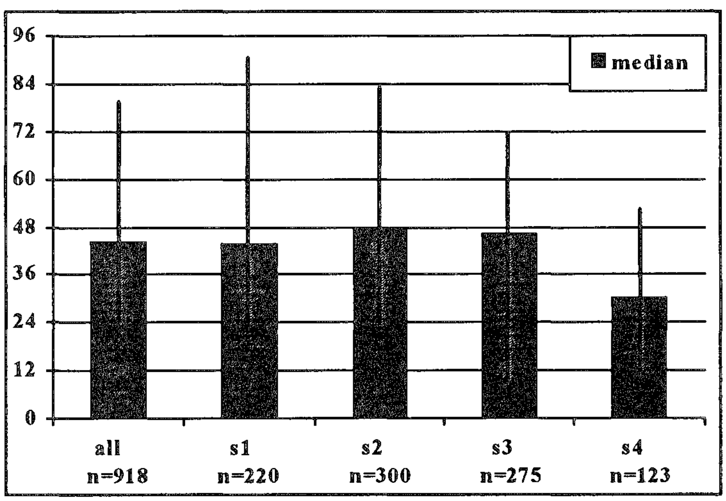

Figure 5. *Median recorded longevity of failed composite resin restorations (in months) according to the number of restoration surfaces (s). Bar = 25%-75% quantities.*

Secondary caries was the most frequent reason for replacement of the composite restorations with one, two, or three surfaces, whereas fracture was the main reason for failure in fillings with four surfaces. The second most frequent reason for replacement of fillings with two or three surfaces was discoloration (Figure 4).

The age was recorded in 918 (67.6%) of the 1358 replaced composite fillings. The median age of the failed restorations in the PRT group was 12 months. The median age of all replaced composite restorations was 43.5 months; in the PET 2 group (n = 863) it was 48 months.

Figure 5 shows the median age of the replaced composite restorations with respect to number of surfaces of the restoration. There was no significant difference in age between fillings with one, two, and three surfaces, but failed fillings with four surfaces had a significant lower median age than fillings with one, two, or three surfaces.

DISCUSSION

In our study, which covered different restorative techniques (e g, amalgams, composite resins), every third new restoration was a composite resin restoration, and in adult patients the percentage reached nearly 50%. Our results and the results of another investigation (Qvist & others, 1990) also show that more amalgam restorations are replaced by composites than vice versa. These findings may be an indication that there is a trend to use composites more frequently, which is confirmed by two Danish surveys from 1982-83 (Qvist & others, 1986) and 1987-88 (Qvist & others, 1990), which showed that the percentage of composite fillings increased from 28% to 42% within 6 years.

More than 95% of the first placements in anterior teeth were composite fillings, which is in agreement with other authors (Qvist & others, 1990; Qvist & others, 1986). Although Hendriks and Letzel (1988) point out that in posterior teeth the 5-year survival rate of class 1 and class 2 fillings in adults is higher in composite fillings than in amalgam fillings, in our investigation only 20% of first placements in posterior teeth were composite fillings. Considering the present discussion about the possible toxicity of amalgams (Schiele, 1991), it should be noted that 6.5% of all composite fillings in our study were replaced by amalgams. This percentage is distinctly higher than the 3% reported by Qvist and others (1990).

Contrary to the fluoride-releasing glass-ionomer cements, composites accelerate the growth of *Streptococcus mutans* (Friedl, Schmalz & Hiller, 1992). Svanberg, Mjör, and Ørstavik (1990) found more plaque in composite/tooth interfaces than in amalgam/tooth or glass ionomer/tooth interfaces. In combination with poor oral hygiene, the high proportion of *Streptococcus mutans* may cause secondary caries, which was indeed the most frequent reason for replacement of composite fillings in our and other investigations (Qvist & others, 1990; Mjör & Toffenetti, 1992). The large number of first placements in adult patients, which was about 10% higher than in a similar study in Denmark (Qvist & others, 1990), and the fact that more than 25% of these first placements had three or more surfaces, confirm the demand for effective prophylactic dentistry and good patient oral hygiene (Pieper & Simaitis, 1989).

The median age of the failed composite restorations in primary teeth was 12 months in our study, which is similar to the findings by other authors (Qvist & others, 1986, 1990). It has to be considered that the median longevity of failed restorations in primary teeth is inevitably lower than the longevity in adult teeth because of the preselection of the patients' age structure. However, these data indicate that these materials allow no compromise in placement technique, as is often necessary in the treatment of children, and therefore they seem to be a less than optimal choice for use in primary teeth. The relation between amalgam and composite fillings in primary teeth of 5:1, compared to 1:1 in permanent teeth, seems to support this statement. The replacement rate for esthetic reasons (discoloration) of 23% in our study was distinctly higher than in other investigations (2-12%) (Qvist & others, 1986, 1990). Discoloration may be caused by an inherent material problem, e g, marginal gaps caused by the shrinkage of the material; it may also be caused by inadequate technique in the use of the material, e g, little air bubbles on the surface or marginal discrepancies. However, the design of the study allows no differentiation among reasons for discoloration.

The median longevity of 43.5 months in failed composite restorations in our investigation is lower than the results in two Danish studies (Qvist & others, 1986, 1990), which reported median longevity of failed fillings of 72 months, but it is higher than results in Italy of 39.6 months, as reported by Mjör and Toffenetti (1992). The design of the studies allows no conclusions as to the reasons for the difference in longevity, because no details are available on the patients' oral hygiene, the materials, or any differences in the clinical technique using the materials. Compared to amalgam fillings (Friedl, Hiller & Schmalz, 1994) the median age of the failed composite resin restorations in our study is lower. This result is also consistent with other surveys (Qvist & others, 1986, 1990).

CONCLUSIONS

The percentage of composite restorations placed in adult permanent teeth was much higher than the percentage in primary teeth.

Secondary caries and discoloration were the main reasons for replacement of composite resin restorations in permanent teeth, whereas fracture and secondary caries were the main reasons for replacement in primary teeth.

Failed restorations with four surfaces showed a significant lower median age than restorations with one, two, or three surfaces.

Acknowledgments

The authors would like to thank all the dentists who took part in this study and the local dental association for the distribution of the questionnaires.

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References

ALLAN DN (1969) The durability of conservative restorations *British Dental Journal* **126** 172-177.

ALLANDER L, BIRKHED D & BRATTHALL D (1990) Reasons for replacement of class II amalgam restorations in private practice *Swedish Dental Journal* **14** 179-184.

DAHL JE & ERIKSEN HM (1978) Reasons for replacement of amalgam dental restorations *Scandinavian Journal of Dental Research* **86** 404-407.

FRIEDL K-H, HILLER K-A & SCHMALZ G (1994) Placement and replacement of amalgam restorations in Germany *Operative Dentistry* **19** 228-232.

FRIEDL K-H, SCHMALZ G & HILLER K-A (1992) Flüssigkeitskulturen zur Prüfung der Wirkung zahnärztlicher Werkstoffe auf das Bakterienwachstum *Deutsche Zahnärztliche Zeitschrift* **47** 826-831.

HANSEN EK (1989) Three-year study of cervical erosions restored with resin and dentin-bonding agent *Acta Odontologica Scandinavica* **47** 301-306.

HENDRIKS FHJ & LETZEL H (1988) The durability of amalgam versus composite restorations *Journal of Dental Research* **67** *Divisional Abstracts* p 689 Abstract 54.

KREJCI I, PICCO U & LUTZ F (1990) Dentinhaftung bei zahnfarbenen adhäsiven MOD-Sofortinlays aus Komposit *Schweizer Monatsschrift für Zahnmedizin* **100** 1151-1159.

MJÖR IA, JOKSTAD A & QVIST V (1990) Longevity of posterior restorations *International Dental Journal* **40** 11-17.

MJÖR IA & TOFFENETTI F (1992) Placement and replacement of resin-based composite restorations in Italy *Operative Dentistry* **17** 82-85.

PIEPER K & SIMAITIS K (1989) Kariesbefall, Sanierungsgrad und Mundhygiene bei Kindern im Vorschulalter *Deutsche Zahnärztliche Zeitschrift* **44** 503-506.

QVIST V, QVIST J & MJÖR IA (1990) Placement and longevity of tooth colored restorations in Denmark *Acta Odontologica Scandinavica* **48** 305-311.

QVIST V, THYLSTRUP A & MJÖR IA (1986) Restorative treatment pattern and longevity of resin restorations in Denmark *Acta Odontologica Scandinavica* **44** 351-356.

SCHIELE R (1991) Die Amalgamfüllung—Verträglichkeit *Deutsche Zahnärztliche Zeitschrift* **46** 515-518.

SIEGEL S (1956) *Nonparametric Statistics for the Behavioral Sciences* pp 179-184 New York: McGraw-Hill.

SVANBERG M, MJÖR IA & ØRSTAVIK D (1990) Mutans streptococci in plaque from margins of amalgam, composite, and glass-ionomer restorations *Journal of Dental Research* **69** 861-864.

SWIJNENBURG JT, KORTLAND PJ, LUXWOLDA RJ, de LANGE C & BAUSCH JR (1988) Clinical evaluation of four posterior composite resins: three-year report *Journal of Dental Research* **67** *Divisional Abstracts* p 689 Abstract 51.

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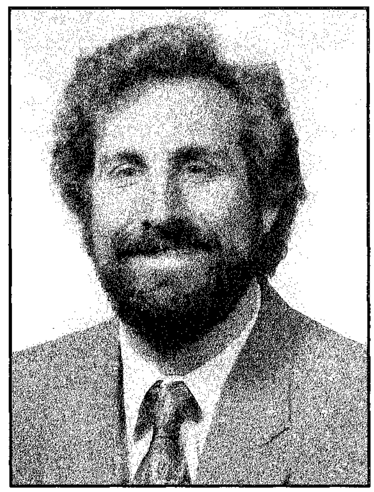
Clinician of the Year Award

Dr Frederick C Eichmiller fulfills perfectly all the criteria Mr Vic Williams spelled out when he donated the Clinician of the Year award to the Academy of Gold Foil Operators on behalf of the Ivoclar/Williams Company. Vic's goal was to recognize annually one of the academy's younger members who is an outstanding individual and a rising professional star. Not only is Fred an outstanding operator and teacher of direct gold techniques, but he is also recognized for many contributions that improve the delivery of dental care.

Dr Eichmiller was born in Minnesota in 1955. At the University of Minnesota, Fred earned a degree in Mechanical Engineering and then his Doctor of Dental Surgery from the dental school. After graduation, he was in private practice in Olivia, Minnesota. At the same time he commuted 60 miles each way, one day a week, to teach clinical operative dentistry at the University of Minnesota School of Dentistry. In 1985, he was appointed clinical director in the Clinical Operative Department. During this time, while in private practice and teaching one day a week, Fred was an active operating member of the G V Black Gold Foil Study Club. In 1986 Dr Eichmiller joined the Paffenbarger Research Center at the National Institute of Standards and Technology, formerly the National Bureau of Standards. In the eight years since, Fred has been awarded one patent and has published 21 journal articles along with lecturing extensively in the United States, Canada, and Europe; his lectures include three presentations at the annual meeting of the Academy of Operative Dentistry. In 1994 he was made director of the Paffenbarger Research Center.



Frederick C Eichmiller

Currently, Fred is an active operating member in the Navy Restorative Seminar; three years ago he was their director. He also is an active member of the George M Hollenback Gold Foil Seminar under the excellent direction of Dr José Medina. In addition, Fred is a member of the Executive Council of our American Academy of Gold Foil Operators.

Dr Eichmiller is a fine role model for any who are interested in pursuing excellence in life as well as dentistry; he is a most deserving recipient of the Clinician of the Year Award. It is an honor and a special personal pleasure for me to make this presentation to Dr Frederick C Eichmiller.

NELSON W RUPP

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Distinguished Member Award

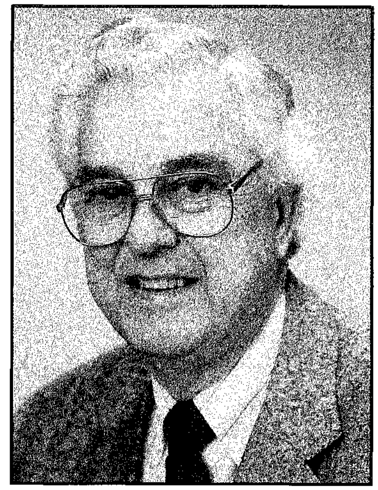
Harold E Schnepper has distinguished himself in the pursuit of excellence in dental education and the clinical practice of dentistry. He has had an impact on the lives of dental students and colleagues, demonstrating that a high level of dentistry can be an achievable goal in daily practice. In particular he has, through the medium of direct gold, perfected his skills and advanced the use of direct gold to both predoctoral students and the postdoctoral community.

Dr Schnepper was born in Argentina, and he received his DMD degree from the University of Oregon in 1946 and an MSD degree in 1954 from the University of Washington. His academic career began as a clinical assistant instructor in 1949 at the University of Washington. In 1954, he was recruited as an assistant professor at the then-new Loma Linda University School of Dentistry. He has continued to teach in Restorative Dentistry to the present time, holding the rank of professor for the past 23 years. Departmental leadership has been realized through his appointment as section chief of Operative Dentistry at Loma Linda for the past seven years. Throughout most of his professional career he has maintained a private dental practice in Rialto, California.

In his academic role Dr Schnepper has taught at both the preclinical and clinical levels in operative and fixed prosthodontics. One does not have to be around Dr Schnepper very long to discover that he is an avid promoter of direct gold as a restorative material. The student quickly recognizes his knowledge and skill in the placement of direct gold and the attention to detail.

The positive influence felt by predoctoral students has extended to his colleagues in both the academic and private practice communities through his mentorship of the Loma Linda Gold Foil Seminar for 35 years. It was in this study club environment that the Loma Linda lingual approach class III design, the Loma Linda modified class III design, and Goldent direct gold came to be. Throughout his career he has also mentored international study seminars of shorter duration.

Dr Schnepper has published in *Operative Dentistry* and the *Journal of Prosthetic Dentistry*, primarily on the topic of direct gold, and one of his significant recent contributions is as the co-author of a teaching manual, *Direct Gold Restorations*. The initial target audience of this manual was upper-division predoctoral students; however, practicing clinicians in this country and abroad have sought to obtain this valuable manual. It is now available in German and Japanese, with a pending translation in Italian.



Harold E Schnepper

He is a life member of the American Dental Association, a member of the California Dental Association and Tri-County Dental Association, fellow of the American College of Dentists, of the International College of Dentists, and the Academy of Dentistry International, a member of the American Academy of Crown and Bridge Prosthodontics, Pacific Coast Society of Prosthodontics, Academy of General Dentistry, and Omicron Kappa Upsilon, a charter member of the Academy of Operative Dentistry, and a charter member and past president (1981-1982) of the Academy of Gold Foil Operators.

Because of his devotion to the Academy, his dedication to excellence, his participation through presentations or clinical demonstrations, and his active participation in this organization, his colleagues and fellow members of the American Academy of Gold Foil Operators take great pride and pleasure in presenting our friend Harold Schnepper with the Distinguished Member Award for 1994.

RONALD K HARRIS

INSTRUCTIONS TO CONTRIBUTORS

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