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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, book reviews, letters, and classified ads for faculty positions also are published.

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Editorial Office

University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457
Telephone: (206) 543-5913, FAX (206) 543-7783
URL: http://weber.u.washington.edu/~opdent/

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EDITORIAL

A Farewell to Arms

With this issue being the last one published under my guidance, I felt an obligation to humbly thank everyone involved for making my five years as your editor an enjoyable and rewarding experience. By everyone I mean the subscribers; authors; Editorial Board members; Special Consultants; Academy of Operative Dentistry; American Academy of Gold Foil Operators; the publishers; Managing Editor Marty Anderson; and our remarkable staff of Kate Flynn Connolly, Darlyne Bales, and Judy Valela. All of you have been very important pieces of this puzzle and have played a valuable role in making our Journal such a high-quality publication as noted by *Dental Materials*, which continues to list *Operative Dentistry* as one of the 17 key primary journals in the world for referencing dental materials. In addition, the recognition by the Institute for Scientific Information listing our Journal as having the eighth most significant international impact in the category of Dentistry/Oral Surgery and Medicine in 1997 and eleventh in the world in 1998 was a significant tribute. This is not bad for a journal of so few pages, published bimonthly!

When I assumed the editorship in 1994, *Operative Dentistry* was publishing 48 pages. In addition, approximately 70 to 75 manuscripts were received each year for publication consideration. This year, we are on our way to a record 100+ manuscripts to consider, so this issue will begin publication of 72-page journals. This is an indication of the esteem that authors place on publishing in our Journal. However, the extra workload placed on reviewers and editorial staff is significant, so we are tremendously fortunate to have the loyal dedication of so many very busy workers who give unselfishly of their time. With the able support of Stephen Thielke, our computer guru, we were able to initiate an *Operative Dentistry* Home Page during my tenure, which has become a much-used resource by many professionals throughout the world. With the availability of electronic communication and ability to accept credit card payment for subscriptions, we have become far more global than ever before. Subscriptions from Russia are now being received, and we currently are sending journals into 54 countries around the world. The only area that has not increased appreciably has been our subscriber base. Our goal of having 2000 subscribers has never been reached and, therefore, must be left in the able hands of our new editor, Dr Mike Cochran, and managing editor, Dr Tim Carlson, to accomplish.

A highlight of my tenure as your editor has been the response to my editorials. Of course not all responses have been positive, but many readers have mentioned that they look forward to reading the editorial in each issue. Even our dean has remarked that, although he disagrees with much of what is said in the editorials, he always reads them! What more could an editor ask of his dean than that?

The University of Washington has been the home of *Operative Dentistry* since its first publication in 1976. The support given by our university and department chair has always been solid and supportive. The cadre of personnel at Indiana, under the competent leadership of Dr Mike Cochran, are enthusiastic, innovative, and superbly capable of reaching new heights in the 21st century. I have taken great pride in serving you and will now join in the excitement of seeing to what illustrious heights our Journal will soar in the future!

RICHARD B McCOY
Editor

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COMMENTARY

Where Has Excellence Gone?

Teaching and learning have long been shown to be interrelated and yet unrelated. Teaching is the giving of information, but it is an unrelated process if the recipient is closed-minded. Learning is the acceptance of material by the recipient. There appears to be two types of learning. On one end is the attempt to learn material that has no personal meaning, such as memorization of lists or the doing of procedures that are not understood. In contrast there is experiential learning that is significant and has meaning for the recipient. This learning occurs in stages or processes, building new layers upon previously accepted layers of knowledge. At what point does the layering stop? Obviously at the level at which the individual is unwilling to accept any more knowledge.

For years it has been proposed that there exists a level called "minimum competence." Further learning brings a person to the next level, that of proficiency. Even more skills will create a level of expert and so on. But the practice of dentistry does not simplistically encompass levels of achievement. Years of training do not make one an expert. There is no feedback in the system, and only a self-critique provides the personal analysis. Instead of the layered progression that has been proposed for years, learning appears to occur in differing components, depending on what individuals are exposed to (from teaching) and what they are willing to accept (through learning).

Techniques of operative dentistry can be separated into two components: (1) quality, or how well procedures are done, and (2) quantity, or the numbers of different techniques or procedures a person has learned. Quality or excellence can be measured in a vertical vector, while quantity can be measured in a horizontal dimension. Excellence has to be learned through exposure and demonstration with a feedback of acquired understanding. It is possible to learn this in the dental school environment if faculty members understand excellence and demand its achievement, and if the philosophy of the institution fosters quality learning. For the majority of students, the best quality of dentistry that many will do is done as they graduate from dental school.

If an individual has not learned excellence by this time, the chances of moving up in the vertical vector are very small. Quality then can only be learned if an individual teams with a study group striving for this ideal. The study group needs to be mentored by someone who understands and can demonstrate excellence and give feedback to the person learning. Individuals could learn excellence if they worked with a guru in a true learning experience that would help them to improve self-understanding. Dentists work daily in an environment with only solitary feedback in terms of how dentistry is done, and this self-analysis is seldom accurate. This is true for gurus and mentors as well. A great deal of care and restraint must be exhibited in choosing a leader and finding one who truly is interested in excellence and has no other underlying motivation.

The horizontal vector, or quantity, represents the various techniques learned by the individual dentist. While these techniques vary in the extent of ability on the vertical scale, to gain excellence in any area would require exposure and opening to learning from an outside source. By learning techniques on a horizontal vector (increased knowledge and methods), one could stay on a level of mediocrity in all fields of dentistry if exposure to excellence never occurred.

Years of practice with only self-feedback does not and will not elevate a practitioner to the highest levels of quality care. Exposure to excellence in a dental education will not guarantee that those high standards will be maintained. Learning that involves a change in self-organization—in the perception of oneself—is threatening and tends to be resisted. Then the question begs to be asked, Does quality or excellence matter? Your answer is probably right for you.

FLOYD TANNER, DDS
President
Western Regional Examining Board

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ORIGINAL ARTICLES

Effect of Mechanical Properties of Resin Composites on the Efficacy of the Dentin Bonding System

T HASEGAWA • K ITOH • T KOIKE
W YUKITANI • H HISAMITSU
S WAKUMOTO • A FUJISHIMA

Clinical Relevance
Higher tensile bond strengths cannot be used to predict improved marginal adaptation of composite restorations.

SUMMARY

This study determined the relationship between marginal adaptation to dentin cavity preparations, tensile bond strength of the restorations, and mechanical properties of the composites. Contraction gaps, tensile bond strengths, flexural strengths, and Young's modulus of eight commercial resin composites were determined. Eight resin composites (Clearfil AP-X, Estelite, Estio LC, Litefil II-A, Prodigy, Progress, Silux Plus, and Z-100) were applied to dentin cavities or flat dentin surfaces mediated with an experimental dentin bonding system consisting of 0.5M EDTA dentin conditioner, priming with 35% glyceryl monomethacrylate solution, and a commercial dentin bonding agent application (Clearfil Photo Bond). The contraction gap of the resin composite in a cylindrical dentin cavity was prevented completely for three of the resin composites tested (Clearfil AP-X, Estelite, and Silux Plus). The measured tensile bond strength correlated significantly not only with the tensile strength ($r^2 = 0.506$; $0.01 < P < 0.05$), but also with the flexural strength ($r^2 = 0.871$; $P < 0.001$) and Young's modulus ($r^2 = 0.712$; $0.001 < P < 0.01$) of the composites, whereas the contraction gap did not correlate significantly with the measured tensile bond strength, the tensile strength, the flexural strength, or Young's modulus ($P > 0.05$). However, the results did indicate that the higher tensile bond strengths measured in the traditional test may be related to the higher mechanical properties of the resin composites because of the number of specimens that exhibited cohesive failure.

Showa University School of Dentistry, Department of Operative Dentistry, 2-1-1 Kitasenzoku, Ohta-ward, Tokyo 1458515, Japan

T Hasegawa, DDS, DDSc, PhD(Medical), assistant professor

K Itoh, DDS, DDSc, associate professor

T Koike, DDS, research fellow

W Yukitani, DDS, DDSc, assistant professor

H Hisamitsu, DDS, DDSc, professor and chair

S Wakumoto, DDS, DMSc, professor emeritus

A Fujishima, DDS, DDSc, assistant professor of Department of Oral Biomaterials and Technology

INTRODUCTION

The efficacy of dentin bonding systems has been widely evaluated by bond strength measurement to flat dentin surfaces (Davidson, de Gee & Feilzer, 1984).

However, many other factors have been reported as having a possible effect on bond strength, such as kind of teeth (Nakamichi, Iwaku & Fusayama, 1983; Retief & others, 1990), storage media or storage period of extracted teeth (Mitchem & Gronas, 1986; Retief & others, 1989), surface roughness of ground dentin (Moweray, Parker & Davis, 1990), and distance of the substrate dentin from the pulp chamber or the thickness of the specimen (Mitchem & Gronas, 1986; Tao & Pashley, 1988; Takemori & others, 1993). Furthermore, standardized methodologies are not available for bond strength measurement (Retief, 1991). Experience has shown that most of the specimens evaluated by traditionally designed experimental bond strength measurement exhibit cohesive fractures in the resin composite or dentin. This indicates that the maximum value of bond strength at the adhesive interface under the resin composite remnant or the dislodged dentin may be greater than the minimum value of the mechanical strength of the resin composite or the substrate dentin within each distribution. It is felt that the measured bond strength strongly reflects the mechanical strength of the resin composite or the substrate dentin itself. The clinical behavior of the dentin bonding system may not be accurately predicted by the measured bond strength; the clinical behavior must be proven not only by marginal adaptation in the dentin cavity but also by interaction between the bond strength and some mechanical properties of the resin composites, e g, Young's modulus against an occlusal loading or thermal coefficient of expansion against temperature changes during the period of function in the oral cavity. Fracture discrepancies between bond strength measurements and marginal integrity of clinical cavities are explained by the contraction stress of the resin composite (Asmussen & Jørgensen, 1972). As suggested by Asmussen (1975), the primary requirement for the dentin bonding system is to prevent the separation of the unpolymerized resin composite paste from the cavity wall during polymerization. The marginal adaptation of the resin composite restoration is determined by the interaction between the efficacy of the dentin bonding system and the polymerization contraction stress of the resin composite. However, the effect of polymerization contraction gap on marginal integrity is impossible to detect in bond strength measurements, because the resin composite paste flows toward only the flat dentin surface in the specimens for bond strength measurement. Flow toward the bulk of the composite restoration is caused by a lack of bonding, while flow toward both the cavity walls and cavity floor is caused by adequate bonding in the clinical cavity (Versluis, Tantbirojn & Douglas, 1998).

In this study, the relationships among the width of the contraction gap of the resin composites, traditionally designed tensile bond strengths of the dentin bonding system, and the mechanical properties of the resin composites were determined for eight resin composite materials.

METHODS AND MATERIALS

The eight commercial light-activated resin composites tested are listed in Table 1. Marginal adaptation of these composites in dentin cavity preparations was examined by measuring the wall-to-wall polymerization contraction gap widths in cylindrical dentin cavities.

Measurement of the Wall-to-Wall Polymerization Contraction Gap Width

The approximal enamel of an extracted human molar was removed using wet 220-grit carborundum paper to form a flat dentin surface. Then a cylindrical dentin cavity, approximately 3 mm in diameter and 1.5 mm deep, was prepared in the exposed dentin by use of the end of a plain fissure bur at low speed using water coolant. The width was verified by use of slide calipers and the depth by use of a periodontal probe. The cavity walls were conditioned with 0.5 mol/L neutralized EDTA (pH 7.4) for 60 seconds followed by rinsing and drying. The cavity was primed with 35 vol% glyceryl monomethacrylate (Blemmer GLM; NOF Co, Tokyo, Japan) solution for 60 seconds and dried completely. Subsequently, a commercial dual-cured dentin bonding agent (Clearfil Photo Bond; Kuraray, Osaka, Japan) was placed in the cavity and irradiated for 10 seconds after eliminating the excess material with a compressed air blast. The cavity was filled with one of the eight tested composites. The composite surface was momentarily pressed on a glass plate mediated with a plastic matrix (Frasaco Polyester Strip; GC, Tokyo, Japan) and irradiated for

Table 1. Commercial Resin Composites Tested

Material	Manufacturer	Batch #
Clearfil AP-X	Kuraray, Osaka 5300021 Japan	0023
Estelite	Tokuyama, Tokyo 1500002 Japan	029
Estio LC	GC, Tokyo 1740052 Japan	960905
Litefil II-A	Shofu, Kyoto 6050983 Japan	089637
Prodigy	Sybron Dental Specialties, Inc, Orange, CA 98267	605069
Progress	Kanebo, Tokyo 1070051 Japan	13H65
Silux Plus	3M Dental Products, St Paul, MN 55144	4CA
Z-100	3M Dental Products	5HB

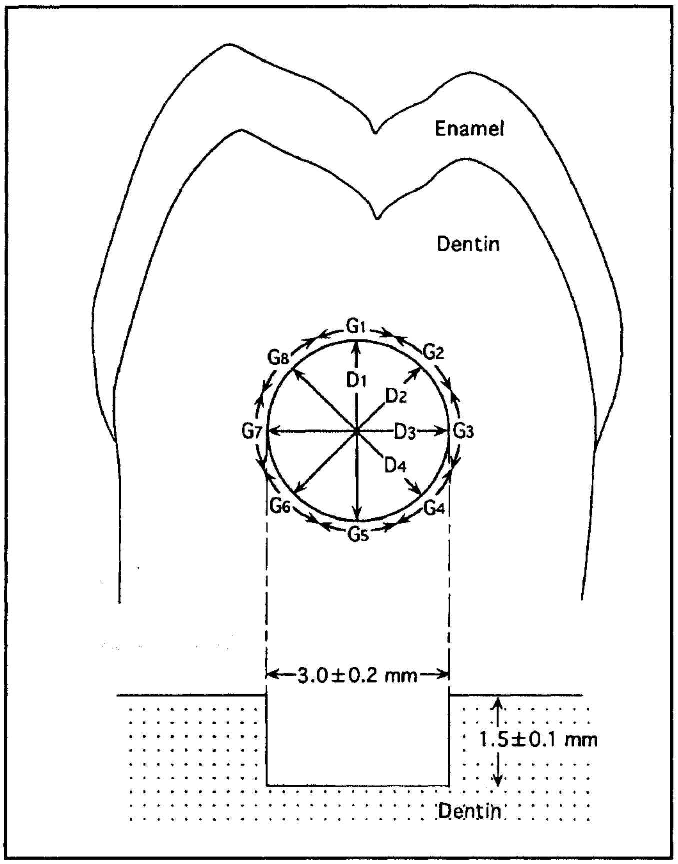

Figure 1. *Contraction gap measurements. G1-8 = measuring points; D1-4 = measured diameters.*

40 seconds. After storing the specimens for 10 minutes in water at room temperature at 24 ± 1 °C, the cavity margin was exposed by eliminating the over-filled composite by use of 1000-grit wet carborundum paper followed by polishing on a linen cloth mediated with an alumina slurry, grain size 0.03 µm. Marginal integrity of the resin composite was inspected under a light microscope (Orthoplan; Leitz, Wetzlar, Germany) at X1024 magnification, and the contraction gap width was measured using a screw microscope (RZDO-DO; Leitz) mounted on the ocular lens of a microscope at eight points every 45 degrees along the cavity preparation margin (Figure 1). The contraction gap values were presented as the sum of the diametrically opposed gap widths expressed as a percentage of the cavity diameter. The maximum of four values was recorded as the maximum contraction gap. Ten specimens for each composite, 80 in total, were measured.

Tensile Bond Strength Measurement

A flat dentin surface was prepared by grinding the approximal surface of extracted human teeth embedded in an epoxy resin (Epofix; Struers A/S, Copenhagen, Denmark). The dentin surface was conditioned and primed using the same methods as those for contraction gap measurement, and a split Teflon mold (inner diameter 3.6 mm, outer diameter 20 mm, and 5 mm high) was clamped on the substrates. The commercial dentin bonding agent was applied to the dentin surface and irradiated for 10 seconds from the top of the center hole of the mold. The resin composite was placed in the lower part of the mold onto the dentin in a layer no more than 2 mm thick and irradiated for 40 seconds. The upper half of the mold was filled with a mixture of a commercial chemical-cured resin composite (P-10; 3M Dental Products, St Paul, MN 55144), and a round bur was inserted in the unpolymerized resin composite paste to provide a grip for bond strength measurements (Figure 2). The Teflon mold was removed from the specimen after polymerization of the chemical-cured resin composite. After storing the specimens for 24 hours in water at a temperature of 37 ± 1 °C, the specimens were mounted on an experimental apparatus in a Universal Testing Machine (Model 4302; Instron Co, Canton, MA 02021), and the tensile bond strengths were measured at a crosshead speed of 0.5 mm/min. The fractured surfaces were observed under a universal projector (Profile Projector 6C-2; Nikon, Tokyo, Japan) at a magnification of X50, and the proportion of the cohesive or adhesive fracture in the resin composite cylinder or in the dentin was calculated by tracing the fractured surface. The proportion of failure in the composites was expressed with an accuracy of 5%. Ten specimens for each composite, 80 total, were prepared.

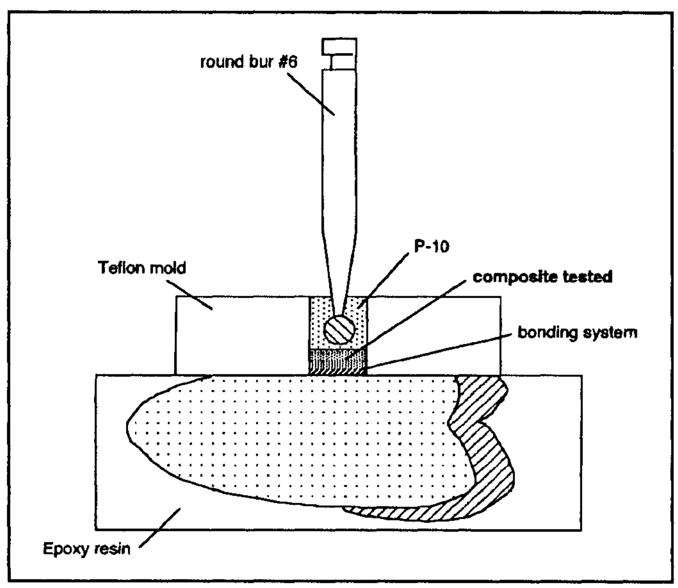

Figure 2. *Split brass mold for tensile strength study*

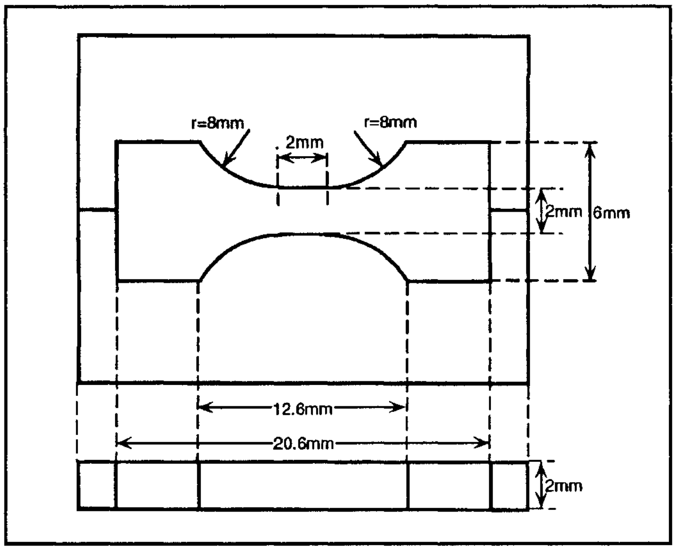

Figure 3. *Specimen for tensile bond strength study with split Teflon mold*

Tensile Strength of the Resin Composite

The specimens for the determination of the tensile strength of the dumbbell-shaped resin composites were prepared by using an experimental brass mold shown in Figure 3. The resin composite paste was transferred into the mold using a commercial syringe (Centrix Inc, Shelton, CT 06484). The composite paste surface was gently pressed with a glass plate mediated with a plastic matrix and irradiated for 60 seconds using a lamp unit (Wite Lite; Takarabelmont Co, Osaka, Japan). After the first irradiation, the resin composite specimen was removed from the mold and the other flat surface, which faced the bottom of the mold, was then irradiated for an additional 60 seconds. After storing the resin composite specimens in distilled water at 37 °C for 24 hours, the tensile strength was measured by using a Universal Testing Machine at a crosshead speed of 0.1 mm/min. Five specimens for each composite, 40 in total, were prepared.

Flexural Properties of the Resin Composite

The flexural properties of the resin composite were determined by a three-point bending test according to ISO 4049. To prepare a test specimen (25 ± 2 mm long, 2 ± 0.1 mm high, 2 ± 0.1 mm deep), the resin composite paste was transferred into a brass mold in one increment using a commercial syringe. The surface of the composite paste was gently pressed with a glass plate mediated with a plastic matrix and irradiated for 60 seconds using a lamp unit. After the first irradiation, the resin composite specimen was removed from the mold, and the other flat surface, which faced the bottom of the mold, was then irradiated for an additional 60 seconds. After storing the resin composite specimens in distilled water at 37 °C for 24 hours, the tensile strength of the resin composite was measured using a Universal Testing Machine at a crosshead speed of 0.1 mm/min. Five specimens for each composite, 40 total, were prepared.

All data were analyzed by one-way ANOVA and Tukey's multiple comparison test (Kleinbaum & others, 1988) at a 5% level of significance.

RESULTS

The contraction gap formation of the resin composite in the cylindrical dentin cavities was prevented completely for three of the eight composites

Table 2. Bonding Efficacy and Tensile Strength of the Resin Composites Tested

	Contraction Gap (%) N = 10		Tensile Bond Strength (MPa) N = 10**		Number of Specimens of Each Fracture Type at interface/in	composite/in	dentin	Proportion of Composite Fractures (%) N = 10**
Clearfil AP-X	0 (10)	*a	25.50 ± 6.47	*c	2	6	2	37 ± 38
Silux Plus	0 (10)		18.63 ± 5.34	*d	1	9	0	52 ± 30
Estelite	0 (10)		17.18 ± 4.91		1	9	0	83 ± 33
Estio LC	0.004 ± 0.011 (9)		17.49 ± 5.53	*c	0	10	0	74 ± 33
Progress	0.020 ± 0.043 (8)		22.67 ± 6.41		3	7	0	46 ± 43
Litefil II-A	0.043 ± 0.038 (3)		23.21 ± 7.45		4	6	0	40 ± 40
Z-100	0.126 ± 0.070 (1)	*b	23.91 ± 3.37		0	10	0	31 ± 27
Prodigy	0.135 ± 0.051 (0)		23.17 ± 6.91		6	4	0	23 ± 35

Contraction gap: Mean ± SD of the contraction gap and number of gap-free specimens are in ( ).
**In Clearfil AP-X group two specimens fractured in dentin were omitted (N = 8) for tensile bond strength and proportion of composite fractures.
Values joined by the same line or the same letter* are not significantly different from Tukey's multiple comparison test ($P > 0.05$).

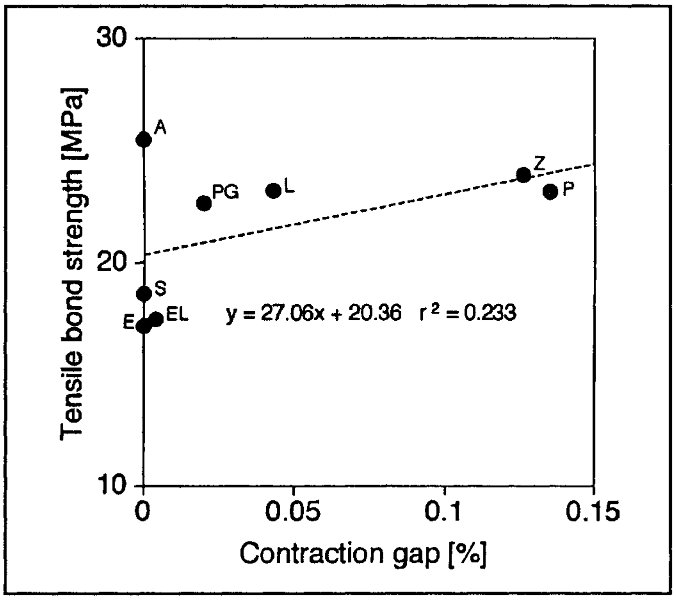

Figure 4. *Correlation and linear regression between the wall-to-wall contraction gap width of eight commercial composites in the cylindrical dentin cavity and the measured tensile bond strength of the composites to the flat dentin surface mediated with 0.5M EDTA conditioning, 35% GM priming, and Clearfil PhotoBond application. A = Clearfil AP-X; E = Estelite; EL = Estio LC; L = Litefil II-A; P = Prodigy; PG = Progress; S = Silux Plus; Z = Z-100.*

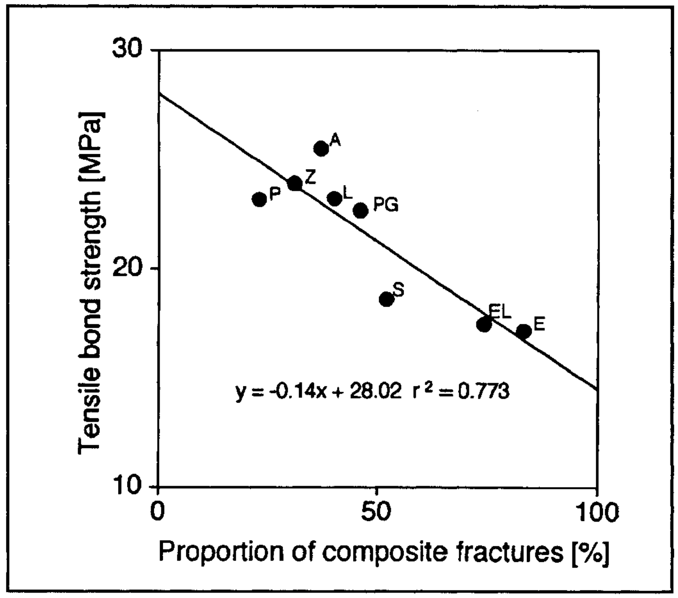

Figure 5. *Correlation and linear regression between the measured tensile bond strength of eight commercial composites to the flat dentin surface mediated with 0.5M EDTA conditioning, 35% GM priming, and Clearfil PhotoBond application, and the proportion of composite fractures on the specimens after tensile bond strength measurement. A = Clearfil AP-X; E = Estelite; EL = Estio LC; L = Litefil II-A; P = Prodigy; PG = Progress; S = Silux Plus; Z = Z-100.*

tested (Clearfil AP-X, Estelite, and Silux Plus) after conditioning the cavities with EDTA, priming with glyceryl monomethacrylate solution, and applying a dentin bonding agent containing 10-methacryloyl oxydecyl dihydrogen phosphate (MDP) (Table 2).

In the tensile bond strength measurements, the mode of fracture failure was classified as "in dentin" when any dislodged dentin was found, as "at interface" when 0% dislodged dentin and 0% composite remnant were found, and as "in composite" when 1-100% composite remnant with 0% dislodged dentin was found. Two specimens of Clearfil AP-X exhibited adhesive fractures in the dentin, and all specimens of Estio LC and Z-100 showed fractures in the resin composite cylinder (Table 2). With Tukey's test, Estelite exhibited significantly lower tensile bond strength than Clearfil AP-X. Correlation between the contraction gap and the measured tensile bond strength was insignificant (Figure 4: $r^2 = 0.233$; $P > 0.05$). The proportion of composite fractures correlated significantly with the tensile bond strength (Figure 5: $r^2 = 0.773$; $0.001 < P < 0.01$).

In the tensile strength measurements, Silux Plus exhibited significantly lower strength than the other

Table 3. Mechanical Properties of the Resin Composite in Direct Tensile Strength Test and Three-Point Bending Test

	Tensile Strength (MPa) N = 5			Flexural Strength (MPa) N = 5				Young's Modulus (GPa) N = 5			
Clearfil AP-X	69.74 ± 6.51	*e		127.50 ± 31.64	*g			11.30 ± 2.96	*j		
Silux Plus	26.45 ± 3.11			63.93 ± 3.68			*i	3.85 ± 0.32			*l
Estelite	47.31 ± 8.28		*f	61.79 ± 5.46				4.87 ± 0.37			
Estio LC	49.13 ± 6.15			66.83 ± 4.01				5.00 ± 0.14			
Progress	50.60 ± 6.18			97.01 ± 17.60	*g	*h		9.33 ± 1.04	*j	*k	
Litefil II-A	57.19 ± 11.61	*e		104.49 ± 14.10				5.65 ± 0.42			*l
Z-100	55.91 ± 7.78			89.08 ± 28.49			*i	11.14 ± 0.80	*j		
Prodigy	52.89 ± 3.30			107.76 ± 11.30	*g			8.26 ± 0.74		*k	

Values joined by the same line or the same letter* are not significantly different from Tukey's multiple comparison test ($P > 0.05$).

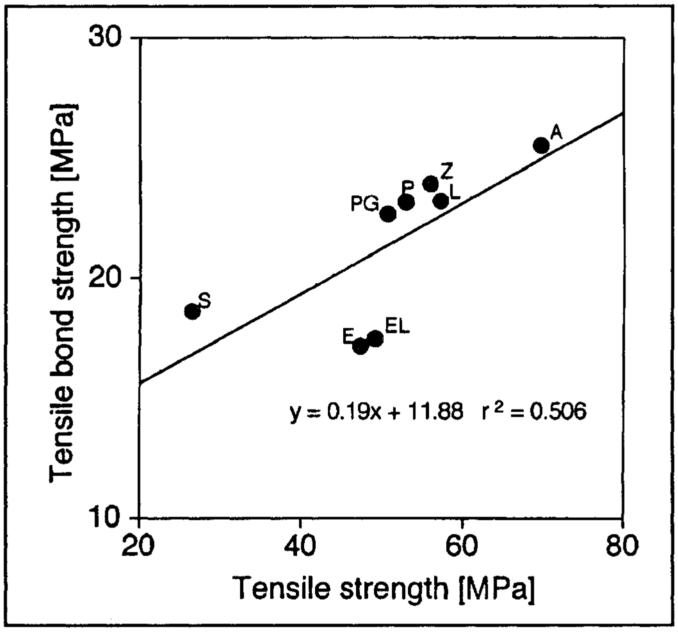

Figure 6. *Correlation and linear regression between the measured tensile bond strength of eight commercial composites to the flat dentin surface mediated with 0.5M EDTA conditioning, 35% GM priming, and Clearfil PhotoBond application, and the tensile strength of the composites. A = Clearfil AP-X; E = Estelite; EL = Estio LC; L = Litefil II-A; P = Prodigy; PG = Progress; S = Silux Plus; Z = Z-100.*

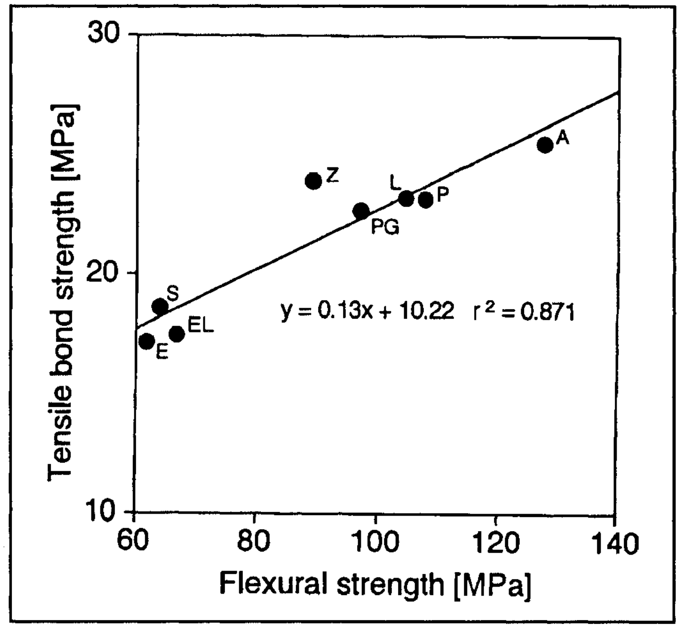

Figure 7. *Correlation and linear regression between the measured tensile bond strength of eight commercial composites to the flat dentin surface mediated with 0.5M EDTA conditioning, 35% GM priming, and Clearfil PhotoBond application, and the flexural strength of the composites in a three-point bending test. A = Clearfil AP-X; E = Estelite; EL = Estio LC; L = Litefil II-A; P = Prodigy; PG = Progress; S = Silux Plus; Z = Z-100.*

seven composites (Table 3). The tensile strength correlated significantly with the measured tensile bond strength (Figure 6: $r^2 = 0.506$; $0.01 < P < 0.05$), whereas it did not correlate significantly with contraction gap width ($r^2 = 0.049$; $P > 0.05$).

In the three-point bending test, the flexural strength and Young's modulus of the resin composites correlated significantly with the measured tensile bond strength (Figures 7, 8: $r^2 = 0.871$; $r^2 = 0.712$; $P < 0.001$; $0.01 < P < 0.001$ respectively), whereas they did not correlate significantly with contraction gap width ($r^2 = 0.100$; $r^2 = 0.202$ respectively; $P > 0.05$).

DISCUSSION

Tensile bond strength at the adhesive interface between the dentin bonding system and the flat dentin surface is impossible to measure exactly, because it is frequently greater than the mechanical strength of the resin composite cylinder and the substrate dentin itself; consequently, the fracture occurs within the composite or dentin (Van Noort & others, 1989; Versluis, Tantbirojn & Douglas, 1997). As demonstrated in this study, the bond strength measured by a traditionally designed test was significantly influenced by the eight resin composites even when the composites were bonded to the flat dentin surface mediated with the same dentin bonding system. In addition, higher bond strength was obtained when the bonded resin composite exhibited higher mechanical strength, i e, greater tensile strength, flexural strength, and Young's modulus. The higher tensile bond strength may be enhanced by the higher filler concentration in the resin composite because the mechanical properties of the resin composite are strongly affected by its filler concentration (Willems & others, 1993). On the other hand, the stress distribution in the tooth that was restored with resin composite (Morin & others, 1988), and the stress distribution in the specimens for shear and tensile bond strength measurements (Van Noort & others, 1989) have already been reported. In the present study, since the measured tensile bond strength correlated better with the flexural strength ($P < 0.001$) than the tensile strength ($0.01 < P < 0.05$), the cohesive fracture may not occur at the weakest region of the resin composite cylinder but at the geometrical region with concentrated stress. Correlation between the bond strength to the flat dentin surface and marginal adaptation in the dentin cavity has been demonstrated; in addition, the early bond strength that prevents the marginal gap (Komatsu & Finger, 1986; Munksgaard, Irie & Asmussen, 1985) or quantitative microleakage (Barkmeier & Cooley, 1989;

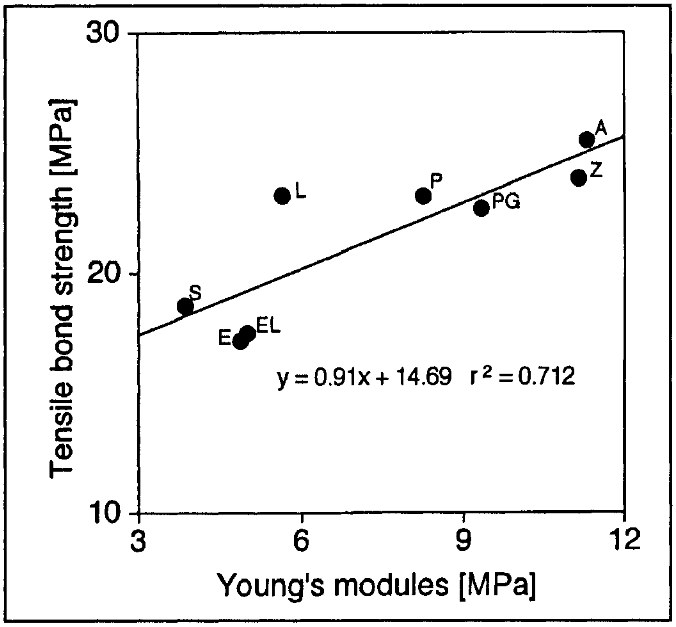

Figure 8. *Correlation and linear regression between the measured tensile bond strength of eight commercial composites to the flat dentin surface mediated with 0.5M EDTA conditioning, 35% GM priming, and Clearfil PhotoBond application, and Young's modulus of the composites in a three-point bending test. A = Clearfil AP-X; E = Estelite; EL = Estio LC; L = Litefil II-A; P = Prodigy; PG = Progress; S = Silux Plus; Z = Z-100.*

Retief, 1994) in the dentin cavity has been estimated. However, no correlation was found between the mechanical strength and marginal adaptation of a resin composite placed in a dentin cavity preparation.

In addition, the correlation between measured tensile bond strength and wall-to-wall polymerization contraction gap width was not significant ($r^2 = 0.233$; $P > 0.05$). In the specimens for the measurement of contraction gaps, the success of the dentin bonding system was evaluated by its ability to maintain the attachment between the unpolymerized resin composite paste and the dentin cavity wall until the completion of polymerization. In the bond strength measurements, the success of the dentin bonding system was estimated by the stress required to break the bond between the resin and a flat dentin surface. Thus, the success of a dentin bonding system was evaluated three-dimensionally in the wall-to-wall polymerization contraction gap measurements just after the polymerization of the resin composite, whereas the bond strength measurements were examined two-dimensionally.

Bonding between the resin composite and the dentin cavity wall has not occurred (bond strength = 0) as zero for any dentin bonding system that is not able to prevent contraction gap formation. Therefore, the success of a dentin bonding/resin composite system should be determined by evaluation of the wall-to-wall contraction gap in the dentin cavity rather than by measurement of the bond strength to a flat dentin surface.

Yanagawa and others (1996) reported that the frequency of contraction gap formation in the oral cavity correlated well with that observed in extracted human teeth; no composite bonding failure on the cavity wall and no dislodged dentin during polymerization was observed either in vivo and in vitro. Recently, a new microtensile bond strength test has been developed (Carvalho & others, 1995). Although most specimens exhibited fractures at the adhesive interface during the test, the characterization of the adhesive interface did not reflect the contraction behavior of the resin composite during polymerization. Therefore, clinical performance data of a dentin bonding system based on the bond strength measurement may be inconsistent.

It is impossible to examine bonding durability by measurement of the wall-to-wall contraction gap in cylindrical dentin cavity preparations, because resin composites elastically expand toward the cavity wall and decrease the gap width by water sorption (Koike & others, 1990). Therefore, it is first essential to ensure that contraction gap formation is prevented completely by the employed dentin bonding system, and second, to evaluate the stability of the bond strength during storage.

As demonstrated in this study, marginal adaptation of the resin composites tested could not be correlated to either traditionally designed bond strength measurements, nor to mechanical strength results of the resin composite. More study is required to examine other factors affecting the behavior of resin composite pastes during polymerization for possible correlation to marginal gap width.

CONCLUSIONS

Marginal adaptation of the resin composite restorations tested could not be predicted either by the tensile bond strength measured by a traditionally designed bond strength test nor by the mechanical properties of the resin composites.

The bond strengths were significantly influenced by the mechanical properties of the resin composites even when the composites were bonded to the flat dentin surface mediated with the same bonding system.

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Evaluation of Different Methods for Cleaning and Preparing Occlusal Fissures

D C N CHAN • J B SUMMITT • F GARCÍA-GODOY
T J HILTON • K-H CHUNG

Clinical Relevance
Teeth prepared with the #1/4 round bur and air abrasion demonstrated a better marginal seal.

SUMMARY

The effectiveness of different methods for cleaning and preparing occlusal fissures before placing sealants was evaluated. Extracted mandibular molars received such treatments as brushing, pumicing, bur preparing, and air abrasion before application of fissure sealants. FluroShield fissure sealant was then applied to the occlusal fissures. Specimens were subjected to thermocycling and then immersed in a 10% solution of methylene blue, and finally sectioned. The sections were examined and photographed in a stereomicroscope, and the dye penetration was recorded using a scoring system. The results indicated that only the control (brushing with a dry brush) and the pumicing groups demonstrated dye penetration to the base of the sealant. Teeth prepared with the #1/4 round bur and air abrasion demonstrated a better seal in evaluated fissures. For this study, those three groups (occlusal fissures prepared with the #1/4 round bur and two air abrasion methods), demonstrated significantly better sealing ($P < 0.01$) than the control group and the other groups tested.

Medical College of Georgia, School of Dentistry, Department of Oral Rehabilitation, Section of Operative Dentistry, Augusta, GA 30912-1260

Daniel C N Chan, DDS, MS, associate professor and section director

James B Summitt, DDS, MS, chair and associate professor, University of Texas, Health Science Center at San Antonio, Division of Operative Dentistry

Franklin García-Godoy, DDS, MS, professor, University of Texas, Health Science Center at San Antonio, Department of Restorative Dentistry

Thomas J Hilton, DMD, Col, USAF, DC, chief, Dental Investigation Service, Brooks AFB, TX 78235-5117

Kwok-hung Chung, DDS, MS, PhD, graduate student, University of Texas, Health Science Center at San Antonio, School of Dentistry

INTRODUCTION

Sealing fissures with resin sealants is regarded as a definitive mode of treatment in the prevention of fissure caries (Swift, 1988). The preventive benefit of sealants is only gained and maintained as long as sealants remain completely intact and bonded in place (Gwinnett, 1982). An important requirement of a pit and fissure sealant is that it prevents microleakage at its periphery; otherwise a carious process might be supported and continue underneath the sealant (Jeronimus, Till & Sveen, 1975; Jensen & Handalman, 1980). Many investigations have reported that if there is active caries in fissures when they are sealed, there is a dramatic decrease in the number of viable microorganisms in the carious lesions, and the caries progression is halted (Handelman, Buonocore

& Heseck, 1972; Handelman, Buonocore & Schoute, 1973; Going & others, 1978; Mertz-Fairhurst, Schuster & Fairhurst, 1986).

The morphology of pits and fissures, as well as their contents, will affect the successful placement and retention of fissure sealants. Deep fissures are more difficult to clean, etch, and dry, thus affecting the ability of the sealant resin to obturate these fissures (Taylor & Gwinnett, 1973). The integrity of the enamel-sealant interface determines, to a great extent, the ability of a pit and fissure sealant to resist the introduction of caries. Reports (Houpt & Shey, 1983; Mertz-Fairhurst & others, 1984) have demonstrated a decline in the retention rates of fissure sealants with increasing time. A clinical study has demonstrated an increased retention rate at 3 years when there had been mechanical preparation of the fissures of maxillary teeth (Shapira & Eidelman, 1984). Retention rate for the mechanically prepared teeth was reported to be 88% compared to 65% for the control group after 6 years (Shapira & Eidelman, 1986).

The successful application of fissure sealants is dependent upon good clinical technique. Therefore, proper cleaning and fissure preparation before sealant placement are of the utmost importance (Gwinnett, 1982). Several studies have evaluated techniques for cleaning fissures to prepare them for etching and sealing and improving sealant penetration and effectiveness (Gwinnett & Buonocore, 1972; Taylor & Gwinnett, 1973; Main & others, 1983). Studies have revealed that remaining debris and pellicle were not removed in the bases of fissures by the etching process and that the use of a dental explorer had little or no effect (Rock, 1974; Burrow & Makinson, 1990).

The use of a polishing device has been advocated to clean plaque and extrinsic stain from fissures (Willmann, Norling & Johnson, 1980; Weaks & others, 1984). The efficiency of cleaning fissures with air-polishing instruments was investigated (Strand & Raadal, 1988; García-Godoy & Medlock, 1988; Brocklehurst, Joshi & Northeast, 1992). Air polishing was found to provide thorough cleaning, and it removed residual debris from pits and fissures, while conventional pumice prophylaxis left fissures filled with residue and pumice powder. In addition, fissure cleaning with air-polishing units produced a significant increase in depth of sealant resin penetration.

An approach for managing borderline or questionable carious fissures by partially eliminating the fissures with a dental bur has been suggested (Meiers & Jensen, 1984). In order to be able to completely fill a fissure with a sealant, several investigators found that the fissures should first be emptied of debris with a rotating diamond point (McLean & Wilson, 1974; Raadal, 1978; Simonsen, 1978). The results of the in vitro studies on the invasive technique with mechanical preparation have indicated that the risk of microleakage is reduced when the fissure is preventively enlarged with rotating burs (Le Bell & Forston, 1980; Feldens & others, 1994; Theodoridou-Pahini, Tolidis & Papadogiannis, 1996). Clinically, higher retention rates were obtained following mechanical preparation of the fissure area (Shapira & Eidelman, 1984, 1986; De Craene, Martens & Dermaut, 1988). The current generation of polishing devices and mechanical systems are improved over the earlier versions.

The purpose of this in vitro study was to evaluate the effectiveness of different methods for cleaning and preparing occlusal fissures before placing fissure sealants for controlling microleakage.

METHODS AND MATERIALS

Ninety extracted human mandibular molars that had been stored in tap water were selected based on the existence of a centralized fissure system in each occlusal surface. Any periodontal tissues attached to the roots of the teeth were removed with periodontal scalers, and the teeth were rinsed with water. Teeth were then distributed into nine groups of 10 teeth each, with each group containing a similar range of occlusal table sizes. Fissures were treated as follows. **Group 1:** Control—Brushing only; fissures were cleaned with a dry, pointed bristle brush using a low-speed handpiece for approximately 10 seconds; **Group 2:** Pumicing—Fissures were cleaned with a fine flour of pumice (5 g pumice/4 mL water) using a rubber cup in a low-speed handpiece for approximately 10 seconds (Strand & Raadal, 1988; Pope & others, 1996); **Group 3:** Round Carbide Bur—Fissures were slightly opened with the side of a new #1/4 carbide bur (FG1/4; Midwest Dental Products Corp, Des Plaines, IL 60018) in a high-speed handpiece to approximately the width and depth of the bur diameter (0.5 mm); **Group 4:** Needle Finishing Bur—Fissures were opened with the side of the tip of a #7901 bur (Brasseler USA, Savannah, GA 31419) in a high-speed handpiece to an approximate depth of 0.5 mm; **Group 5:** Diamond Fissure Bur—Fissures were opened with a diamond bur especially designed for preparing fissures (Komet #8833; Gebr Brasseler GmbH & Co, Lemgo, Germany) in a high-speed handpiece to an approximate depth of 0.5 mm (Felden & others, 1994); **Group 6:** Air Polishing—Fissures were prepared with one or two passes of the handpiece of the Microprophy EX System (Danville Engineering Inc, San Ramon, CA 94583) with a 0.026-inch nozzle opening, 15 μm alumina particles, propelled with an 80 psi air pressure flow and with a small curtain of water surrounding the powder stream; **Group 7:** Air Abrasion—Fissures were prepared with one or two passes of the handpiece of the Microetcher System

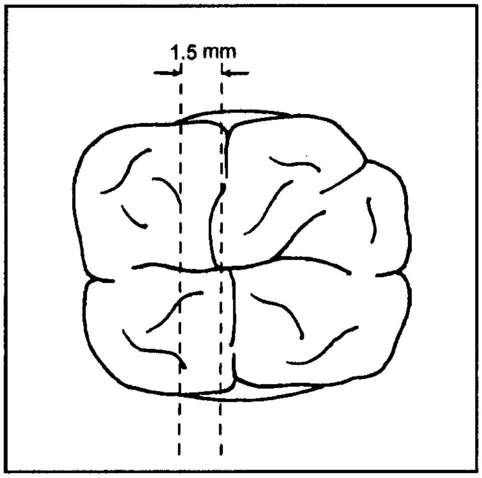

Figure 1. *Schematic drawing of the cutting lines for preparing of the section*

(Danville Engineering) with a 0.032-inch nozzle opening, 50 µm alumina particles and 80 psi air pressure flow; **Group 8:** Air Abrasion—Fissures were prepared with one or two passes of the handpiece of the KCP 2000 System (American Dental Technologies, Troy, MI 48084) with 27 µm alumina particles and 80 psi air pressure flow; **Group 9:** Brush and longer etching time—Fissures were cleaned with a dry, pointed bristle brush using a low-speed handpiece as in Group 1 (the control group). However, a 60-second etching procedure was used instead of the 30-second etching described below.

The prepared occlusal fissures were etched using 37% phosphoric acid gel (Tooth Conditioner Gel, L D Caulk/Dentsply, Milford, DE 19963) for 30 seconds (60 seconds for Group 9). They were then rinsed for 10 seconds using an air-water spray and dried with compressed air for 10 seconds. The etched surfaces of enamel at the entrances to the fissures were examined to ensure a frosted appearance. FluroShield (Caulk/Dentsply) fissure sealant was applied according to the manufacturer's instructions. To prevent voids and air entrapment, the sealant was applied adjacent to the fissure and then pushed through the fissure system with a periodontal probe with a 0.5 mm tip diameter, and any obvious bubbles were removed with the tip of the probe. The material was then polymerized for 20 seconds with an Optilux 400 visible-light-curing unit (Demetron Research Corp, Danbury, CT 06810). In addition, the effectiveness of the curing light was confirmed at least daily using a Demetron curing radiometer.

After sealant placement, specimen teeth were incubated for 24 hours in distilled water at room temperature. All teeth were then thermocycled 500 times in water baths of 5 °C and 55 °C, with a dwell time of 30 seconds in each bath. Specimens were then painted with two coats of acid-resistant varnish, leaving exposed 1 mm of enamel around the periphery of the sealant. Specimens were stored in distilled water at room temperature for 24 hours, then immersed in a 10% methylene blue dye solution for a 4-hour period (Brackett & others, 1995). After the teeth were removed from the dye solution, they were sectioned longitudinally with an Isomet saw (Buehler Ltd, Lake Bluff, IL 60044) in a buccolingual direction (Figure 1) in order to evaluate sealant penetration and microleakage in fissures. A section of approximately 1.5 mm thickness was obtained from each of the teeth by cutting through the central fossa area and 1.5 mm mesially to the first cut. Sections were kept dry until they were evaluated. Each section was examined and photographed on both sides using a stereoscopic microscope (X10 magnification). Each photographed section was examined by two examiners, who were "blinded" to the groups, for dye penetration between sealant and enamel. Dye penetration was scored according to the following system (Cooley & others, 1990): 0 = No marginal penetration by dye; 1 = Dye penetration along the enamel-sealant interface; 2 = Dye penetration to the depth of sealant. The data were statistically analyzed using the Pearson Chi-square analysis with the confidence level at 99%.

RESULTS

The sums of microleakage scores of the tested groups are listed in Table 1. The statistical analysis among test groups is shown in Table 2. Only the control (Group 1) and the pumice groups (Groups 2 and 9) demonstrated dye penetration to the depth of the sealant (Score = 2). Teeth prepared with the #1/4 round bur and air abrasion demonstrated a better seal in evaluated sections. Those three groups (Groups 3, 7, 8) demonstrated significantly better sealing ($P < 0.01$) than the control group (Group 1) (Figures 2A-D).

DISCUSSION

Optimal bonding of resin fissure sealants is dependent upon proper and adequate treatment of

Table 1. Individual Microleakage Scores

	GROUPS								
Score	1	2	3	4	5	6	7	8	9
0	14	17	20	18	18	18	20	20	17
1	4	2	0	2	2	2	0	0	2
2	2	1	0	0	0	0	0	0	1

Table 2. Statistical Comparison (Pearson Chi-Square Analysis) of Microleakage Scores among Test Groups

	GROUPS							
Group 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	0.25	0.007	0.11	0.11	0.11	0.007	0.007	0.25
2		0.070	0.63	0.63	0.63	0.070	0.070	1.00
3			0.14	0.14	0.14	1.000	1.000	0.07
4				1.00	1.00	0.140	0.140	0.63
5					1.00	0.140	0.140	0.63
6						0.140	0.140	0.63
7							1.000	0.07
8								0.07
9								

enamel (Roydhouse, 1968; Ripa, 1980). Plaque, pellicle, and other contaminants inhibit the dispersion of sealant and also the ability of sealants to closely contact enamel. The selection of cleaning and preparation methods for this study was based on materials and instruments currently used in clinical practice for fissure preparation. From a micromorphological standpoint, several previous studies have shown that prophylaxis with pumice and a pointed bristle brush or rubber cup is less effective than other preparation methods (García-Godoy & Medlock, 1988; Brocklehurst & others, 1992; Pope & others, 1996). Pumicing removes only organic material on smooth enamel surfaces and is unable to clean the enamel walls of the fissures (Taylor & Gwinnett, 1973). Although etching enamel is the routine procedure in preparing fissures for sealant, many studies have revealed that remaining debris and pellicle were not removed from the bases of fissures by routine cleaning and etching procedures (García-Godoy & Gwinnett, 1987; Burrow & Makinson, 1990). These studies have disclosed that acid etching and sealant retention were limited to the inclined enamel cuspal planes and were not seen in the deepest recesses of the fissures. The results of this study disclosed that brushing with a pointed bristle brush or pumicing were not significantly different in regard to microleakage in sealed fissures. In addition, a longer etching time (60 seconds in Group 9) did not improve the seal ($P > 0.01$) compared with the shorter etching time (30 seconds) (Groups 1 & 2). The possible explanation would be that prophylaxis with a rubber cup or pointed bristle brush with pumice did not adequately clean fissures to allow the etchant to produce a surface area as receptive to bonding as the other methods evaluated.

Mechanical preparation of fissures with burs is believed to provide certain advantages, such as removal of surface demineralization, creating a higher retention rate, and reducing the risk of microleakage (Meiers & Jensen, 1984; De Craene & others, 1988). Studies have given support to the suggestion that mechanically opening fissures promotes sealant retention and reduces microleakage, but another advantage proponents claim for mechanical opening is that it also permits diagnosis of the presence or extent of occult carious lesions (Shapira & Eidelman, 1986; Weerheijm & others, 1992).

Higher retention rates for sealants were obtained following mechanical preparation of fissures in some studies (Le Bell & Forsten, 1980; Shapira & Eidelman, 1984). Investigators in one laboratory study reported

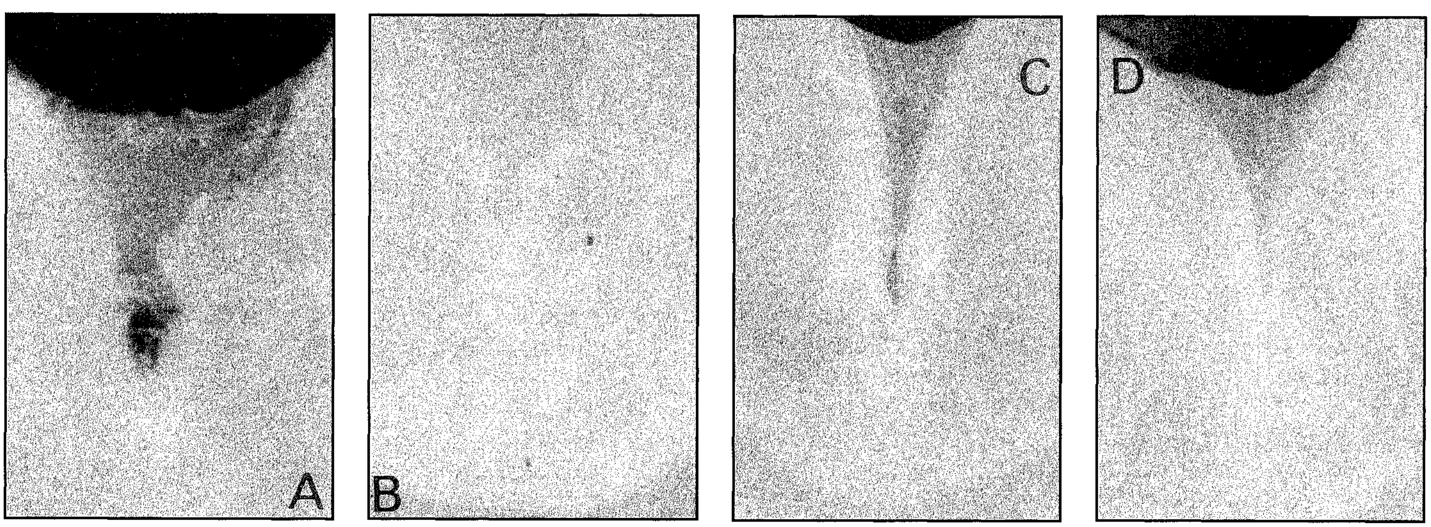

Figure 2. *Representative photographs of sectioned surfaces of teeth with sealing fissures.* **A.** *Group 1, control with brushing only, score = 2.* **B.** *Group 3, round carbide bur preparation, score = 0.* **C.** *Group 7, air abrasion preparation, score = 0.* **D.** *Group 8, air abrasion preparation, score = 0.*

that the risk of microleakage was reduced when fissures were enlarged and that sealant material easily penetrated the mechanically opened fissures and adhered better to the walls. Consequently, they stated that there was no need to cover a wide area outside the prepared area to assure adequate retention (Tadokoro, Iwaku & Fusayama, 1982).

Another reported possible explanation for better sealant adaptation following mechanical preparation was that the procedure eliminates organic material and plaque as well as removing a very thin layer of surface enamel (Shapira & Eidelman, 1984). Within the tested mechanical preparation methods in that study, only the #1/4 round bur allowed a perfect seal. An explanation of this improved seal could be the resulting consistent plug of resin that has been formed rather than resin layers of varying thicknesses.

Results of several studies have shown that air polishing removed debris in the deeper aspects of fissures (Strand & Raadal, 1988; Brocklehurst & others, 1992). In addition, no morphological differences were observed in comparison with groups treated with pumicing (García-Godoy & Medlock, 1988). However, in this study, no significant difference in leakage was found between specimens prepared with air polishing (Group 6) and the control group. Statistically significant differences were disclosed only between the air-abrasion methods plus preparation with the #1/4 round bur and the other groups ($P < 0.01$). The application of air-abrasion techniques and #1/4 round bur preparation offered better results in this microleakage study. The better results with air-abrasion techniques than with air polishing may be due to the use of 50 μm (Group 7) and 27 μm (Group 8) instead of 15 μm (Group 6) alumina particles. The effect of particle size in the air-polishing process on the roughness of enamel surface needs further investigation.

CONCLUSIONS

In this in vitro study, occlusal fissures cleaned with either brushing or pumicing only were demonstrated to have dye penetration to the depth of the sealant. Fissures prepared with the #1/4 round carbide bur and air abrasion demonstrated a better seal in evaluated sections. Fissure sealant applied after fissure preparation with a #1/4 round bur and two air-abrasion methods demonstrated significantly better sealing ($P < 0.01$) than the control group.

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Cuspal Deflection of Maxillary Premolars Restored with Bonded Amalgam

W A EL-BADRAWY

Clinical Relevance
Bonded MOD amalgam restorations decreased cuspal deflection of maxillary premolars.

SUMMARY

The aims of this study were to measure cuspal deflection of premolars restored with bonded amalgam and to investigate bond resistance to thermocycling and cyclic loading. Strain gauges were used to measure cuspal deflection of maxillary premolars restored with MOD bonded amalgam restorations. A nondestructive method was used in which teeth were loaded repeatedly to record cuspal deflection following different restorative procedures. Ten extracted premolars with similar dimensions were selected and their roots mounted in resin bases 2 mm below the CEJ. Two single-element strain gauges were bonded to the buccal and lingual surfaces of the cusps of each tooth at a level that corresponded to the pulpal floor of MOD cavities. These were connected to a strain indicator with a built-in wheat-stone bridge. An Instron machine was used to apply a 100 N compressive load. Microstrain readings were recorded with each loading at the following stages: (1) sound unprepared teeth (baseline reading), (2) following preparation of a medium-size MOD cavity, (3) 24 hours following restoration with amalgam, (4) following amalgam removal, (5) 24 hours following restoration with bonded amalgam. Durability of the bond was further tested by cyclic loading of 2000, 4000, 6000, and 8000 load cycles. Mean microstrain values recorded at the buccal cusp were: 48.0 (21.6), 126.8(57.2), 121.4(53.3), 120.8(56.1), and 65.2(36.5) for test stages 1, 2, 3, 4, and 5 respectively. Cuspal deflections following cyclic loading recorded at the buccal cusp were: 60.0(41.0), 63.6(51.9), 59.6(36.3), and 61.6(36.8) at the above four cyclic loading stages respectively. A similar trend was also observed for measurements of the lingual cusp. It was concluded that bonding amalgam restorations decreases cuspal deflection and consequently may assist in restoring tooth strength under conditions of the oral environment.

University of Toronto, Faculty of Dentistry, Department of Restorative Dentistry, 124 Edward Street, Toronto M5G 1G6, Ontario, Canada

Wafa A El-Badrawy, BDS, MSc, assistant professor

INTRODUCTION

Dental amalgam has been used by dentists since the 19th century. Durability, low cost, and ease of use were the main advantages that led to its clinical popularity. Some of its drawbacks, such as marginal breakdown, metallic color, and lack of adhesion to tooth structure, however, have recently put some limits on its success.

The use of adhesive resins with amalgam was first reported in 1983 (Stevenson, 1983; Zardiackas & Stoner, 1983). Amalgam bonding was first suggested in an effort to reduce the incidence of cuspal fracture, to improve marginal seal, and to encourage the use of a more conservative cavity design. Studies have shown that the use of dentin bonding resins with resin composites increased tooth strength, decreased marginal leakage, and reduced postoperative sensitivity (Fissore, Nicholls & Yuodelis, 1991; Morin, DeLong & Douglas, 1984; Watts, El-Mowafy & Grant, 1987; Reel & Mitchell, 1987). The use of several adhesive liners for amalgam bonding such as Amalgambond, All-Bond 2, and Panavia EX has been documented (Covey & Moon, 1991; Santos & Meiers, 1994; Bagley, Wakefield & Robbins, 1994). Their bond to amalgam has been evaluated using varied testing techniques, including shear and tensile bond testing as well as microleakage. In general, microleakage testing results indicated better marginal seal with adhesive bonding resins compared to conventional cavity varnish (Saiku, St Germain & Meiers, 1993; Charlton, Moore & Swartz, 1992; Weiczkowski & others, 1992). Contrary to this, Mahler and others (1996) reported little or no benefit from bonding amalgam restorations with regard to postoperative sensitivity and marginal fracture. Their results, however, were based on data collected only 1 to 2 weeks after placement. Ölmez, Cula, and Ulusu (1997) reported no significant difference in retention, marginal adaptation, secondary caries, postoperative sensitivity, or microleakage over a period of 3 years between bonded amalgam and resin composite restorations.

Studying the nature of the bond with scanning electron microscopy showed that microscopic mechanical interlocking occurred during condensation of amalgam into the unset resin liner (Covey & Moon, 1991; Miller & others, 1992; Al-Moayad, Aboush & Elderton, 1993; Pashley & others, 1991). This resulted in a fairly strong bond between amalgam and tooth structure. Shear bond strength values reported in the literature range from 3.5 to 17.5 MPa (Charlton & others, 1992; Pashley & others, 1991; Vargas, Denehy & Ratananakin, 1994; McComb, Brown & Forman, 1995). Few studies investigated the tooth strengthening effect of bonded amalgam restorations, using a catastrophic loading of teeth. Eakle, Staninec, and Lacy (1992) reported increased fracture resistance of teeth restored with bonded amalgam compared with teeth restored with nonbonded amalgam. Temple-Smithson, Causton, and Marshall (1992) found that the energy required to break bonded amalgam restorations was higher than that needed for the nonbonded ones. The successful treatment of cracked tooth syndrome was also reported using bonded amalgam (Bearn, Saunders & Saunders, 1994). This was carried out to prevent flexure of the cracked cusp and hence avoid pain and further crack propagation. However, other studies reported conflicting results. Santos and Meiers (1994) did not find any significant difference in the strength of bonded and nonbonded amalgam-restored teeth when specimens were aged for a period of 67 days and thermocycled for 3500 cycles. Bonilla and White (1996) also found no significant difference in fracture resistance between teeth with bonded amalgam restorations and those with nonbonded amalgam restorations following severe aging conditions. In contrast, Oliveira, Cochran, and Moore (1996) reported variable tooth strengthening of bonded amalgam restorations with different adhesive products.

Reeh, Douglas, and Messer (1989) reported that testing tooth reinforcement by loading to fracture (destructive technique) made it difficult to demonstrate statistical differences with small numbers of samples, while measuring cuspal deformation using strain gauges under more realistic physiological loads permitted sequential use of the same tooth, and leads to more meaningful results.

The aims of this study were to measure cuspal deflection of teeth restored with bonded amalgam and compare it to that of teeth restored with nonbonded amalgam, and to investigate the durability of the bond by examining the effect of cyclic loading on cuspal deflection of teeth with bonded amalgam restorations.

METHODS AND MATERIALS

Extracted teeth were collected from private offices of oral surgeons in the Toronto area. These teeth were cleaned and stored in distilled water in the refrigerator until testing. They were examined under light microscopy and transilluminating fiber-optic light to detect the presence of cracks, and those with apparent cracks were excluded from the study. Selected teeth were chosen so that they were of similar crown size. Ten sound maxillary premolars were selected and included in the study.

Single-element precalibrated strain gauges measuring 3.56 x 4.3 mm (Vishay Measurement Group, Micro-Measurements Division, Raleigh, NC 27611) were bonded to the buccal and lingual cusps of each tooth using M-bond 200 (Vishay Measurement Group) prior to cavity preparation. Two strain

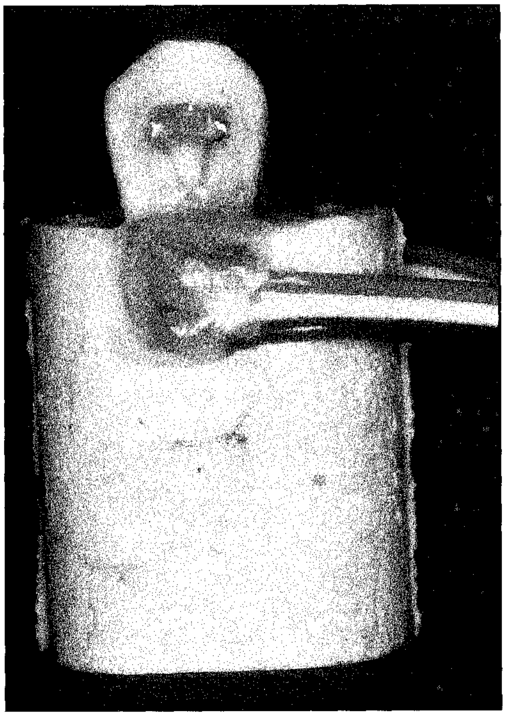

Figure 1. *Maxillary premolar tooth embedded in an acrylic resin base with strain gauges attached to the buccal and lingual cusps*

gauges were bonded to each tooth, one to the buccal and one to the lingual surface of the crown of the tooth, in order to measure the deflection of each cusp independently. The gauges were bonded at a level that corresponded to the intended pulpal floor of an MOD cavity (Figure 1). This was reported to be the level where the highest strains leading to cuspal fracture typically occurs (Bell, Smith & dePont, 1982; Peters & Poort, 1983). The strain gauge and the lead wire attachment were coated with a waterproof seal (W1 wax; Vishay Measurement Group) in order to permit storage in water at 37 °C throughout the study without damage to the strain gauges. Also, a shielding layer of silicon rubber was applied on top of the wax to protect the gauges during restorative procedures (Figure 2).

Each of the selected teeth was mounted in a cylindrical base of autopolymerizing acrylic resin using a split aluminum mold. Roots of the teeth were embedded in the acrylic resin to 2 mm below the cementoenamel junction. Teeth were then loaded as described below to obtain the baseline microstrain readings. Standardized large MOD cavity preparations were prepared using new tungsten carbide burs (#245) at high speed with air/water spray cooling. Cavity preparations were made to represent a clinical situation where bonding of amalgam restorations would be of benefit. Cavity depth was standardized to 2.5 mm, and cavity width to 1/2 the intercuspal

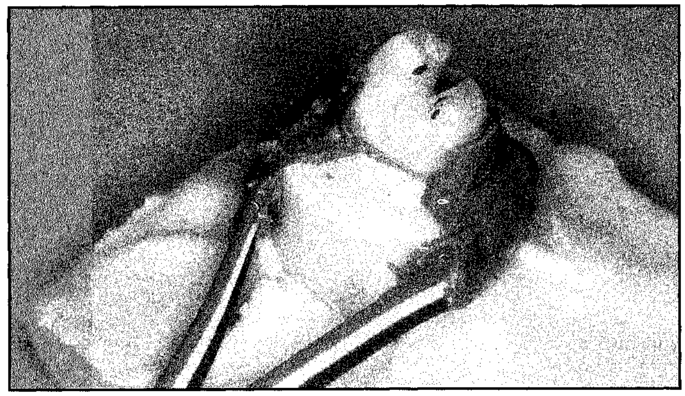

Figure 2. *Maxillary premolar tooth embedded in an acrylic resin base with an MOD cavity preparation and the strain gauges covered with a protective layer of silicon rubber*

distance. Gingival seats were maintained at 1 mm above the cementoenamel junction, and gingival seat width was 1.5 mm (Figure 2).

Teeth were restored with a dispersed-phase amalgam (Permite C; Southern Dental Industries LTD, Bayswater, Australia) and bonded using All-Bond 2 Adhesive System (Bisco, Schaumberg, IL 60193); the dentin-enamel bonding resin with the dual-cure component was used. Both amalgam and bonding system were used according to their manufacturers' instructions. Mechanical testing was carried out on a Universal Testing Machine (Instron Corp, Canton, MA 02021). A uniaxial compressive load of 100 N was applied using a rounded-end metal rod. The diameter of the rod was chosen so that during loading the rod was only contacting the enamel

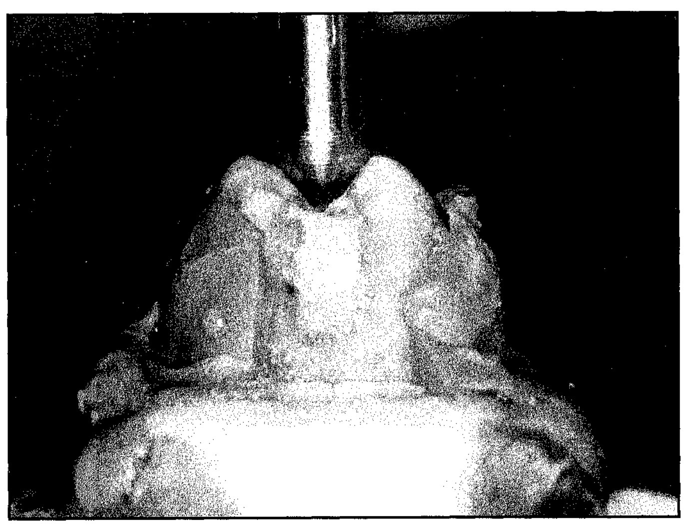

Figure 3. *An MOD amalgam restoration in a maxillary premolar tooth being loaded in compression for mechanical testing. Note where the loading rod contacts the tooth at points up on the cuspal inclines away from the restoration.*

Means and Standard Deviations (SD) of Microstrain Cuspal Deflection Values of 10 Specimens

		Mean	SD
Sound tooth	Buccal	48.0	21.6
	Lingual	73.2	29.8
Cavity preparation	Buccal	126.8	57.2
	Lingual	152.1	100.5
Amalgam restored	Buccal	121.4	53.3
	Lingual	134.1	96.9
Amalgam removed	Buccal	120.8	56.1
	Lingual	147.7	83.4
Bonded amalgam	Buccal	65.2	36.5
	Lingual	86.9	61.4

cuspal triangular ridges away from the restoration (Figure 3). Therefore, the load was transmitted directly through the cusps, and outward flexure occurred in response to the applied force. A strain reading was then recorded for each cusp. The load was released and reapplied, and a second microstrain measurement was made. This step was repeated for a third time, and the average of the three measurements was recorded. A positioning jig was used to relocate the rod in the same position each time the load was applied.

Each tooth was tested and restored in the following sequence: (1) Baseline—The load was applied to the unprepared, unrestored tooth, and cuspal flexure was recorded on the strain recorder; (2) Following cavity preparation, measurements were made for each cusp of the prepared unrestored teeth; (3) Loading was repeated and cuspal flexure recorded following amalgam restorations that were stored for 24 hours in water at 37 °C; (4) Amalgam restorations were removed with great care so that no change in the cavity dimensions took place, and cuspal flexure was again recorded for the prepared restored/unrestored tooth; (5) The teeth were finally re-restored with bonded amalgam, and following 24 hours of water storage at 37 °C, the teeth were loaded and cuspal flexure measurements made.

Five of the 10 teeth were further tested by cyclic loading using a load cycle of 1 to 100 N repeated at a rate of 1 Hz for a total of 8000 cycles. Microstrain measurements were recorded for each cusp after every 2000 cycles. The microstrain unit is $\mu\ \Delta L/L$.

Statistical analyses were carried out using ANOVA followed by Friedman's nonparameteric ANOVA.

RESULTS

The table records mean and standard deviation values of microstrain for the 10 specimens. Figures 4 and 5 are two chosen representative graphs showing the changes in outward cuspal deflection of buccal and lingual cusps of two teeth. It is clear from these graphs that the two teeth had similar patterns of cuspal deflection throughout the five test stages. First there was an increase in both buccal and lingual

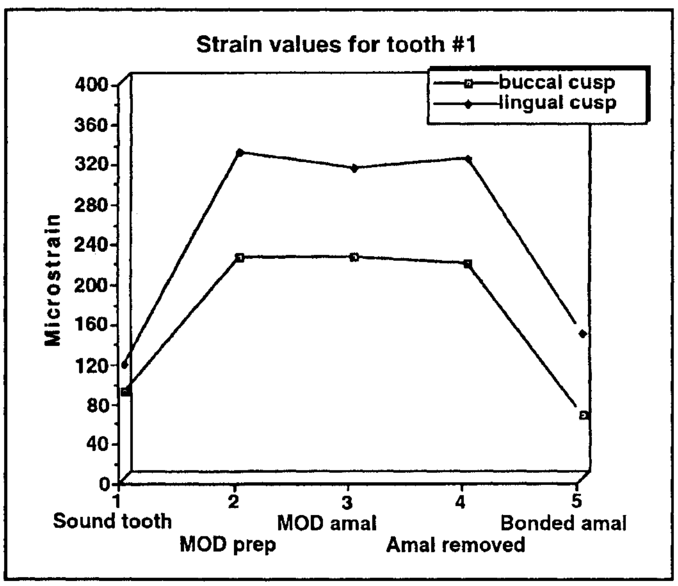

Figure 4. *Representative microstrain values for tooth #1 at the five stages of the test. Notice how the value returns back to almost its original level at stage #5 after placement of the bonded amalgam restoration.*

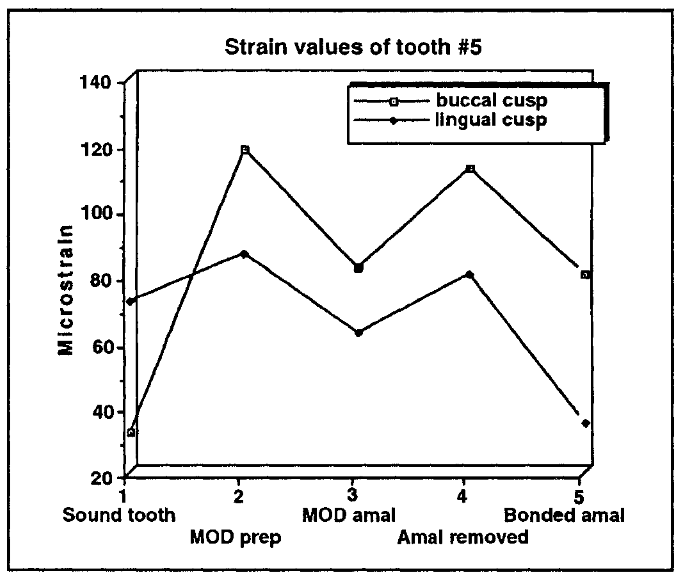

Figure 5. *Representative microstrain values for tooth #5 at the five stages of the test. Unlike with tooth #1, here the patterns exhibited by the buccal and lingual cusps are not identical. However, overall there was a decrease in cuspal deflection after placement of the bonded amalgam restoration.*

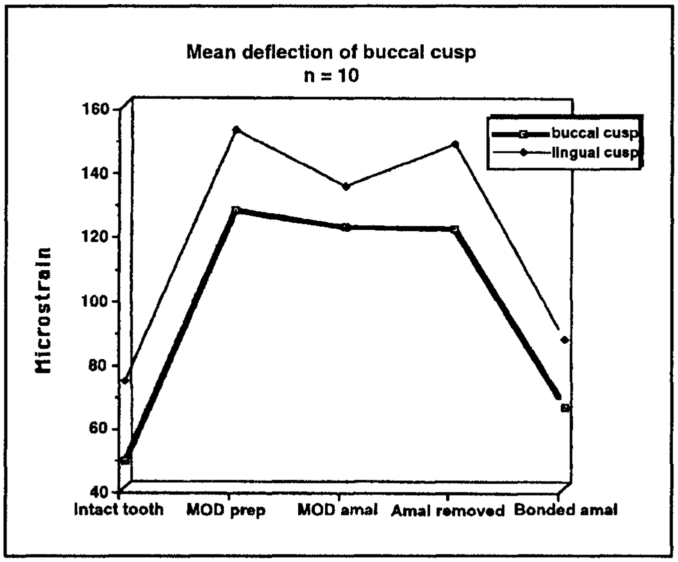

Figure 6. *Mean microstrain values for buccal and lingual cusps of all 10 teeth. Overall, the microstrain value returns back to almost its original level at stage #5 after placement of the bonded amalgam restoration.*

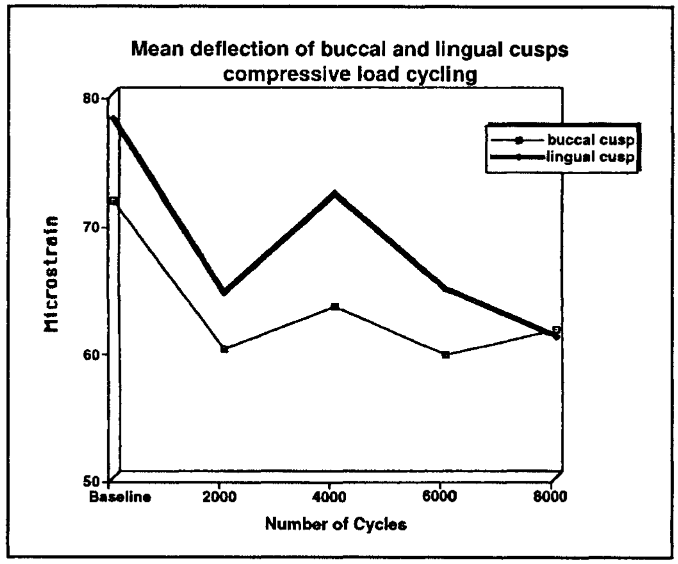

Figure 7. *Mean microstrain values for buccal and lingual cusps of teeth that were subjected to load cycling*

cuspal deflection following cavity preparation. Upon placement of the amalgam restoration, a minimal decrease in cuspal deflection occurred. This was followed by a minimal increase in cuspal deflection following the removal of amalgam. When the bonded amalgam restorations were inserted, there was a dramatic reduction in the cuspal deflection with microstrain values almost approaching those of the teeth before cavity preparation. A similar trend was also observed with the remainder of the test teeth.

Figure 6 gives mean values for cuspal deflection of buccal and lingual cusps of all test teeth. ANOVA revealed that the increase in cuspal deflection following cavity preparation was significant for both the buccal and lingual cusps ($P = 0.0005$ for buccal and $P = 0.008$ for lingual cusp). Following restoration with nonbonded amalgam, cuspal deflection values of both cusps remained significantly higher than those of sound teeth ($P = 0.0005$ for buccal, and $P = 0.026$ for the lingual cusp). However, cuspal deflection values of teeth restored with bonded amalgam restorations were not statistically different from those of sound teeth. ANOVA revealed significant differences in cuspal deflection values of teeth with the nonbonded amalgam restorations compared with the values obtained after placement of bonded amalgam restorations ($P = 0.002$ for buccal and $P = 0.024$ for lingual).

Figure 7 shows cuspal deflection measurements made at different stages of cyclic loading of the buccal and lingual cusps. Microstrain values recorded at 2000, 4000, 6000, and 8000 cycles were compared to the values recorded at baseline (bonded amalgam before load cycling). Cuspal deflection did not increase under cyclic loading; on the contrary, a minimal reduction in cuspal deflection took place. This reduction, however, was not significant in the case of the lingual cusps, while it was only marginally significant in the case of the buccal cusps ($P = 0.042$).

DISCUSSION

The use of the nondestructive technique in this study eliminated the factor of sample variability as well as the need for large sample size in order to ensure meaningful findings. Utilizing strain gauges in measuring cuspal deformation allowed the sequential use of the same tooth at different stages of the testing without the need to obtain human teeth of similar anatomical configuration for each stage of testing.

The variability encountered in microstrain measurement among the teeth as evident by the range of cuspal deflection values as well as by the standard deviation values obtained under the same loading conditions must be related to variability in the geometrical configuration of the teeth and perhaps to minor structural variability. However, the nondestructive testing technique that was followed in this study allowed the values of the different test stages to be compared to those of baseline for each tooth. This sequential use of the same teeth throughout the test eliminated the need for a control group. Oliveira and others (1996) evaluated the effect of bonded amalgam on the fracture strength of teeth and found that the use of a different group of unrestored teeth as a control group was questionable due to the high coefficient of variation. They also stated that the use of natural teeth for testing introduced a significant variable, and the reduction or elimination of such a variable was essential.

Measuring cuspal deflection using strain gauges was previously reported by Morin and others (1984), Fissore and others (1991), Sakaguchi and others (1991), and Lopes, Lietao, and Douglas (1994). The technique was reported to provide more clinically relevant results. However, it is crucial for such testing to ensure that the load is applied by means of a guiding jig so that the metal rod contacts the same point each time a loading procedure is performed. The use of a repositioning jig in this study helped in standardizing the loading procedures throughout the different stages of testing in this study. In addition, the loading points were marked clearly at the buccal and lingual cusp ridges so that the load was applied directly through the ridges without touching the surface of the restoration. The load used (100 N) falls within the masticatory physiological load limits (13 - 147 N) as reported by de Boever and others (1978).

Nondestructive methods use more realistic loads and provide information that is more relevant to the clinical situation (Reeh & others, 1989). In contrast, studies that use catastrophic techniques result in fracture loads that are much higher than upper boundaries of the physiological range. Santos and Meiers (1994) reported fracture loads for teeth with bonded amalgam restorations ranging between 1300 and 1470 N, while Oliveira and others (1996) reported values ranging between 1150 and 800 N. Eakle and others (1992) reported loads of 750 N for the same. Such results cannot be directly related to the clinical situation, as these forces do not take place in the oral cavity under normal masticatory function.

The increase in cuspal deflection following cavity preparation as indicated by the highest peak in microstrain values (Figures 4 & 5) is yet more evidence of the weakening effect that cavity preparation has on teeth. This was expected, however, as the mesio-occlusodistal cavity preparation resulted in separation of the buccal and lingual cusps with increased outward cuspal deflection. The work by El-Mowafy (1993) demonstrated that mesio-occlusodistal cavity preparations or amalgam restorations on maxillary premolars resulted in more severe cuspal fractures compared with mesio-occlusal/disto-occlusal cavity preparations or amalgam restorations, which indicates the importance of maintaining the integrity of the connectivity and interaction between the buccal and lingual cusps of these teeth. Microstrain readings obtained following removal of nonbonded amalgam were not significantly different from those obtained before placement of the amalgam restorations, which is not surprising. This step was included in the study to ensure that removal of the amalgam restorations had no adverse effect on the strength of the cusps. The reduction in cuspal deflection following restoration with bonded amalgam indicated the strengthening effect that bonded amalgam restorations have on teeth with such cavity preparations. Cuspal deflection of teeth with bonded amalgam restorations dropped almost to the level of those of sound teeth.

It is interesting to note that the bond between amalgam and tooth structure, when investigated using SEM, was found to be micromechanical in nature when there was mechanical interlocking of the amalgam particles into the set layer of the bonding resin. To test the durability of such a bond, cyclic loading was conducted. Contrary to what one would expect, the findings indicated that there was no deterioration in the bond strength under the conditions of the test. For the buccal cusp, there was a marginally significant reduction in cuspal deflection as indicated by the mean microstrain value obtained at the end of cyclic loading. While difficult to explain, this might be attributed to delayed maturity of the bond under conditions of the test. These findings are in agreement with findings reported by Tarim and others (1996), who found that 100,000 cycles of 75 N load had no significant effect on marginal gap width of bonded amalgam using different bonding systems.

An attempt was made to test the durability of the bond after 3000 thermocycles. The intention was to measure cuspal deflection after every 1000 thermocycles. However, this was not possible, as the strain gauges failed to respond reliably following the first 1000 cycles. This was attributed to water leakage through the wax barrier of the strain gauges with subsequent disturbance of the fine electrical wiring within the gauges.

CONCLUSIONS

Bonding amalgam restorations to tooth structure significantly decreased outward cuspal deflection of premolar teeth compared to nonbonded amalgam restorations. Cyclic loading for up to 8000 cycles had no adverse effect on the bond. Consequently, bonded amalgam restorations may have a strengthening effect on teeth weakened by extensive cavity preparation.

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Influence of Two Dentin Bonding Systems on the Demineralization of the Root Surface

P HAHN • H G SCHALLER
C GERNHARDT • E HELLWIG

Clinical Relevance
The application of dentin adhesives on exposed root surfaces is possibly a caries prophylactic preventive measure.

SUMMARY

It has been assumed that dentin adhesives can prevent root surface caries. The aim of this study was to determine the caries-protective effect of two different dentin bonding systems on the demineralization of root surfaces in vitro. The root surfaces of 60 freshly extracted caries-free human molars were thoroughly cleaned and polished, thereby removing the cementum. The teeth were then coated with acid-resistant nail varnish, exposing two rectangular windows of 6 mm² each. One window served as an untreated control, while the other window was treated with a dentin bonding system. The specimens were distributed among the following experimental groups—Group 1: Syntac, Heliobond (no air thinning); Group 2: Syntac, Heliobond (as recommended); Group 3: Syntac , without Heliobond; Group 4: Prime & Bond 2.0 (no air drying); Group 5: Prime & Bond 2.0 (as recommended); Group 6: Prime & Bond 2.0 (dentin pretreated with 36% phosphoric acid). Subsequently, all specimens were demineralized for 6 days with acidified gel (HEC, pH 4.8, 37 °C). From each tooth, three dentinal slabs were cut perpendicular to the polished surface of the windows. The slabs were ground to a thickness of 80 µm and imbibed with water. The depth of the respective demineralized areas was determined using a polarized light microscope. All control specimens exhibited lesions with a mean depth of 67 µm. In Groups 2, 3, and 5 the lesion depth was reduced significantly, while in Groups 1, 4, and 6 no lesions could be detected. It was concluded that the demineralization of the root surface can be impeded by application of the dentin adhesives tested.

Albert-Ludwigs-University Freiburg, Dental Clinic, Department of Operative Dentistry and Periodontology, Hugstetterstraße 55, 79106 Freiburg, Germany

Petra Hahn, DDS, PhD, senior lecturer

Hans-Guenter Schaller, DDS, PhD, professor and senior lecturer

Christian Gernhardt, DDS, assistant professor, Department of Prosthodontics

Elmar Hellwig, DDS, PhD, professor and chair

INTRODUCTION

Root caries is a disease that has been known for a long time, as investigations in exhumed skulls of the 4th and 13th century showed (Moore & Corbet, 1971, 1973). Today a growing interest in the etiology and prevention of root caries is discernible.

Demographic data show a continuous increase of an older (65+) population in the United States (US Bureau of Census, 1988). As a result of better health education, as well as improved preventive and therapeutical treatment, tooth loss caused by coronal caries is reduced. Thus it is possible for people to retain their teeth longer. With increasing age the gingival tissues recede and many vulnerable root surfaces become exposed to the oral environment. Under certain circumstances these surfaces are susceptible to carious attack (Jordan & Sumney, 1973).

With application of different fluoride preparations, the root caries incidence can be reduced, but not eliminated (Jensen & Kohout, 1988; Almquist & Lagerlöf, 1993). Thus, new preventive concepts had to be found to protect the increasing number of bare-root surfaces against cariogenic challenge. In addition to fluoride, dentin bonding materials are supposed to create a high acid resistance of the root surface, due to a thin layer of resin-reinforced dentin: the hybrid layer (Nakabayashi, Nakamura & Yasuda, 1991). The objective of this study was to evaluate the influence of two different dentin bonding systems on the development and progression of root surface caries in vitro.

METHODS AND MATERIALS

Extracted caries-free human molars (n=60) were collected and stored at 8 °C, in a 0.9% sodium chloride solution, for a maximum of 8 days before the start of the experiments. The root surfaces of the molars were thoroughly cleaned. The cementum of the experimental area was removed by polishing with Sof-Lex disks (3M Dental Products, St Paul, MN 55144). Then the samples were coated with acid-resistant nail varnish, exposing two rectangular windows of 2 x 3 mm on the buccal root surfaces, 1 mm apical to the cementoenamel junction. The teeth were bisected and embedded in acrylic resin (Technovit 4071; Heraeus Kulzer, 63405 Hanau, Germany). One half of the tooth served as a control; the other half was used for the experiments (Figure 1). The teeth were randomly distributed among six

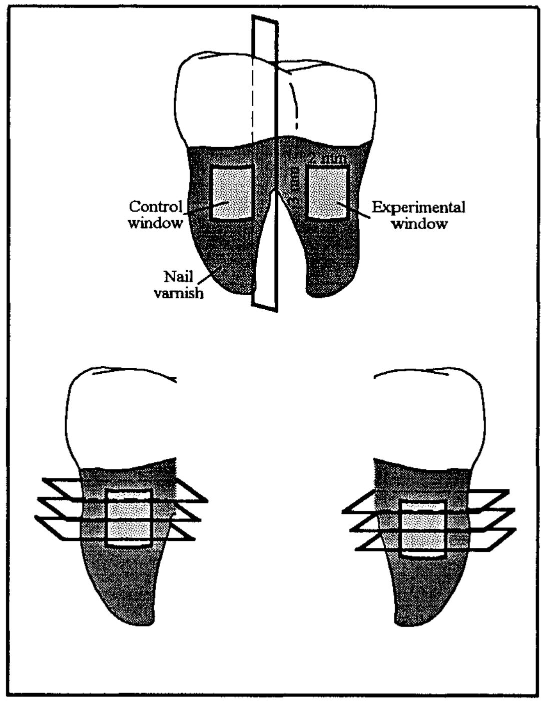


Figure 1. *Preparation of the samples*

Table 1. Materials Used

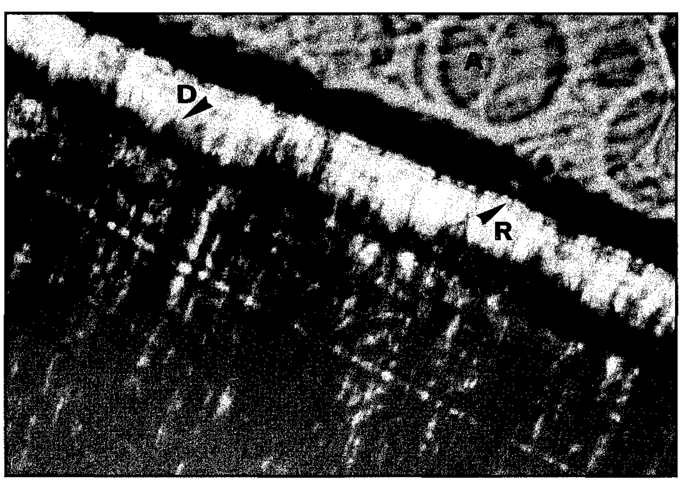
Material	Manufacturer	Essential Ingredients (Batch Number)
Syntac	Vivadent, Ellwangen, Germany	**Primer**: Tetraethyleneglycolmethacrylate, maleic acid, dimethylketone, water (708786) **Adhesive**: Polyethyleneglycoldimethacrylate, maleic acid, glutaraldehyde, water (713313)
Heliobond	Vivadent	Bisphenylglycidylmethacrylate, dioxactomethylene dimethacrylate (709349)
Prime & Bond 2.0	DeTrey Dentsply, Dreieich, Germany	Dipentaerythritole-pentacrylate-phosphoric acid ester, urethandimethacrylate, bisphenol-A-dimethacrylate, butylhydroxytoluole, camphoroquinone, 4-ethyl-dimethyl-aminobenzoate, acetone (9503241)

Table 2. Treatment of the Root Surfaces

Group	Bonding System	Treatment
1	Syntac/Heliobond	No air thinning of the Heliobond
2	Syntac/Heliobond	Air thinning of the Heliobond
3	Syntac	No Heliobond
4	Prime & Bond 2.0	No air drying of the second layer
5	Prime & Bond 2.0	Air drying of the second layer
6	Prime & Bond 2.0	Dentin conditioning, no air drying of the second layer

groups. Subsequently the specimens were treated with two different dentin bonding systems (Table 1). Three groups were treated with the two-bottle bonding material Syntac (Vivadent, 73479 Ellwangen, Germany), a dentin bonding system of the third generation. The Syntac primer and adhesive were used according to the manufacturer's instructions. In Group 1, an unfilled resin (Heliobond;Vivadent) was applied and immediately light cured. In Group 2, Heliobond was gently thinned with an air stream after application. In Group 3 the specimens were treated only with Syntac primer and adhesive, without Heliobond. In Groups 1, 2, and 3 the bonding materials were light cured for 10 seconds at the end of the application process (Table 2). The specimens of the remaining three groups were treated with the one-bottle bonding system Prime & Bond 2.0 (DeTrey Dentsply, 63303 Dreieich, Germany). The bonding material was applied on the root surface in two layers. After evaporation of the solvent with an air stream, the first layer was light cured for 10 seconds in all three groups. In Group 4, the second layer was not air dried prior to light curing (10 seconds). In Group 5 the second layer was air dried before light curing. In Group 6 the dentin surface was acid etched with 36% phosphoric acid (DeTrey Conditioner 36; DeTrey Dentsply) prior to application of the two layers of the dentin bonding system. Again no air drying of the second layer was performed (Table 2). The dentin surfaces of all control halves were left untreated.

For preparation of the demineralizing solution, sodium hydroxide (0.1n) was acidified by titration with lactic acid (0.1n) to pH 4.5. Hydroxyethylcellulose (6% by weight) was added, resulting in a final pH of 4.8 (Hellwig & Klimek, 1984). Each five samples were immersed in 100 ml demineralizing solution for 144 hours at 37 °C. After exposure the tooth samples were washed under running tap water and air dried. Then the specimens were embedded into acrylic resin, and three plano-parallel sections of each sample (Figure 1), perpendicular to the experimental surface, were cut with a band saw (Exakt Apparatebau, 22851 Norderstedt, Germany), using the sawing and grinding technique described by Donath and Breuner (1982). Subsequently the slices were ground in a three-step procedure with sand paper (1200-, 2400-, and 4000-grit) to a thickness of 80 µm (±20µm). A qualitative evaluation of the sections was performed, and the



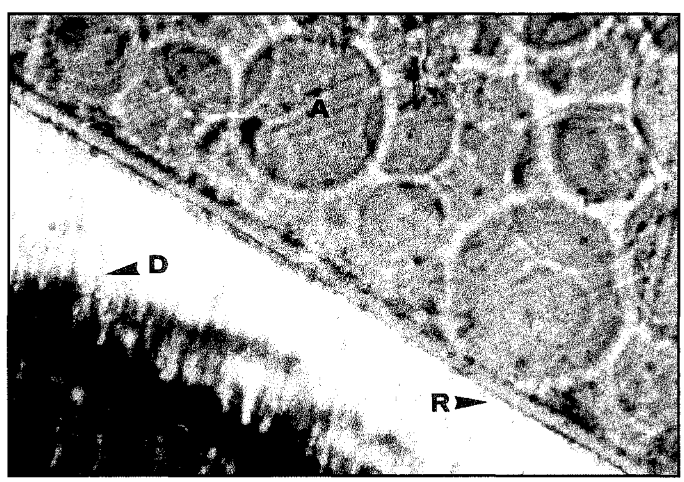


Figure 2. *Polarized light photomicrographs of a root surface lesion imbibed in water (magnification X99.8). Reduced demineralization in the experimental specimen (A) compared to control specimen (B) in Group 2 (Syntac and Heliobond, with air thinning). A = acrylic resin; R = root surface; D = demineralization front.*

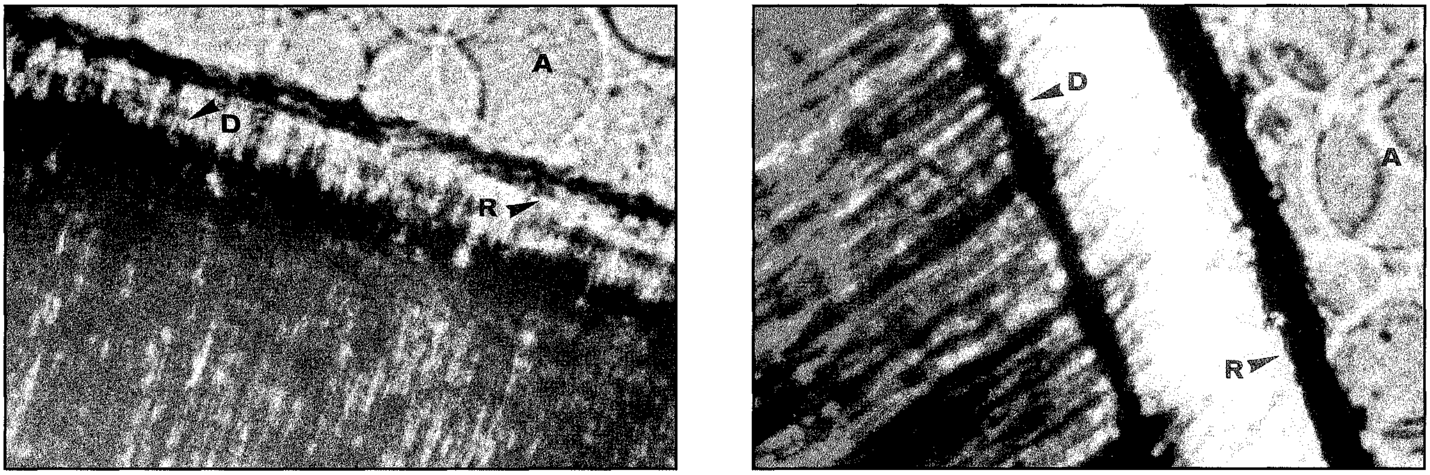


Figure 3. *Polarized light photomicrographs of a root surface lesion imbibed in water (magnification X99.8). Reduced demineralization in the experimental specimen (A) compared to control specimen (B) in Group 3 (Syntac without Heliobond). A = acrylic resin; R = root surface; D = demineralization front.*

experimental area was compared with the varnish-coated area. The lesion depths were measured with an inverse polarizing light microscope at an original magnification of X128 (Carl Zeiss, 73447 Oberkochen, Germany). In each section 10 measurements were done.

The data of the lesion depths were statistically analyzed with respect to the mean values of the three different locations of the control and experimental sections and with respect to the mean values of the different experimental groups using the ANOVA and the Kruskal-Wallis tests.

RESULTS

The mean lesion depth of the control specimens caused by the demineralization of the root surfaces was 66.9 μm (±5.2 μm). Regarding the cervical,

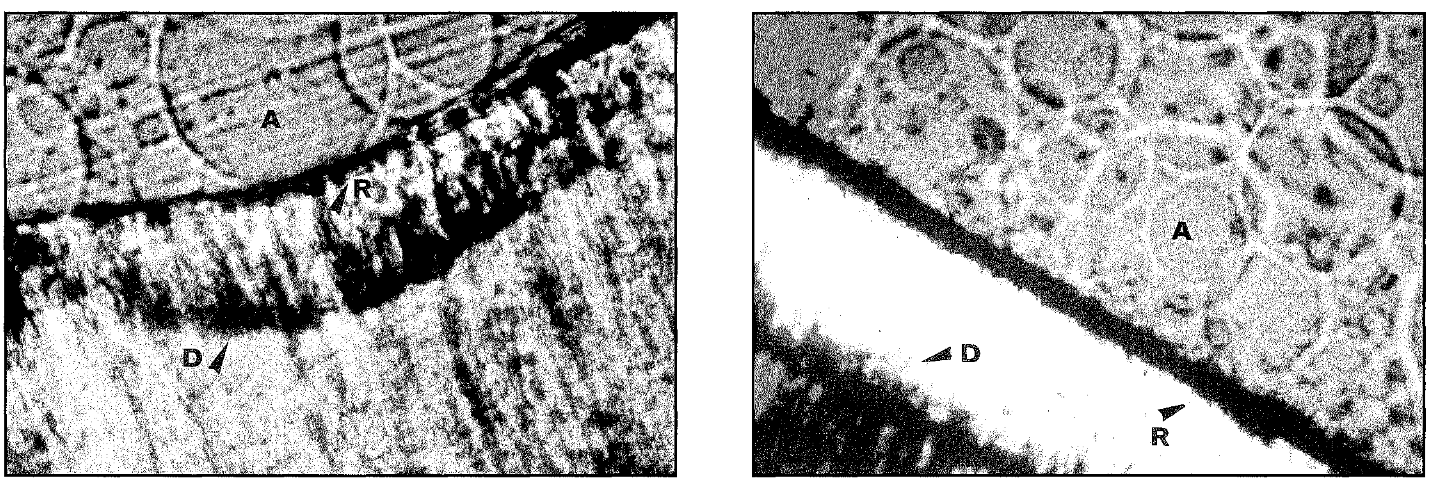


Figure 4. *Polarized light photomicrographs of a root surface lesion imbibed in water (magnification X99.8). Reduced demineralization in the experimental specimen (A) compared to control specimen (B) in Group 5 (Prime & Bond 2.0, with air drying of the second layer). A = acrylic resin; R = root surface; D = demineralization front.*

Table 3. Significance of Differences among the Experimental Groups (ns = not significant)

1	x				
2	$P \leq 0.001$	x			
3	$P \leq 0.001$	ns	x		
4	ns	$P \leq 0.001$	$P \leq 0.001$	x	
5	$P \leq 0.001$	$P \leq 0.050$	$P \leq 0.050$	$P \leq 0.001$	x
6	ns	$P \leq 0.001$	$P \leq 0.001$	ns	$P \leq 0.001$
Group	1	2	3	4	5

central, and apical sections, the control as well as the experimental samples showed no significant differences. Thus the results of the different sections were pooled.

ANOVA revealed that the lesion depths among the six experimental groups proved to be significantly different ($P < 0.0001$). The lesions of all groups with air thinning of the bonding material were significantly deeper than the lesions of the groups without air thinning ($P < 0.001$). In accordance with these results, the qualitative analysis showed bonding layers of different thicknesses, depending on the application process. There was no difference in the histological structure of the dentin in Groups 1, 4, and 6, compared with the areas of the root surface coated with the nail varnish. These groups exhibited no demineralization at all.

The demineralization zones of experimental Groups 2, 3, and 5 were like the control specimens concerning the histological structure, but the lesion depths were reduced (Figures 2-4). The Group 5 samples showed an irregular distribution of carious and noncarious areas, with varying lesion depths in the quantitative analysis (Figures 4A & 4B). Pairwise comparison revealed a significantly lower lesion depth for Group 5 compared to Groups 2 and 3 ($P = 0.05$). The differences between Groups 2 and 3 were not significant (Table 3). Group 2 (application of Syntac and Heliobond, with air thinning) showed a lesion depth of 44.6 µm (±5.5), Group 3 (application of Syntac without Heliobond) of 46.3 µm (±4.8), and Group 5 (application of Prime & Bond 2.0 with air drying) of 35.5 µm (±22). That means a reduction of demineralization of 34%, 31.5%, and 46.9% respectively compared with the control (Table 4).

DISCUSSION

In the present study saline solution was used for the storage of extracted teeth. This a common procedure (Hoppenbrouwers, Driessens & Borggreven, 1986; Zuidgeest, Herkströter & Arends, 1990; Sterrett, Dhillon & Murphy, 1995), as it does not influence the physical properties of dentin (Cooley & Dodge, 1989; Retief & others, 1989).

After gingival recession, normally the cementum is lost very soon, due to its low abrasion resistance (Mellberg & Sánchez, 1986). In most cases, there is no cementum on the root surface where caries occurs (Wefel, Clarkson & Heilmann, 1985). Therefore, it was removed before starting the present experiments. The resulting dentinal tooth surface facilitated a more standardized demineralization of the samples with reproducible lesions.

Shellis (1994) demonstrated that the progression of root caries is smaller when simulating pulpal pressure with perfused dentinal tubules, compared with control samples without this simulation. We did not use this model, as in our experiments the

Table 4. Average Lesion Depth (µm) and Standard Deviations (SD) of the Different Experimental Groups

	GROUP 1 Syn/Helio no air drying	**GROUP 2** Syn/Helio air drying	**GROUP 3** Syntac	**GROUP 4** P & B no air drying	**GROUP 5** P & B + air drying	**GROUP 6** P & B dentin cond, no air drying	**CONTROL**
Mean	0	44.6	46.3	0	35.5	0	66.9
SD	0	05.5	04.8	0	22.0	0	05.2
% reduction compared with the respective controls	100	34.0	31.5	100	46.9	100	x

difference between the experimental and the control lesions, within the same tooth, comprised sufficient information about the effectiveness of the dentin bonding systems tested. However, an interaction between the fluid in the tubules and the acid on the root surface cannot be excluded.

Before starting with the present study, preliminary experiments with different periods of time proved that the demineralization over a period of 6 days resulted in reproducible lesions of sufficient depth. A longer exposure time did not influence the lesion depth markedly.

The mean lesion depths of the control specimens were comparable to the results of Mellberg and Sánchez (1986), who also used acidified hydroxyethylcellulose.

The location showed no significant influence on lesion depth, corresponding to the results of Zuidgeest and others (1990).

The two bonding systems used in our study reduced the demineralization depth independent of the tested application mode. These observations are in accordance with the results of Grogono and Mayo (1993) and of Swift and others (1994), who also found a reduction of the lesion depth after application of dentin bonding agents. But they used different caries models.

The bonding agents tested were able to seal the root surface completely, if the thickness of the material was sufficient. Groups 1, 4, and 6 did not show any demineralization after the acid attack. In the experimental Groups 2, 3, and 5, the lesions were similar to the control specimens concerning the histomorphologic aspect, but they were reduced significantly. Corresponding to these results, Glasspoole and Erickson (1992) reported that excessive air thinning of an adhesive resin did reduce significantly the bond strength between dentin and composite.

Dentin bonding systems containing acids or chelating agents (maleic acid, phosphoric acid, EDTA) can demineralize the intertubular dentin (Van Meerbeek & others, 1992).

After application of the dentin bonding systems, the dentinal tubules are filled with resin tags, and the monomers infiltrate the collagen, forming the hybrid layer. This has already been shown by Nakabayashi and others (1991). They described it as the forming of an acid-resistant envelope that seals the dentin, preventing secondary caries. The reduction of the demineralization depth, observed in our experiments, may be caused by this process.

Additionally, glutardialdehyde, which is included in Syntac, could be responsible for the reduced demineralization obtained with this material. Similar to our results, Dijkman, de Vries, and Arends (1992) found that glutardialdehyde decreased demineralization of dentin to 70% in situ.

According to the quantitative results of Group 5, Prime & Bond 2.0, with air drying of the second layer, seemed to protect the root surface better than did the dentin bonding agents of Groups 2 and 3. But there was an irregular distribution of carious and noncarious areas of the specimens in Group 5, which was probably caused by the solvent acetone, which evaporates with a different velocity at the surface. The efficacy of Prime & Bond 2.0 used together with air drying is not predictable concerning the protection against an acid attack, while the Syntac system resulted in a uniform decrease of the demineralization with every application mode.

CONCLUSIONS

For both systems tested in this study, air thinning of the bonding agents reduced the protection of the root surface against demineralization. Consequently, excessive air thinning of adhesives used for caries prophylactic treatment of exposed root surfaces cannot be recommended.

Clinical experiments must prove the efficacy of dentin bonding agents for caries prevention. Additional studies must show if and how long the bonding agents are able to withstand the mechanical, chemical, and physical challenges of the oral environment.

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Effect of Saliva Contamination on the Bond of Dentin to Resin-modified Glass-Ionomer Cement

J A SAFAR • R D DAVIS • J D OVERTON

Clinical Relevance

Salivary contamination adversely affects the adhesion of resin-modified glass-ionomer cement to dentin. Rinsing and re-etching the dentin failed to result in strength as great as to noncontaminated dentin, indicating the importance of moisture control when using these materials.

SUMMARY

This in vitro study compared the shear bond strength of a resin-modified glass-ionomer restorative material (Fuji II LC) bonded to saliva-contaminated dentin versus noncontaminated dentin. Seventy-five extracted human molar teeth were randomly divided into five groups of 15 samples each. The dentin was treated with 10% polyacrylic acid for 20 seconds, rinsed, and dried. The acid-treated dentin surfaces in Groups 1-4 were contaminated with saliva. In Group 1, the saliva was air thinned. In Groups 2-4, saliva was dried completely with compressed air. The saliva-contaminated dentin in Group 3 was rinsed and dried. The saliva-contaminated dentin in Group 4 was rinsed, dried, treated with 10% polyacrylic acid, and dried. Specimens in Group 5 received no contamination. The resin-modified glass-ionomer cement restorative material was mixed and applied to the dentin surfaces. Following placement of the restorative material and 7 days of storage, the specimens were thermocycled 300 times. Using the Instron Universal Testing Machine, a shear force was applied to the restorative material. Shear bond strength values were compared among the groups using a one-way ANOVA and Student-Neuman-Keuls Multiple Range Test ($\alpha = 0.05$). The noncontaminated specimens (Group 5) were significantly stronger than the contaminated specimens (Groups 1-4). There were no significant differences in bond strength among the groups containing contaminated specimens. Salivary

81st Dental Squadron, 606 Fisher Street, Keesler AFB, MS, 39534

John A Safar, DDS, major, USAF, DC

Richard D Davis, DDS, colonel, USAF, DC

Johnie D Overton, DDS, colonel, USAF, DC

contamination occurring after dentin etching significantly reduced the bond strength of the resin-modified glass-ionomer restorative material to dentin. Neither rinsing nor rinsing and re-etching resulted in bond strengths as great as to noncontaminated dentin.

INTRODUCTION

Glass-ionomer cement is a tooth-colored, fluoride-releasing, direct adhesive restorative material composed of calcium aluminofluorosilicate glass and polyacrylic acid. It was first reported in the dental literature by Wilson and Kent in 1972. As a direct-fill restorative material, it provides a number of clinical advantages. A cariostatic potential has been shown with glass-ionomer cements because of their release of fluoride (Souto & Donly, 1994; Qvist & others, 1997). They possess a coefficient of thermal expansion similar to tooth structure, making them less susceptible to debonding due to thermal stresses (McCaghren & others, 1990). Glass-ionomer cements adhere to dentin and have proven useful for the restoration of class 5 abrasion lesions (Vargas, Fortin & Swift, 1995). In vivo research has demonstrated long-term retention of class 5 restorations. Matis, Cochran, and Carlson (1996) reported 83% retention of class 5 glass-ionomer cement restorations after 10 years, and Mount (1986) reported a retention rate of 93% after 7 years. Because conventional glass ionomers demonstrated early moisture sensitivity, low mechanical strength, and solubility, resin was added to the glass-ionomer cement formulation. The resulting resin-modified glass-ionomer cement demonstrated reduced moisture sensitivity, and in addition, provided the advantage of light-activated command set (Fruits & others, 1996; Cho, Kopel & White, 1995). Resin-modified glass-ionomer cements were found to exhibit greater cohesive strength and adhesive strength to tooth structure than conventional glass-ionomer cements (Mount, 1995). Research by Sidhu and Watson (1995) indicated that the addition of resin did not reduce the effective release of fluoride.

One of the clinical factors that can affect adhesion and retention of resin-containing restorative materials is contamination of the restorative field with saliva. Silverstone's microscopic examination of saliva-contaminated acid-etched enamel showed the formation of a tenacious coating that could not be removed by rinsing with water (Silverstone, Hicks & Featherstone, 1985). The coating masked underlying enamel pores, decreased resin accessibility, and impaired mechanical adhesion. A number of researchers have investigated the effect of salivary contamination on the bond strength of composite resin to enamel. Findings consistently indicated a significant decrease in resin-enamel adhesion in the presence of salivary contamination (Barghi, Knight & Berry, 1991; Hormati, Fuller & Denehy, 1980; Powers, Finger & Xie, 1995).

Moisture contamination during the early setting reaction of conventional glass-ionomer cement causes the partial loss of unreacted ions and newly formed polyacrylates, weakening the final cement (Suliman & others, 1989; Phillips & others, 1987). Resin-modified glass-ionomer cements are more resistant to dissolution than conventional glass-ionomer cement because of the early hardening of the resin component; however, it is not known if they suffer the same decrease in adhesion as composite resins when polymerized in the presence of saliva.

The possibility exists that salivary contamination may adversely affect the bond of resin-modified glass-ionomer cements to dentin; however, no published research has reported the effect of salivary contamination on the bond strength of resin-modified glass-ionomer cements to dentin. The purpose of this in vitro study was to compare the shear bond strength of a resin-modified glass-ionomer restorative material bonded to dentin contaminated with saliva versus the bond strength of the same material bonded to noncontaminated dentin.

METHODS AND MATERIALS

Seventy-five noncarious extracted human third molars were collected and stored in formalin at room temperature. The teeth were randomly divided into five groups of 15 samples each. The occlusal enamel was removed by abrasion using a cast-trimming machine. The teeth were secured in cylindrical molds (phenolic rings) with fast-set acrylic resin such that the flattened dentin surface was exposed and was parallel to the base of the mold. The flattened dentin surface was smoothed using a series of water-lubricated abrasive silicon carbide disks. The final surface finish was created with 600-grit SiC abrasive disks. Each dentin surface was cleaned with a pumice-water slurry and then rinsed. The dentin surfaces were dried with oil-free, compressed air. A 10% polyacrylic acid (PAA) solution (Dentin Conditioner; GC America, Chicago, IL 60658) was applied to the dentin surfaces for 20 seconds with a light rubbing motion using a cotton pledget. Dentin surfaces were then rinsed, dried, but not desiccated, with oil-free compressed air. Experimental groups were treated as follows:

Group 1: (Dentin contaminated with saliva and left wet) Following acid conditioning, rinsing, and drying, saliva collected from a single individual was applied to the dentin surface with a dropper. The saliva remained on the dentin surface for 10 seconds and then was thinned with a stream of compressed air until only a thin, wet film remained. Following this,

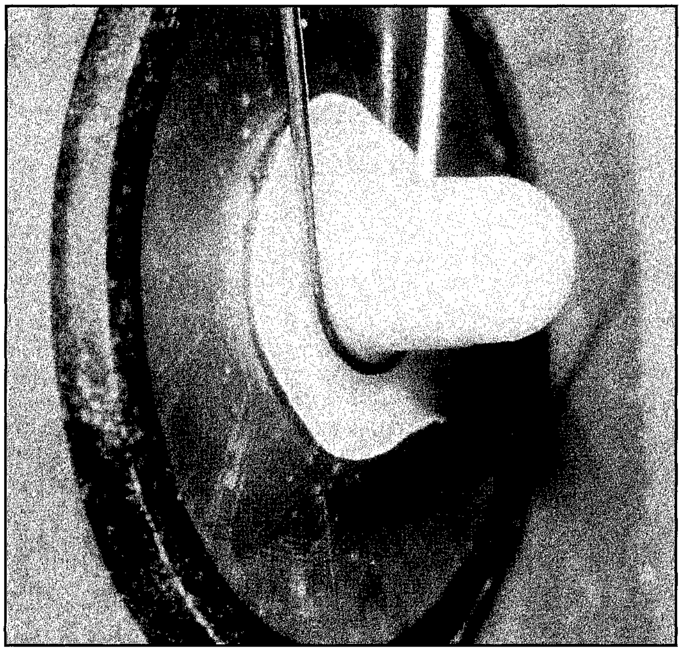

Figure 1. *Shear bond testing apparatus*

the resin-modified glass-ionomer cement (Fuji II LC; GC America) was mixed and applied against the wet dentin surface and light activated for a total of 40 seconds from two directions using a curing light with a light output of 700 mw/cm^2 (Optilux 400; Demetron Research Corp, Danbury, CT 06810).

Group 2: (Dentin contaminated with saliva that was then dried) The specimens in Group 2 were treated the same as those in Group 1 except that the dentin was kept continuously wet for 10 seconds and then air dried with oil-free compressed air until the dentin surface appeared to be free of pooled saliva but did not appear desiccated. The restorative material was mixed and placed against the (dried) saliva-coated dentin surface and light activated as in Group 1.

Group 3: (Dentin contaminated with saliva, dried, then rinsed with water) The specimens were contaminated the same as were those in Group 2, then the dentin was rinsed for 20 seconds with water and dried with air until the surface was free of standing moisture, but did not appear desiccated. The restorative material was then placed against the dentin surface and light activated.

Group 4: (Dentin contaminated with saliva, dried, then rinsed with water and treated again with 10% PAA.) The specimens were treated the same as were those in Groups 2 and 3 except that following the rinsing of the saliva-contaminated surfaces, the dentin surface was reconditioned with 10% polyacrylic acid for 20 seconds, rinsed, and dried with air in the same manner as Group 3 specimens. The restorative material was then mixed and placed against the dentin surface and light activated.

Group 5: (Noncontaminated dentin) Specimens in Group 5 received no saliva contamination prior to placement of the resin-modified glass-ionomer cement against the dentin surface. The restorative material was light activated as in Groups 1-4.

The resin-modified glass-ionomer cement restorative material was mixed and applied as per the manufacturers' directions. Each capsule of Fuji II LC was mixed for 10 seconds using a Caulk Varimix II triturator (L D Caulk, Milford, DE 19963). The mixed material was inserted into standard 5 mm-in-internal-diameter clear gelatin capsules, which were then gently pressed against the dentin surface. Excess restorative material was removed, and these capsules were held in place by hand during light polymerization. Following polymerization, samples were allowed to sit undisturbed for 15 minutes and then placed in distilled water and stored for 7 days at room temperature. Following 7 days of storage, the specimens were thermocycled 300 times between water baths maintained at 5 and 55 °C, with a dwell time of 30 seconds in each bath. After thermocycling, the specimens were stored for an additional week in distilled water. Each specimen was then mounted in a holding device. A wire was looped around the glass-ionomer cement cylinder, making contact through half its circumference, and was gently held flush against the glass-ionomer/dentin interface (Figure 1). Using the Instron Universal Testing Machine, a shear force was applied at a strain rate of 1 mm/min. The resistance at failure was noted, and the failure stress in megapascals (MPa) was calculated. The mode of failure was noted after a visual examination using a stereomicroscope at X10 magnification. Failures were recorded as adhesive (those which occurred between the glass-ionomer cement and dentin),

Table 1. Shear Bond Strength Comparisons

Group	Mean (MPa)	SD
1 (saliva, wet)	12.78	2.22
2 (saliva, dried)	12.19	1.61
3 (saliva, rinsed)	11.29	3.35
4 (saliva, rinsed/re-etched)	12.58	2.79
5 (control, no contamination)	17.85	1.66

Groups that are not statistically different are linked by a bar (ANOVA, Student-Keuls; $\alpha = 0.05$).

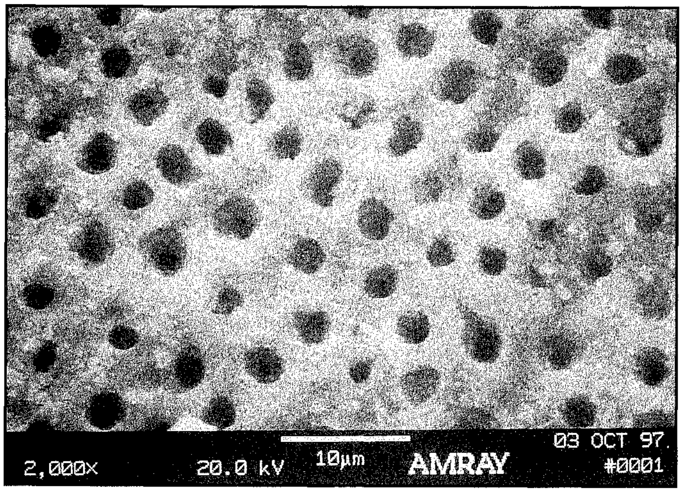

Figure 2. *SEM (X1220) of a dentin surface treated with 10% PAA*

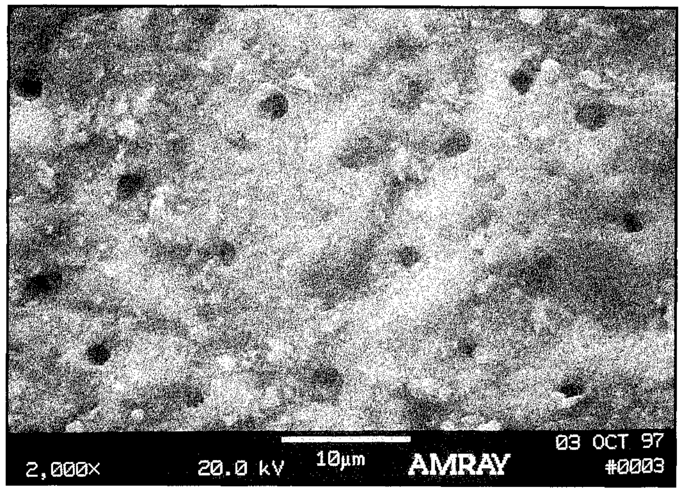

Figure 3. *SEM (X1220) of an acid-treated and saliva-contaminated dentin surface*

cohesive (those which occurred within the glass-ionomer cement or dentin), or mixed (combination of adhesive and cohesive).

Group means and standard deviations were calculated and the data were analyzed using a one-way Analysis of Variance (ANOVA), followed by a Student-Newman-Keuls test ($\alpha = 0.05$). Mode of failure comparisons were made using a chi-square test.

RESULTS

Table 1 depicts the mean shear bond strengths of the five experimental groups. The noncontaminated specimens in Group 5 had the highest overall shear bond strength, which was significantly stronger than those of Groups 1 - 4 ($P = 0.0001$). The mean bond strengths of Groups 1-4 were not significantly different ($P > 0.05$).

Scanning electron photomicrographs of representative dentin samples are shown in Figures 2-6. A typical noncontaminated dentin surface demonstrating open dentinal tubules following the use of the polyacrylic acid conditioner is shown in Figure 2. A dentin surface with saliva contamination is shown in Figure 3. Specimens that were rinsed and those that were rinsed and reconditioned after saliva contamination are depicted in Figures 4 and 5 respectively.

Table 2 depicts the number of specimens in each group displaying the different bond failure modes. Microscopic evaluation of the failed interfaces

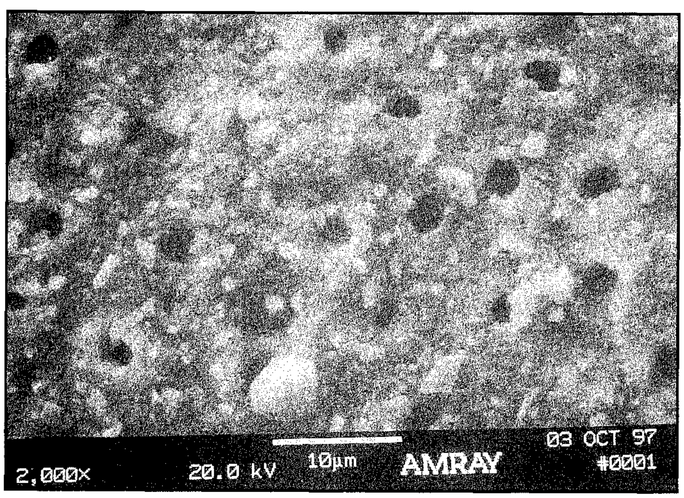

Figure 4. *SEM (X1220) of an acid-treated dentin surface, contaminated with saliva and rinsed with water*

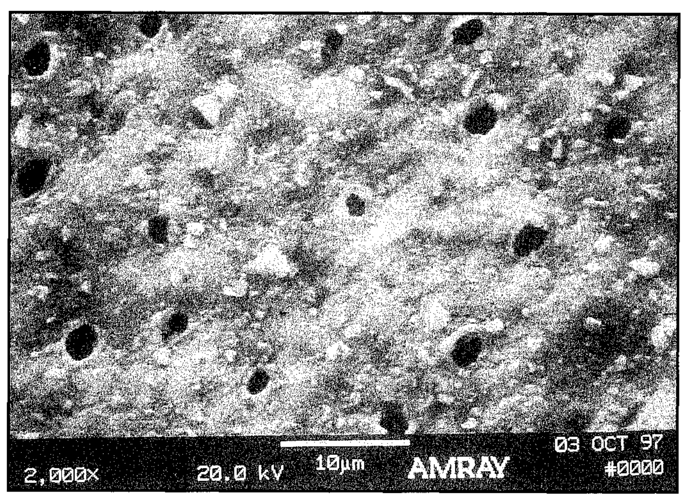

Figure 5. *SEM (X1220) of an acid-treated dentin-treated dentin surface, contaminated with saliva, rinsed with water, and re-treated with 10% PAA*

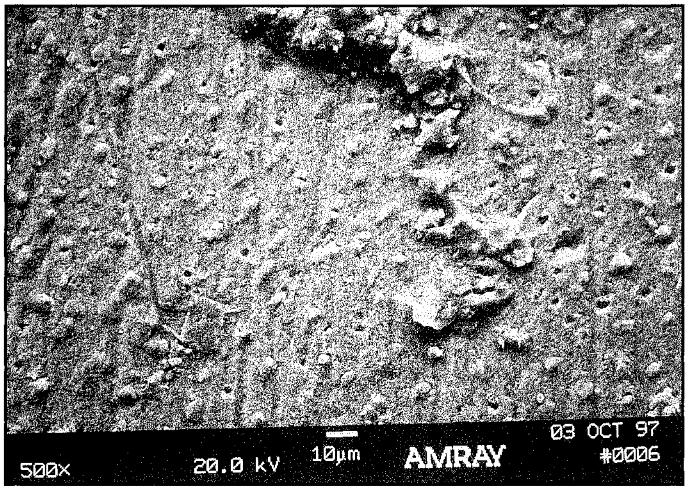

Figure 6. *SEM (X305) of a mixed adhesive-cohesive failure on an acid-treated and saliva-contaminated specimen*

(dentin and restorative material) indicated an adhesive or a mixture of adhesive and cohesive cement failure in the majority of the saliva-contaminated specimens (Figure 6.) The majority of the failures of the noncontaminated Group 5 specimens were cohesive, with breakage occurring within the cement. The chi-square test indicated that Group 5 specimens demonstrated significantly more cohesive fractures than any of the other groups ($P < 0.05$).

DISCUSSION

The primary indication for the use of Type 2 resin-modified glass-ionomer restorative material is the restoration of class 5 lesions in high-caries-risk individuals. The release of fluoride from this class of restorative material may provide a degree of resistance to demineralization in caries-prone patients. Ten Cate and van Duinen (1995) reported that the placement of a glass-ionomer restoration resulted in hypermineralization of the adjacent dentin. This hypermineralized dentin has been shown to inhibit acid-related demineralization (Mount, 1995). Few in vivo data are available; however, Qvist and others (1997) reported the results of a clinical investigation in which caries incidence was assessed in tooth structure adjacent to class 2 amalgam and glass-ionomer restorations. Their findings indicated that caries occurred significantly more often adjacent to amalgam restorations (21%) than adjacent to glass-ionomer restorations (12%). Because the fluoride release of resin-modified glass-ionomer cement has been shown to be similar to that of conventional glass-ionomer cement, one would anticipate that these materials would be similar in their anti-caries potential (Sidhu & Watson, 1995).

The present study indicated that salivary contamination has a detrimental effect on the resin-modified glass-ionomer cement-to-dentin bond. This is particularly significant given the survey research by Hagge and others (1981), which indicated that only 5% of dentists use rubber dam isolation for moisture control during restorative dental procedures. Restoring class 5 carious lesions, which extend subgingivally, without salivary contamination may be difficult.

The authors speculate that the decrease in bond strength found in the present study is due to the presence of salivary residue on the dentin surface. The salivary contaminant apparently precluded the thorough wetting of the dentin surface by the resin-modified glass-ionomer cement. The bond strength data, failure patterns, and SEM photos from the present study indicated that the salivary contamination was resistant to rinsing, and surprisingly, was also resistant to acid conditioning with 10% PAA. Figures 4 and 5 illustrate the presence of this residual salivary contamination both before and after acid treatment.

In the study conducted by Hormati and others (1980) on the effect of saliva contamination on enamel-resin bonds, the 37% phosphoric acid used to re-etch the enamel surface after salivary contamination seemed to dissolve away the remaining saliva. Powers and others (1995) showed similar findings with saliva-contaminated dentin after re-etching with aluminate-oxalate conditioning solution of pH 1.25. The 10% polyacrylic acid used with the resin-modified glass-ionomer cement utilized in the present study was sufficiently acidic to remove the smear layer from the noncontaminated dentin surface (Figure 2), but was not strong enough to remove the residual salivary contamination. The saliva

Table 2. Failure Mode Comparisons

Group	Adhesive	Cohesive	Mixed
1 (saliva, wet)	1	0	14
2 (saliva, dried)	3	1	11
3 (saliva, rinsed)	6	2	7
4 (saliva, rinsed/re-etched)	3	4	8
5 (control, no contamination)	0	10	5

The number of cohesive cement failures was compared among the groups using a chi-square analysis (α = 0.05). Groups that are not statistically different are linked by a bar.

covering the dentinal tubule orifices remained on the dentin surface even after rinsing and reconditioning. Additional research will be required to determine what other acids or procedures may be used to remove the salivary contamination from the dentin surface and restore the resin-modified glass-ionomer cement-to-dentin bond strength.

It should be noted that the majority of the bond failures for the saliva-contaminated groups, even the group that was bonded through a thin layer of saliva, were mixed cohesive/adhesive failures. This indicated that some bonding with dentin was possible even in the presence of saliva. This might be explained by the relatively hydrophilic nature of the resin-modified glass-ionomer cement, permitting it to penetrate through the saliva and bond to dentin. The cohesive nature of the failures of the specimens in Group 5 (resin-modified glass-ionomer cement bonded to noncontaminated dentin) is consistent with the findings of Triana and others (1994). Because the majority of the bond failures within the noncontaminated control group were cohesive, the actual dentin bond strength for this group is understated by the fracture data reported here.

Saliva contamination decreased the bond of a resin-modified glass-ionomer cement to dentin. The relationship of this contamination-related bond strength decrease to clinical success is not known; however, because the detrimental effects of saliva contamination were not reversible by rinsing or acid conditioning, the results of the present study indicate that moisture control is important when using resin-modified glass-ionomer cements.

CONCLUSION

Saliva contamination occurring after dentin conditioning significantly reduced the bond strength of a resin-modified glass-ionomer restorative material to dentin. Rinsing the saliva-contaminated dentin or rinsing then reconditioning failed to result in bond strength as great as the bond to noncontaminated dentin.

Disclaimer

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Human-Eye versus Computerized Color Matching

A U J YAP • C P C SIM
W L LOH • J H TEO

Clinical Relevance
Difference in color matching between human-eye assessment and computerized colorimetry is shade dependent.

SUMMARY

This project compared the difference in color matching between human-eye assessment and computerized colorimetry. Fifty dental personnel were asked to color match Vita Lumin shade tabs to seven different randomly arranged test tabs from the Z100 shade guide. All evaluators were blinded to the shades of the test tabs and were asked to match only body shade of the Vita Lumin tab to the middle third or body of each test tab. The results obtained were subsequently computed into L*a*b* values and compared with results obtained by computerized colorimetry. Results indicate that the difference in color matching between human-eye assessment and computerized colorimetry is shade dependent. Discrepancy was significant for b* coordinates for shades A1 and B2 and L* and b* coordinates for shade C4. For all shades evaluated, color difference between human-eye and computerized color matching is perceivable under clinical settings, as ΔE values are greater than 3. There is a need for correction factors in the formal specification of the color-matching software due to the discrepancy between human-eye and computerized colorimetric color matching.

National University of Singapore, Faculty of Dentistry, Department of Restorative Dentistry, 5 Lower Kent Ridge Road, Singapore 119074

Adrian U J Yap, BDS, MSc, FRSH, senior lecturer and assistant director of Centre for Biomedical Materials Applications and Technology

Christina P C Sim, BDS, MSc, FAMS, senior registrar, Department of Restorative Dentistry, National Dental Centre

Wai Lung Loh, BSc, PhD, lecturer, Department of Information Systems and Computer Science, Faculty of Science

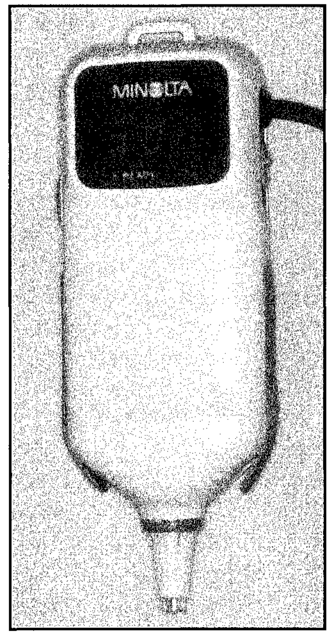
Juey Hea Teo, BSc, student, Department of Information Systems and Computer Science, Faculty of Science

INTRODUCTION

Selection of proper restorative shades and color matching restorations to the natural teeth continues to be one of the most complex and frustrating problems in restorative dentistry. Inadequate technology to aid clinicians and laboratory technologists in appropriate shade selection has reduced this part of dentistry into more of an art form than science. Unlike science, an art form is subordinate to the individual abilities of the clinician that influence the predictability and reproducibility of the finished restoration (Sorensen & Torres, 1987). Culpepper (1970) found disagreement between dentists in shade matching the same tooth, and individual dentists could not duplicate their shade selections on different days. As light is composed of different source-dependent wavelengths, color matching is also highly affected by viewing conditions. The light sources in the operatory and laboratory, amount of sunlight, the color of walls, the patient's clothing and makeup, and the viewing angle of the tooth can all affect color matching. Fluorescent light tends to accentuate the blue range of the color spectrum, whereas incandescent light accentuates the yellow-red range. This problem of metamerism can be avoided by selecting a shade and confirming the color match under different lighting conditions such as natural daylight and fluorescent light (Rosenstiel, Land & Fukimoto, 1995). Color-corrected lights with a color-rendering index of 90 or greater should be used by clinicians and laboratory technologists for shade selection and evaluation of completed restoratives (Preston, Ward & Bobrick, 1978).

Ideally, a clinician should have a spectrophotometer or colorimeter linked to a computer for shade-selection restoration (Sorensen & Torres, 1987). An optical reader held against a tooth would give the best shade match of restorative material and/or give the formulation of powder required for reproducing the natural tooth color. Presently, the technology is still lacking to perform the latter function. A computerized color-matching system, which can select the best shade for tooth-colored plastic restoratives like composites, compomers, and glass ionomers based on the set and age of material, is being developed at the National University of Singapore and National Dental Centre. The system, when completed, will minimize some of the problems faced clinically, like the subjectivity of the human observer, influence of light source, and inadequacies with currently available commercial shade guides (Sorensen & Torres, 1987). As photodetectors can measure smaller color changes than the human eye, one of the critical steps in the clinical application of this new technology is to determine the difference in color matching between human-eye assessment and computerized colorimetry.

The objective of this project was to compare color differences recorded by human-eye assessment and computerized colorimetry. Differences in color parameters between human-eye and computerized color matching for the various shades were also investigated. The need for the incorporation of "correction factors" in the formal specification of the computerized color-matching system, which may be necessary to compensate for the discrepancy in color recorded by human-eye and computerized colorimetry, was also determined.



The small-area colorimeter used

METHODS AND MATERIALS

Seven different shade tabs from the Z100 shade guide (3M Dental Products, St Paul, MN 55144) were used as test tabs for this study. The shades selected were A1, A4, B2, B3, C2, C4, and D3. The test tabs were covered with black opaque plastic tape, leaving only the tooth-form visible for shade matching. The test tabs were then randomly arranged, and 50 dental personnel were asked to match Vita Lumin shade tabs (Vita Zahnfabrik, Bad Säckingen, Germany) to the test tabs under similar color-corrected lighting conditions (Trucolor TLM 40W/33 RS, Phillips, Le Mans, France). The 50 dental personnel consisted of 10 prosthodontists, 15 general practitioners, 10 dental technologists, and 15 final-year dental students. All evaluators were blinded to the shades of the test tabs and were asked to match only body shade of the Vita Lumin tab to the middle third or body of each test tab. The results obtained were subsequently computed into L*a*b* values, where L* indicates lightness and a* and b* are the chromaticity coordinates, by using the data obtained from colorimetry (Dental Colorimeter, Minolta Camera Co Ltd, Tokyo, Japan). The a* and b* coordinates designate positions on red/green and yellow/blue axes respectively (+a = red, -a = green; +b = yellow, -b = blue). Colorimetric readings were taken at the body of each Vita shade tab. These same data also served as the database for the computerized color-matching system.

The computerized system consisted of a small-area colorimeter (Dental Colorimeter, Minolta Camera Co

Ltd, Tokyo, Japan) (figure), the colorimeter-computer interface, and the color-matching software. The colorimeter uses CIELAB color space for its color attributes, and illumination corresponding to "average" daylight (CIE illuminant D65) from a pulsed xenon light source was used. The colorimeter was calibrated before each measurement period using the white calibration tile (calibration cap) supplied by the manufacturer. As it was not designed to be integrated with a personal computer, an interface for data transmission was constructed. The programming language, Microsoft Visual Basic 5.0 (Microsoft Corp, Redmond, WA 98052) was used for development of the color-matching software, as it allows very quick user-interface prototyping and supports a complete object-oriented design and implementation. With each object, the user can also define its properties, methods, and event procedures. To further facilitate and ease data storage and retrieval of information, the database portion of the system was implemented using Microsoft Joint Engine Technology (Microsoft Corp).

With respect to the CIELAB color space, the color difference between a test tab i and a Vita tab j can be measured by the Euclidean distance (ρE) between them in the CIE space as follows:

$$\text{Diff(i,j) or } \rho E = \sqrt{(L_i - L_j)^2 + (a_i - a_j)^2 + (b_i - b_j)^2}$$

The software utilizes this equation to select the best color match based on the database of the Vita test tabs constructed earlier. The software allows the database to be expanded or limited to include different materials used clinically. Once a test tab has been read, the shade-matching software selects the Vita tab that had the lowest Diff value against the test tab. Each test tab was shade matched five times by the computerized system. For all test tabs, the Vita shade tab selected was the same for all five instances of shade matching. The L*a*b* values of the Vita shade tabs selected by computerized shade matching were then computed and compared with that obtained by human-eye color matching. The data were subjected to the Komolgorov-Smirnov test of normality. Statistical analysis was then done using Kruskal-Wallis and Mann-Whitney tests at a significance level of 0.05, as data were nonparametric.

RESULTS

The mean L*a*b* values for human-eye and computerized color matching are shown in Table 1. Table 2 reflects the mean ΔL, Δa, Δb, and ΔE for the different tabs. The results of the statistical analysis are shown in Table 3. Significant difference between human-eye and computerized color matching was observed for three out of the seven test tabs evaluated. For test tabs shade A1 and B2, there was statistical difference in b* values between human-eye and computerized color matching. No significant differences were noted for L* and a* values. For test tab shade C4, all three color parameters, L*a*b*, were significantly different between human-eye and computerized color matching. The L* values obtained from human-eye matching were generally greater than that of computerized matching. No obvious trend in a* and b* differences between matching techniques were noted. Ranking of ΔL, Δa, Δb, and ΔE from smallest to greatest by shades is as follows: ΔL — B3 < C2 < B2 < D3 < A4 < C4 < A1; Δa — A1 <B2 < C2 < C4 < A4 < B3 < D3; Δb — A1 < B2 < D3 < B3 < C2 < C4 < A4; ΔE — B3 < B2 < C2 < D3 < A1 < A4 < C4. Statistical differences were noted among ΔL, Δa, Δb, and ΔE values for the different shades. Mean ΔE values for all shades evaluated were greater than 3 and ranged from 3.08 to 5.78.

DISCUSSION

Shade selection of dental restoratives is usually done visually by matching a shade sample. In

*Table 1. Mean L*a*b* Values*

Tab	Human-Eye Matching			Computerized Matching		
	L* (SD)	a* (SD)	b* (SD)	L* (SD)	a* (SD)	b* (SD)
1 (Shade A1)	74.86 (1.13)	-2.16 (0.23)	14.27 (1.65)#	70.90 (0.00)	-1.90 (0.00)	12.50 (0.00)#
2 (Shade A4)	68.04 (2.11)	0.49 (0.72)	27.16 (2.64)	64.10 (0.00)	1.00 (0.00)	23.70 (0.00)
3 (Shade B2)	74.06 (2.51)	-1.76 (0.30)	16.40 (1.52)#	68.10 (0.00)	-1.80 (0.00)	16.80 (0.00)#
4 (Shade B3)	70.10 (1.25)	-0.26 (0.60)	26.68 (2.66)	65.30 (0.00)	-0.20 (0.00)	23.50 (0.00)
5 (Shade C2)	68.30 (2.63)	-0.64 (0.58)	21.04 (1.95)	65.30 (0.00)	-0.20 (0.00)	23.50 (0.00)
6 (Shade C4)	60.65 (1.57)#	0.97 (0.40)#	23.55 (0.84)#	57.90 (0.00)#	1.00 (0.00)#	19.60 (0.00)#
7 (Shade D3)	70.50 (3.01)	-0.99 (0.64)	16.45 (2.13)	66.70 (0.00)	0.00 (0.00)	16.70 (0.00)

= statistically significant differences between human eye and computerized color-matching (results of Mann-Whitney test at a significance level of 0.05).

Table 2. Values for ΔL, Δa, Δb, and ΔE for the Different Tabs

Tab	Color Parameters			
	ΔL (SD)	Δa (SD)	Δb (SD)	ΔE (SD)
1 (Shade A1)	4.56 (1.13)	0.44 (0.23)	1.01 (1.57)	4.97 (1.00)
2 (Shade A4)	3.81 (1.76)	0.75 (0.44)	3.91 (1.25)	5.76 (1.41)
3 (Shade B2)	3.53 (2.27)	0.45 (0.28)	1.13 (1.11)	4.07 (1.93)
4 (Shade B3)	1.39 (0.78)	0.86 (0.44)	2.42 (2.37)	3.08 (2.34)
5 (Shade C2)	3.02 (2.12)	0.53 (0.33)	2.56 (1.66)	4.20 (2.38)
6 (Shade C4)	4.15 (1.57)	0.69 (0.12)	3.75 (0.84)	5.78 (1.24)
7 (Shade D3)	3.80 (3.01)	1.09 (0.64)	1.90 (2.08)	4.71 (3.29)

industry, electronic color-measuring equipment is used. This consists of spectrophotometers that measure light reflectance at wavelength intervals over the visible spectrum, and colorimeters that provide direct color-coordinate specifications without mathematical manipulation. This is done by sampling light reflected from an object through three color filters that simulate the response of the color receptors in the eye (Rosenstiel & others, 1995).

Light from the test tab enters the eye and acts on receptors (rods and cones) in the retina. Impulses from this are then passed to the optical center of the brain, where an interpretation is made. Different persons will make different interpretations of the same stimulus, and thus shade selection depends on subjective assessment. This accounts for the large standard deviations noted with human-eye color matching. Color vision is dependent on the cones in the retina, which are active under higher lighting conditions. Although the exact mechanism of color vision is not known, it has been demonstrated (Land, 1977) that there are three types of cones—sensitive to red, green, and blue light. This forms an image in a manner similar to the additive effect of pixels in hardware devices and color television pictures. The color space chosen for computerized shade matching should therefore have equal physical distance between two colors in the space corresponding to the equal perceptual differences sensed by the human eye. These requirements were satisfied by specifying colors in the CIE color system, which was determined by the Commission Internationale De l'Éclairage (International Commission on Illumination) in 1978. The system has the advantage of color graduations that are less arbitrary when compared to the Munsell system (Rosenstiel & others, 1995). In this perceptually uniform color space, the method of color evaluation is related to human color perceptually by the three

Table 3. Statistical Comparison of Difference in Color Parameters among Shades

Parameter	Difference
ΔL	A1 > all other shades; A4 > B3, C4; B2 > B3; B3 < C2, C4, D3 and C2 < C4
Δa	A1 < all other shades; A4 > B2, C2, C4; B2 < B3, C2, C4, D3; B3 > C2 and C2 < C4, D3
Δb	A1 < all other shades; A4 > B2, B3, C2, C4; B2 < B3, C2, C4, D3; B3 <C2, C4; B3 > D3; C2 < C4 and C4 > D3
ΔE	A1 < A4, C4; A1 > B3, C2, D3; A4 > B2, B3, C2, C4; B2 > B3, C4; B3 < C2, C4, D3; C2 < C4; C2 > D3 and C4 > D3

attributes L*, a*, and b*. In addition to its uniformity, the CIELAB system was also selected because it was widely used in dental research (O'Brien, Boenke & Groh, 1991; Swift, Hammel & Lund, 1994; Balderamos, O'Keefe & Powers, 1997; Johnston & Reisbick, 1997).

The small-area colorimeter makes use of photodetectors to measure the reflectance of the light source from the test sample. The reflectance data obtained were subsequently transformed via a microprocessor into color dimensions. Although errors may occur in absolute color measurements due to curved surfaces and gradation of shades of the Vita tabs, accurate quantitative color measurements can still be made with these devices (Seghi, Johnston & O'Brien, 1989; Seghi, 1990). Emphasis was placed on measuring only the body shades to reduce errors.

The results of this experiment showed that the difference in color matching between human-eye assessment and computerized colorimetry was shade dependent. Three out of seven shades showed significant differences in color parameters between human-eye and computerized color matching. The shades were either very light (A1, B2) or very dark (C4) as reflected by their L* values from both human-eye and computerized color matching. No significant difference was noted for the test tabs of medium shades. The findings suggest that computerized color matching may be more sensitive only in detecting chromatic changes in light shades and both lightness and chromatic changes in dark shades. It is important to note that although the mean values were reflected in Tables 1 and 2, it was the median values that were used for statistical analysis, as nonparametric analysis was used. Mean values were reflected for simplification of presentation. Statistical comparison of ΔL, Δa, Δb, and ΔE among shades showed significant differences. This lends additional support to the hypothesis that the difference in color matching between human-eye assessment and computerized colorimetry is shade dependent.

Rutyer, Nilner, and Moller (1987) showed that under clinical conditions, the human eye could sense ΔE values of 3.3 or greater. In controlled settings, other investigators found that the human eye could perceive color changes of between 1 and 2 (Seghi, Johnston & O'Brien, 1986; Seghi, Hewlett & Kim, 1989). Based on a ΔE value of 3 as the lower limit of perceptibility for color change, the difference between human-eye and computerized color matching is theoretically perceivable under clinical settings for all test tabs, as the mean ΔE values ranged from 3.08 for shade B3 to 5.78 for shade C4. Since the human eye perceives color differently than the colorimeter, shade selection by computerized colorimeter will differ from that of human-eye assessment. Correction factors are therefore necessary for compensation purposes. Assuming that a correction factor is needed, the speculated difference in the test tab/tooth color *i* and Vita tab/restorative color *j* should be changed from the above mentioned formula to:

$$\mathrm{Diff}(i,j) = \sqrt{(L_i - L_j + L_{CF})^2 + (a_i - a_j + a_{CF})^2 + b_i - b_j + b_{CF})^2}$$

where L_{CF}, a_{CF}, b_{CF} are the correction factors for the L*, a*, and b* attributes of the CIELAB color space respectively. The formal specification for programming purposes is, however, more complex, as the correction factor will differ for different shades. Compensation factors may also differ for practitioners of different age and gender (Moser & others, 1985). Improvements must also be made to the programming algorithm, as usage of ρE/ΔE may not be specific and accurate enough. Using computerized color matching, two of the test tabs (B3 and C2) had identical Vita shade selections. Selection based on the smallest difference in L*, a*, and b* values in addition to ΔE may yield greater accuracy between the test and Vita shade tab. The software is currently being modified for this purpose. More data and research are required before a computerized color-matching system with correction factors can be developed for clinical use.

CONCLUSIONS

This study compared the difference between human-eye and computerized colorimetry color matching. Within the limitations of this, several conclusions can be drawn from the results.

1) Difference in color matching between human-eye assessment and computerized colorimetry is shade dependent.

2) Discrepancy is significant for b* coordinates for light shades and L* and b* coordinates for dark shades.

3) For all shades evaluated, color difference between human-eye and computerized color matching is perceivable under clinical settings as ΔE values were greater than 3.

4) There is a need for correction factors in the formal specification of the color-matching software due to the discrepancy between human-eye and computerized colorimetric color matching.

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Cuspal Reinforcement in Endodontically Treated Molars

M Y UYEHARA • R D DAVIS • J D OVERTON

Clinical Relevance
When restoring endodontically treated mandibular molars with intact facial cusps, horizontal pins in combination with an amalgam adhesive may be used to reinforce the facial cusps, permitting the use of an esthetically conservative MODL amalgam restoration without incurring significant risk of cuspal fracture.

SUMMARY

This in vitro study compared the ability of horizontal pins and a dental adhesive to reinforce the facial cusps of endodontically treated mandibular molars. Seventy-two mandibular molars were divided into six groups and mounted in acrylic blocks (n=12). In Groups 1-5 standardized endodontic access and instrumentation in the coronal one-third of each root canal were completed. In Groups 1-4 the lingual cusps were reduced, leaving the buccal cusps intact. The facial cusps of the teeth in each group received one of the following modes of reinforcement: Group 1—no reinforcement; Group 2—dentin adhesive (Amalgambond Plus); Group 3—two horizontal TMS Minim pins; Group 4—two horizontal TMS Minim pins and Amalgambond Plus. Teeth in Group 5 were prepared for and restored with a complete cuspal coverage amalgam restoration using four vertical TMS Minim pins. Group 6 consisted of intact natural teeth.

Using an Instron Universal Testing Machine, the lingual slope of the facial cusp of each specimen was loaded to failure using a compressive force applied at an angle 60 degrees to the long axis of the tooth. The mean fracture strengths for all groups were analyzed using a one-way ANOVA and Student-Newman-Keuls multiple range test (α = 0.05). Fracture patterns and modes of failure were also evaluated. Results: The intact teeth (Group 6) were significantly more fracture resistant than all other groups, with the exception of Group 4 (combination of pins and adhesive). Group 1 (nonreinforced teeth) was significantly weaker than all other groups. Groups 2-4 (specimens with reinforced cusps) were not significantly different from each other. The use of horizontal

81st Dental Squadron, 606 Fisher Street, Keesler AFB, MS 39534

Mark Y Uyehara, DDS, major, USAF, comprehensive dentist

Richard D Davis, DDS, colonel, USAF, director of research and dental materials

Johnie D Overton, DDS, colonel, USAF, training officer of the AEGD II program

pins or a combination of horizontal pins plus dentin adhesive for cuspal reinforcement resulted in significantly more teeth demonstrating favorable fracture patterns than did the use of adhesives alone. Conclusion: The buccal cusps of endodontically treated mandibular molars reinforced with a combination of horizontal pins and dentin adhesive were not significantly weaker than intact teeth. Of the restored teeth, those which had buccal cusps reinforced with horizontal pins and those treated with complete cuspal coverage amalgam restorations exhibited the most favorable restorative prognosis following cusp fracture.

INTRODUCTION

In vivo studies have shown that the presence of a coronal-coverage restoration significantly improves the clinical survival of endodontically treated posterior teeth (Sorensen & Martinoff, 1984; Gelfand, Goldman & Sunderman, 1984). While generally appropriate, complete cuspal coverage is not without disadvantages. All-metal restorations may not satisfy the esthetically conscious patient, and restorations with ceramic occlusal coverage may cause significant wear of the opposing dentition (Jacobi, Shillingburg & Duncanson, 1991; Seghi, Rosenstiel & Bauer, 1991). Occlusal coverage with a secondarily cured, laboratory-fabricated composite resin may provide a viable alternative restoration; however, the clinical longevity of this form of restoration has not yet been adequately documented.

When restoring endodontically treated maxillary posterior teeth, this problem can be resolved with the use of a metal-ceramic crown. With a metal-ceramic crown, the facial cusps may be restored with a ceramic material, while the central portion of the tooth and the palatal functional cusps may be restored with a cast metal alloy. This provides both an esthetic appearance and a fracture-resistant restoration with little potential for abrasion of the opposing dentition. The restoration of the endodontically treated mandibular molar does not provide as ideal a restorative circumstance. Because the functional cusps of mandibular teeth are the buccal cusps, the restorative dentist faces a difficult decision: Should the buccal cusps be restored using a strong, minimally abrasive, but "esthetically challenged" metal, or should the buccal cusps be restored using a ceramic material with significant abrasive potential? When the buccal cusps have been destroyed or significantly weakened, there is little choice but to select one of these options; however, in situations where the buccal cusps remain largely intact, it may be possible to retain the buccal cusps while restoring the remainder of the tooth.

Critical to the success of a restoration intended to preserve the buccal cusps of an endodontically treated mandibular molar is the ability to reinforce these cusps. In an in vitro investigation Burgess (1985) found that horizontally placed threaded pins reinforced lone-standing cusps in bicuspids. Resin adhesives have also been found to reduce cuspal flexure and increase cusp stiffness (Ario & others, 1995; Ross & others, 1995; El-Badrawy, 1996; Teigen & Boyer, 1994; Borchert & Boyer, 1996) as well as increase cusp fracture resistance (Roth & Boyer, 1994). No research is available regarding the ability of pins and adhesives to reinforce the buccal cusps of endodontically treated mandibular molars.

The purpose of this in vitro experiment was to compare the fracture resistance of the intact facial cusps of endodontically treated mandibular molars when pins, a resin bonding agent, or a combination of pins and a bonding agent were used to reinforce the cusps.

METHODS AND MATERIALS

Seventy-two mandibular molars were collected and stored in 10% formalin. They were sorted by size and randomly divided into six groups (n=12). Using autopolymerizing acrylic resin, each specimen was mounted in 1 inch-square aluminum blocks to a depth approximately 1.5 mm apical to the cementoenamel junction (CEJ). The long axis of each tooth was perpendicular to the surface of the acrylic base. The samples were stored in tap water at room temperature except during preparation and testing.

In Groups 1-5 a standardized endodontic access was completed and endodontic instrumentation accomplished in the coronal one-third of each root

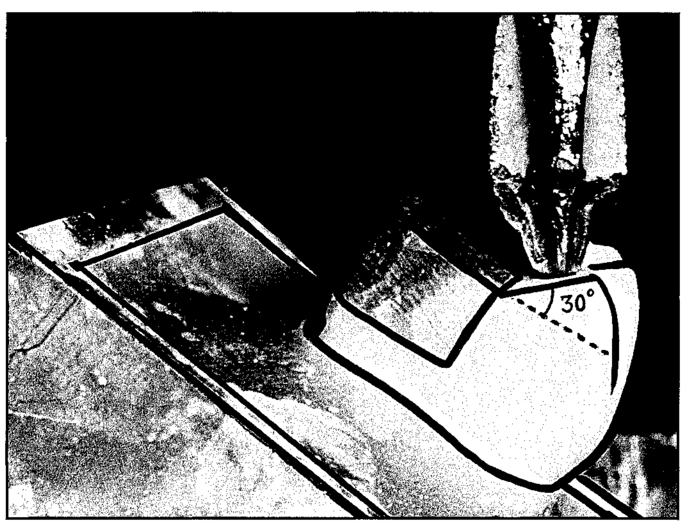

Figure 1. *Standardized specimen designs and compression testing on Instron machine*

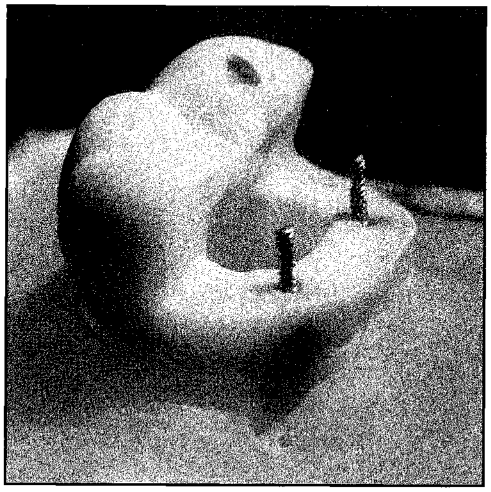

Figure 2. *Preparation design for specimens in Groups 1 and 2*

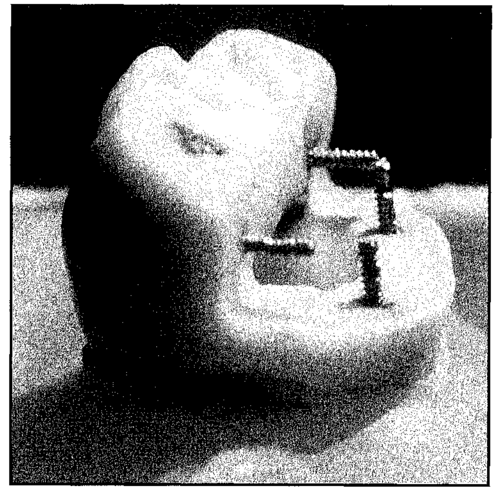

Figure 3. *Preparation design for specimens in Groups 3 and 4*

canal. The endodontic access preparations were completed using high- and slow-speed round burs (Caulk/Dentsply, Milford, DE 19963) and tapered diamond burs (Brassler USA, Savannah, GA 31419) under constant water spray. The pulp chamber was debrided of all tissue, pulp horn undercuts were eliminated, and unsupported enamel was removed. The coronal 3 mm of each canal was mechanically prepared using a Gates Glidden #3 bur (Caulk/Dentsply) to a depth 3 mm apical to the pulp chamber floor. No obturation material was placed in the canals. The lingual cusps were reduced using diamond disks (Brasseler) and water spray, leaving the remaining facial cusps 4 mm in buccolingual thickness as measured at the height of contour. This created a flat surface surrounding the pulp chamber, lingual to the facial cusps. The cavosurface margin of the pulpal floor was approximately 1.5 mm coronal to the CEJ. The lingual slopes of the mesiofacial cusps were beveled at 60 degrees from the long axis of the tooth in order to provide a flat area for compression testing (Figure 1).

In Groups 1-4 the lingual portion of the pulpal floor received two vertically placed TMS Minim pins (Whaledent Inc, Mahwah, NJ 07430) with one pin located at the mesiolingual line angle and one at the distolingual line angle. Pins were placed 0.5 mm from the dentinoenamel junction (DEJ) and extended 2 mm into dentin. The pin drill was replaced after every 10 holes. The pins were reduced in height using a high-

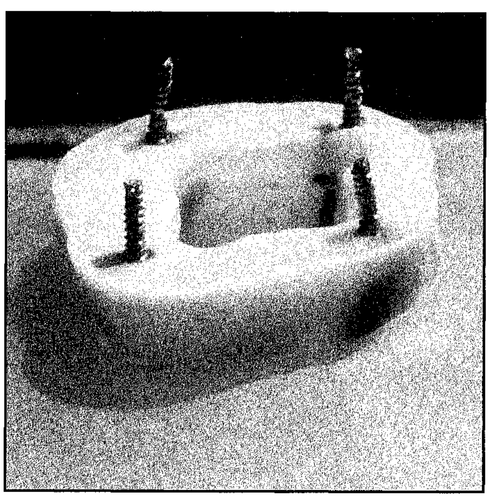

Figure 4. *Preparation design for control Group 5 (four vertical pins, complete-coverage amalgam restoration)*

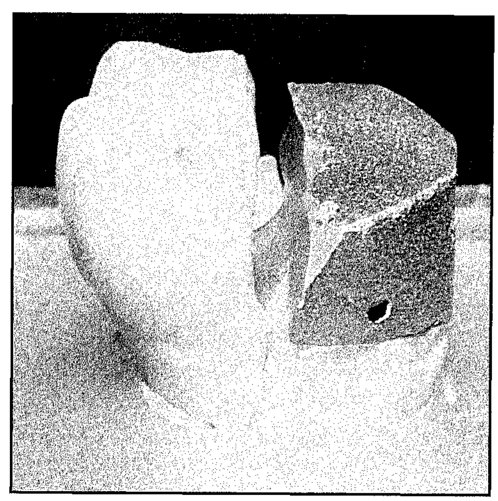

Figure 5. *Example of an unfavorable cusp fracture*

Table 1. Facial Cusp Fracture Resistance

Group 1	Design	Load to Fracture (Newtons)		SD
1	two vertical pins (no cusp reinforcement)	600.58		134.45
2	two vertical pins + Amalgambond Plus	882.75		138.68
3	two vertical pins + two horizontal pins	873.17		161.11
4	two vertical pins + two horizontal pins + Amalgambond Plus	988.17	*	154.97
5	Control 1 (four vertical pins + complete coverage amalgam restoration)	851.08		143.99
6	Control 2 (intact tooth)	1080.25	*	184.01

Statistical analysis: one-way ANOVA and Student-Newman-Keuls post hoc test (α = 0.05). Groups that are not significantly different are joined by a vertical line or are annotated with *.

speed diamond bur while stabilizing the base of the pin with a pin wrench, leaving a 2 mm length of pin extending above the tooth.

The facial cusps of the teeth in Groups 1-4 received one of the following modes of reinforcement: Group 1—no reinforcement; Group 2—dentin adhesive (Amalgambond Plus; Parkell, Biomaterials Division, Farmingdale, NY 11735); Group 3—two horizontal TMS Minim pins; Group 4—two horizontal TMS Minim pins and the Amalgambond Plus dentin adhesive. Figures 2 and 3 depict the resistance features of Groups 1-4.

The horizontal pins used in Groups 3 and 4 were placed 2 mm deep into dentin, 0.5 mm inside the approximal DEJ, and 1 mm below the occlusal cavosurface margin. One pin each was placed in the mesiofacial and distofacial cusps. The pins were stabilized and reduced, leaving 2 mm extending from the tooth in the same manner that the vertical pins were prepared.

The dentin adhesive used in Groups 2 and 4, including the methylmethacrylate HPA (High Performance Additive) powder, was applied according to the manufacturer's instructions. The additive was applied after placement of a copper tube matrix, which was stabilized using a second matrix band (Tofflemire; Teledyne Getz, Elk Grove Village, IL 60007).

Amalgam (Tytin; Kerr USA, Romulus, MI 48174) was triturated according to the manufacturer's instructions and inserted. In the groups receiving the dentin adhesive, Groups 2 and 4, the amalgam was inserted immediately after application of the dentin adhesive. In Groups 1-5, the amalgam was condensed using a mechanical condenser (Condensaire; Teledyne Water Pik, Fort Collins, CO 80553) using a 0.8 mm-in-diameter condenser tip, compacting the amalgam into the prepared portion of each root canal and around each pin. The remainder of the amalgam was condensed using a 1.5 mm-in-diameter condenser. Each preparation was filled 2 mm above the height of the occlusal margin and then carved to approximately 1 mm above the occlusal cavosurface margin. After remaining undisturbed in air for 30 minutes, the matrix band was removed and each specimen was stored in room-temperature tap water for 24 hours. Following storage, the occlusal portion of each restoration was reduced approximately 1 mm using diamond disks to the level of the occlusal cavosurface margin (Figure 1).

Group 5 teeth were restored with complete coronal amalgam restorations using four vertically placed TMS Minim pins. Following the standard endodontic access preparation and reduction of the lingual cusps, as in Groups 1-4, the facial cusps of teeth in Group 5 were reduced, leaving the entire occlusal surface flattened at a level 1.5 mm above the CEJ and perpendicular to the long axis of the tooth. One TMS Minim pin was placed vertically at each line angle for a total of four pins, each 0.5 mm inside the DEJ, with 2.0 mm of pin extending into dentin and 2.0 mm extending above the tooth (Figure 4). Amalgam was placed as in Groups 1-4, and specimens were stored in tap water for 24 hours. The restorations were then

Table 2. Cusp Fracture Patterns

Group	Favorable	Unfavorable
1	0	12
2	1	11
3	9	3
4	9	3
5	10	2
6	9	3

Favorable fractures: fractures ending above the CEJ or less than 1 mm below the CEJ.
Unfavorable fractures: fractures ending greater than 1 mm below the CEJ.
Statistical analysis: chi-square analysis (α = 0.5).
Groups that are not significantly different are joined by a vertical line.

prepared using diamond disks to create dimensions similar to those of the restored teeth in Groups 1-4.

Group 6 consisted of intact natural teeth. These teeth did not receive endodontic or restorative treatment. The lingual slope of the mesiofacial cusp was beveled at 60 degrees from the long axis as in all other groups to give a flat surface for compression testing.

Following amalgam placement and carving, all specimens were stored for 1 week in room-temperature tap water and then thermocycled 500 times between 5 and 55 °C using a dwell time of 30 seconds. Specimens were then stored in room-temperature tap water for an additional week until testing was completed.

The fracture resistance of each specimen was determined as follows. The mounting blocks were placed in a standardized holding device. Using an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021), the mesiofacial cusp of each tooth was loaded in compression (strain rate of 2.0 mm/min). The load was applied perpendicular to the beveled cusp surface using a pointed rod with a 1 mm area of tooth contact. The contact point on each tooth was on the lingual slope of the mesiofacial cusp (1.0 mm from the cavosurface margin), such that a compressive force was directed 60 degrees to the long axis of the tooth (Figure 1). The mean fracture strengths for all groups were recorded and analyzed using a one-way ANOVA followed by a post hoc analysis using a Student-Newman-Keuls multiple range test ($\alpha = 0.05$).

The fracture pattern for each specimen was classified according to the location of the fracture of the facial cusps. Favorable fractures were defined as those that occurred above the CEJ or less than 1 mm below the CEJ. Unfavorable fractures were those which occurred greater than 1 mm below the CEJ (Figure 5). Chi-square analysis was used to compare the fracture patterns among the groups ($\alpha = 0.05$).

RESULTS

The fracture strengths for all groups are depicted in Table 1. The fracture patterns are described in Table 2. The fracture resistance of the nonreinforced cusps of Group 1 teeth was significantly less than that of all other specimens. The intact teeth (Group 6) were significantly more fracture resistant than teeth in Groups 1-3 and Group 5. There was no significant difference among Groups 2-5; however, the fracture resistance of Group 4 specimens (pins combined with adhesive) was not significantly different from that of the intact controls (Group 6). Endodontically treated teeth whose buccal cusps were reinforced with horizontally placed pins (Groups 3 and 4) exhibited a significantly greater number of favorable fractures than did those with no cuspal pin reinforcement (Groups 1 and 2).

DISCUSSION

The present study addresses a very discrete question concerning the esthetic restoration of endodontically treated mandibular molars. For some patients mandibular first molars are visible during smiling, speaking, and chewing, and therefore are of esthetic concern. Given that the research of Sorensen and Martinoff (1984) clearly indicated a need for cusp protection in endodontically treated posterior teeth, the authors intended to explore possible mechanisms of cusp reinforcement to determine the feasibility of retaining the buccal cusps of endodontically treated mandibular molars.

A combination of pins plus adhesives was investigated because, individually, each of these resistance features has been shown to reinforce free-standing cusps. Burgess (1985) found that the facial cusps of maxillary premolars reinforced with two horizontal TMS Minim pins required twice as much force to fracture as unreinforced cusps. Roth and Boyer (1994) found that molar cusps reinforced with dentin adhesives and restored with amalgam were significantly more fracture resistant than unreinforced cusps. Dosset and others (1994) studied cuspal reinforcement in maxillary premolars and found that two horizontal Minim pins provided significantly greater reinforcement than the dentin adhesive Amalgambond Plus used without the HPA powder.

Mandibular molars were the subject of this investigation because, unlike many other posterior teeth receiving endodontic treatment, mandibular molars often retain sufficient bulk of dentin in the buccal cusps to retain threaded pins. In the present study, the buccal cusps of all the samples were at least 4 mm in buccolingual thickness. In fact, the buccal cusps of most samples required reduction of over 1 mm to achieve the standard 4 mm buccolingual dimension. With this much intact tooth remaining after endodontic treatment, the authors considered the possibility that the mandibular molar may present one of the few situations in which the optimum treatment for an endodontically treated posterior tooth would consist of cusp reinforcement rather than cusp replacement. This consideration is supported by the esthetic advantage provided by buccal cusp retention.

Although one cannot draw direct clinical conclusions based solely on in vitro data, the results of this investigation indicated that buccal cusps of at least 4 mm in thickness may be retained with little risk of fracture when threaded pins and dentin adhesives are used in combination to provide cuspal reinforcement.

Additionally, the use of horizontal pins tended to create stress patterns, which, when cusp fracture did occur, resulted in fractures ending at or near the CEJ. These were considered to be restoratively "favorable" fracture patterns. Similar results were reported by McClenny, Davis, and Murchison (1997), who found that the use of horizontal pins tended to decrease the number of oblique unfavorable fractures of lone-standing facial cusps of maxillary premolars. The advantage of techniques that create favorable stress patterns is that fractures extending to the CEJ are relatively simple to restore. Fractures extending significant distances below the CEJ often require crown lengthening procedures prior to restoration or may even require extraction.

A result that was somewhat surprising was the finding that specimens in both Group 2 (adhesive only) and Group 3 (horizontal pins) were as fracture resistant as the complete cuspal coverage amalgam restorations. This finding bodes well for the clinical survivability of reinforced cusps, even those in endodontically treated teeth. The fact that the use of pins and adhesive provided an additive effect is not surprising, given the results found by other investigators (Imbery, Burgess & Batzer, 1995; Burgess, Álvarez & Summitt, 1997).

The manner in which specimens are treated can affect the results of in vitro studies. Thermocycling has been shown to significantly reduce the fracture resistance of premolars restored with amalgam and a dentin adhesive (Santos & Meiers, 1994) and was utilized to simulate clinical aging in this study. Although not used in the present study, cyclic loading has also been shown to reduce the strength of amalgam bonded to dentin and may be useful when attempting to relate laboratory results to clinical situations (McComb, Brown & Forman, 1995; Bonilla & White, 1996). Thus, while it is unclear whether the bond strength of dentin adhesives may deteriorate with time and clinical stresses, the addition of horizontal pins may provide significant cuspal reinforcement and enhance the prognosis of repair should fracture occur.

Variations in laboratory bond strength measurements are often attributed to the different adhesives being tested, when in fact many differences may be due to improper standardization of the experimental procedures (Van Noort & others, 1989; Retief, 1991). In the present study, the dimensions of the tooth preparations and location of the applied compressive load were standardized and designed to simulate clinical situations involving endodontically treated mandibular molars with intact facial cusps. The angle of the applied force was standardized at 60 degrees from the long axis of the specimen and located on the flattened mesiofacial cusp 1.0 mm from the occlusal cavosurface margin. The consistent and relatively low standard deviations found among all groups reflected the control of experimental variables. While cyclic loading may more accurately reflect intraoral forces, the compressive forces used in this study resulted in cuspal fracture patterns that are commonly encountered and seem clinically relevant. Studies using a ball to simultaneously compress the facial and lingual cusps of premolars or molars may introduce a significant variable. When a ball is used to apply compressive stresses, teeth with steeper cuspal inclines will have contact points significantly higher on the tooth, creating a longer lever arm and potentially greater cusp-fracturing forces. The method used in the present study was designed to avoid this potentially confounding variable.

Since buccal cusps of mandibular molars are functional centric-holding cusps, they often receive tremendous occlusal forces. It is the authors' opinion that clinical judgment should be exercised to select endodontically treated teeth suitable for cusp retention. Teeth should be selected that show little evidence of excessive occlusal stress and yet are of esthetic concern. Teeth demonstrating evidence of significant occlusal stress may be best treated by preparation for a complete coverage restoration. In addition, it should be emphasized that the placement of horizontal pins into the remaining facial cusps of mandibular molars is a technique-sensitive procedure, requiring sufficient access. Nonetheless, the present study indicated that when patients present with endodontically treated mandibular molars with intact facial cusps requiring an esthetic restoration, the mesio-occlusodistolingual (MODL) amalgam restoration with facial cusps reinforced using pins and a dentin adhesive may provide a viable and conservative restoration. These findings may not be generalized to lingual cusps or to posterior teeth other than mandibular first molars.

CONCLUSIONS

The following conclusions apply to the fracture resistance of the buccal cusps of endodontically treated mandibular molars with at least 4 mm of remaining cusp thickness.

1) Cusps reinforced with either a dentin adhesive or horizontal pins were as fracture resistant as complete coverage amalgam restorations.

2) Cusps reinforced with a combination of a dentin adhesive plus pins were as strong as intact teeth.

3) The use of horizontal pins or a combination of pins and a dentin adhesive for cuspal reinforcement resulted in significantly fewer unfavorable cuspal fractures than the use of the dentin adhesive alone.

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Disclaimer

The opinions and assertions contained herein are the private views of the authors and are not to be construed as the official policy or position of the US Government, the Department of Defense, or the Department of Air Force.

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Effects of Aging on Repair Bond Strengths of a Polyacid-modified Composite Resin

A U J YAP • C W SAU • K W LYE

Clinical Relevance
After 3 and 6 months of aging, surface conditioning with sandblasting and resin application resulted in the highest repair bond strength for the repair of polyacid-modified composite resins.

SUMMARY

The effect of age of a polyacid-modified composite resin on repair bond strength after different methods of surface conditioning was studied. Surface conditioning methods included the following: maleic acid with resin application; polyacrylic acid with resin application; sandblasting with resin application. Shear bond testing between the aged and new material was carried out with an Instron Universal Testing Machine. Although repair bonds strengths after all surface conditioning methods were significantly higher than the control group at 1 week, no statistically significant differences in bond strengths were noted after aging the material for 6 months. After all aging periods, surface conditioning with sandblasting and resin application resulted in the highest repair bond for polyacid-modified composite resins. Specimens with cohesive failure in the material gave significantly higher repair bond strengths than specimens with adhesive failure at the repaired interface.

National University of Singapore, Faculty of Dentistry, Department of Restorative Dentistry, 5 Lower Kent Ridge Road, Singapore 119074, Republic of Singapore

Adrian U J Yap, BDS, MSc, FRSH, senior lecturer and assistant director, Center for Biomedical Materials Applications and Technology

C W Sau, student

K W Lye, student

INTRODUCTION

Wilson and Kent (1972) first introduced glass-ionomer cements to the dental profession in 1972. Their favorable fluoride-releasing and adhesive properties have led to their wide-spread use as luting, lining, and restorative materials (Sidhu & Watson, 1995). Disadvantages of these cements, however, include early moisture sensitivity, low physical properties, and inferior translucency to composite resin restoratives. Improvements in the performance qualities of glass-ionomer cements are, therefore, a research priority. A key objective of research has been to match the handling and aesthetic properties afforded by composite resin restoratives. Through the innovation of new resin systems, a new class of dental materials was established: the polyacid-modified composite resins. They combine the major advantages of glass-ionomer cements, e g, chemical bonding to tooth structure, fluoride release, and good biocompatibility with the easy handling and aesthetic property of a light-polymerized composite (Dentsply, 1994). Even though these new materials can contain up to 72% of the reactive fluorosilicate glass of conventional glass-ionomer cements, their initial setting is due to light-activated radical polymerization. Upon hydration, the filler and matrix undergo an acid-base reaction over time. This acid-base reaction has been claimed to promote further crosslinking, thus hardening of the entire matrix (Dentsply, 1994). One of the applications of polyacid-modified composite resins is the restoration of noncarious cervical tooth loss (Yap & Neo, 1995). The loss of contours of cervical restorations has, however, been reported following continued erosion or abrasion (Ngo, Earl & Mount, 1986) and repair may be necessary (Mjör, 1993). While the short-term repair of polyacid-modified composite resin has been studied (Yap, Quek & Kau, 1998), little research has been conducted on the repair of this new hybrid material following long-term storage.

This study examined differences in repair bond strengths using different methods of surface conditioning after aging a polyacid-modified composite resin for 1 week and 3 and 6 months. The mode of bond failure of the repaired materials was also investigated.

METHODS AND MATERIALS

Polyacid-modified composite resin (Dyract; Dentsply, Weybridge, UK) was first syringed into the central cylindrical recess (10 mm in diameter and 1.5 mm deep) of customized cylindrical acrylic molds. A glass slide was placed on the mold and excess material extruded out. The composite resin was then light polymerized for 40 seconds through the glass plate. A total of 48 specimens were prepared. Half of the specimens were stored for 3 months, and the remaining half were stored for 6 months in distilled water at 37 °C. After the above aging periods, the specimens were adjusted with a model trimmer (MT1; Renfert-GmbH, Hilzingen, Germany) to ensure a flat bonding surface. This surface was subsequently treated with 320-grit sandpaper and washed for 15 seconds with a water spray from a triple function syringe. At no point were the composites allowed to desiccate. The specimens were then divided into four groups of six and treated as follows.

Group 1 (control): surface was left untreated, gently air dried for 5 seconds; Group 2: etched for 20 seconds with 10% maleic acid (Scotchbond Multi-Purpose Dental Adhesive; 3M Dental Products, St Paul, MN 55144), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied, and light polymerized for 20 seconds; Group 3: conditioned for 20 seconds with 10% polyacrylic acid (GC Conditioner; GC Corporation, Tokyo, Japan), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied, and light polymerized for 20 seconds; Group 4: sandblasted for 2 seconds with 50 µm aluminous oxide (Keramo 3; Renfert-GmbH), washed for 30 seconds, gently air dried for 5 seconds, low-viscosity resin (Scotchbond Multi-Purpose) applied, and light polymerized for 20 seconds.

Shear Bond Strength

Hollow plastic cylinders of 3.4 mm in internal diameter and 1.5 mm in height were centered on the pretreated surfaces of the specimens. The cylinders were filled with uncured polyacid-modified composite resin, light polymerized for 40 seconds, and removed. The restorative was condensed into the cylinders with a Teflon-coated instrument, and a thickness of material no greater than 1.5 mm was maintained to ensure total light polymerization. A circular bond area of 9.0 mm², simulating repair, was

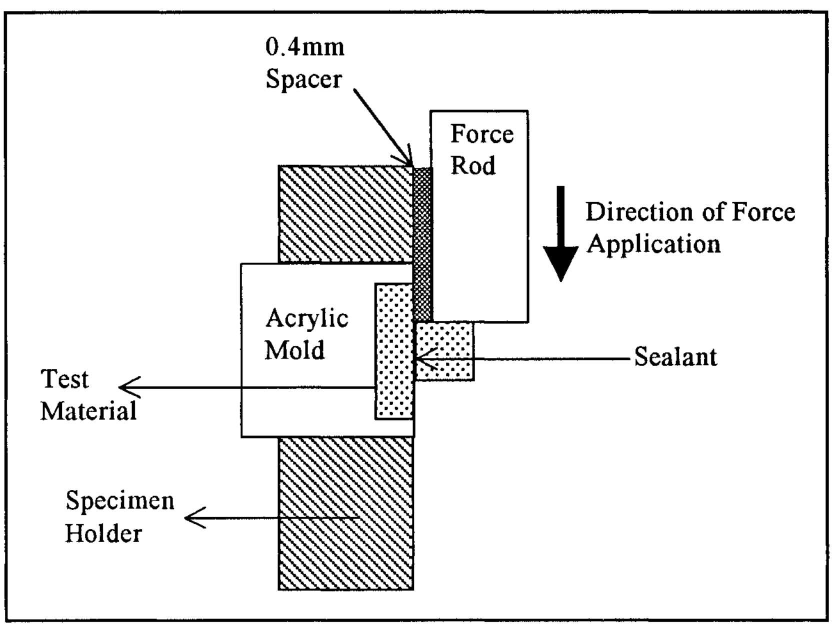

Figure 1. *Schematic drawing of the shear bond test setup*

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

Storage Time	Group 1	Group 2	Group 3	Group 4
1 week	6.03 (3.67)	17.21 (5.64)	19.38 (6.64)	22.21 (3.21)
3 months	8.78 (3.43)	19.70 (5.64)	10.87 (4.90)	20.67 (3.67)
6 months	12.52 (3.37)	13.43 (5.73)	17.62 (7.49)	21.04 (6.33)

thus achieved. Shear bond testing was carried out 30 minutes after repair.

The bonded specimens were placed into a test jig (Figure 1), which ensured that the shear load could be applied parallel to the bonded interface. A 0.4 mm spacer was placed so that a constant distance was maintained between the pretreated restorative surface and the point of force application through the force rod. The specimens were tested at a crosshead speed of 0.5 mm/min with an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021). The maximum strength (MPa) was calculated based on the internal cross-sectional area of the hollow cylinders.

Mode of Bond Failure

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

Statistical Analysis

The mean and standard deviation were calculated for the different treatment groups and aging periods. One-way analysis of variance and Scheffé's multiple-range tests were performed to determine significance differences in bond strength data between treatment groups. The data obtained from this study were compared with data after 1 week of aging from the study by Yap and others (1998). For failure modes, the data were subjected to Kruskal-Wallis one-way analysis of variance, and intergroup comparisons were performed using the Mann-Whitney U and Wilcoxson Rank Sum W tests. All statistical tests were conducted at a significance level of 0.05. The relationship between failure mode and bond strength was investigated using the Mann-Whitney test at a significance level of 0.05.

RESULTS

The mean shear bond strengths and standard deviations after the different aging periods are reflected in Table 1 and Figure 2. Ranking from highest to lowest bond strength after 1 week and 6 months of storage was similar: Group 4 > Group 3 > Group 2 > Group 1. Ranking from highest to lowest bond strength after aging for 3 months was as follows: Group 4 > Group 2 > Group 3 > Group 1. The control group gave the lowest repair bond strength at all time periods. Results of intergroup comparisons using Scheffé's tests are shown in Table 2. At 1 week, Groups 2, 3, and 4 had significantly higher repair bond strength than the control (Group 1). At 3 months, Groups 2 and 4 had significantly higher repair bond strengths than Groups 1 and 3. At 6 months, no significant difference in repair bond strengths was noted between the four treatment groups. For Groups 2, 3, and 4, no significant difference was noted between bond strengths at 1 week, 3 months, and 6 months. For the control group (Group 1), repair bond strengths at 6 months were significantly higher than that at 1 week and 3 months.

The failure modes after repair by percentage are shown in Table 3, and intergroup comparisons (Table 4) revealed significant difference in failure

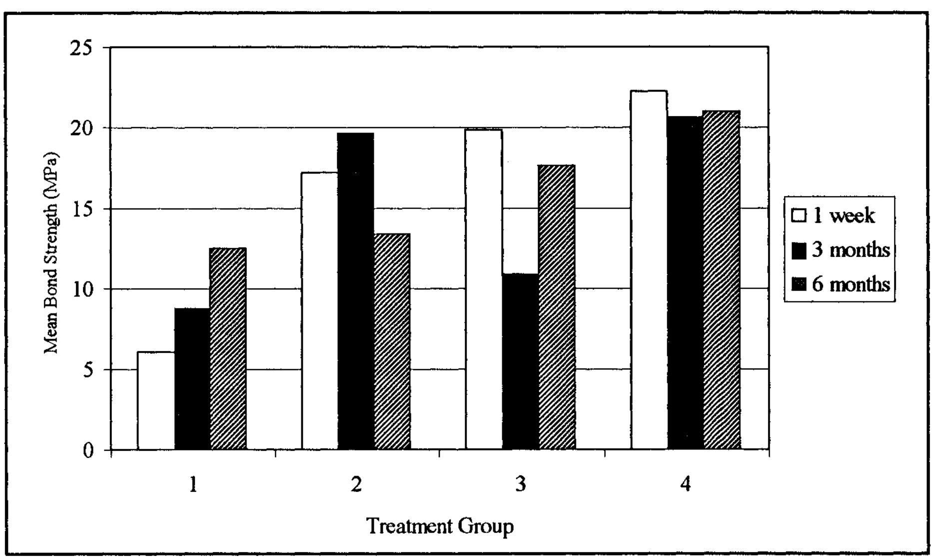

Figure 2. *Mean Shear Bond Strengths*

Table 2. Intergroup Comparison of Repair Bond Strengths (Results of ANOVA and Scheffé Tests; P < 0.05); > = Statistical Significance.

Storage Time	Difference
1 week	2, 3, 4 > 1
3 months	2, 4 > 1, 3
6 months	No

modes among treatment groups at all time periods. After aging for 1 week and 6 months, the control group (Group 1) had significantly more adhesive failure (Type I) than Groups 2, 3, and 4. At 3 months, Group 1 had significantly more adhesive failures than Groups 2 and 4. Specimens with Type II failure had significantly higher repair bond strengths when compared to specimens with Type I failure.

DISCUSSION

Replacement of restorations invariably leads to cavity enlargement (Elderton, 1977), as the demarcation between tooth-colored restoratives and tooth structure is often hard to identify. Intact areas, not associated with the defect, are often involved, especially with highly aesthetic materials like composite resins. Repair may therefore be a more conservative alternative. As the repair of restorations can occur several months after initial placement, the influence of aging on repair bond strengths warrants investigation. This study was an extension of the research by Yap and others (1998) on the methods of surface conditioning for the repair of tooth-colored restoratives. They found that for polyacid-modified composite resins, treatment with maleic acid, polyacrylic acid, and sandblasting together with resin application gave significantly higher repair bond strengths when compared to the control. The application of low-viscosity resin was of paramount importance, as it enhanced bonding of the repaired specimens. These three surface-conditioning methods were thus selected for this study. The conditioning and shear bond test methods of the current study were similar to that of Yap and others (1998), with the exception of storage time. One of the major indications for polyacid-modified composite resins is the restoration of cervical lesions. As the stresses on the repaired material here are expected to be parallel to the tooth surface, the shear bond test was used. Despite keeping the bonding area controlled, a moderate standard deviation was noted. This was due to polymerization shrinkage of the resin components during the setting reaction, which is a phenomenon noted with all composite resins (Söderholm, 1991).

A significant difference in repair bond strengths was noted for the control group among aging periods. Repair bond strength after 6 months was significantly higher than that at 1 week. This may be attributed to the ionic acid-base reaction when polyacid-modified composite resins are hydrated (Sustercic & others, 1995). The polyacid-modified composite resin evaluated contains radiopaque fluorosilicate glass in a matrix of TCB resin (a reaction product between butane tetracarboxylic acid and HEMA). TCB resin is an acidic polymerizable monomer with innovative features. Besides the two methacrylate groups terminating the chemical structure, it also contains two carboxyl groups, which can undergo an acid-base reaction with the leachable aluminum and strontium ions of the glass phase and bond to the calcium of tooth structure (Dentsply, 1994). The formation of free carboxyl groups after water uptake

Table 3. Failure Modes after Repair by Percentage

Time	1 Week			3 Months			6 Months		
Failure Mode	Type I	Type II	Type III	Type I	Type II	Type III	Type I	Type II	Type III
Group 1	100%	0%	NA	100%	0%	NA	100%	0%	NA
Group 2	0%	100%	0%	0%	100%	0%	0%	100%	0%
Group 3	0%	100%	0%	50%	50%	0%	0%	100%	0%
Group 4	0%	100%	0%	0%	100%	0%	0%	100%	0%

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

Table 4. Intergroup Comparison of Failure Modes (Results of ANOVA and Mann-Whitney U and Wilcoxon Rank Sum W Tests; $P < 0.05$*); > = Statistical Significance.*

Storage Time	Difference
1 week	1 > 2, 3, 4
3 months	1 > 2, 4
6 months	1 > 2, 3, 4

of the previously anhydrous material may result in chemical bonding between the new and aged material and thus higher repair bond strengths in the control group. The availability of free carboxyl groups for chemical interaction may, however, be only effective after 3 months of hydration. The repair bond strengths at 3 months, though higher than that at 1 week, was not statistically significant.

For all storage periods evaluated, the control group had significantly more adhesive bond failure when compared to Groups 2 and 4. Group 3 only had significantly lower adhesive failure at 1 week and 6 months. At 3 months, there was no significance between failure modes between the control and Group 3. When the data were pooled for the three storage periods, specimens with cohesive failure in the material (Type II) gave significantly higher repair bond strengths when compared to specimens with adhesive failure (Type I) at the repaired interface. The adhesive bond between the resin applied and polyacid-modified composite resin after surface conditioning appeared to be stronger than the cohesive bond of the modified composite. This can be attributed to the strong chemical bonding between the resin and the composite, which are both methacrylate based.

At 1 week, all treatment groups had significantly higher repair strengths than the control. This can be attributed to micromechanical and chemical retention consequent to surface conditioning and resin application. The topographical changes at microscopic levels resulting from the different conditioning methods warrant some in-depth investigation. At 3 months, however, only treatment with maleic acid (Group 2) and sandblasting (Group 4) with resin application gave significantly higher repair bond strengths. No significant difference in repair bond strengths was noted between treatment with polyacrylic acid with resin application (Group 3) and the control. This was due to the increase in repair bond strength of the control and the decrease in strength of Group 3. Chemical interaction between the polyacrylic acid applied and the remaining unreacted exposed glass particles of the aged composite could have resulted in the formation of a polysalt gel layer, which may mitigate the beneficial effects of resin application. Completion of all acid-base reactions on the surface of the composite should theoretically result in an increase in repair bond strength with polyacid and resin application, as the formation of the polysalt gel layer would no longer be possible. This explains the increase in repair shear bond strength noted in Group 3 after 6 months of aging and is supported by the increased bond strength in the control group (Group 1) after 6 months.

After aging for 6 months, no significance in repair bond strengths was noted among all groups. The large increase in repair bond strength of the control group after 6 months of aging, which was twice that at 1 week, was largely responsible for the absence of statistical significance. After all aging periods, surface conditioning with sandblasting and resin application resulted in the highest repair bond strength. This appears, therefore, to be the technique of choice for intraoral repair of polyacid-modified composite resins using the materials.

CONCLUSIONS

The effects of aging on the repair bond strengths of a polyacid-modified composite resin after different methods of surface conditioning was studied. Although repair bond strengths after all surface conditioning methods were significantly higher than that of the control group at 1 week, no statistically significant differences in bond strengths were noted after aging the material for 6 months. After all aging periods, surface conditioning with sandblasting and resin application resulted in the highest repair bond strength and should be considered for intraoral repair of polyacid-modified composite resins. Specimens with cohesive failure in the material had significantly higher repair bond strength than specimens with adhesive failures at the repaired interface.

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CLINICAL ARTICLE

Amalgam Restorations: Postoperative Sensitivity as a Function of Liner Treatment and Cavity Depth

V V GORDAN • I A MJÖR • J E MOORHEAD

Clinical Relevance
Cavity depth does not seem to affect postoperative sensitivity of amalgam restorations.

SUMMARY

The purpose of this clinical study was to assess the sensitivity reported by patients following the insertion of class 1 or class 2 amalgam restorations in the treatment of primary carious lesions of different depths. Ninety subjects with previously untreated teeth requiring restorations due to caries lesions were selected: 32 teeth had lesions that were clinically and radiographically judged to be located in the outer one-third of dentin, 30 were located in the middle one-third of dentin, and 28 were located in the inner one-third of dentin. Four different lining regimens were employed: Group 1—no liner; Group 2—two coats of Copalite liner; Group 3—a dentin adhesive resin liner (Scotchbond Multi-Purpose); Group 4—a resin-modified glass ionomer (Fuji Bond LC). Patients were contacted on days 2 and 7 postoperatively and questioned regarding the presence or absence of sensitivity, the stimuli that created the sensitivity, if any, the duration of any sensitivity, and the intensity of any sensitivity using a rating from None to Severe. If sensitivity was experienced on day 7, patients were also contacted on days 14, 30, and 90 to assess the sensitivity at those intervals. The chi-square test of independence showed no significance at the 0.05 level between the different dentin treatments and cavity depths. By day 2, 19% of lesions located in the outer one-third, 27% of lesions located in the middle one-third, and 29% of lesions located in the inner one-third of dentin were sensitive. On day 30, four teeth were still sensitive, two located in the middle

University of Florida, College of Dentistry, Department of Operative Dentistry, Health Science Center, P O Box 100415, Gainesville, FL 32610-0415

Valeria V Gordan, DDS, MS, assistant professor

Ivar A Mjör, BDS, MSD, MS, Dr odont, professor, Academy 100 eminent scholar

Jacquelyn E Moorhead, M Stat, associate in statistics

one-third and two located in the outer one-third of dentin. On day 90 all teeth were without sensitivity.

INTRODUCTION

Sensitivity after the placement of an amalgam restoration is not uncommon. Postoperative sensitivity may result from the inability of the restorative material to seal off the dentinal tubules (Brännström & Åström, 1972; Brännström, 1984).

Studies have shown that the deeper the cavity preparation, the greater the response of underlying pulp to materials and/or procedures (Stanley, 1968a,b; el-Kafrawy & Mitchell, 1963; el-Kafrawy & others, 1974; Wennberg, Mjör, & Heide, 1982; Plamondon & others, 1990). Other studies indicate that cavity depth may not significantly affect the pulp reaction (Dowden, 1970; Plant & Anderson, 1978). Different restorative and/or lining materials have also been shown to produce different pulpal responses (Brännström, Nordenvall & Torstenson, 1981; Hanks & others, 1988).

In a study of sensitivity reported by patients following different treatments of the dentin prior to inserting amalgam restorations, most sensitivity reactions occurred during the first week. Different responses depended on the dentin treatment (Gordan & others, 1999). The purpose of this paper was to relate the sensitivity reported by patients following treatment of primary carious lesions to different dentin depths and dentin treatments in class 1 or class 2 amalgam restorations.

METHODS AND MATERIALS

Ninety subjects with primary caries lesions resulting in either class 1 or class 2 amalgam restorations were included in the study. The depth of each lesion was classified clinically and radiographically to be in the outer, middle, or inner one-third of the dentin (Table 1). The restorations were further divided into four lining regimens: Group 1—no liner; Group 2—two coats of copal varnish liner (Copalite liner, batch #131E; Cooley & Cooley, Ltd, Houston, TX 77041); Group 3—a dentin adhesive resin liner (Scotchbond Multi-Purpose/SBMP, Batch #7542; 3M Dental Products, St Paul, MN 55144); Group 4—a resin-modified glass-ionomer liner (Fuji Bond LC, Batch #110461; GC Corp, Tokyo, Japan).

The restorations were placed in patients treated in the student clinic at University of Florida College of Dentistry by third- and fourth-year undergraduate students under faculty supervision. Cavity preparations in teeth with a previous history of sensitivity or with previous restorations were excluded from the study. Patients who were taking analgesics that could alter their normal pain perception were also not included in the study. The mean age of the patients was 36.5 years with a range from 18 to 81 years.

After cavity preparation was completed, cavity depth was assessed, and any dentin treatment was applied according to the manufacturer's instructions (Table 2). Rubber dam was used for all treatments. The teeth were then restored with a dispersed-phase amalgam (Original D; Wykle Research Inc, Carson City, NV 89706), carved, and burnished. The restorations were checked for appropriate occlusion and contact points if applicable.

Patients were contacted on days 2 and 7 postoperatively. They were questioned regarding the presence or absence of sensitivity (Fitzgerald & Heys, 1991). Dentin-sensitivity stimuli included cold (ice cream, cold drinks), heat (coffee or tea), chewing, and spontaneous sensitivity. If sensitivity and/or discomfort was experienced, they reported which stimuli created the sensitivity, the length of time it lasted, and its intensity, using a rating 0-3 scale: 0 for no sensitivity, 1 for slight sensitivity, 2 for moderate sensitivity, and 3 for severe sensitivity. If discomfort

Table 1. Dentin Treatments

Product	n	Outer 1/3	Middle 1/3	Inner 1/3
Copalite	22	8	7	7
No Liner	22	8	7	7
SBMP*	22	7	8	7
Fuji Bond LC	24	9	8	7
Total	**90**	**32**	**30**	**28**

*Scotchbond Multi-Purpose

Table 2. Surface Treatment Steps

Bonding System	Dentin
No Liner	Rinsing with water, drying (not desiccating), amalgam condensation
Copalite (Cooley & Cooley)	Rinsing with water, drying (not desiccating), Copalite, slightly drying for 30 seconds, Copalite, slight drying, amalgam condensation
Scotchbond Multi-Purpose (3M)	Etching (15 seconds), rinsing (15 seconds), moistening, SBMP primer, adhesive, light curing (10 seconds), amalgam condensation
Fuji Bond LC (GC America)	Conditioning (10 seconds), rinsing (15 seconds), light drying, Fuji II LC, light curing (20 seconds), amalgam condensation

Table 3. Positive Sensitive Response According to Dentin Depth and Dentin Treatment at Day 2

	POSITIVE SENSITIVE RESPONSE				
	Dentin Treatment				
Dentin Depth	Copalite	No Liner	SBMP*	Fuji Bond LC	n
Outer 1/3	2	2	1	1	32
Middle 1/3	1	3	3	1	30
Inner 1/3	3	1	2	2	28
# of Teeth	6	6	6	4	90

Fisher's exact text, P = 0.749; *Scotchbond Multi-Purpose.

Table 4. Teeth that Remained Sensitive after the Period of 2, 7, 14, 30, and 90 Days, Regardless of Dentin Treatment

	Postoperative Days						
Dentin Depth	2	7	14	30	90	n	n sensitive
Outer 1/3	6	3	3	2	0	32	6 (19%)
Middle 1/3	8	5	3	2	0	30	8 (27%)
Inner 1/3	8	3	1	0	0	28	8 (29%)
# of Teeth	22	11	7	4	0	90	

Chi-square test, P = 0.638.

was experienced on day 7, patients were also contacted on days 14, 30, and 90 to assess the degree of sensitivity at those intervals (Gordan & others, 1999). However, all patients, including those who did not have a positive sensitivity record on days 2 and 7, were instructed to report to the principal investigator if any sensitivity or other discomfort was experienced.

For consistency purposes, both cavity depth judgment and the contact of patients for sensitivity responses were done by only one operator throughout the study.

Data management and analysis were done using the Statistical Analysis System (SAS). Results were obtained using the chi-square test, Fisher's exact test, and Spearman's correlation.

RESULTS

Some sensitivity was noted in all groups with no statistical significance (P = 0.638) shown between outer, middle, or inner one-third of dentin. The number of teeth that experienced sensitivity on day 2 was similar for all dentin treatment groups (Table 3). Dentin treatment with Fuji Bond LC had fewer sensitive teeth; however, this result was not statistically significant (P = 0.749).

On day 2, six teeth (19%) located in the outer one-third, eight (27%) located in the middle, and eight (29%) in the inner one-third were sensitive. The numbers were gradually reduced after 7 and 14 days (Table 4). On day 30 the sensitivity rates were reduced for all dentin depth groups, but four teeth were still sensitive: two with depth in the middle one-third and two with depth in the outer one-third of the dentin. On day 90, all teeth were without sensitivity or discomfort.

No significant difference (P = 0.248) was found between the stimuli initiating sensitivity and dentin depth. The stimulus that initiated the sensitivity reactions was predominantly cold (Table 5). Furthermore, no significance (P = 0.206) was found between degree of pain and dentin depth (Table 6).

Significant response (P = 0.024) was found for different dentin treatments (Table 7) at day 14, with no sensitivity reported by Fuji Bond LC and no liner groups.

DISCUSSION

Dentin thickness has been suggested as playing an important role in modifying the responses of the pulp to operative procedures (Stanley, 1968a,b; Hanks &

Table 5. Stimuli that Initiated the Sensitivity

	STIMULI					
Dentin Depth	Cold	Heat	Cold+ Heat	Chewing	Spontaneous	n
Outer 1/3	4	0	2	0	0	6
Middle 1/3	5	0	1	2	0	8
Inner 1/3	3	0	3	0	2	8
# of Teeth	12	0	6	2	2	22

Chi-square test, P = 0.248.

Table 6. Degree of Sensitivity

	Degree of Sensitivity			
Dentin Depth	1	2	3	n
Outer 1/3	3	3	0	6
Middle 1/3	5	1	2	8
Inner 1/3	6	0	2	8

1 = slight sensitivity, mild discomfort, slightly irritating; 2 = moderate sensitivity, uncomfortable, painful but tolerable; 3 = severe sensitivity, very uncomfortable, intolerable pain. Spearman's correlation, P = 0.206.

Table 7. Positive Response to Different Dentin Treatment at Day 14

Product	n	Positive	Negative
Copalite	22	4	18
No Liner	22	0	22
SBMP*	22	3	19
Fuji Bond LC	24	0	24
Total	**90**	**7 (8%)**	**83 (92%)**

*Scotchbond Multi-Purpose; Fisher's exact test, $P = 0.024$.

others, 1988). Theoretically, the thicker the remaining dentin in the floor of a cavity preparation, the lower the concentration of the substance diffusing into the pulp (Pashley, 1985).

The relative permeability of dentin to water versus solutes determines how semipermeable a membrane dentin is, and hence, how much water movement (osmosis) can be obtained for any given solute concentration gradient. This is an important consideration in the hydrodynamic theory of dentin sensitivity proposed by Brännström and Åström (1972). This hypothesis stated that dentin sensitivity is mediated by fluid movement through dentinal tubules. Whereas this movement could be induced by numerous stimuli such as temperature changes or hydrostatic pressure, others believe that dental pain is primarily elicited by evaporation of water from the dentinal fluid (Matthews, Showman & Pashley, 1993). Although the patient may sense thermal changes in the teeth or thermally induced fluid shifts, it is quite likely that they are actually responding to the rate of outward dentinal fluid movement created by air-induced evaporation of water.

The rate of permeation is determined by the number of tubules per mm², the dentin thickness, the diameter of the dentinal tubules, the molecular size of the penetrant, and the pulpal tissue fluid pressure (Pashley, 1979). The thicker the dentin the greater the dissipation of the concentration of solute that drives diffusion (Pashley, 1985). The larger the cavity preparation, the larger the area of dentin tubules exposed. The number of tubules/mm² in the mid-dentin areas coronally is about 30,000, with a range from 10,000 peripherally to more than 50,000 close to the predentin (Garberoglio & Brännström, 1976; Mjör & Nordahl, 1996). The diameter of the dentinal tubules near the pulp chamber is about 2.5 μm in newly erupted teeth, while in the middle part of the dentin the diameter is 1.2 μm. Peripherally, where the tubules terminate as major branches (Mjör & Nordahl, 1996) the diameter is 0.9 μm (Garberoglio & Brännström, 1976). Furthermore, age is an important factor, since in older patients partial or complete obturation of tubules may occur, resulting in growth of the peritubular dentin (Azaz, Michaeli & Nitzan, 1977; Stanley & others, 1983). Sclerosis may also be a reaction to caries by crystalline deposits within the tubules (Frank, Wolff & Gutmann, 1964). Caries will also result in the localized formation of irregular secondary/tertiary dentin, which may affect the sensitivity reaction of teeth (Mjör, 1985). The mean age of patients who experienced sensitivity in this study was 33.2 years, as opposed to 39.7 years for patients who did not experience any sensitivity.

Since the number of dentinal tubules per mm² is higher in deeper than in shallower cavities, it could be expected that the teeth with restorations located in the inner one-third would be more sensitive than those located in the outer or middle one-third. However, no difference was observed in this study.

Some studies have shown that the deeper the preparation, the greater the histologic response of underlying pulp to different materials (Stanley, 1968a;b). Therefore, pulp reactions to materials or procedures increase markedly as remaining dentin thickness decreases (el-Kafrawy & Mitchell, 1963; el-Kafrawy & others, 1974; Wennberg & others, 1982; Plamondon & others, 1990). However, in the present clinical study no significant associations could be observed between cavity depth and tooth sensitivity. Furthermore, different dentin treatments did not produce any statistically significant results, not even in the inner one-third of dentin.

A significant response was found between different dentin treatments and the period of time that the restoration was sensitive. The sensitivity lasted longer in the copal varnish and resin liner groups. The resin liner results are consistent with previous studies (Chohayeb, Bowen & Adrian, 1988; Gordan & others, 1999) where resin-based systems were shown to demonstrate postoperative sensitivity up to 30 days. In both resin-based and glass-ionomer-based bonding systems the smear layer was removed by either phosphoric or polyacrylic acid pretreatments. The importance of the smear layer as a determinant of dentin permeability has been indicated (Pashley, 1985; Pashley & Matthews, 1993). In vitro studies have reported different responses in dentin permeability with and without smear layer removal (Pashley & Livingston, 1978; Pashley, Michelich & Kehl, 1981; Koutsi & others, 1994; Hanks & others, 1988). However, similar to another clinical investigation (Felton, Bergenholtz & Kanoy, 1991) and an in vitro study (Mahler & others, 1996), the smear layer does not seem to have a direct correlation with the results of this study. The responses, rather, seem to be related to the sealing ability of the liner material.

The copal varnish group did not have the smear layer removed and still produced a longer-lasting sensitivity response. Studies indicate that resin-based agents may provide some type of pulp protection (Ben-Amar & other, 1987; Suzuki, Cox & White, 1994; Browning, Johnson & Gregory, 1997) as long as the dentin is sealed by hydrophilic resins (Pashley & others, 1978; Pashley, 1992; Fujitani, Inokoshi & Hosoda, 1992).

Even though several studies reported a superiority of resin liners over copal varnish when sealing amalgam restorations (Meiers & Turner, 1998; Tangsgoolwatana & others, 1997; Berry & others, 1996), other studies have indicated postoperative sensitivity responses after 7 days using resin liners (Browning & others, 1997). Studies have also emphasized the importance of further research to investigate the ability of resin penetration preceding amalgam restorations. Saiku, St Germain, and Meiers (1993) reported an increase in microleakage with aged bonded-lined restorations, suggesting that the resin underwent hydrolytic degradation. Nakabayashi, Ashizawa, and Nakamura (1992) suggested that deterioration of resin adhesion after long-term immersion in water occurred in a band of exposed collagen that lay between the resin-reinforced hybrid dentin layer and the unaltered dentin. With excessive demineralization from etching and incomplete monomer impregnation into the weakened dentin, a band of dentin was left unprotected by resin and accessible to degradation of exposed peptides. This could be a possible explanation for the long-lasting postoperative response in the resin group.

It should be acknowledged that the results could be dependent on the alloy used. It has been suggested that a spherical alloy has a greater propensity for microleakage, and consequently for postoperative sensitivity, compared to an admix high-copper alloy (Saiku & others, 1993; Mahler & Nelson, 1994). The superior performance may be related to better adaptation of the admix alloy to cavity walls through greater condensation forces achievable with the admix particle configuration (Saiku & others, 1993). Ben-Amar and others (1986) found that copal varnish significantly reduced microleakage around spherical and conventional amalgam restorations. However, an admix amalgam produced the best results without any copal varnish, which is confirmed in this study with regards to the length of postoperative sensitivity. A possible explanation for the long-lasting postoperative response with the copal varnish group is the fact that a permanent seal is not maintained when this product is used (Liberman & others, 1989).

CONCLUSION

Different dentin depths and dentin treatments did not result in clinically or statistically significant sensitivity experienced by patients following insertion of class 1 or class 2 amalgam restoration in the treatment of primary caries lesions. However, teeth that became sensitive after treatment with resin liner or copal varnish exhibited sensitivity that lasted longer than those that became sensitive after being treated with a glass-ionomer liner or with no liner.

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DEPARTMENTS

BOOK REVIEWS

DENTOFACIAL ORTHOPEDICS WITH FUNCTIONAL APPLIANCES
Second Edition

Thomas M Graber, Thomas Rakosi & Alexandre G Petrovic

Published by Mosby-Year Book, Inc, St Louis, 1997. 493 pages, 1630 illustrations. $79.99.

The term "functional appliance" may conjure up in the imagination of some, images of lecture-circuit gurus and slick brochures touting weekend courses that would provide the attendee ample information for success in treating skeleto/dental discrepancies with removable appliances and the promise of subsequent financial rewards. Unfortunately, since a given appliance may not have been the ready panacea for every case, a clinician may have had mixed experiences, with the result of becoming somewhat discouraged with the use of functional appliances.

In the preface to this book, the principal author, Dr T M Graber, indicates his belief that functional appliance therapy has received somewhat less than rave reviews in recent years, due to its indiscriminate use by inadequately trained clinicians. His practice philosophy has been: "Let the diagnosis dictate the appliances and their use, not vice versa." He therefore states that the purpose of this book is to aid the clinician in making a proper case diagnosis, which must entail some understanding of the direction and timing of craniofacial growth. Also included in the purpose is to detail instructions for the reader on how to obtain a correct construction bite, descriptions of various appliances and their uses, and specific appliance therapies for specific types of malocclusions.

The book was authored by three people who have made considerable contributions to the art and science of orthodontics: Professor T M Graber of the University of Illinois in Chicago, Professor Emeritus Thomas Rakosi of the University of Freiburg in Germany, and Professor Emeritus Alexandre Petrovic of the Louis Pasteur Medical School in Strasbourg. The book is given additional credibility by the corroboration of 15 prominent contributing authors, who collectively have expertise in the clinical use of functional appliances as well as in correlative areas such as craniofacial growth, physiology, and biomechanics.

The book is divided into two parts, four chapters in Part One and 18 chapters in Part Two. Part One introduces the reader to current thinking in regards to craniofacial growth with emphasis on the functional matrix idea, which reflects the concept that "form follows function." There is detailed research biology and physiology in the first few chapters, with the idea that, with the proper functional appliance at the proper time, the possibility exists to redirect growth, with the end result being the desirable orthopedic form.

Well over 80 per cent of the text pages are in Part Two, which is devoted to helping the reader understand functional diagnosis and treatment. The illustrations are excellent throughout the book and are especially noteworthy in Part Two, where there are not only graphic illustrations of specific appliances, but also photographic illustrations of sample appliances and cases. All of the principal functional appliances are covered, from Andresen's Activator to the recent Jasper Jumper, which is a modified Herbst Appliance. Of special interest to me were the last few chapters of Part Two, where the correction of class 2 and class 3 sagittal plane discrepancies were discussed along with the appropriate functional appliances. Also, this section covered the functional appliance correction of coronal plane deep overbite and open bite.

The book ends with an extensive literature reference and selected reading list, as well as an ample index. Overall, I believe this book to be a benchmark text on the subject of functional appliances. Even though it is earmarked for the specialist interested in effecting dentofacial orthopedics with functional appliances, I would highly recommend it for any practitioner who is interested in understanding more about functional appliances and their appropriate uses. Like T M Graber says, "It's not the tool but how you use it."

R DAVID RYNEARSON, DDS, MS
Department of Orthodontics
School of Dentistry
Loma Linda University
Loma Linda, CA 92354

REMOVABLE PARTIAL DENTURES ON OSSEOINTEGRATED IMPLANTS

Christian Besimo

Published by Quintessence Publishing Company, Inc, Chicago, 1997. 270 pages, 384 illustrations (284 color). $98.00.

Dr Besimo is an assistant professor in the Department of Prosthodontics at the University of Basel School of Dentistry. He has led the Subdepartment of Removable Prosthodontics since 1987. He specializes in fixed and removable suprastructures in implantology, geriatric dentistry, fixed and removable etched cast resin-bonded restorations, and the development and use of CAD/CAM methods in restorative dentistry.

The purpose of this book is to demonstrate the development and utilization of three types of implant-supported removable partial dentures. It presents a comprehensive, interdisciplinary concept for the treatment of the edentulous mandible. In the first section of the book, Dr Besimo discusses seven different implant attachment scenarios, and describes in vitro research studies of these systems. He describes the positive and negative factors of each system and makes treatment planning recommendations for each system.

In Part 2, the author covers the techniques required to use the three systems he favors in great detail. He shows methods of treatment planning for each system, and exactly what procedures are effective to successfully complete each system. He ends the book with several case presentations of his in vitro studies on the functional and technical aspects of the three treatment concepts, all of which he has expertly completed and documented.

Any practitioner who is actively engaged in implant prosthodontics will benefit from understanding Dr Besimo's research and treatment planning. He does recommend a Swiss implant system, the Ha-Ti system, but there are several systems available in the United States that have equivalent parts and that are more familiar to American practitioners. Dr Besimo clearly describes methods currently in use, both in Europe and America, and shows how to easily follow his techniques to obtain an excellent clinical result.

THOMAS W MITCHELL, DDS
Auxiliary Faculty
Department of Restorative Dentistry
School of Dentistry
University of Washington
Box 357456
Seattle, WA 98195-7456

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1100 - 1150 Buonocore Memorial Lecture by Dr Francois Roulet

1400 - 1455 "Partial Coverage Restorations: Gold or Porcelain?" by Dr William Strupp, Jr

1500 - 1555 "Innovative Approach to Selecting Restorative Options" by Dr Peter Yamen

Friday 25 February

0830 - 0930 "Redefinition of Esthetic Restorative Dentistry-based Adhesion and Biomimetics" by Dr Pascal Magne

0930 - 1030 "Treatment Planning: the Restorative Definition" by Dr Samuel Low

1050 - 1145 "Evidence-based Dentistry: What It Is and What It Isn't" by Dr Maxwell Anderson

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