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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 also are published.

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GUEST EDITORIAL

Honesty, Treatment Decisions, and Other Illusions of Life

Recently, *Reader's Digest* presented an unflattering and potentially damaging report on dentistry (February: 50-56, 1997). A patient seeing several dentists throughout the U S received a wide variety of treatment plans and cost estimates. The suggestion made by the article and title was that dentists are trying to cheat patients. I was not surprised by the data presented, but felt the conclusion reached by the author was misleading.

Rytomaa, Jarvinen, and Jarvinen (*Community Dentistry and Oral Epidemiology* 7:335-339, 1979), Elderton and Nuttall (*British Dental Journal* 154:201-206,1983), and others since have pointed out that the decision-making process in dentistry is highly variable. Bader and Shugars (*Journal of Dental Research* 72:891-896, 1993) showed that a second examining dentist is not likely to agree with a treatment procedure. Moreover, they emphasize that there is little scientific data to support many of the treatment decisions we make (Baders & Shugars, *Journal of Dental Education* 59:61-95, 1995).

If you strongly question this, think back to your dental school experience. If two fixed prosthodontists were working with you on a bridge, you wondered if you would ever graduate. Operative was the same except it only involved a one-appointment procedure, so you could somehow get around one of the instructors. The most reassuring part of this student dilemma was the final argument by the instructors, "In my hands, this works."

Hujoel, Powell, and Kiyak (*Journal of Dental Research* 76:867-874, 1997) stated that in 1993, $37.4 billion or 4.8% of the total health care costs in the U S are dental related. This is a greater amount than spent on strokes, on HIV infections, or on breast cancer. And for each of these medical conditions, outcome assessment research on appropriate therapies has been conducted. Because of this research, certain treatments were eliminated, others modified, and new ones developed. Yet dentistry seems to pay little attention to the concept of outcome research and the refinement of diagnosis, treatment planning, and prognosis.

All the medical conditions mentioned above (stroke, HIV, and breast cancer) are concerned with mortality. Dentistry's ultimate mortality is the loss of the tooth. For dentistry this is a problem; tooth loss is not life threatening. And we are faced with treatment decisions that in most cases are not right or wrong, but are in the grayer areas of more or less likely to be successful.

An Institute of Medicine report (*Journal of Dental Education* 59:6-15, 1995) pointed out that we need outcome research in dentistry. These outcome data need to evolve into stricter decision-making procedures ("decision trees"). Many argue that dentistry can't do this. But, examining all the treatment regimens we prescribe, and the high degree of variations among those treatment plans, not all of them can be best for the patients. Dentistry has to engage in clinical assessment research programs so that we can promote or discourage treatment options. We must get rid of the "in my hands" defense.

Medicine has seen the advantages of outcome research and is now conducting research on techniques for nonfatal conditions such as correction of nearsightedness, liposuction, and removal of tattoos, pimples, and scar tissue. If we do not jump on the bandwagon, reports much more derogatory than *Reader's Digest*'s "How Honest Is Your Dentist?" will be forthcoming.

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ORIGINAL ARTICLES

Evaluation of Curing Units Used in Private Dental Offices

M MIYAZAKI • T HATTORI • Y ICHIISHI
M KONDO • H ONOSE • B K MOORE

Clinical Relevance
It is important to check curing lights frequently to ensure that adequate light intensity is maintained.

SUMMARY

It is well known that numerous factors influence the light output of curing units, but many dentists are unaware that the output of their curing lights are inadequate. This study was conducted to evaluate the light intensity of visible-light curing units in private dental offices and to assess their curing efficiency by measuring compressive strength of a light-cured resin. Also, in order to determine the maximum light intensity of the curing units, lamps, filters, and fiber optic bundles were replaced by new ones and curing efficiency remeasured. Light intensity was measured by employing a Quantum Radiometer LI-189 at a wavelength of 470±40 nm using a bandpass filter. Compressive strength of a light-cured resin using the light units was measured employing an Instron Testing Machine at a crosshead speed of 1.0 mm/min. From the evaluation of 105 light units, the light intensity ranged from 28 to 1368 W/m² (0~500 W/m²; 41.9%, 500~1000 W/m²; 45.7%, 1000~1500 W/m²; 12.4%). Light intensity of the light unit in private offices decreased 15.9~82.1% compared to brand-new units. Reduction of light intensity impaired compressive strength of the light-cured resin to varying degrees (148.3~279.9 MPa) compared with the highest value (317 MPa) obtained from brand-new light units. The replacement of the parts increased the light intensity, with maximum increases of 36.0% for lamps, 157.7% for filters, 46.2% for fiber optics, and 322.7% for all three parts. The results of this study indicated that the light intensities of the curing units used in private practice were lower than expected.

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INTRODUCTION

There has been a rapid increase in demand for esthetic restorative materials as well as light curing

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units since the introduction of single-paste light-cured composites. There are also many other types of light-cured dental materials available to the dentist. Since most of these light-cured materials employ camphoroquinone as a photosensitizer (Taira & others, 1988), an adequate intensity of visible light around 470 nm wavelength is required to activate polymerization. The spectral distribution around the absorption peak wavelength of the photosensitizer is an important factor in the cure of light-cured resins (Cook, 1982). Also, sufficient exposure light is needed to raise the photosensitizer to its excited state (Miyazaki & others, 1995). Barghi, Berry, and Hatton (1994) evaluated light intensity of 209 curing units in Texas area dental offices. They reported that about 30% of the units tested revealed light intensities below 200 mW/cm², which was considered inadequate even with increased exposure times. Most of the dentists who participated in this survey were satisfied with the performance of their curing units. Many dentists were unaware that the output of their curing lights was inadequate (Barghi & others, 1994; Oya & others, 1995).

It is well known that numerous factors influence the light output of curing units, including line voltage (Takamizu & others, 1988), deterioration of the bulb and filter, contamination of the light tip end, and breakage of photoconductive fibers. Lower than optimal light intensity may lead to impaired polymerization of the light-cured resins, even though curing times recommended by manufacturers are followed, and adversely affect the resin's physical properties (Lee & Greener, 1994; Rueggeberg, Caughman & Curtis, 1994). When the light intensity of a curing unit decreases below an adequate level as determined by a radiometer, dentists should inspect the unit for deterioration of the parts such as lamps, filters, and fiber optic bundles.

The purpose of this study was to evaluate the light intensity of visible-light curing units in private dental offices and to assess the curing efficiency of the units by measuring compressive strength of a light-cured composite. In addition, differences in light intensity and curing efficiency were determined when replacement of lamps, filters, and fiber optic bundles was completed individually and all together for 10 of the Visilux 2 curing units.

METHODS AND MATERIALS

Letters asking for cooperation were sent to general practitioners in four wards in the Tokyo area, based on the alumni directory of Nihon University School of Dentistry. A total of 105 private dental offices agreed to participate in this study and 105 curing units were evaluated. Two investigators went to the private offices and evaluated their curing units under controlled conditions. Dentists in each office were asked for information about the year of purchase, frequency of use, and frequency of checking the unit's light output.

Light intensity was measured by employing a calibrated digital radiometer (Quantum Radiometer LI-189, Li-Cor Inc, Lincoln, NE 68504) fitted with a bandpass filter (470±40 nm) on the aperture to limit its response to the most effective wavelengths for curing visible light-cured materials. Ten seconds after the start of irradiation, the light intensity (W/m²) was recorded. The readings were taken three times using the same protocol and the average intensity calculated.

The light-cured composite used in the compressive strength test was Lite-Fil II A (Shade A2, Batch No 109465, Shofu Inc, Kyoto, Japan). The resin composite was condensed into a Teflon mold (4 mm in diameter, 6 mm high) between two sheets of matrix

Table 1. Light Curing Units Evaluated

Curing Unit	Manufacturer	Type*	Number of Units
Visilux 2	3M Dental Products, St Paul, MN 55144	G	16
Wite Lite	Tokuyama Corp, Tokyo, Japan	G	11
Optilux 400	Demetron Research Corp, Danbury, CT 06810	G	11
Daylight Lamp II	Shofu Inc, Kyoto, Japan	F	11
Quick Light	Kuraray Co, Osaka, Japan	F	11
New Light VL-II	GC Corp, Tokyo, Japan	G	9
Arcus 1	Litema GMBH, Baden, Germany	G, CL	9
Griplight II	Shofu Inc, Kyoto, Japan	G	8
Lightel	Kuraray Co	G	8
Translux CL	Kulzer, Wehrheim, Germany	G	6
Tokuso Cordless	Tokuyama Corp	G, CL	5
Max	L D Caulk, Milford, DE 19963	G	2

*Type of curing unit: G = gun; F = flexible light conductor; CL = cordless

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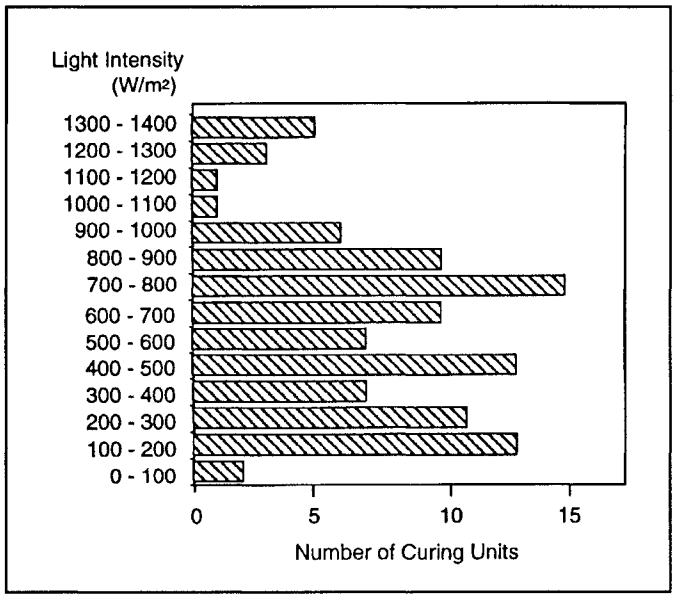

Variations of light intensities of curing unit evaluated

strips, and pressed with a glass plate with a 5 N load followed by light exposure for 30 seconds. About 2 hours after the curing, the specimens were carefully removed from the molds and tested. After reviewing the international standard (ISO) 4049 for resin-based setting materials and ISO 7489 for dental glass polyalkenoate cements, sample sizes of five were selected and subjected to the compressive strength test using an Instron Testing Machine (Type 4204, Instron Corp, Canton, MA 02021) at a crosshead speed of 1.0 mm/minute.

Visilux 2 (3M Dental Products, St Paul, MN 55144) was selected as the curing unit for determining the effect of parts replacement, because this unit had the highest percentage of representation among the 105 units sampled. Lamps, filters, and fiber optic bundles of the Visilux 2 were replaced by new ones and the light intensities were remeasured using the above protocol.

RESULTS

Models and numbers of each type of the 105 curing units employed in this study are listed in Table 1. Eighty-four units of 10 models were the gun-type, and 21 units of two models were the flexible light-conductor type. The Visilux 2 had the most units (15.2%) and the Max had the least (1.9%) out of the 12 models.

The variations in measured light intensities are shown in the figure. The highest intensity was 1364 W/m^2 and the lowest 28 W/m^2. The distribution of intensities was 41.9% between 0 to 500 W/m^2, 45.7% between 500 to 1000 W/m^2, and 12.4% between 100 to 1500 W/m^2. When compared to light intensities of the new units, the units used exhibited less intensity (15.9~82.1%).

Table 2. Light Intensities (W/m^2) of the Curing Units (Visilux 2) and Compressive Strength (Mean ± SD, MPa) of Lite-Fil IIA

Light Intensity	Compressive Strength	Year of Purchase
1400 (control)	317.0 ± 11.1	1995
250	148.3 ± 5.3	1989
260	183.8 ± 7.2	1989
515	250.9 ± 8.1	1989
675	235.7 ± 6.9	1993
708	212.3 ± 7.0	1989
730	279.9 ± 10.6	1989
750	242.3 ± 8.3	1990
771	228.4 ± 7.7	1989
780	274.2 ± 9.5	1991
860	257.7 ± 8.6	1992

Table 3. Effect of Parts Replacement on Light Intensity (W/m^2) of the Curing Units (Visilux 2)

Before Replacement	Replacement of the Parts			
	Lamp	Filter	Optic Bundle	All Three
250	340	470	340	770
260	315	670	380	1099
515	315	670	380	590
675	693	822	730	960
708	928	908	738	1108
730	860	850	710	880
750	820	860	824	1030
771	887	881	730	997
780	852	830	858	1000
860	870	956	869	996

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Compressive strengths of the light-cured composite polymerized with the curing units are presented in Table 2. Compared with new units, compressive strengths tended to decrease as light intensities decreased. Reduction of light intensity impaired the compressive strength of the light-cured resin to varying degrees when compared with the highest value obtained with new curing units. Correlation between the compressive strengths and light intensities was r^2=0.697 for Visilux 2.

The effect of parts replacement on light intensity for the 10 Visilux 2 curing units are presented in Table 3. The replacement of the parts increased the light intensity. The maximum percentage increases were 36.0% for lamps, 157.7% for filters, 46.2% for fiber optics, and 322.7% for all three parts together. In general, replacement of all three parts had the greatest effect on the light intensity.

DISCUSSION

This study showed that the light intensities measured for different curing units varied significantly among the same models made by one manufacturer. A negative correlation between light intensity and increasing age of the unit has been reported (Barghi & others, 1994). The problem is that it is impossible to determine visually the adequacy of the light intensity emitted by a curing unit. Other ways such as measuring depth of cure, hardness, and surface scraping are required.

In general practice, assessment of the effectiveness of a curing unit is presumably based on whether the surface of a light-cured resin is hard. The surface hardness of the restoration is not a reliable index, because even an inferior curing unit was able to polymerize the surface as well as an effective unit (Hansen & Asmussen, 1993a; Fowler, Swartz & Moore, 1994). Recently, several dental radiometers (light meters) have been marketed and accepted as an effective method for determining the effectiveness of curing units in polymerizing light-cured materials (Manga, Charlton & Wakefield, 1995). Hansen and Asmussen (1993b) examined three dental radiometers to assess their suitability in general practice. They found discrepancies between the actual depth of cure and the radiometer readings. Hence it is important that the readings of dental radiometers should be used solely as a reference that can be compared to the maximum intensity of the curing unit.

Light-cured composites are now being more widely used in the restoration of occlusal cavities in posterior teeth where severe mastication force occurs. Compressive strength, which was employed in this study, has been used as a measure of the ability to withstand forces of mastication. Maintaining compressive strength for a long period of service may be an indication of the mechanical integrity of a material. However, our results indicated that the compressive strength of the resin composite decreased with decreased light intensity.

It is known that light intensity is a very important factor in determining the degree of polymerization of resin composites (Sakaguchi, Douglas & Peters, 1992). The quality of resin composites has been controlled by the manufacturers to maintain standard performance. However, from the clinical point of view, the quality of restorations should be controlled by the dentist. The results of this study revealed that quality control to ensure a maximum performance of light-cured resins was not occurring.

All current curing units in dental offices use tungsten halogen lamps as their source of light. Their light intensity gradually decreases over time, although it is impossible to detect those changes with the human eye. Based on the examination of lamp degradation over time (Friedman, 1989), light intensity decreases can occur as a result of- a) lamp envelope blackening, b) lamp envelope frosting, c) reflector degradation, and d) filament burn out. Blackening of the envelope is due to the plating of filament material onto the inner surface of the glass, causing as much as a 74% drop in output. Envelope frosting, causing up to a 45% drop in output can be due to devitrification, whereby the quartz envelope crystallizes; to leakage of the glass-to-metal seal, allowing air to enter the lamp envelope; or to deposition of the embedding cement, which vaporizes and forms a coating on the lamp envelope. Reflector degradation, with up to a 66% drop in output, is a result of either a volatilization of the reflective coating or a deposition of impurities from the cement that forms a coating on the reflector surface. The replacement of the lamp was the most effective way to maintain maximum performance from the curing units, and it is recommended that dentists should frequently inspect the lamp and replace it as necessary. Lamp replacement at least every 6 months has been recommended to assure optimum performance of the curing unit (Friedman, 1989).

Dental curing units have selective filtering devices to block unsuitable wave lengths leaving the blue range light (400~500 nm), which matches the absorbance wavelength of the photoinitiator. Optic filters can become cracked or blasted over time. If either of these conditions exists, the filter should be replaced. Light from a curing unit is directed and brought to the point of application by a fiber optic light guide. If optic fiber bundles are broken, the performance of a curing unit is reduced and the fiber optic should be replaced. The end of the light guide should be maintained in a smooth and shiny condition. Foreign matter on the surface, such as restorative materials, must be removed before use.

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From our previous study on the status of utilizing curing units in general practice (Oya & others, 1995), only 25.4% of the respondents reported that they routinely checked for reduction in light intensity. Checking curing units and replacement of parts may ensure the longevity of restorations. Therefore, it is emphasized that the curing units should be checked regularly as part of the dentist's responsibility for quality control.

CONCLUSION

The results of this study indicate that the light intensities of the curing units used in private practice were lower than necessary for optimum curing of light-cured restorations. It is important to check the curing light regularly to assure that adequate light intensity is maintained. Replacement of lamps, filters, and fiber optic light guides all increased light intensity. Therefore, if any parts have degraded, they must be replaced by new ones to help ensure maximum performance of light-cured restorations.

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Effect of Eugenol-containing Temporary Cements on Bond Strength of Composite to Dentin

C GANSS • M JUNG

Clinical Relevance
Shear bond strength of composite to dentin does not seem to be affected after pretreatment with eugenol-containing or eugenol-free temporary cements.

SUMMARY

The effect of temporary materials on shear bond strength of composite to dentin was investigated. Sixty previously impacted (caries-free) human third molars were embedded and sectioned horizontally at the pulp chamber and at the half of the crown. The samples were covered with ZOE, Temp Bond (eugenol-containing), Fermit, (temporary resin material, used without cementing) and Provicol, (eugenol-free, calcium hydroxide-containing). All specimens were stored in saline for 10 days. After mechanical cleaning the dentin was pretreated with a dentin bonding agent (Syntac), and the composite columns were applied. Debonding was performed using a Zwick Universal Testing Machine (cross-head speed 1.5mm/min). The mode of failure was noted using a light microscope, and the thickness of the dentin at the composite/dentin interface was measured. The median shear bond strength values for the treated and control samples were: ZOE 7.46 MPa, Temp Bond 10.22 MPa, Fermit 6.49 MPa, Provicol 8.43 MPa, and control 10.06 MPa. No two groups were significantly different at the 0.05 level (one-way ANOVA and Scheffé test). In all groups the predominant mode of failure was adhesive and there was a slight tendency towards lower shear bond strength values at lower values for the thickness of the dentin. Under the conditions described the use of eugenol-containing temporary cements had no adverse effect on shear bond strength of a dual-curing composite luting cement to dentin.

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INTRODUCTION

More and more tooth-colored restorations are being inserted even in the posterior region. This is essentially due to the improved properties of the adhesive agents. But because of the complex chemical composition of the adhesive and the complex and varying structure of dentin, bond strength is affected by various factors. In this connection contaminants such as blood, saliva, handpiece lubricant, and especially liners, bases, and temporary materials are discussed (Xie, Powers & McGuckin, 1993; Mayer, Lentz & Koch, 1994). Since indirect techniques require at least a temporary restoration, provisional materials

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are used for sealing the cavity or as a luting cement. An adverse effect of temporary materials may either be due to changes in wetability and reactivity of the dentin (Baier, 1992) or due to remnants of the material on the surface (Terata, 1993). Additionally, residual contents of the temporary cements may interact with the setting composite materials and therefore impair polymerization (Marshall, Marshall & Harcourt, 1982). Eugenol has been suggested as having the most deleterious effect, because it is known to be a radical scavenger (Taira & others, 1992). However, eugenol-containing provisional materials are cheap and easily removable, so therefore are widely used in the dental practice. Furthermore, many clinicians also use these materials because of their sedative effect on sensitive teeth.

The purpose of this investigation was to evaluate the effect of eugenol-free and eugenol-containing temporary materials on bond strength of a dual-curing luting composite to dentin. Because the structure and permeability of the sample may influence shear bond strength and diffusion characteristics of the dentin (Friedl & others, 1995; Prati & others, 1995), shear bond strength values and thickness of the dentin were correlated.

METHODS AND MATERIALS

Sixty previously impacted human third molars were embedded into a light-curing resin material (Finotray, DT, Bad Kissingen, Germany) and sectioned horizontally at the pulp chamber and at the middle of the crown using a water-cooled diamond saw (Exact-Trennschleifsystem, Exact Apparatebau, Norderstedt, Germany). Residual pulpal soft tissue was carefully removed with a forceps and the coronal surface was gound flat with an automated polisher (Wirtz, Düsseldorf, Germany) using wet 600-grit SiC abrasive disks (Leco, St Joseph, MI 49085) at 120 rpm for 60 seconds.

The specimens were randomly divided into five groups of 12 and the cut dentin surfaces of specimens in four of the groups were completely coated with the appropriate temporary material. In Group 1 the samples were covered with ZOE, in Group 2 with Temp Bond (eugenol-containing, Kerr, Karlsruhe, Germany), in Group 3 with Fermit (temporary composite resin, Vivadent, Ellwangen, Germany) and in Group 4 with Provicol (calcium hydroxide-containing, eugenol-free, Voco, Cuxhaven, Germany). All materials (Table 1) were used according to the manufacturers' directions; the ZOE was mixed

Table 1. Materials Used

Material	Manufacturer	Essential Ingredients (batch numbers)
Mayer's Hemalum (staining material)	Merck, Darmstadt, Germany	hematoxyline $NaJO_3$ potassium alum chloral hydrate citric acid
ZOE (provisional material)	as delivered by pharmacist	zinc oxide/eugenol powder/liquid approx 10:1
Temp Bond (provisional luting cement)	Kerr, Karlsruhe, Germany	50 g of base material contains: 44 g zinc oxide (41093) 15 g of accelerator material contains: 4.4 g eugenol (41092)
Provicol (provisional luting cement)	Voco, Cuxhaven, Germany	calcium hydroxide (base: 45165, accelerator: 45164)
Fermit (provisional material)	Vivadent, Ellwangen, Germany	light-curing composite resin primarily composed of dimethacrylates (539137 ND)
Syntac (adhesive)	Vivadent	primer (616318): tetraethyleneglycolmethacrylate maleic acid dimetylketone adhesive (710738): polyethyleneglycoldimethacrylate maleic acid glutaraldehyde
Heliobond (bonding agent)	Vivadent	BIS-GMA, dioxaoctamethylene dimethacrylate (700014)
Dual Cement (luting resin)	Vivadent	base (601616) and catalyst (602593) UDMA, decamethylenemethacrylate, YbF_3, microfilled, dual curing

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in a large quantity (powder:liquid approx 10:1 w/w) so that all samples could be coated with the same mixture. The samples of Group 5 were kept clean and served as a control. All specimens were then stored in saline (37°C) for 10 days.

After the incubation time the materials were mechanically removed with a scaler until the surface was macroscopically free of material. The specimens of the treatment groups as well as the controls were cleaned with chlorhexidine using a cotton swab (15 seconds), rinsed with tap water (5 seconds), and gently dried with oil-free air (5 seconds). As an adhesive Syntac (Vivadent) was used according to the manufacturer's directions. Heliobond (Vivadent) was applied as a bonding agent and air thinned to remove excess material.

For the application of the composite, standardized plastic cylinders were filled with Dual Cement (Vivadent). These were placed onto the dentin and light cured for 60 seconds with a new Optilux 400 (Demetron Research Corp, Danbury, CT 06810). The resulting columns were 1.4 mm in diameter, and two to four columns were placed on each tooth. The plastic molds were kept in place to leave the dentin/composite interface undisturbed. To assure that the composite was not placed partly onto enamel, the correct position was checked using a light microscope (Nikon, Tokyo, Japan) at a magnification of X3. After that, the samples were returned to storage (saline, 37°C) for 48 hours.

Shear bond strength was evaluated with a Zwick Universal Testing Machine (Zwick of America Inc, East Windsor, CT 06088) using a rectangular-based rod with a cross-head speed of 1.5mm/min. The maximum load at failure was recorded. Shear bond strength was calculated in MPa. Samples configuration and the debonding procedure are schematically shown in Figure 1.

After debonding, the thickness of the dentin at the composite/dentin interface, depending on the depth of the pulp chamber, was measured with a micrometer screw (Mitutoyo, Tokyo, Japan).

For determining the mode of failure the samples were stained with Mayer's Hemalum solution (Merck, Darmstadt, Germany) for 5 minutes to get a better contrast between composite and dentin. The result of staining with hemalum is a stain of nuclei, but other structures also can take stain. Ergastoplasm or calcic structures appear blue, and some mucins stain very deeply (Gabe, 1976). The dentin and enamel surfaces of the samples took an intense violet stain, whereas the composite remained completely unstained. A light microscope (Nikon, Tokyo, Japan) at magnification X6 was used. Similar to the classification used by Powers, Finger, and Xie (1995), five categories were defined for the mode of failure: Type 1, adhesive; Type 2, adhesive with remnants of composite; Type 3, partly cohesive/partly adhesive; Type 4, cohesive within the dentin; Type 5, cohesive within the composite.

Shear bond strengths as well as the thickness of the dentin samples were compared by one-way ANOVA and Scheffé test. To correlate the thickness of the dentin and the shear bond strength, Spearman correlation coefficients were used. An explanation of the boxplots used for the presentation of shear bond strength values and the thickness of the dentin is given in Figure 2.

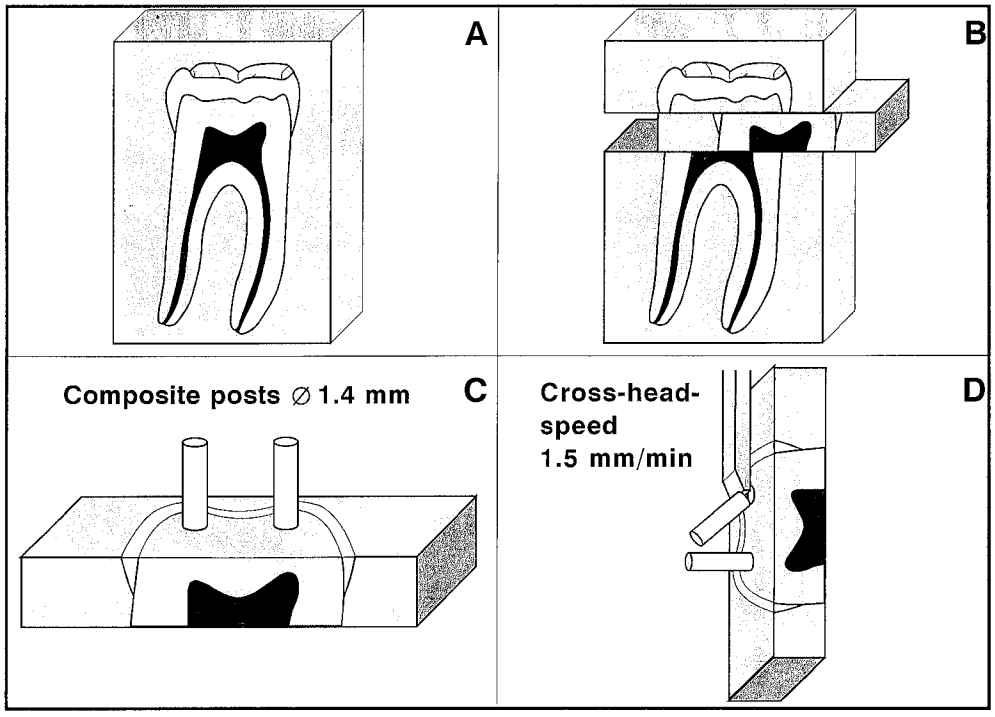

Figure 1. *Schematic drawing of the preparation of the samples and the debonding procedure. A = tooth embedded into a light-curing resin material; B = sectioned at the pulp chamber and at the middle of the crown; C = two to four columns each applied after pretreatment; D = debonding procedure.*

RESULTS

No significant differences in shear bond strength could be found among the groups at the 0.05 level (Figure 3). Median shear bond values were 7.46 MPa for Group 1 (ZOE, n=33), 10.22 MPa for Group 2 (Temp Bond, n=35), 6.49 MPa

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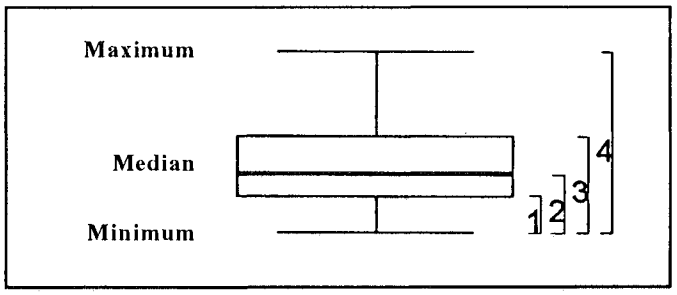

Figure 2. *Explanation of the boxplot: 1 = 25% of the values range below the first quartile; 2 = 50% of the values range below the second quartile; 3 = 75% of the values range below the third quartile; 4 = 100% of the values range below the fourth quartile.*

for Group 3 (Fermit, n=32), 8.43 MPa for Group 4 (Provicol, n=35), and 10.06 MPa for the control group (n=33).

The median thickness of the dentin (Figure 4) was 2.43 mm for Group 1 (n=21), 2.34 mm for Group 2 (n=24), 2.04 mm for Group 3 (n=25), 2.09 mm for Group 4 (n=28), and 1.90 mm for the control group (n=23). No two groups were significantly different at the 0.05 level. The thickness of the dentin varied greatly even within small areas. Therefore values were excluded if the position of the debonded column could not be re-identified exactly.

There was a slight tendency (r=0.21, P=0.017) towards lower shear bond strength values at lower values for the thickness of the dentin (Figure 5).

The predominant mode of failure (Table 2) was adhesive (Type 1); only in a few samples were remnants of composite at the failed surface (Type 2) found; no failure occurred in the partly adhesive/partly cohesive (Type 3) category or in the cohesive within the dentin (Type 4) category. Only a few samples failed cohesively within the composite (Type 5).

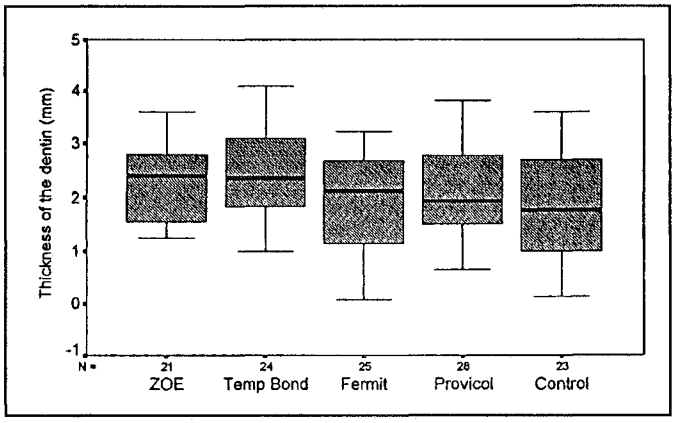

Figure 4. *Boxplot of the thickness of the dentin measured from the composite/dentin interface to the pulp chamber for all groups. No two groups were significantly different at the 0.05 level (one-way ANOVA).*

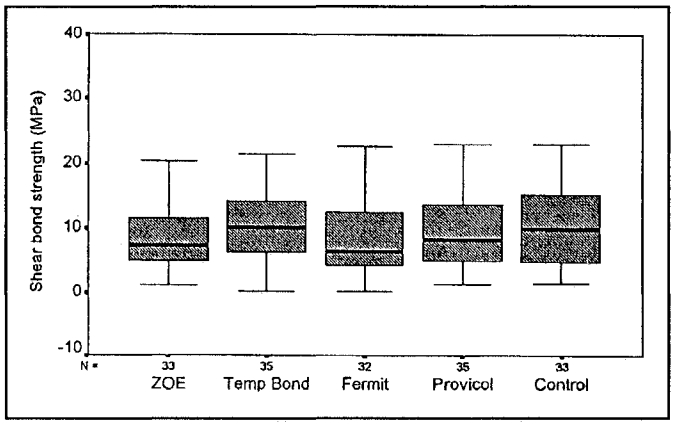

Figure 3. *Boxplot of the shear bond strength for all groups. No two groups were significantly different at the 0.05 level (one-way ANOVA).*

DISCUSSION

Eugenol is the principal constituent of clove oil and has the structure 4-allyl 2 methoxy phenol. A chelating reaction occurs when zinc oxide is mixed with eugenol, which is conjectural in the presence of water, due to hydrolysis. Ultrastructurally, grains of zinc oxide are embedded in a zinc eugenolate matrix (Markowitz & others, 1992). Since all eugenol reacts to ZOE, none is available for diffusion after setting is complete. Therefore a certain amount of water is necessary to release eugenol from zinc eugenolate. Because water seems to be unable to penetrate the set bulk material, only tubule fluid has an effect on the rate of release of eugenol towards the pulp. It is well documented that eugenol is able to penetrate dentin. The concentration of eugenol in dentin is about 10^{-2}

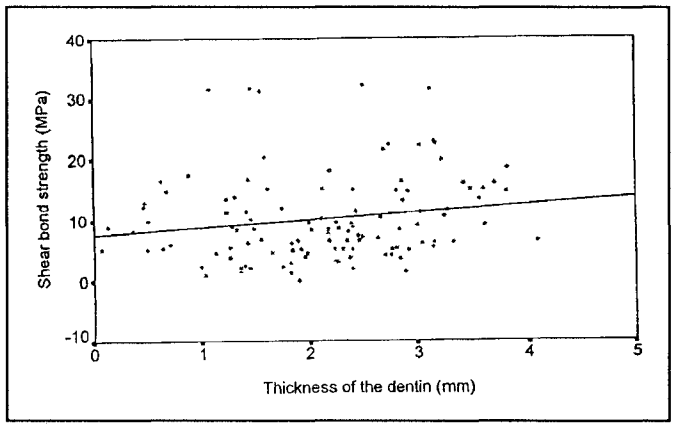

Figure 5. *Scatterplot of the thickness of the dentin (mm) and shear bond strength (MPa) for all groups (*P = 0.017, r = 0.21, *Spearman correlation coefficient)*

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Table 2. Mode of Failure for All Groups

Mode of Failure	Group 1 (ZOE)	Group 2 (Temp Bond)	Group 3 (Fermit)	Group 4 (Provicol)	Group 5 (Control)
adhesive	29	34	32	32	28
adhesive with remnants of composite	2	1	0	1	2
partly adhesive/partly cohesive	0	0	0	0	0
cohesive within dentin	0	0	0	0	0
cohesive within composite	2	0	0	2	3
n	33	35	32	35	33

molar adjacent to a ZOE/dentin interface and about 10^{-4} molar adjacent to the pulp. The diffusion rate of eugenol relased from ZOE increased to a peak after 1 day (about 0.3 nmol/min) and then decreased slowly. After 14 days the outflow through dentin diminished to 0.08 nmol/min (Hume, 1988). From these data an incubation time of 10 days as was used in this study seemed to achieve a sufficient concentration of eugenol into the dentin. The release of eugenol from Temp Bond seems to be in the same range as it was from ZOE. Kielbassa and others (1995) found a release through dentin of 6.2 mg eugenol/l from Temp Bond vs 4.4 mg eugenol/l from ZOE mixed in a dry consistency (zinc oxide:eugenol = 10:1) after 24 hours. However, the release pattern of eugenol from dentin after removal of a eugenol-containing dressing is still unclear, as well as whether a 10^{-2} molar concentration of eugenol into the dentin can cause any adverse effect on adhesive/composite systems.

As shown by Rotberg and DeShazer (1966) eugenol as well as ZOE can cause a release of calcium from the dentin, which is due to the complexing properties of eugenol. This may have a softening effect on dentin and is, on the other hand, considered to be one of the factors that lower the diffusion rate through dentin and may decrease the release rate from dentin towards a composite filling material as well. But this slight demineralization may be superposed by the demineralization due to the adhesive system and therefore seems unlikely to influence bond strength.

Little is known about the interaction of eugenol and resin adhesive agents. One possible side effect may be the inhibition of the polymerization of the composite due to the radical scavenger properties of the phenols. This would result in a decrease of microhardness of the set composite. Accordingly, Lingard, Davies, and von Fraunhofer (1981) and Marshall and others (1982) found a reduction of the microhardness of composites cured in contact with eugenol-containing materials. This was also true for glass-ionomer cement and polycarboxylate cement, whereas calcium hydroxide-containing materials showed the least effect. These effects do not seem to be strong enough to alter tensile strength as well as compressive strength of the bulk material (Powell & Huget, 1993). Additionally it is questionable if even small remnants of provisional cements left in a cavity would be able to cause a significant effect. Concerning this question, Hotz, Schlatter, and Lussi (1992) evaluated the microhardness of composite restorations that were placed in cavities previously dressed with ZOE. Only Brilliant Lux (Coltène, Altstätten, Switzerland) was affected, whereas the other materials showed no decrease in microhardness. This was also true for Dual Cement, which was used in this study. The other side effect of phenols may be the softening of the cured composite. This was shown for eugenol, formocresol, or camphorated monochlorophenol and some previous-generation composite resins (Lorecki & Astiz, 1981), but it seems unlikely that the low concentration of eugenol in the dentin after removal of ZOE may have a significant long-term effect on the latest adhesive/composite systems. Phenols have even been contents of adhesive agents. Stackhouse and others (1989) substituted HEMA and HHMA with eugenol, o-methoxyphenol, o-chlorophenol, and p-cresol, and these experimental dentin bonding agents had bond strength values around 10.3 MPa.

Another aspect may be of much more importance: Can provisional materials be completely removed from a dentin surface, and how does residual material alter the properties of the dentin? Terata (1993) performed SEM evaluations of dentin surfaces after mechanical removal of temporary materials (eugenol-containing and eugenol-free). Although the samples were macroscopically free of remnants, he found, in addition to the smear layer, a layer of remaining cement. After etching with 37% phosphoric acid, open dentinal tubules were present as well as remnants of the material. Contact angle measurements with distilled water showed significantly greater values for pretreated dentin surfaces (eugenol-

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containing and eugenol-free materials) compared with dentin that was not contaminated with temporary material. This indicated a decreased wetability for hydrophilic liquids on pretreated dentinal surfaces regardless of the material used. Since improved wetability for bonding agents correlated directly with their better infiltration and anchoring of composites (Baier, 1992), pretreatment of the dentin per se whether with eugenol-free or eugenol-containing material may have effects on bond strength. Additionally, in a clinical situation it is much more difficult to obtain a clean cavity after a provisional dressing has been placed than it is in vitro.

One reason for the use of Syntac/Dual Cement system in this study was that it is commonly used for the insertion of indirect tooth-colored restorations in dental practice in Germany. The primer mainly consists of tetraethyleneglycoldimethacrylate, maleic acid, and dimethylacetone. The acidic primer modifies the smear layer and at the same time the solvent component ensures wetting of the dentin surface by the resin. The adhesive mainly consists of polyethyleneglycoldimethacrylate, maleic acid, and glutaraldehyde. It acts as a linkage between the hydrophilic dentin and the relatively hydrophobic bonding resin, whereas the aldehyde may react with the organic portion of the dentin (McCabe & Rusby, 1994). The other reason was that an effect of pretreatment on bond strength may be more likely in this system because the smear layer is only modified (as described above) compared to systems that remove the smear layer and therefore have a more intense cleansing effect.

As to the design of the samples, the clinical situation was simulated by creating a standardized smear layer on the dentinal surface but leaving the pulpal side of the specimens undisturbed, because a smear layer would affect the diffusion abilities of water. Since a certain amount of dentinal fluid is essential for the release of eugenol (see above) the intactness of the pulpal dentin structure seems to be important. Using the physical law of the altitude of fluids in capillaries $h = 2 \times \sigma / r \times g \times \rho$ with σ = surface tension of water at 20°C = 72.5×10^{-3} N/m; r = radius of the capillary = 1 µm; g = constant of gravitation = 9.81 m/s; ρ = density of water = 10^3 kg/m^3; a theoretical height of the fluid in the dentinal tubule is 14.8 m. This indicates a complete filling of the dentinal tubules and therefore wet dentin (Friedl & others, 1995). On the other hand, the thickness of the dentin varied due to the depth of the pulp chamber. This may influence shear bond strength, as was shown by Friedl and others (1995), who used Syntac at deep and superficial dentin. This is in accordance with the findings in this study. Figure 5 shows that there was a slight tendency towards higher shear bond strength values at thicker dentin areas. However, since there were no significant differences among the groups regarding the thickness of the dentin (Figure 4), this aspect did not seem to be of importance.

In this study shear bond strength values for the control group were consistent with values found in the literature. Friedl and others (1995) found shear bond strength values of 13.0 MPa for superficial and 8.7 MPa for deep dentin, Holtan and others (1994) found mean shear bond strength values of 13.5±8.6 MPa. The Syntac system seemed to be sensitive to humidity; Retief and others (1993) found relatively high values for dry dentin (15.9±2.13 MPa), whereas Plasmans and others (1993) found very low values (<3 MPa) at 95% air humidity. To avoid differences concerning humidity as far as possible, we took one sample at a time from the saline, air dried it in a standardized manner (5 seconds, slight pressure), and immediately applied the adhesive and the composite. All specimens were prepared in the same room during the same day at constant conditions.

Another factor affecting bond strength may be the application technique utilized for the adhesive. There is evidence that air thinning of the adhesive can significantly reduce bond strength (Hilton & Schwartz, 1995), but on the other hand there are adverse effects on bond strength when the adhesive is placed over 200 to 500 µm thick (Langdon, Moon & Barnes, 1994; Retief, Wendt & Bradley, 1989). Since this study focused on the effect of pretreatment with temporary materials but not on the determination of the maximum shear bond strength of the Syntac system, air thinning seemed to be an appropriate method to standardize sample treatment and to achieve a constant thickness of the adhesive for all specimens.

The median shear bond strength value for the ZOE group was 7.46 MPa, which according to tendency was lower than the controls (10.06 MPa), whereas the eugenol-containing Temp Bond group (10.22 MPa) reached the same values as did the controls. Even pretreatment with a eugenol-free material (8.43 MPa) did not achieve the same bond strength as the controls. However, we did not expect the lowest bond strength in the Fermit group (6.49 MPa), because this material is a noncemented light-curing temporary composite, which is thought to be removable without any remnants and/or alterations of the dentin surface. Similar results were stated by Mayer, Lentz, and Koch (1994), who found a significant reduction of bond strength after pretreatment with a composite (urethanemethacrylate-containing) material, whereas eugenol-containing materials as well as the other eugenol-free materials had no adverse effect. Even Schwartz, Davis, and Hilton (1992) found that shear bond strength was not affected by temporary cements. They used the Prisma Universal Bond 3 dentin bonding system and cleaned the specimens

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with pumice prior to the bonding procedure.

The analysis of the mode of failure supported the results above: In all groups the columns predominantly failed at the composite/dentin interface, and no differences in fracture characteristics could be found between the treated and control groups.

Because these results were not statistically significant, only tendencies could be described. Except for pretreatment with Temp Bond, all materials decreased shear bond strength values, but it is questionable if this is of clinical significance. Besides, shear bond strength is not necessarily related to microleakage. There is evidence that temporary materials may enhance microleakage in resin-bonded restorations (Hansen & Asmussen, 1987).

Macchi and others (1991) found significant differences between phenol-treated groups after 15 minutes and 48 hours as well as for no-phenol groups after 15 minutes' and 48 hours' incubation time, but not between phenol and no-phenol groups or between the control group compared with treatment groups. They used Prisma Universal Bond (L D Caulk/Dentsply, Milford, DE 19963) and, therefore, achieved relatively low bond strength values using a small sample size (n = 7 to 15).

In contrast Xie, Powers, and McGuckin (1993) found a significant decrease in bond strength when the dentin was pretreated with a eugenol-containing as well as with a eugenol-free material. As adhesives they used All-Bond 2 (Bisco, Itasca, IL 60143) and Scotchbond MP (3M Dental Products, St Paul, MN 55144). Similar results were pointed out from Paul and Schärer (1994). They found a significant reduction of shear bond strength after pretreatment with eugenol-free and eugenol-containing materials compared with untreated controls using the All-Bond 2 system under simulated pulpal pressure. These results correlated with the findings of Woody and Davies (1992), who found significantly more leakage at nonenamel margins when the cavities were pretreated with a provisional material (eugenol-free and eugenol-containing) compared to the control. They used Prisma Universal Bond and Coltène Duo Cement.

Comparing data from the literature seems to be difficult, because various adhesive systems and temporary materials under various conditions are tested. Since the mode of action of the adhesives is complex and may be different for each of them, the effect of contaminants is not easy to determine, and additional research is needed on this subject. But most data from the literature indicate that merely the pretreatment with temporary materials in general and not the pretreatment with eugenol in particular may have adverse effects on shear bond strength. Therefore, from our results as well, it seemed questionable to agree with the recommendation not to use eugenol-containing provisional materials prior to placing tooth-colored restorations.

CONCLUSION

Based on the results of this in vitro experiment, pretreatment of dentin with eugenol-containing or eugenol-free temporary materials had no adverse effect on shear bond strength of a dual-curing luting composite (Dual Cement) when Syntac was used as an adhesive.

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Effect of Eugenol-containing Temporary Cements on Bond Strength of Composite to Enamel

M JUNG • C GANSS • S SENGER

Clinical Relevance
Eugenol-containing and eugenol-free temporary cements or filling materials had no adverse effect on shear bond strength of a dual-curing resin luting cement to enamel.

SUMMARY

The purpose of this study was to find out the degree to which eugenol-containing temporary cements or temporary filling materials affected shear bond strength of a dual-cure resin luting cement to acid-etched enamel. For this purpose 56 human caries-free third molars were embedded in acrylic resin and cross sectioned mesiodistally. One of the corresponding halves was covered with Temp-Bond (eugenol-containing, Group 1), Provicol (eugenol-free, Group 2), ZOE (Group 3), and eugenol (Group 4). The other half of each sectioned tooth was kept clean and served as a control. After 1 week the cements were removed; the pure eugenol group (Group 4) was terminated after 24 hours. Plastic cylinders were filled with Dual Cement and placed on the etched enamel and light cured. Shear bond strength data were recorded using a Zwick Universal Testing Machine, and the mode of failure was diagnosed using a light microscope. Significant differences in shear bond strength could neither be found between the treated halves and the controls nor among the four groups pretreated with eugenol-containing or eugenol-free temporary cements. Based on the results of this study, no adverse effects of eugenol on shear bond strength of a resin luting cement to enamel could be found.

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INTRODUCTION

The effects of direct contact of eugenol-containing cements and composites have been discussed several times in recent literature. While some authors have described the inhibition of composite polymerization (Lussi & Hotz, 1994) or a reduction of hardness (Marshall, Marshall & Harcourt, 1982), as well as an alteration of the cured composite surface (Millstein & Nathanson, 1983), Powell and Huget (1993) did not find any influence of eugenol-containing materials on compressive strain and tensile stress of composites. Hotz, Schlatter, and Lussi (1992) showed that the polymerization of five out of six composites was not influenced by the prior application of eugenol-containing temporary restorations. Woody and Davis

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(1992) demonstrated that eugenol-containing temporary cements had no influence on the microleakage of resin-luted inlays. One aspect of adhesively cemented composite and ceramic inlays is the necessity to temporize the prepared cavities prior to the use of a resin luting cement. Many of the existing temporary cements contain eugenol and might, therefore, have a negative effect on the quality of the adhesive fixation, although subsequent acid etching has been shown to remove about 10 μm of enamel (Silverstone, 1974). A common method of investigating the quality of an adhesive fixation between enamel and composite resin is to perform shear bond strength tests. Shear bond strength values between composite resin and enamel ranging from 15-20 MPa (Aboush, Tareen & Elderton, 1991; Holtan & others, 1995; Royer & Meiers, 1995) have been reported. Some reports of higher shear bond strengths from 22-28 MPa (Xie, Powers & McGuckin, 1993; Mixson & others, 1989) have been made. Schwartz, Davis, and Mayhew (1990) investigated the effect of two temporary cements on the bond strength of a resin luting cement by using flattened buccal or lingual enamel surfaces and reported shear bond strength values from 17.9-20.2 MPa. However, little is known about the effect that temporary eugenol cements would have on the shear bond strength of luting composites to etched enamel.

The purpose of this study, therefore, was to determine whether the shear bond strength of a commonly used dual-cure composite cement to enamel was affected by the prior use of eugenol-containing or eugenol-free temporary cements, ZOE, or pure eugenol. An additional aim was to determine the predominant mode of failure depending on the type of pretreatment.

METHODS AND MATERIALS

Fifty-six previously impacted caries-free human third molars were used for this study. Residual soft tissue was mechanically removed and the enamel cleaned with pumice. Subsequently, the teeth were embedded in Technovit 4070 (Kulzer, Wehrheim, Germany). The Technovit blocks were then fixed to a plastic plate, which allowed the mounting of the specimens to a tape-saw (Exakt-Trennschleifsystem, Exakt Apparatebau, Norderstedt, Germany). Cooled by running tap water, the teeth were cross sectioned mesiodistally along a line connecting two cusp tips. Subsequently, the surfaces were ground flat with a 600-grit sandpaper disk (Leco, St Joseph, MI 49085) by use of an automated polisher A-250 (Jean Wirtz, Düsseldorf, Germany) at 120 rpm for 60 seconds. After that the teeth were randomly divided into four groups (Table 1). One half of each tooth was covered with a temporary material or eugenol, the other was kept clean and served as a control. In the first group the sectioned surfaces were covered with Temp Bond (eugenol-containing, n=16), in the second group with Provicol (eugenol-free, n=16), in the third group with ZOE (n=16), and in the fourth group the sectioned surfaces were covered with pure eugenol (n=8). The samples of Groups 1-3 were stored in isotonic saline solution (0.9% NaCl) at 37 °C for 1 week; the covering with eugenol in Group 4 was terminated after 24 hours. The untreated halves of the sectioned teeth were stored in isotonic saline solution for 1 week.

After mechanical removal of the cements with a scaler and cleaning all the tooth surfaces by scrubbing with a chlorhexidine-soaked cotton pellet for 30 seconds and subsequent drying for 10 seconds, the enamel was etched with 37% phosphoric acid (Email Preparator GS, Vivadent, Schaan, Liechtenstein; Batch No 560601) for 40 seconds. The surfaces were rinsed with tap water for 30 seconds; subsequently the enamel was dried again for 15 seconds. Heliobond (Vivadent, Batch No 560581) was applied to the etched enamel and short air thinning removed the excess bonding liquid. Dual Cement radiopaque (dual-curing luting resin;Vivadent, Batch No 662468) was mixed according to the

Table 1. Temporary Cements and Filling Material Used

Group	N	Material	Main Ingredient	Coverage	Manufacturer	Batch Number
1	16	Temp Bond	zinc oxide (base) eugenol (accelerator)	1 week	Kerr USA, Romulus, MI 48174	41309 (base) 41042 (accelerator)
2	16	Provicol	calcium hydroxide	1 week	Voco, Cuxhaven, Germany	45165 (base) 45164 (catalyst)
3	16	ZOE	zinc oxide/eugenol powder/liquid approx 10:1	1 week	as delivered by pharmacist	
4	8	eugenol		24 hours	as delivered by pharmacist	

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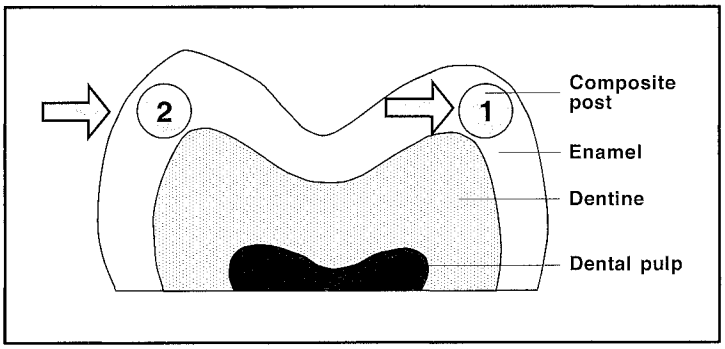

Figure 1. *Schematic drawing of a sectioned tooth surface with two composite cylinders placed on the enamel*

manufacturer's guidelines. Immediately afterwards transparent plastic cylinders that were open at the two ends (diameter 1.4 mm, height 3 mm) were filled with freshly mixed luting cement. Excess cement was removed by a hand instrument, and the cylinders were then placed on the pretreated enamel. From the upper end of the cylinder slight pressure with a cylindrical-shaped instrument was exerted to ensure a sufficient wetting of the enamel by the luting cement. The composite was light cured for 60 seconds with a new Optilux 400 curing light (Demetron Research Corp, Danbury, CT 06810). Two cylinders were cemented to each half of the sectioned teeth, one mesially, the other distally (Figure 1). After light curing, the plastic cylinders were removed with the help of a scalpel and the cylinder area on the enamel checked with a light microscope.

All specimens were then stored in NaCl for 24 hours at 37 °C. Shear bond strength tests were performed by mounting the specimens in a Zwick Universal Testing Machine (Zwick of America Inc, East Windsor, CT 06088) using a rectangular-based rod at a crosshead speed of 1.5 mm/min. The maximum load at failure was recorded in N and then transformed to MPa.

After shearing of the composite cylinders was completed, the surfaces were stained using Mayer's hemalum solution (Gabe, 1976) for 5 minutes to enable a more accurate mode of failure to be determined by use of a light microscope (Nikon SMZ-2T, Tokyo, Japan) at a magnification of X6.

A statistical analysis of the data was done by one-way ANOVA and pairwise contrasts by Tukey.

The failed composite cylinders were collected, and the debonded surface was examined for incomplete wetting of the enamel (e g, trapped air bubbles).

To relate the molecular size of eugenol to the size of pores in human enamel, we calculated the molecular volume of eugenol (4-allyl-2-methoxyphenol) with the Gaussian 94 package of programs (Frisch & others, 1995). This package is a tool offering ab initio electronic structure methods for the computation of molecular properties. The term "ab initio" implies a rigorous, nonparametrized molecular orbital treatment derived from the first principles, which means that no experimental parameters are used. First a geometry optimization with the 6-31G* basis set at Hartree-Fock level was performed, which led to the lowest energy molecular structure, and subsequently a molecular volume calculation was done.

RESULTS

The results for the shear bond strength of the four treated groups and the untreated controls are shown in Table 2. The mean values for shear bond strength in Groups 1-4 varied from 28-32 MPa. There was a tendency towards slightly higher values in the controls, but no significant differences in shear bond strength could be found between the treated tooth-halves and their controls. When comparing the four treated groups, we again observed that there were no significant differences in shear bond strength. In fact, pretreatment with ZOE (Group 3) and pure eugenol (Group 4) achieved higher shear bond strength values than the first two groups, but the differences were statistically not significant.

The direction into which the composite cylinders were sheared off was of a greater influence on the recorded shear bond strength data than the kind of pretreatment (Figure 2). Shear bond strength was significantly greater when shearing was done towards the middle of the tooth (composite cylinder 2, Figure 1) than to the surface of the tooth (composite cylinder 1).

As far as the mode of failure was concerned, we observed five different types: cohesive within enamel (Type 1), predominantly adhesive with cohesive parts within enamel (Type 2), adhesive (Type 3), predominantly adhesive with residues of composite (Type 4), and cohesive both within enamel and composite (Type 5).

For all specimens, failure Types 4 and 5 played a minor role. Failure Type 2 was observed most often both for the treated samples and for the controls.

Table 2. Average Shear Bond Strength (in MPa) and Standard Deviation

Group 1 (Temp Bond)	23.00 ± 8.28	control	27.99 ± 11.37
Group 2 (Provicol)	27.19 ± 7.57	control	29.69 ± 6.69
Group 3 (ZOE)	29.10 ± 7.44	control	32.12 ± 8.94
Group 4 (Eugenol)	31.47 ± 5.32	control	30.27 ± 8.11

No two groups were significantly different at the 0.05 level.

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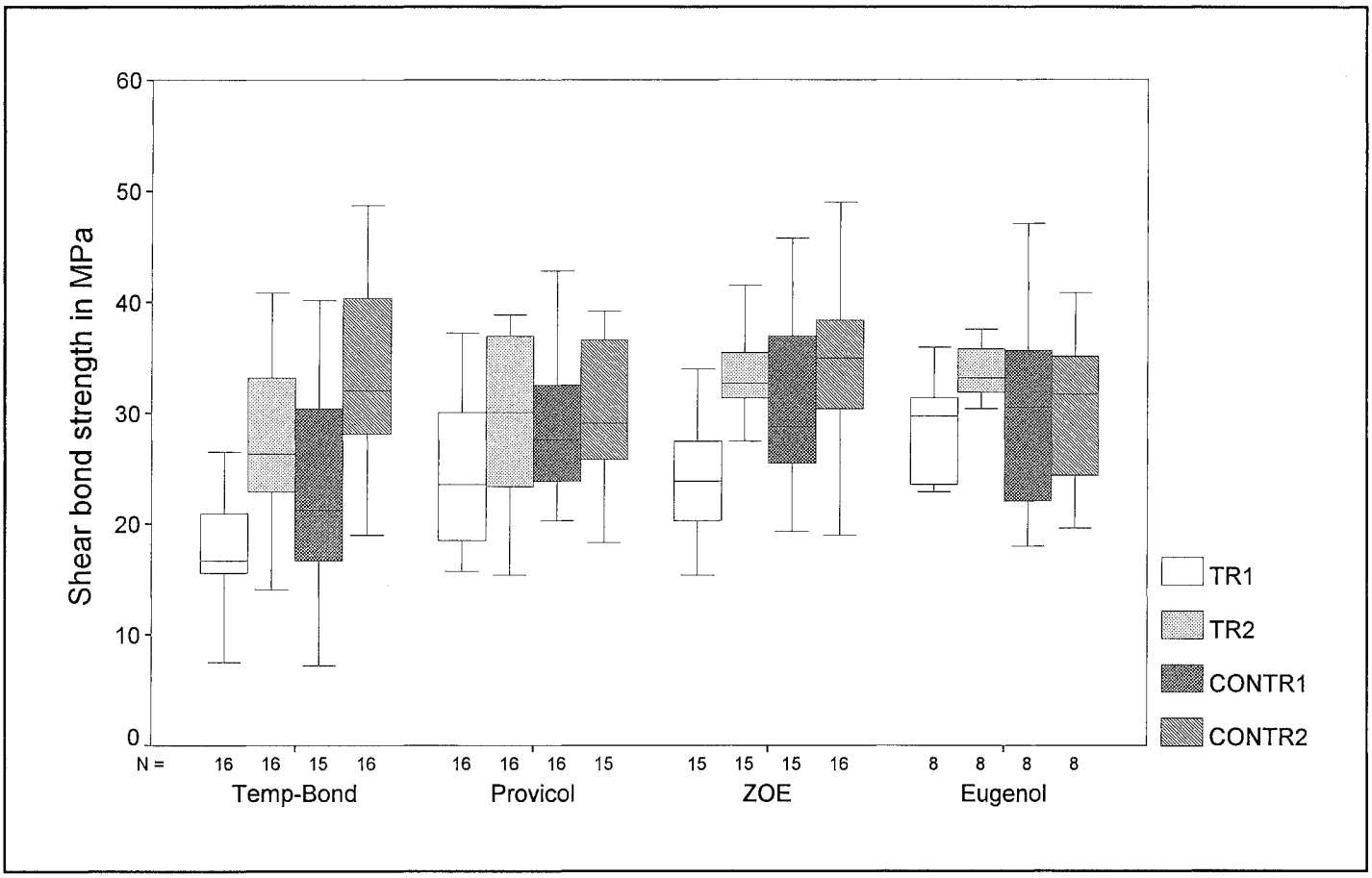

Figure 2. *Shear bond strength of Dual Cement to enamel of the four treated groups and the controls depending on the direction of shearing (TR1/TR2 = treated samples with shear direction to the surface and to the middle of the tooth; CONTR1/CONTR2 = untreated samples with shear direction to the surface and to the middle of the tooth.)*

When comparing the treated specimens and the controls, the predominant modes of failure for Groups 1-4 were Types 1 and 2; for the controls we mainly observed Types 2 and 3 (Table 3). No significant difference regarding the distribution of the mode of failure could be found among Groups 1-4. One representative enamel surface after failure is shown in Figure 3.

The molecular volume of eugenol is approximated as being spherical, and therefore its size can be represented by its diameter, which was calculated to be 0.8 nm.

DISCUSSION

There have been a number of studies in recent years investigating shear bond strength of composite to enamel under varying conditions. The obtained results of this study, ranging from 23 to 32 MPa, are in agreement with the shear bond strength values found by Xie and others (1993) and by Mixson and others (1989).

Schwartz and others (1990) investigated the effect of a eugenol-containing and eugenol-free temporary cement on the bond strength of a resin luting cement by using flattened buccal or lingual enamel surfaces. This study attempted to simulate the clinical situation

Table 3. Mode of Failure for Treated Groups and Control (in %)

Type of Failure	Group 1	Group 2	Group 3	Group 4	Control
1	50.0	34.4	20.0	25.0	22.3
2	28.1	37.5	56.7	43.8	36.6
3	9.4	18.8	20.0	25.0	31.3
4	9.4	3.1	3.3	0.0	6.3
5	3.1	6.3	0.0	6.3	3.6

No two groups were significantly different at the 0.05 level.

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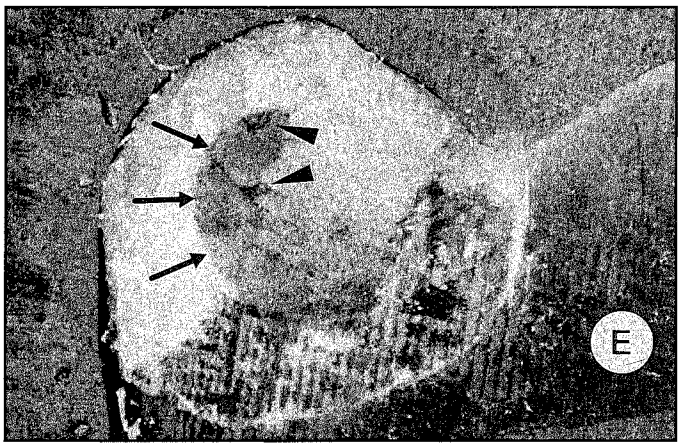

Figure 3. *The sectioned enamel surface of a lower molar after failure with the outlines of the prior composite cylinder placement (skinny arrows). The type of fracture is predominantly adhesive with cohesive fragments (wide arrows) in enamel (Type 2).*

of a preparation of a class 2 cavity. By sectioning the molars mesiodistally from cusp-tip to cusp-tip, a smaller enamel area was available for etching but had the advantage of the localization of the etched enamel and the orientation of the prisms resembling the clinical situation of a class 2 cavity margin. Furthermore, the cemented composite cylinders on the corresponding half of the same tooth, which served as a control, were positioned on identically structured enamel.

After coverage with the temporary cements, the enamel was cleaned mechanically. Terata (1993) showed that mechanical removal did not completely eliminate all the temporary cement from enamel, but a subsequent etching with 37% phosphoric acid effectively removed the temporary cement that remained on enamel surfaces.

One problem often involved in this type of study is a complete wetting of the enamel by the composite without surplus material. Therefore, the failed cylinders were collected and the failed surfaces investigated for signs of incomplete enamel wetting. All the composite cylinders had a homogeneous surface with no signs of trapped air bubbles.

The direction of shearing was found to have a considerable effect on the shear bond strength data. This could be due to a different orientation of the enamel rods in front of and behind the composite cylinders. When shearing was directed from the surface toward the middle of the tooth, the enamel rods in front of the composite cylinder were mainly orientated longitudinally, while the enamel rods behind the cylinder were mainly orientated transversely (composite cylinder 2, Figure 1). When shearing toward the surface, the orientation of the rods in front of and behind the composite cylinder was just the opposite (cylinder 1, Figure 1). Further research would be helpful to clarify the effect of shearing direction.

In accordance with Schwartz and others (1990) our results also demonstrated no significant difference in shear bond strength of enamel being pretreated with eugenol-containing or eugenol-free temporary cements. Additionally, the results supported the findings of Hotz and others (1992), who showed that the polymerization of five out of six composites was not influenced by prior application of eugenol-containing temporary restorations.

Evaluation of the shear bond strength failure mode revealed no differences among the four groups. The use of Mayer's hemalum solution (Gabe, 1976) stained the enamel around the composite cylinders, while the composite itself and resin-infiltrated enamel were left completely unstained. For all groups, including controls, a combination of adhesive and cohesive failures in enamel (type 2) occurred most often. Under the circumstances of this study, the variation of cohesive forces within enamel and adhesive forces of the composite resin to enamel were similar. This could be due to the way the prisms were sectioned; near the outer surface of the enamel the prisms were mainly orientated longitudinally. This is in agreement with Munechika and others (1984), who observed adhesive and cohesive failures in enamel when the prisms were sectioned longitudinally. Mixson and others (1989) described a variety of enamel fracture patterns, including cohesive failures. Several other studies describe cohesive fractures in composite, adhesive failures, or mixed types (Holtan & others, 1995; Royer & Meiers, 1995; Xie & others, 1993). The differences in the failure modes observed can be explained by the different conditions used for the above-mentioned studies.

Dibdin and Poole (1982) showed that the pore-size distribution of human whole enamel has a peak at approximately 2 nm. The calculation of the molecular volume of eugenol yielded a diameter of 0.8 nm, so that, at least with regard to the molecular size, a permeation of eugenol into the enamel pore system seems possible.

To explain the findings of our study, two other points might be relevant. First, the amount of eugenol permeating into enamel could be too low to impair composite adhesion. Secondly, acid etching completely removes a layer of enamel of about 10 µm (Silverstone, 1974), which in our study had previously been in direct contact with the eugenol-containing cements or pure eugenol.

CONCLUSION

Based on the results of this in vitro experiment, the exposure of enamel to a temporary cement or filling

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material containing either eugenol or no eugenol had no adverse effect on shear bond strength of a dual-curing resin luting cement (Dual Cement) to enamel when acid etching was performed according to clinically accepted standards.

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Shear Bond Strengths of Six Bonding Systems Using the Pushout Method of In Vitro Testing

C W WAKEFIELD • R A DRAUGHN
W D SNEED • T N DAVIS

Clinical Relevance
Some of the more recently introduced dentin adhesives showed significant differences in in vitro shear bond strengths.

SUMMARY

The newest generation of bonding systems consolidates multiple components into fewer containers in order to simplify clinical procedures and save clinicians time. Six newer adhesive systems (Scotchbond Multi-Purpose Plus, PROBOND, OptiBond FL, Prime & Bond, One Step, and Tenure Quik) were tested for in vitro shear bond strength (SBS) of a hybrid composite to both superficial and deep dentin at 24 hours and 6 months employing a pushout test method. Results showed significant differences in SBS between superficial and deep dentin for both 1-day and 6-month values for all adhesive systems except Tenure Quik. The SBS of OptiBond FL increased significantly for both superficial and deep dentin after 6 months' storage in 37 °C water. None of the other adhesive systems showed a significant change in SBS at 6 months. There appear to be several advantages to the testing method.

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INTRODUCTION

Dentin bonding systems continue to be developed at a rapid rate. Many current-generation materials have demonstrated shear bond strengths over 20 MPa, which approaches the tensile strength of human dentin (Barkmeier & Erickson, 1994; Gwinnett & Kanca, 1992; Sano & others, 1994, 1995; Yoshiyama & others, 1995). Bond values of optimal strength, however, are more difficult to achieve as dentin closer to the pulp is encountered (McCabe & Rusby, 1992; Pashley, 1991a; Pashley & others, 1993). This is because dentin nearest the pulp is composed of larger and more numerous tubules, resulting in a reduced amount of available mineralized intertubular dentin and an increased amount of peritubular dentin and tubules with associated moisture.

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Commercial dentin bonding systems differ in chemistry and complexity of application, but most depend upon removal or modification of the smear layer, demineralization of the superficial dentin, and then permeation by a hydrophilic, bifunctional monomer to form a hybrid layer (Nakabayashi, 1982; Nakabayashi, Ashizawa & Nakamura, 1992). Most dentin bonding systems consist of a single-component acidic conditioner; a hydrophilic resin primer (which may require mixing); and an unfilled, or lightly filled, resin adhesive. Some manufacturers have recently introduced products that combine one or more of these steps in order to make their materials more convenient to use.

Scotchbond Multi-Purpose Plus (3M Dental Products, St Paul, MN 55144), PROBOND (L D Caulk, Milford, DE 19963), and OptiBond FL (Kerr, Orange, CA 92667) use a single-component dentin primer followed by a light-cured adhesive resin. Recently introduced materials, Prime & Bond (L D Caulk), One Step (Bisco, Itasca, IL 60143) and Tenure Quik (Den-Mat Corp, Santa Maria, CA 93456), each combine the primer with the adhesive resin in a single bottle, further simplifying the clinical application. Bond strengths of 17-25 MPa have been reported for Scotchbond Multi-Purpose Plus and 15-21 MPa for PROBOND (Swift & Triolo, 1992; Swift, Denehy & Beck, 1993; Eick & others, 1993; Caulk/Dentsply, 1993). The manufacturers of the original, previous-generation OptiBond Multi-Use and Tenure materials claim shear bond strengths of 26 MPa and 21 MPa respectively (Kerr, 1992; Den-Mat Corp, 1993). However, very little information exists for the recently introduced materials, Prime & Bond, One Step, OptiBond FL, and Tenure Quik.

Most in vitro shear bond strength testing is done by applying a force perpendicular to the long axis of a composite cylinder that has been bonded to the flattened tooth surface. It is impossible to load this apparatus in shear without a component of tensile load being introduced as well (Barkmeier & others, 1994). A pushout test methodology is widely employed to investigate bonding and mechanical stabilization of orthopedic biomaterials in bone (Wang & others, 1993; Friedman & others, 1996). In this test, the material to be evaluated is placed in cylindrical holes drilled in bone. In most experiments, the bone is harvested after prescribed periods of time, and the force required to dislodge the test material when pushed out of the holes with a smaller cylinder is measured. Finite element modeling studies (Dhert & others, 1992) have shown that with appropriate selection of test parameters, a uniform shear stress can be applied at the material/bone interface when using the pushout test. According to finite element analysis (Dhert & others, 1992), these test fixture and specimen dimensions should produce an essentially uniform shear stress at the composite-dentin interface when force is uniformly applied to the face of the composite specimen. The development of a uniform shear stress without the presence of a tensile component is an important advantage of the pushout test methodology.

The purpose of this study was (1) to describe an in vitro, pushout testing technique that can provide shear bond strength measurement of multiple specimens on the same tooth at various dentin depths and (2) to use the pushout test to compare the shear bond strengths of six recently introduced dentin bonding agents to both superficial and deep dentin after storage in water for 24 hours and 6 months.

METHODS AND MATERIALS

Intact permanent molars were stored in Chloramine-T solution (Mallinckrodt, Inc, Paris, KY 40361) for not more than 90 days following extraction. Before laboratory investigation began, the teeth were stored in 37°C distilled water for 1 week, with the water being changed daily in order to assure absence of amine residue from the Chloramine-T. The molars were then individually embedded in cubic blocks of tray acrylic of approximately 25 mm on a side and stored in 37 °C distilled water.

The teeth were then sectioned on a horizontal plane just below the dentinoenamel junction, so that no enamel remained, using a 0.3 mm-thick Buehler Diamond Wafering Blade—High Concentration #11-4243 (Buehler Ltd, Lake Bluff, IL 60044). Then with the tooth in position on its side, the diamond blade was moved apically and another section cut so that a 3.0 mm-thick wafer of occlusally oriented dentin was produced. The blade was moved further apically and the same procedure followed to yield another 3.0 mm-thick wafer from more pulpally oriented

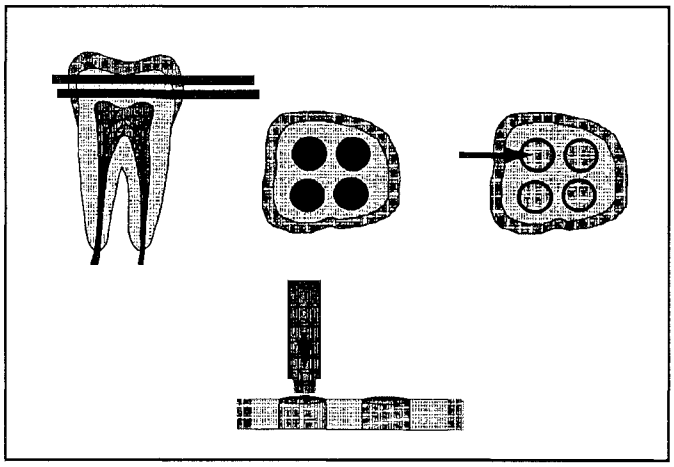

Figure 1. *Schematic of the pushout test method*

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Table 1. Bonding Systems Investigated

Bonding System	Batch		Exp Date
One Step			
light-cured universal dental system			
Bisco Inc, Itasca, IL 60143	Uni-Etch	029215	2/97
	Adhesive	049045	10/96
Opti-Bond FL			
filled light-cured adhesive with fluoride release			
Kerr Corp, Orange, CA 92667	Gel Etchant	504611	5/98
	Prime	504415	4/97
	Adhesive	505046	10/96
Prime & Bond			
direct composite bonding agent			
L D Caulk/Dentsply, Milford, DE 19663	Prime & Bond	950426	4/98
PROBOND			
all-purpose bonding agent			
L D Caulk/Dentsply	Primer	941123	11/97
	Adhesive	950228	2/98
Scotchbond Multi-Purpose Plus			
dental adhesive system	Etchant	4AY	4/97
3M Dental Products, St Paul, MN 55144	Primer	4HE	4/97
	Adhesive	4AX	4/97
Tenure Quik			
Den-Mat Corp, Santa Maria, CA 93456	Etchant	251033	7/98
	Tenure Quik	226001	8/97
Prodigy Hybrid Composite			
shade Vita B-1			
Kerr Corp		503183	3/98

dentin. These sections were labelled "superficial" and "deep" dentin, and the molar from which they were cut recorded (Figure 1). All wafers were stored in 37 °C distilled water prior to preparation.

Cylindrical holes were drilled through the wafers by clamping them on a platform over a 2.0 mm-in-diameter hole and using a 0.5-horsepower 10-inch drill press (Sears Craftsman, Chicago, IL 60641) and a 1.55 mm-in-diameter steel twist drill. Holes were drilled through each section a minimum of 0.3 mm from the DEJ and with 1-2 mm intact dentin remaining between holes. The area of each wafer allowed three or four holes to be placed in most sections. Thus, each tooth should have provided two disks with three or four test specimens per disk. The orientation of the sections on the platform was such that the holes were drilled from the occlusal aspect of each section. The shear bond strength determination was later measured with the sections oriented in the same manner to assure that each hole was always perpendicular to the base of the section. All drilled specimens were stored in 37 °C distilled water prior to placement of the bonded resin composites.

Sections to be tested were randomly selected. In order to assure the presence of an intact smear layer, all holes were restored with Prodigy Composite (Kerr Corp, Orange, CA 92267) shade Vita B-1 (Vita Zahnfabrik, Bad Säckingen, Germany) within 24 hours after drilling the holes using one of six bonding systems (Table 1) following the manufacturer's directions. After placement of each bonding system, the dentin wafer was placed on a glass slab and the composite placed in two increments. Each increment was cured for 60 seconds from the occlusal aspect using an Optilux 400 (Demetron/Kerr, Danbury, CT 06810) visible-light-curing system with a 10 mm-in-diameter light guide. The intensity of the light was maintained above 450 mW/sq cm throughout the procedure (Caughman, Rueggeburg & Curtis, 1995; Manga, Charleton & Wakefield, 1995) as verified with a radiometer (Demetron/Kerr). At least 14 holes were restored in both superficial and deep dentin with each bonding system, of which at least seven would be tested for SBS at 24 hours after placement and seven after 6 months.

The placement of composite for each bonding system was as follows.

One Step

The drilled hole was etched with Bisco Uni-Etch 32% phosphoric acid for 15 seconds. After thorough rinsing, excess water was removed with a brief burst of air, taking care to leave the dentin shiny and slightly moist and not desiccated. Two consecutive coats of adhesive were applied to the dentin lining the hole.

The hole was gently air dried for 5-10 seconds to remove excess solvent and water, leaving a shiny surface. The hole was light cured for 10 seconds from the occlusal aspect of the dentin section. The adhesive remaining on the brush tip was applied to the preparation and air dried. Prodigy hybrid composite was placed and cured in two increments

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with the specimen on a glass slab. Each increment was light cured for 60 seconds. The sample was stored in 37 °C distilled water.

OptiBond FL

The walls of the specimen were etched for 15-20 seconds with the supplied phosphoric acid etchant. The preparation was rinsed for 15 seconds and gently dried for 5 seconds, leaving the dentin slightly moist. Using the Kerr applicator, OptiBond FL Prime was applied with a scrubbing motion for 30 seconds, replenishing the applicator to keep it wet. The sample was air dried for 5 seconds, followed by application of OptiBond FL adhesive in a thin layer and a 30-second light cure from the occlusal surface of the preparation. Prodigy composite was placed as before and the specimens stored.

Prime & Bond

The drilled hole was etched for 15 seconds with Bisco Uni-Etch 32% phosphoric acid, rinsed for 15 seconds, and gently air dried, avoiding desiccation. Prime & Bond adhesive was applied using Kerr applicators and left undisturbed for 30 seconds. Excess solvent was removed with a gentle 5-second air burst, and the preparation was light cured for 10 seconds. For optimal results (as per the manufacturer's instructions), a second coat was applied in exactly the same sequence as the first. Prodigy composite was then placed in the same manner as before and the samples stored.

PROBOND

The prepared dentin specimen was etched for 15 seconds with Bisco Uni-Etch 32% phosphoric acid, rinsed for 15 seconds and air dried, leaving the dentin moist and not desiccated. PROBOND primer was applied using a Kerr applicator for 30 seconds. The dentin was not scrubbed, but primer was continually added to assure dentin wetting. The preparation was air dried for 5 seconds. A thin layer of PROBOND adhesive was then placed on the preparation walls, followed by a gentle air blast to remove excess and eliminate pooling. The preparation was light cured for 10 seconds, followed by placement of Prodigy composite as before.

Scotchbond Multi-Purpose Plus

Scotchbond 35% phosphoric acid etchant was applied to the dentin holes for 15 seconds, followed by thorough rinsing for 15 seconds and gentle air drying, leaving the dentin moist. The Scotchbond primer was applied using supplied brushes and was immediately followed by gentle air drying for 5 seconds. After confirmation of the presence of a shiny surface, one coat of Scotchbond adhesive was applied and light cured for 10 seconds. Prodigy composite was used to restore the prepared hole in the same manner as before.

Tenure Quik

The preparations were etched for 15 seconds with the supplied Den-Mat 37% phosphoric acid etchant, rinsed for 15 seconds, and gently air dried for 5 seconds. Using a fully saturated brush tip, two consecutive coats of Tenure Quik adhesive were applied to the prepared surface. The specimen was then gently air dried for 1-2 seconds to remove excess solvent and water. The Prodigy hybrid was placed and cured as before.

After restoration, any composite flash present on the occlusal or cervical side of the dentin section was removed using a Hollenback carver, and all specimens were stored in 37 °C distilled water. Each bonding agent was employed in 14 superficial and 14 deep dentin specimens. Using the testing procedure described below, seven superficial and seven deep dentin samples for each bonding system were tested at 24 hours after restoration. The remaining restored

Table 2. Shear Bond Strengths from Pushout Tests

	Superficial Dentin				Deep Dentin			
	1 Day		6 Months		1 Day		6 Months	
	N	MPa	N	MPa	N	MPa	N	MPa
Tenure Quik	8	4.1 (2.2)	6	2.8 (2.1)	6	4.9 (2.5)	6	3.4 (1.9)
PROBOND	10	12.0 (4.7)	7	14.8 (4.8)	6	5.6 (3.3)	10	6.5 (3.2)
One Step	8	16.8 (4.7)	8	22.2 (7.6)	6	12.1 (2.6)	6	13.1 (6.4)
Prime & Bond	6	23.9 (3.4)	7	19.9 (7.2)	6	15.9 (6.9)	7	13.1 (4.7)
Scotchbond MP+	6	25.5 (7.9)	7	26.2 (10.1)	6	13.9 (5.8)	6	13.4 (4.4)
OptiBond FL	6	30.3 (11.1)	7	49.2 (8.7)	7	13.6 (5.0)	7	26.7 (1.4)

Standard deviations of the means in parentheses

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specimens were kept in 37 °C distilled water, with the water being changed weekly, and tested in the same manner at the 6-month postrestoration point.

After 24 hours or at the end of 6 months' storage in 37 °C distilled water, the 3.0 mm-thick dentin disks were positioned on a steel support platform with the 1.55 mm-in-diameter composite specimen centered over a 2.0 mm hole in the platform. A steel probe 1.27 mm in diameter was centered over the restoration and used to apply force to the test specimen. Specimens were tested using a hydraulically activated materials test system (Model 810, MTS Corp, St Paul, MN 55101). The test machine was operated in the displacement control mode with a linear displacement rate of 1.0 mm per minute. The force required to dislodge the bonded composite specimen was recorded in kilograms of force and converted to stress by dividing the force by the nominal interfacial area of the composite-dentin interface. Data for each bonding system were analyzed by *t*-tests ($P = 0.05$) to determine significant differences in SBS values between superficial and deep dentin specimens and between 24-hour and 6-month storage times. ANOVA and the Scheffé multiple range test were applied to determine significant differences in SBS values between the different adhesive systems.

RESULTS

Shear bond strengths as measured by the pushout test are shown in Table 2 and Figure 2. Application of *t*-tests ($P = 0.05$) showed significant differences between the shear strengths in superficial and deep dentin for both 24-hour and 6-month tests for all bonding systems except Tenure Quik. OptiBond FL showed significant increases in strength (*t*-test, $P = 0.05$) between 24 hours and 6 months for both superficial and deep dentin specimens. No other adhesive system showed a significant difference between 24-hour and 6-month SBS values. As indicated in Table 2, application of the Scheffé multiple range test ($P = 0.05$) showed the OptiBond FL shear strengths at 6 months to be significantly higher than the strengths of the other bonding systems.

DISCUSSION

Testing Method

The purpose of this portion of the study was to employ the pushout testing technique for SBS as it is commonly used in orthopedic biomaterials studies. This method offers a significant advantage over test methodologies that allow only one test specimen per tooth. In this study, it would have been ideal if each tooth had yielded one 3.0 mm-thick disk of superficial dentin and one 3.0 mm-thick section of deep dentin as per the initial study design. In fact, only approximately 50% of the molars provided samples at both depths that could be used for the tests. This was due to the fact that, after the cutting of the superficial sections, the deeper section often involved large amounts of the pulp chamber, and these sections were not used in the study.

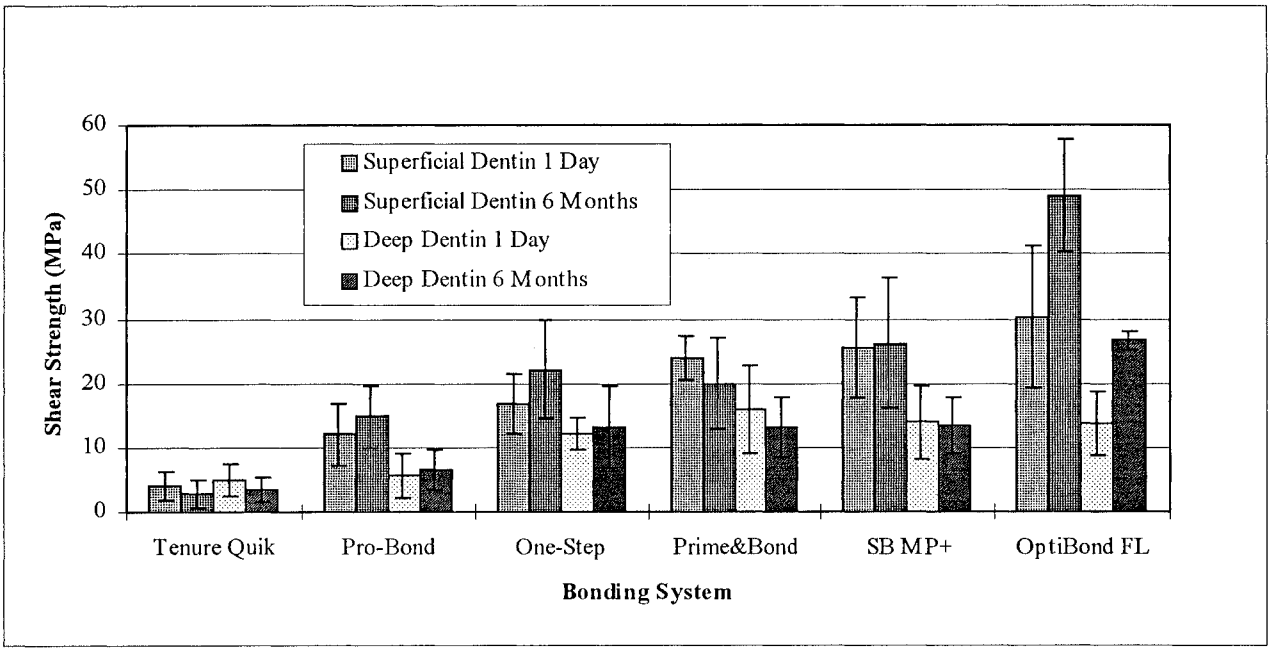

Figure 2. *Shear bond strengths from pushout tests. Vertical bars indicate standard deviations of the means.*

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Consequently, 50% of the comparison values between superficial and deep dentin do not come from the same tooth. Of course, in teeth with shorter clinical crowns that yielded only one section that was able to be used (and was labelled superficial), these specimens included both the most superficial and the deepest dentin in the same restoration. Even with the great diversity of dentin and variation between individual teeth, the results still indicate that significantly more successful bonding was obtained when more superficial dentin was involved. Thus, one must conclude that, when bonding to dentin, it is not only the adhesive system, but also the nature of the available dentin that determines the ultimate SBS values. When bonding clinically, other significant variables such as isolation, access, and operator technique complicate procedures even further.

When drilling holes in the deeper section, one may speculate that those holes placed closest to the DEJ on the lateral aspect of the specimens may be more representative of superficial dentin, but lower SBS values were still obtained in these cases. This may be due to the fact that, not only are the cervical dentinal tubules shorter, but, in these samples, these tubules were probably oriented so that they were horizontal to the surface of the wafer rather than vertical like the majority of tubules in the more occlusal sections. This may have contributed to the low SBS values attained in the deep dentin samples.

In general, however, SBS values seemed to approximate those found in many studies. Further studies are needed with controls to determine differences between the pushout test and the standard composite cylinder test for SBS. If there is a difference, this potentially could be attributed to tensile components of the bond affecting SBS values in the cylinder test.

SBS Tests

The SBS values at 24 hours showed that dentin bonding systems in general yield higher shear bond strengths in more superficial dentin. This is due to a greater amount of available intertubular dentin when closer to the DEJ (Pashley, 1991b; Paul & Scharer, 1993). The critical value for initial SBS of the hybrid and adhesive layers required to resist the formation of a contraction gap due to polymerization contraction of the composite material is 17-20 MPa (Munksgaard, Irie & Asmussen, 1985). This study did not test the SBS of the adhesives immediately upon placement, which would be of great importance as, clinically, composite is placed right after light curing of the adhesive system. In vitro investigation can, however, indicate relative trends when comparing different systems. Ultimately, clinical performance would provide an accurate assessment of each adhesive system, but in vitro studies are conducted under strict controls that are often not duplicated in many clinical practices. In vivo studies take long periods of time, at the end of which most manufacturers would be marketing a newer-generation adhesive system anyway.

In this study, for superficial dentin, four adhesives out of the six studied yielded satisfactory SBS values at 1 day and at 6 months. For deep dentin, none showed SBS values above 17 MPa at 24 hours, and only OptiBond FL was above this level after 6 months' storage in 37 °C distilled water. Four of the systems showed an increase in SBS to superficial dentin over 6 months, indicating continuing maturation of the bond after the 24-hour test. Of these four systems, three showed a slight increase, while OptiBond FL increased in SBS significantly. In addition, presumably, since this was an in vitro study, the presence of in vivo pulp pressure, dentinal fluids, hydrolysis, and the oral environment may compromise these values even further. When preparing teeth for direct composite restorations, clinicians should conserve as much tooth structure as possible in order to bond to more superficial dentin. It is important to remember that, with each successive generation of adhesives technique sensitivity increases, so it is essential that product directions are followed carefully in order to achieve the potential of each adhesive system.

As the newest-generation bonding systems stress high bond strengths, simplified applications, and less time for use, some compromises in performance may be found. Consolidation of systems into one bottle in the latest group of bonding systems includes Prime & Bond, One Step, and Tenure Quik. To include all the components required in a bonding agent in one bottle (primer and adhesive), changes in chemistry are necessary in order to prevent autopolymerization in the bottle. Stabilizers help to prevent autopolymerization, but shelf lives are shortened (Dr John Gwinnett, personal communication), and clinicians must be aware of these new expiration dates. As a result of these changes, Prime & Bond and One Step do not contain water, and thus it is highly stressed in the directions for these one-bottle products that the dentin must remain moist in order to achieve adequate wetting of the intertubular dentin. Therefore, these new products are increasingly more technique sensitive. It is interesting to note that, for all systems tested, etching of the dentin is now a standard procedure. Also included are instructions to not desiccate the dentin after rinsing, confirming the acceptance of the advantages of "wet bonding" (Kanca, 1992).

Tenure Quik contains water, and the manufacturer states that this agent is the "fastest" one-bottle system. It may be that low bond strength values

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were obtained with this product because it is the only system that was not light cured before placement of the composite. Tenure Quik relies on simultaneous cure, as the light is applied to the first increment of composite. However, this cure may not occur at a rapid-enough rate to enable it to resist contraction gap formation as the composite polymerizes, possibly yielding a lower bond strength. According to a recent study (Tay & others, 1995), the most important part of the bonding process may be the thorough volatilization of the solvents before addition of the composite. For Tenure Quik, only a 1-2 second air blast is recommended in the directions, possibly preventing complete polymerization of both the bonding agent and the deepest layer of composite due to residual acetone and water. For the single-bottle bonding systems currently on the market, Prime & Bond yielded the highest SBS values in this study, followed by One Step and then Tenure Quik. The directions for Prime & Bond state that, for optimum performance, two coats should be used, which has the disadvantage of using more time.

As mentioned, many of the deep dentin sections included pulp horns and were at the level of the pulp chamber. Most clinical preparations are not this close to the pulp, and the SBS values in this study may be lower than the average values achieved in a quality clinical practice. The highest values in the study were obtained with OptiBond FL. This system was the only filled bonding agent used in the study. Studies have shown that filled adhesives yield higher SBS values (Fanning & others, 1995) due to the "shock absorber" effect and the intermediate modulus of elasticity that they possess between that of the tooth and the restorative material. In addition to being filled, OptiBond FL is also radiopaque and releases fluoride. The increase in bond strength observed with OptiBond FL after 6 months' storage in 37 °C water may be due to strengthening of the bonding system/dentin interface region by diffusion of fluoride from the bonding resin into adjacent dentin, resulting in increased strength of the resin-dentin interdiffusion zone (Dr John Gwinnett, personal communication). It can also be hypothesized that the observed strength increase is due to continuing polymerization of the filled adhesive resin over time. The filled system may have an initially lower degree of polymerization than the unfilled systems, but because of the strengthening effects of the filler, it may have initial strength equivalent to the better unfilled resin adhesive systems. During the 6-month storage time at 37 °C, the filled resin may convert to a higher degree of polymerization, increasing the shear bond strength. Additionally, microleakage may have been less in this system, which may have decreased detrimental hydrolysis of the hybrid or adhesive layers. Microleakage may theoretically be less in a filled adhesive system, because the filler decreases the coefficient of thermal expansion of the bonding agent. The OptiBond FL SBS values at 6 months are higher than generally reported but are within the values reported for dentin shear strengths (Watanabe, Marshall & Marshall, 1996).

Finally, the solvent used in bonding systems may have a significant influence on the initial and long-term SBS when bonding dentin to a hybrid composite. OptiBond FL had the highest SBS values in this study and is an ethanol-based system. The second highest SBS values were recorded with Scotchbond Multi-Purpose Plus, which is water based and has no other solvents in the components used for direct light-cured composite bonding. The remaining bonding systems used in this study were all acetone based. Acetone may be so highly hydrophilic that it is difficult to be completely volatilized. Remaining portions of acetone may then compromise polymerization. Further studies are needed to test this hypothesis.

This study did not examine the nature of bond failure, whether adhesive between the bonding system and the tooth or cohesive within the bonding agents, composite, or tooth. Nor was microleakage studied. More investigations are needed to determine which bonding systems yield the greatest and most consistent clinical success and which in vitro tests correlate best with in vivo performance.

CONCLUSIONS

Advantages of the pushout test methodology are: 1) multiple specimens can be obtained from a single tooth; 2) a uniform shear stress can be applied to the tooth-material interface region; and 3) superficial and deep dentin bonding sites can be differentiated in a single tooth if specimens from both levels can be obtained.

The shear bond strength of the OptiBond FL system was significantly greater after 6 months' storage of test specimens in 37 °C distilled water than after 24 hours.

Of the one-bottle systems, Prime & Bond yielded the highest SBS values, followed by One Step and then Tenure Quik. Prime & Bond and One Step attained significantly higher SBS values compared to Tenure Quik.

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Clinical Evaluation of a Polyacid-modified Resin Composite (Compomer)

M J TYAS

Clinical Relevance
Dyract showed mixed promise as a direct tooth-colored restorative material in nonstress-bearing areas.

SUMMARY

The purpose of this study was to evaluate the clinical performance over 1 year of the proprietary polyacid-modified composite resin Dyract (DeTrey Dentsply).

Forty-one restorations (five in interproximal anterior cavities, 36 in noncarious cervical cavities) were placed following the manufacturer's instructions. After 1 year, one of the cervical restorations had been lost, and eight restorations showed some degree of marginal discoloration.

Overall, Dyract showed mixed results as a tooth-colored restorative material in nonstress-bearing areas. The long-term clinical performance and reasons for incipient marginal discoloration need further investigation.

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INTRODUCTION

During the last 5 years there has been a convergence of two types of aesthetic restorative materials: self-cure glass-ionomer (polyalkenoate) cement and resin composite.

Self-cure (conventional) glass-ionomer cements are two-component systems, usually powder-liquid. The powder consists of a fluoroaluminosilicate glass, and the liquid consists of one or more polyalkenoic acids. On mixing, an acid-base reaction takes place to form the set cement. Resin composite consists of a diacrylate resin matrix, commonly bis-glycidyl dimethacrylate (BIS-GMA) or urethane dimethacrylate (UDMA), often with small amounts of other monomers. Setting takes place by polymerization, initiated either by self-curing or light-curing.

Two types of combination materials have been developed in the last 5 years. The first is resin-modified glass ionomers (sometimes inappropriately termed "light-cured" or "dual-cured" glass ionomers), which consist essentially of two components, a powder of fluoroaluminosilicate glass, and a liquid of water-soluble polyalkenoic acid with pendant light-sensitive side-chains that can cross-link and thus polymerize. Polymerization can be light and/or

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chemically initiated (Sidhu & Watson, 1995). The second is polyacid-modified resin composites, which may be either single- or dual-component materials, containing either or both of the essential components of a glass ionomer; however, the components do not react as part of the setting process (McLean, Nicholson & Wilson, 1994). Two commercial examples of single-component polyacid-modified resin composites (Dyract, Dentsply DeTrey-DeDent, Konstanz, Germany and Compoglass, Ivoclar, Liechtenstein) both contain, as part of the resin matrix, an acid monomer. Both manufacturers use the term "compomer," to reflect the composite/glass-ionomer derivation of their products. The resin matrix in Dyract is TCB, the reaction product of butane tetracarboxylic acid and hydroxymethylmethacrylate, and contains two methacrylate groups and two carboxylate groups per molecule. The filler is a reactive silicate glass (72% w/w) containing fluoride, which is also used in a DeTrey Dentsply glass-ionomer cement (BaseLine). The monomer ionizes, following water uptake during the days/weeks after clinical light curing, and the hydrogen ions that are released then react with the glass filler to initiate an acid-base reaction. Ionic crosslinking also occurs, and fluoride is released (Dentsply DeTrey-DeDent, 1994).

Bonding of Dyract tooth structure is achieved by means of a primer (PSA Prime), which is applied to the clean, but unetched, enamel and dentin. PSA Prime consists of dipentaerythritolpentacrylate phosphoric acid monomer (PENTA) as the active ingredient, which is claimed to bond ionically to the tooth structure.

The purpose of this trial was to evaluate the 1-year clinical performance of Dyract.

METHODS AND MATERIALS

Ethics Committee approval was obtained, and 41 restorations were placed by a single clinician according to the manufacturer's instructions in nine patients of mean age 62 years (range 50 - 75 years). Cavities were cleaned with pumice and water using a rubber cup, then washed and dried. PSA Prime was applied for 30 seconds, dried with oil-free air, and light cured for 10 seconds. A second coat was applied, immediately dried, and light cured for 10 seconds. Dyract restorative was placed in slight excess, light cured for 40 seconds, and polished. Thirty-six restorations were placed without rubber dam in nonundercut cervical abrasion/erosion/abfraction lesions, with dentin/cementum cervical margins, distributed as follows: upper molars, 3; upper premolars, 6; upper canines, 4; lower molars, 6; upper incisors, 2; lower premolars, 10; lower anteriors, 5. Five restorations were placed in interproximal cavities in lower anterior teeth. Restorations were finished and polished at the placement visit with fine diamonds, then photographs were taken at 1:1 magnification on color slide film for base-line evaluation. Patients were recalled at 1 year, and further photographs taken.

The base-line and 1-year photographs were used to evaluate color match and marginal discoloration of the restorations, using standard photographs. The standard photographs enabled each restoration to be scored on a range of 1-17 for color match (1 = extreme color mismatch, restoration lighter than tooth; 17 = extreme color mismatch, restoration darker than tooth; 9 = no color mismatch) and marginal discoloration (0 = no marginal discoloration; 8 = severe marginal discoloration).

RESULTS

All patients returned for the 1-year recall. One cervical restoration was missing, from a lower molar. The retention rate was therefore 97% for the nonmechanically retained restorations, i e, excluding the interproximal restorations. The mean color match score at base line was 8.83, and at 1 year was 8.81 ($P = 0.97$), indicating a close color match to tooth that remained unchanged over the observation period. Of the 28 restorations photographed at 1 year (the remaining photographs being unsuitable for evaluation), eight showed some degree of marginal discoloration. The mean marginal discoloration score at base line was 0.02, and at 1 year was 0.56. The difference was statistically significant ($P = 0.001$), but overall, the extent of marginal discoloration did not warrant replacement of any of the restorations. No sensitivity was reported in any teeth.

DISCUSSION

The 1-year retention rate of 97% is consistent with the retention rates reported by others in similar restorations: 97.6% (van Dijken, 1995), 100% (Elderton & others, 1996), >98% (Jedynakiewicz, Martin & Fletcher, 1995), 100% (Barnes & others, 1996). Such a retention rate is remarkably high, given that the adhesive agent (PSA Prime) is claimed to bond chemically to enamel and dentin by ionic interaction between the hydrophilic phosphate group on the PENTA and the calcium ions in hydroxyapatite. When the 3-year results are reported, the effectiveness of the bond will become more meaningful. Previous experience with phosphate bonding, a feature of the early dentin adhesives (e g, Scotchbond Dual Cure, 3M Dental Products, St Paul, MN 55144), was disappointing, with high loss rates from nonundercut class 5 lesions (Tyas, 1993).

The bond strengths are claimed by the manufacturer

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to be 9.6 - 14.5 MPa to enamel and 10.6 - 14.5 MPa to dentin, depending on the test method, when PSA Prime (Dentsply DeTrey-DeDent, 1994) was used in all cases. Independent studies have reported values of 8.26 MPa to unetched enamel (Cortes, García-Godoy & Boj, 1993), 4.21 MPa to unetched enamel (Desai & Tyas, 1996), and 21.1 MPa to dentin (Triana & others, 1994). Although the manufacturers do not recommend enamel etching, it would be reasonable to expect a high bond strength to etched enamel, since Dyract is essentially a resin composite. This contention is supported by others, who recorded bond strength to etched enamel of 22.04 MPa (Cortes & others, 1993) and 14.3 MPa (Desai & Tyas, 1996), i e, an approximately three-fold increase compared to these authors' reports on unetched enamel. It is therefore pertinent to ask why the manufacturers do not recommend enamel etching. Is it possibly because of the practical problem of keeping etchant off the dentin? Since PSA Prime is claimed to bond ionically to dentinal calcium, then presumably etching the dentin could deplete the surface calcium and compromise the bond. However, this does not appear to have been tested experimentally.

The incipient marginal discoloration around some restorations is of concern, for it may indicate deterioration of the bond. In the present study, such discoloration affected eight of the 28 restorations photographed (all cervical restorations), and for three of these restorations, the discoloration was clinically conspicuous. Other clinical reports on Dyract have also reported marginal discoloration. For example, one study reported "statistically significant deterioration" at 2 years, but only one was considered clinically unacceptable (Elderton & others, 1996); in another study, one restoration was reported with "obvious marginal discoloration" (van Dijken, 1995). The site of the marginal discoloration was not given in these two studies, but in the present trial the restorations showing the most marginal discoloration did so at the enamel margin. This may reflect the comparative enamel and dentin bond strengths, which in one of the manufacturer's graphs, was less to enamel (9.6 MPa) than to dentin (14.5 MPa) (Dentsply DeTrey-DeDent, 1994).

In the present study, the five interproximal restorations retained their excellent color match, translucency, and polish at 1 year. None showed marginal discoloration; however, there were too few of this class of restoration to draw any meaningful conclusions.

One of the important determinants of restoration failure of dentin-bonded resin composites has been shown to be occlusal stress, at least for one dentin adhesive (Heymann & others, 1991). The product used (Prisma Universal Bond 2, DeTrey) was, like PSA Prime, also claimed to bond chemically to hydroxyapatite. Loss of restorations associated with occlusal stress was thought to be a consequence of tooth flexure, which was maximum at the cervical margin, thus rupturing the bond. This process was enhanced by a high elastic (Young's) modulus resin composite, since it did not flex in the same way as the tooth. The elastic modulus of Dyract has been reported to be 11.6 GPa (Braem & others, 1995) and 8.39 GPa (Attin, Vataschki & Hellwig, 1996), compared with 7.7 GPa for a microfill resin composite (Silux Plus, 3M Dental Products) and 16 GPa for a hybrid resin composite (Z-100, 3M Dental Products). It has been suggested that the elastic modulus of a cervical restorative material should be similar to dentin (Heymann & others, 1991). A value of ≥18 GPa for dentin has been cited, but no test method reported. It is well known that dentin is anisotropic, i e, the elastic modulus depends on the specimen orientation; thus unfortunately, no conclusions can be drawn from such data with respect to the performance of Dyract in the cervical region.

Dyract has had some clinical evaluation in stress-bearing areas (Peters, Roeters & Frankenmolen, 1995). After 1 year in class 1 and class 2 cavities in deciduous teeth, 190 μm mean wear was found. This would be unacceptable for permanent teeth, but not necessarily so for deciduous teeth.

CONCLUSIONS

Dyract showed mixed promise as a direct tooth-colored restorative material in nonstress-bearing areas. Longer-term clinical trials are needed, however, to assess the effectiveness of the bond. In addition, color stability and optical properties require confirmation. Fluoride release is a desirable property, and although fluoride release from Dyract can be measured, it is considerably less than that from glass-ionomer cements (Aboush, Torabzadeh & Lee, 1995). The clinical significance of this is unknown.

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Artificial Secondary Caries around Two New F-containing Restoratives

P DIONYSOPOULOS • N KOTSANOS
Y PAPADOGIANNIS • A KONSTANTINIDIS

Clinical Relevance
Light-cured fluoride-releasing restorations can inhibit caries-like lesions.

SUMMARY

Replacement of restorations due to secondary caries is a continuing problem in restorative dentistry. This investigation evaluated the ability of two new light-cured fluoride-containing restorative materials to inhibit caries in vitro. Class 5 cavities were prepared in buccal and lingual surfaces of 20 extracted premolars. The occlusal cavosurface margin of each preparation was on enamel and the gingival cavosurface margin was on root surface.

The four materials used were: glass-ionomer cement (Fuji II), composite resin (Silux Plus), light-cured glass ionomer (Vitremer), and compomer (Dyract).

After 5 weeks in an acid gel for caries-like lesion formation, the teeth were sectioned longitudinally and examined with polarized light. The results showed that use of a light-cured glass ionomer and/or compomer may prevent both secondary caries around restorations and primary caries in surface enamel adjacent to the restorations.

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INTRODUCTION

Replacement of restorations due to secondary caries is a continuing problem in restorative dentistry. The ability of a restorative material to resist secondary caries and microleakage at its margins will, to a great extent, determine whether a restoration will succeed or fail. Glass-ionomer materials have been introduced as restorative materials, and they may offer certain advantages in resisting secondary caries formation around restorations (Wilson, 1977). The glass-ionomer restorative material adheres to enamel and dentin by physicochemical means and is composed of a calcium aluminosilicate glass powder prepared with a fluoride flux and polyacrylic acid in an aqueous phase. Because of the presence of fluoride in the glass-ionomer material, a caries-resistant benefit has been claimed (Hicks, Flaitz & Silverstone, 1986; Dionysopoulos & others, 1994; Pourton & Rodda, 1988).

The conventional glass-ionomer systems, however, suffer from certain disadvantages. These disadvantages are the short working time, the long set time,

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susceptibility to early moisture contamination, dessication after setting, and brittleness. Recently, in order to overcome these limitations yet preserve their benefits, 3M Dental Products introduced the Vitremer Tri-Cure glass-ionomer system. According to information supplied by the manufacturers, when the power and liquid components are mixed together, the conventional ionomer reaction begins immediately. The photoinitiated free-radical methacrylate cure begins when the powder/liquid mix is exposed to light. The third reaction is a dark cure of the methacrylate groups of the polymer system and HEMA. This reaction is initiated by a system of water-activated redox catalysts, which allows the methacrylate cure to proceed in the dark.

Another restorative material introduced by De Trey Dentsply in order to overcome the limitations of conventional glass ionomers, yet preserve their benefits, is the compomer Dyract restorative. According to information supplied by the manufacturers, this material contains the TCB resin (resin formed by a reaction of butane tetracarboxylic acid and hydroxyethylmethacrylate) that contains acidic as well as acrylate groups and strontium fluorosilicate glass. The glass has a mean particle size of 2.5 μ and contains 13% (w/w) fluoride. After the initial light-activated polymerization, the traditional glass-ionomer reaction slowly emerges through the uptake of water and the establishment of an acid-base reaction resulting in a partially ionic structure within the polymeric matrix. This results in fluoride release in a similar manner to that of glass ionomers.

The aim of this study was to evaluate the ability of two new light-cured commercially available fluoride-containing restorative materials to inhibit caries at restoration margins. An acidified gel technique was used to create caries-like lesions around restorations.

Table 1. Materials Used in Each Group

Materials	Group	Manufacturer	Number of Cavity Preparations
Glass-ionomer cement (Fuji II)	1	GC International Corp, Tokyo, Japan	10
Composite resin (Silux Plus)	2	3M Dental Products, St Paul, MN 55144	10
Light-cured glass ionomer (Vitremer)	3	3M Dental Products	10
Compomer (Dyract)	4	De Trey Dentsply, Weybridge, Surrey, England	10

METHODS AND MATERIALS

Twenty extracted human upper premolars, free of caries and other defects, that had been stored in 10% neutral formalin were selected and randomly assigned to four groups. The teeth were not allowed to dry during any stage of the experiment. Before use the teeth were washed in tap water to eliminate the formalin fixative, and then cleaned with an aqueous slurry of pumice using a handpiece and rubber cup. For each tooth, two class 5 cavity preparations were cut, one each in the buccal and lingual surface. The occlusal cavosurface margin of each preparation was on enamel and the gingival cavosurface margin was on root surface.

The approximate dimensions of the formed cavity were: 3 mm mesiodistally, 1.5 mm occlusogingivally, and 1.5 mm in depth. A #557 straight fissure carbide bur was used in a high-speed handpiece with water spray as coolant. The bur was maintained at a right angle to the tooth surface to produce a cavosurface angle close to 90°. The preparation margins were finished with a flat fissure bur (#56, S S White Burs Inc, Lakewood, NJ 08701) using a slow-speed handpiece. After rinsing with water, the cavities were dried with compressed air. The preparations were restored using each of the four materials (Table 1). Group 1 (Fuji II) and Group 2 (Silux Plus) were used as control groups. The composite resin Silux and the compomer Dyract are light-cured single-paste systems. Fuji II glass-ionomer cement and Vitremer were mixed according to the manufacturers' instructions. Before the glass-ionomer restorative material Fuji II was inserted, the liquid portion of the glass-ionomer restorative material, polyacrylic acid, was placed in the cavity preparation, and a gentle airstream was used to wet the cavity walls and base with a thin cover of polyacrylic acid. The cavity preparation was exposed to the polyacrylic acid for 10 seconds, rinsed with an air/water stream for 5 seconds, and then dried for 5 seconds. After the glass-ionomer materials were placed into the cavity preparations, a foil matrix was pressed to ensure good adaptation. Immediately after removal of the matrix, the surfaces of the restorations were coated with a moisture-resistant varnish.

The enamel surface of the preparations designated for composite resin was etched with 37% phosphoric acid for 30 seconds, then thoroughly rinsed and dried. The acid-etched enamel was covered with Scotchbond Multi-Purpose (3M Dental Products) before insertion of the Silux. The composite resin was placed in the preparation in two increments. The overfilled resin was reduced to the correct contour during polishing.

In compomer restorations enamel and dentin were covered with Dyract-PSA Prime/Adhesive according to the manufacturers' instruction. The compomer was placed in the preparation in two increments. The overfilled resin was reduced to the correct contour during polishing.

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For the Vitremer restorations, the enamel and dentin were covered with Vitremer Primer according to the manufacturers' instruction before insertion of the glass ionomer. The overfilled resin was reduced to the correct contour during polishing in similar fashion to the other restorations.

The materials Silux, Vitremer, and Dyract were light cured according to the instructions of the manufacturers using a visible light unit (Visilux, 3M Dental Products).

All restored teeth were stored in a humid environment for 24 hours before finishing and polishing the restorations to ensure maximum polymerization of the materials. The glass ionomers, compomer, and composite resin restorations were finished by sequential use of three grades of Sof-Lex disks (3M Dental Products). The teeth were then subjected to thermocycling for 800 cycles between 5 and 55 °C with a dwell time of 30 seconds. Subsequently, all teeth were painted with an acid-resistant varnish to within 1 mm of the cavosurface margins surrounding the restorations. The teeth were then immersed in jars containing an acid gel for caries-like lesion formation (Kotsanos & others, 1989). The gel contained 10% methylcellulose and 0.1 M lactic acid, and the pH was adjusted to 4.5 with potassium hydroxide.

After 5 weeks the teeth were removed from the acid gel, rinsed thoroughly with water, and sectioned buccolingually/longitudinally through the restorations using a diamond sectioning saw. The sections were then ground to a thickness of about 80 µm. Three sections were obtained through the middle part of each restoration. After 24 hours of imbibition in water, the sections were examined and photographed in polarized light. The lesions formed in enamel consisted of outer surface and cavity wall lesions (Figure 1). Measurements were made of the lesion using a calibrated eyepiece reticule. The measurements included: 1) the depth of the outer lesion as the largest distance between the enamel surface and the inner border of the lesion, and 2) the depth of the wall lesion as the largest distance between the restoration and the inner border of the lesion, and the wall lesion extent from the enamel surface to the axial wall of the cavity preparation. The altered sign of birefringence of demineralized dentin (Silverstone, 1967; Pourton & Rodda, 1988) was used to detect caries-like lesions in the cavity preparation walls. The depths of the demineralized lesions were measured from the cavosurface angle along the line of the apical wall of each cavity. Measurements are illustrated in Figure 1.

All relative measurements from the three sections of each lesion were averaged, and the data were compared statistically using analysis of variance (ANOVA) and Tukey's HSD test. One examiner did the scoring and was blind to knowing which were test and which were control specimens.

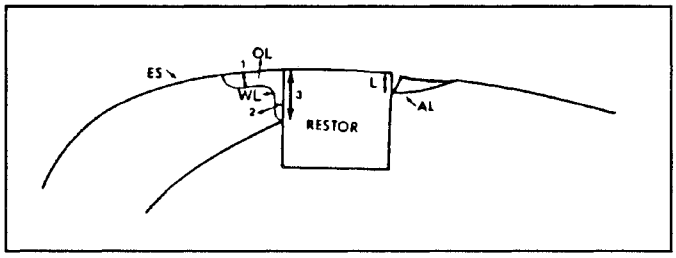

Figure 1. *Schematic representation of various parts of caries-like lesions formed around a restoration. The carious lesion in enamel consists of a primary outer surface lesion (OL) and a secondary cavity wall lesion (WL). The measurements made on each enamel lesion are: (1) the body depth of the outer surface lesion is measured as the largest distance lesion; (2) the body depth of the wall lesion is measured as the largest distance between the restoration and the inner border of the lesion; (3) the wall lesion length is measured from the enamel surface to the innermost extended portion of the WL towards the axial wall of the cavity. The altered sign of birefringence of demineralized dentin was used to detect caries-like lesions in the cavity walls. The depths of the demineralized lesions (L) were measured from the cavosurface angle along the line of the apical wall (AL) of each cavity.*

RESULTS

Figure 2 shows a typical lesion in enamel produced after a 5-week immersion in acid gel, consisting of an outer surface lesion (OL) and cavity wall lesion (WL).

The caries-like lesions in the cementum and dentin were clearly demarcated from the surrounding tissue by their altered sign of birefringence.

The outer surfaces of the lesions were concave, or sunken, in contour, and V-shaped notches separating dentin from the restorative material were evident at the cavosurface margins (Figures 3-5).

The mean thickness of the depth of the body of the lesion for the outer and wall lesions, the wall lesion length in enamel, as well as mean lesion depths in dentin

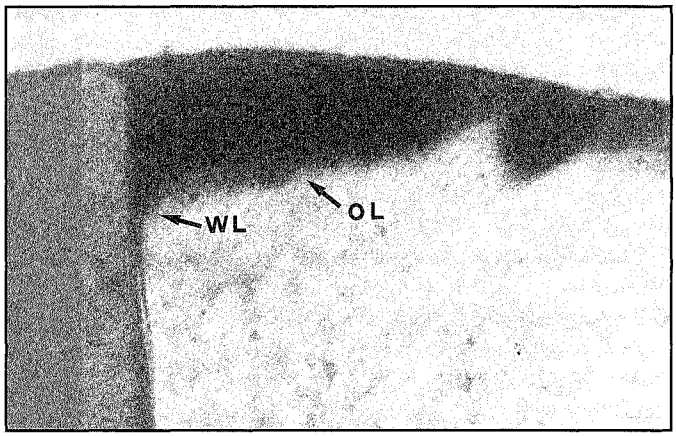

Figure 2. *A typical caries-like lesion formed in enamel around a compomer-restored cavity. It consists of an outer surface lesion (OL) and a cavity wall lesion (WL).*

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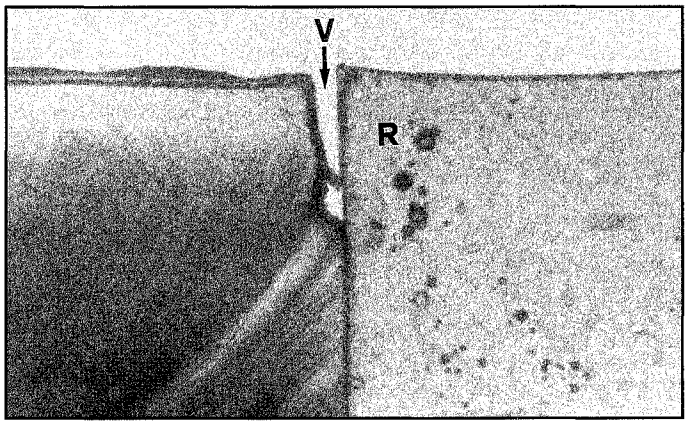

Figure 3. *Section showing a compomer restoration (R) and V-shaped notch (V) at the cavity wall*

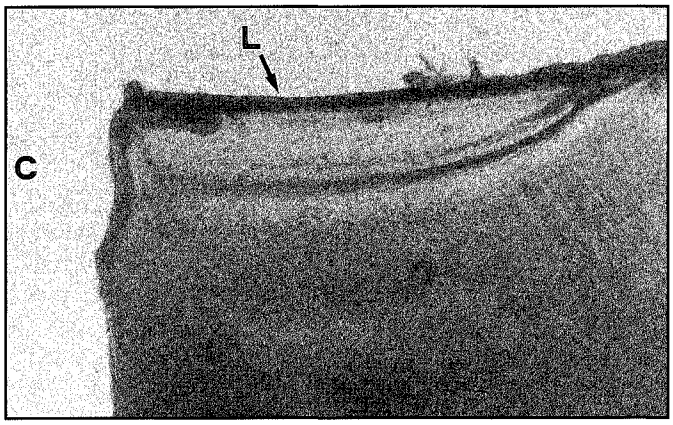

Figure 4. *View of a section showing a caries-like lesion (L) formed adjacent to the composite resin restoration that has been lost from the cavity preparation (C) during sectioning*

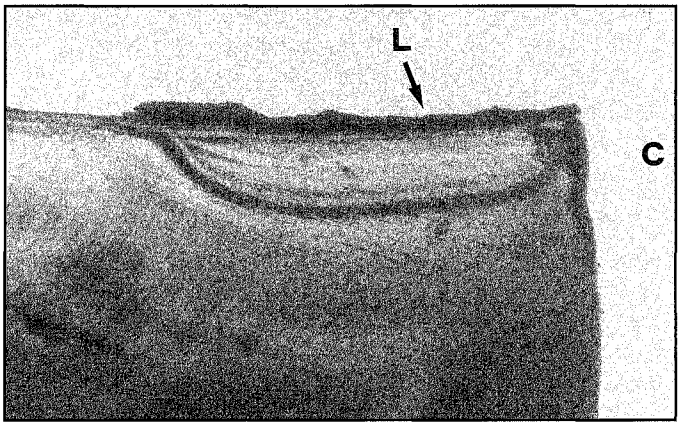

Figure 5. *View of a section showing a caries-like lesion (L) formed adjacent to the light-cured glass-ionomer restoration that has been lost from the cavity preparation (C) during sectioning*

are shown in Table 2. The mean depth of the body of the outer lesions ranged from 64 μm for Fuji II restorations to 136 μm for composite resin restorations (Silux). The average depths of the body of the outer lesions in teeth restored with composite resin (Silux) were significantly higher than for the teeth restored with Fuji II and Vitremer ($P < 0.05$). There was no significant difference in the depth of the body of the outer lesion among teeth restored with Vitremer, Dyract, and Fuji II ($P < 0.05$).

The mean wall lesion length ranged from 54 μm for Fuji II to 182 μm for Silux. The wall lesion length for the teeth restored with Fuji II and Vitremer was significantly smaller than for the teeth restored with Silux ($P < 0.05$). The wall lesion length for teeth restored with Dyract was significantly higher than for the teeth restored with Fuji II and significantly smaller than for the teeth restored with Silux ($P < 0.05$). There was no significant difference in wall lesion length between Vitremer and Dyract nor between Vitremer and Fuji II.

The mean depth of the body of the wall lesions ranged from 16 μm for Vitremer restorations to 58 μm for Silux. The depth of the body of the wall lesions for teeth restored with Fuji II and Vitremer was significantly smaller than the teeth restored with Silux ($P < 0.05$). There was no significant difference in depth of the body of the wall lesion between Vitremer and Dyract nor between Dyract and Silux. The mean lesion depth in dentin ranged from 124 μm for Vitremer restorations to 362 μm for Silux. The lesion depth for the teeth restored with Silux was significantly higher than for the other groups ($P < 0.05$). There was no significant difference in lesion depth among the other groups.

DISCUSSION

The acidified gel technique is a valuable method for the production of caries-like lesions around restorations, and its histopathology is similar to early secondary natural caries (Hals, Andreassen & Bie, 1974; Kidd & Silverstone, 1978; Hicks & Silverstone, 1982; Kidd, 1983). The lesion consists of two parts, an outer surface lesion showing the features of primary attack on the tooth surface, and the cavity wall lesion forming as a consequence of microleakage of acidic products from dental plaque or acidified gelatin gel along the tooth-restoration interface.

The features of dentin shrinkage and open V-shaped notches at cavosurface margins have been described in several previous studies that used a variety of in vitro and in vivo experimental caries techniques (Hals & Kvinnsland, 1974; Hals & Laegred, 1976; Clarkson, Wefel & Miller, 1984). An explanation for the shrinkage is that dissolution of the mineral crystallites is followed by the collapse of the collagen matrix of the hard tissues (Purton & Rodda, 1988).

The technique used in this study was efficient in creating caries-like lesions at rates comparable to

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Table 2. Mean and Standard Deviation (±SD) Measurements (μm) of Lesions around Restorative Materials of the Four Test Groups

Restorative Material	Enamel			Dentin
	Outer Lesion	Wall Lesion		
	Body Depth	Lesion Length	Body Depth	Lesion Depth
Fuji II	64 (±57)	54 (±47)	16 (±12)	188 (±80)
Vitremer	69 (±38)	80 (±62)	26 (±19)	124 (±97)
Dyract	105 (±44)	120 (±59)	40 (±26)	164 (±79)
Silux Plus	136 (±41)	182 (±53)	58 (±24)	362 (±119)

Number of sections = 60; number of measurements = 240. Brackets indicate significant difference by ANOVA and Tukey's HSD test; $P < 0.05$.

those occurring in vivo, and utilized a gel medium with organic and inorganic elements that acted as a substitute for the plaque occurring in vivo (Kotsanos & others, 1989).

The importance of secondary caries around composite restorations has been shown in several epidemiological studies (Mjör, 1985; Qvist, Qvist & Mjör, 1990). Secondary caries is especially important in cavities with margins located beyond the enamel-dentin junction. Polymerization contraction causes the composite to shrink toward the side with the strongest bond, the enamel, resulting in a gap between composite and gingival cavosurface margin. In vitro, the initial gap around composite restorations varies between 10 and 30 μm (Torstenson & Brännström, 1988; Tjan, Bergh & Lidner, 1992).

The results showed that, when compared with a composite resin, the compomer and light-cured glass ionomer had an inhibiting effect on the development of experimental lesions in vitro. The inhibiting effect on the development of experimental cavity wall lesions around compomer and light-cured glass-ionomer fillings reported in this study may be due to fluoride present in the materials and/or less marginal leakage around the fillings. Previous studies indicated that light-cured glass-ionomer materials provided a significant protection against a caries-like attack at restoration interfaces (Bynum & Donly, 1994; Magamine & others, 1994).

The apparent caries resistance of enamel and dentin that forms the cavity walls adjacent to the materials tested is thought to be caused by the availability of fluoride for release from the light-cured glass-ionomer materials (Cao & others, 1994; Musa, Pearson & Davies, 1994; Retief & others, 1984) and compomer Dyract (Aboush, Torabradeh & Lee, 1995).

The fluoride released from the glass ionomers is not lost over time but becomes incorporated into the mineral component of enamel and cementum, perhaps as fluoridated hydroxylapatite (Retief & others, 1984). It is well known that caries initiation and progression decreases significantly when fluoride is incorporated into the mineral structure of enamel dentin and cementum (Hicks, Flaitz & Silverstone, 1985; Dionysopoulos, Kotsanos & Papadogianis, 1990). In addition, fluoride released from glass-ionomer restorations may alter the metabolic activity of plaque formed at the margins of the restorations, thereby altering the cariogenic potential of plaque in the immediate vicinity of the restoration (Norman & others, 1972).

CONCLUSIONS

It can be concluded from this in vitro study that secondary caries progression may be reduced significantly in enamel and dentin when light-cured glass ionomer (Vitremer) and compomer (Dyract) are used as the restorative materials. Initiation of the lesions in surface enamel adjacent to the light-cured glass ionomer was reduced significantly, compared to the control lesions.

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Polymerization of Composite Resins: Argon Laser vs Conventional Light

M A VARGAS • D S COBB • J L SCHMIT

Clinical Relevance
The argon laser adequately polymerized composite resin, as indicated by Knoop hardness values, to a depth of 2 mm in half the time for the hybrid and two-thirds the time for the microfill composite resin compared to a conventional light-curing unit.

SUMMARY

The purpose of this in vitro study was to compare polymerization of composite resins, as indicated by microhardness, at increasing depths using an argon laser versus a conventional light. For this, a microfill (Silux Plus) and a hybrid (TPH) composite resin were used. Five specimens per group were prepared by injecting composite into a rectangular split Teflon mold 3 x 3 x 8 mm. Specimens were then polymerized by either a 40-second exposure to the conventional visible light (VL) or a 30-, 20-, or 10-second exposure to the argon laser (AL). Specimens were stored in a light-proof container for 24 hours at 37° C, then Knoop hardness was determined. Four measurements were taken for each specimen at depths of 0, 1, 2, 3, and 4 mm from the exposed surface. No significant differences were found in surface hardness for either the microfill or hybrid composite regardless of light source or exposure time. For the microfill composite, at 1, 2, 3, and 4 mm depths, VL40 and AL30 exposures produced comparable hardness, which was significantly greater than that found for AL20 and AL10. At a depth of 4 mm, exposure to VL40 resulted in significantly greater hardness compared to AL20. With AL10 exposure, the composite was too soft to determine hardness. The hybrid composite had comparable hardness to a depth of 3 mm for VL40, AL30 and AL20.

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INTRODUCTION

In recent years, the popularity of esthetic tooth-colored restorations has sparked a dramatic rise in the use of resin restorative materials. This use presents the dental practitioner with new restorative challenges, such as incremental placement of direct resin restorations and adequate polymerization of resin materials. These procedures are also technique sensitive and require considerably more time than conventional ones.

Adequate polymerization is a crucial factor in obtaining optimal physical properties and clinical performance of composite resin restorative materials (Bayne, Heymann & Swift, 1994; Ferracane, 1993). Problems associated with inadequate polymerization include inferior physical properties, solubility in the

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oral environment, and increased microleakage with resultant recurrent decay and pulpal irritation (Ferracane, 1993; Blankenau & others, 1991).

Light-activated resins rely on sufficient intensity of light to achieve adequate polymerization (Rueggeberg & others, 1993). As light passes through composite, it is absorbed and scattered, attenuating the intensity and reducing the effectiveness of the light for resin polymerization as the depth increases (Rueggeberg & Craig, 1988). Factors affecting depth of cure of light-activated composite resins include the following: filler type, size, and loading; light transmission attenuation; type, thickness, and shade of restorative resin; exposure time; distance from light source; and light intensity (Bayne & others, 1994; Cook, 1980; Sakaguchi, Douglas & Peters, 1992).

Current visible-light curing units often fail to meet the challenges of today's demands for more complex resin restorations. Inadequate power output, long curing times, narrow light tips (<12 mm in diameter) and the degradation of components (bulbs, reflectors, filters, and light tips) make it difficult to adequately cure composite resin, especially in deeper areas (Sakaguchi, Douglas & Peters, 1992).

Recently, there has been an interest in using an argon laser to initiate polymerization of composite resin restorations. Results of early studies suggest that polymerization of this material with an argon laser results in physical properties superior to those cured by using a conventional visible light (Blankenau & others, 1989, 1991, 1992; Kelsey & others, 1989; Kelsey, Blankenau & Powell, 1991; Powell & others, 1989). Argon laser light differs significantly from conventional visible-light sources. These differences include: 1) energy emission over a narrower band of wavelengths (≈ 40 nm vs 120 nm) centered around 470 nm, which is the optimal wavelength for activating the photoinitiator camphoroquinone (Kelsey & others, 1992), and 2) collimation of the argon laser light, resulting in more consistent power density over distance. In contrast, the power density of conventional visible light decreases with distance, due to greater light divergence from the source (Blankenau & others, 1991; Kelsey & others, 1989; Dederich, 1993). These two factors may lead to an increase in efficiency in the light energy of the laser in activating polymerization of composite resins.

Several studies have looked at physical properties of composite resin polymerized with an argon laser versus a conventional visible light. Few, however, have compared microhardness of resin at varying depths for the two light sources. Microhardness has been shown to be an adequate indicator of the degree of conversion or polymerization of composite resins (Asmussen, 1982; Ferracane, 1985). The degree of polymerization is a valuable predictor of the clinical performance of a resin restorative material (Hansen & Asmussen, 1993; Sakaguchi & others, 1992). In a study by Masutani and others (1990) surface hardness of resin cured with an argon laser was compared at equivalent energy densities, but with varying power output and exposure times. Greater surface hardness was achieved using a lower power output (300 W/m^2) for 40 seconds as compared to 600 W/m^2 for 20 seconds. Severin and Maquin (1989) reported greater surface hardness using an argon laser at a minimum of 100 mW, compared to a conventional light at equivalent exposure times. Puckett and Bennett (1992) compared both surface and bottom hardness of composite resin polymerized by an argon laser for 10 seconds versus a conventional light for 30 seconds. Although surface hardness was not significantly different for either light source, bottom hardness at 3 mm was significantly greater when polymerized by the argon laser versus the conventional light. Waknine and Cipolla (1995) obtained comparable surface hardness with 5 seconds of exposure to an argon laser versus 40 seconds with a conventional light, while comparable bottom hardness through 1 mm thickness of resin was achieved with 10 seconds of exposure by the argon laser.

Although microhardness is a typical parameter for indicating the degree of polymerization of composite resins (Ferracane, 1985), adequate surface hardness does not ensure thorough polymerization throughout the restoration (Asmussen, 1982). It has been shown that the degree of polymerization of a light-activated composite resin decreases with increasing depth from the exposed surface (Hansen & Asmussen, 1993). Previous studies have reported severely underpolymerized material at the bottom of restorations cured according to the manufacturer's recommended curing times (Ishioka, 1983; Yearn, 1985). This poorly polymerized resin can lead to undesirable consequences such as gap formation, marginal leakage, recurrent caries, adverse pulpal effects, and ultimate failure of the restoration (Ferracane, 1993). Bottom hardness greatly influences the long-term prognosis of a restoration (Hansen & Asmussen, 1993). Therefore, it is of interest to evaluate microhardness at varying depths to determine adequate polymerization and thus physical properties of resin restorative materials.

Based on the results of numerous studies (Swartz , Phillips & Rhodes, 1983; Yearn, 1985; Atmadja & Bryant, 1990), manufacturers currently recommend 40 seconds of exposure to a conventional visible light for adequate polymerization of resin restorative materials up to 3 mm depth. However, questions remain as to the appropriate exposure time to achieve comparable polymerization using an argon laser. This study examined the depth of cure of a microfill and a hybrid composite resin by comparing the

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microhardness at 0 to 4 mm when polymerized by an argon laser for 10, 20, and 30 seconds, or a conventional visible light source for 40 seconds.

METHODS AND MATERIALS

Two composite resins were used in this study: Silux Plus (SP) (3M Dental Products, St Paul, MN 55144) microfill universal shade and TPH hybrid (L D Caulk, Milford, DE 19963) shade A2.

Specimen Preparation

Five specimens per group were prepared by placing the composite in a rectangular split Teflon mold: width 3 mm, length 3 mm, and depth 8 mm. Samples were then polymerized by either a 40-second exposure to a Coltolux II (Coltène AG, Alstätten, Switzerland) visible-light curing unit (VL), or a 30-, 20-, or 10-second exposure to an argon laser (AL), ILT Model 5500 A (Ion Laser Technology, Salt Lake City, UT 84116). The power output of the light sources was measured using an Ophir laser power meter, (Ophir Optronics Inc, North Reading, MA 01960) and curing-light performance was verified with the Ophir meter for each group. The power output of the argon laser was maintained at 265 mW. The spot size from the light tip was 6 mm diameter, resulting in a power density of 937 mW/cm^2. The VL had a power output of 470 mW, a 13 mm spot size, and a power density of 354 mW/cm^2.

Testing

Specimens were stored in distilled water in a light-proof container for 24 hours, and hardness was determined using an Ecomet Micro-Hardness Tester (Buehler Ltd, Lake Bluff, IL 60044) (25 g load for 12 seconds for SP and a 50 g load for 12 seconds for TPH). Hardness measurements were made at the surface of each specimen for 0 depth and along one side of the composite specimen perpendicular to the light source at 1, 2, 3, and 4 mm depths (figure). Four measurements were taken at each depth and the average was converted into a Knoop Hardness Number (KHN). Means were then calculated for each group.

Statistical analysis was performed using a three-way analysis of variance (ANOVA) at $\alpha = 0.05$, with the SAS (SAS Institute, Cary, NC 27513) software package. The three main variables were material (2 levels), depth (5 levels), and light exposure (4 levels). Since all interactions were considered and none were significant, one-way ANOVA was done on the three main effects. Duncan's Multiple Range post hoc test for pair-wise comparison was used to determine where significant differences existed.

RESULTS

Mean hardness values, (SD) and *P*-values at depths of 0 to 4 mm for all groups are summarized in Tables 1 to 4. Tables 1 and 3 compare hardness values according to depth and Tables 2 and 4 compare hardness values according to exposure source.

For the three main variables (material, depth, and exposure source), the three-way ANOVA did not reveal any significant interaction in mean hardness values among groups. One-way ANOVAs, however, demonstrated a significant effect in mean hardness values for each of the main variables. In addition, both the exposure source and the depth had a significant effect on the hardness of the resin for both the microfill and the hybrid composite resin.

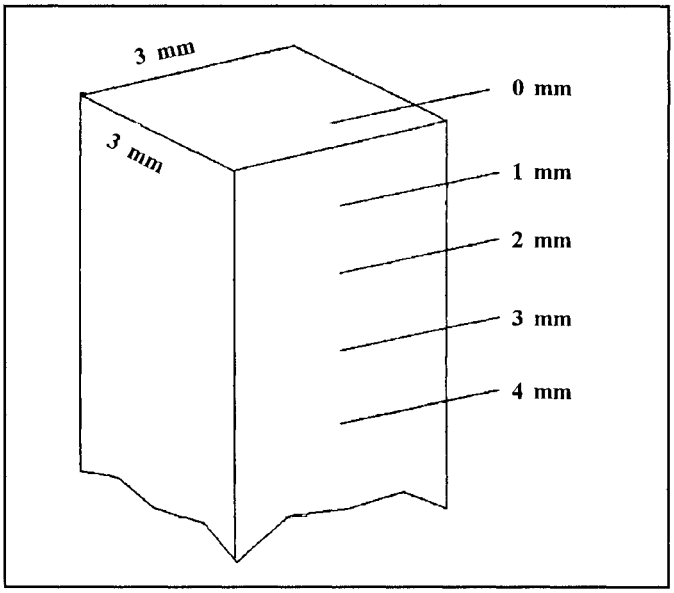
a) Significantly greater KHN was found for the hybrid compared to the microfill composite resin at equivalent depths, for any given light source and exposure time.

b) There was no significant difference in KHN at 0 mm between groups, regardless of light source or exposure time, for both resins (Tables 1 and 3).

c) There was no significant difference in KHN between 0, 1, and 2 mm within a given group, for each light source and exposure time, for both resins (Tables 2 and 4).

Microfill (Silux Plus)

a) There was no significant difference in KHN between VL40 and AL30 regardless of depths; 0-4 mm (Table 1).



Hardness measurement locations

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Table 1. Knoop Hardness Number for the Microfill According to Depth

Depth	0 mm ($P = 0.0976$)	1 mm ($P = 0.016$)	2 mm ($P = 0.0002$)	3 mm ($P = 0.0001$)	4 mm ($P = 0.0078$)
VL40	31.5 (1.7)	33.4 (5.6)	33.2 (2.2)	30.4 (0.7)	24.4 (2.7)
AL30	33.1 (2.5)	33.4 (4.3)	32.2 (1.7)	28.1 (1.3)	21.6 (1.2)
AL20	25.7 (1.6)	26.1 (3.4)	27.0 (3.0)	22.7 (2.1)	18.3 (3.1)
AL10	28.6 (8.7)	24.7 (5.8)	20.5 (6.0)	14.6 (5.9)	

Values connected by lines are not significantly different at $\alpha = 0.05$.

b) There was significantly less KHN between AL20 and AL10 compared to VL40 and AL30 at 1, 2, and 3 mm (Table 1).

c) At a depth of 4 mm, exposure to VL40 produced significantly greater hardness than AL20. At AL10, the resin was too soft to determine hardness (Table 1).

d) There was significantly less KHN for AL10 compared to AL20 at 2 and 3 mm (Table 1).

e) There was significantly less KHN for 3 and 4 mm, compared to 0, 1, and 2 mm, for the laser exposure sources, except at 2 mm for AL10 (Table 2).

f) There was significantly less KHN for 4 mm compared to 3 mm for all light sources (Table 2).

g) VL40 produced similar KHN at 0, 1, 2, and 3 mm depths. These values were significantly greater than hardness at 4 mm depth (Table 2).

Table 2. Knoop Hardness Number for the Microfill According to Exposure Source

Depth	VL40 ($P = 0.0009$)	AL30 ($P = 0.0001$)	AL20 ($P = 0.0003$)	AL10 ($P = 0.0269$)
0 mm	31.5 (1.7)	33.1 (2.5)	25.7 (1.6)	28.5 (8.7)
1 mm	33.4 (5.6)	33.4 (4.3)	26.1 (3.4)	24.6 (5.8)
2 mm	33.1 (2.2)	32.1 (1.7)	27.0 (3.0)	20.4 (6.0)
3 mm	30.3 (0.7)	28.1 (1.3)	22.6 (2.1)	14.5 (5.9)
4 mm	24.3 (2.7)	21.5 (1.2)	18.3 (3.1)	

Values connected by lines are not significantly different at $\alpha = 0.05$.

Hybrid Composite (TPH)

a) There was no significant difference in KHN between VL40, AL30 and AL20 regardless of depth, except AL20 at 4 mm (Table 3).

b) There was significantly less KHN for AL10, compared to other light sources, at depths greater than or equal to 2 mm (Table 3).

c) There was no significant difference in KHN at 0 and 1 mm depths between groups, regardless of light source or exposure time (Table 3).

d) There was significantly less KHN at 4 mm depth compared to 0 mm for AL20 (Table 4).

e) There was significantly less KHN at 3 and 4 mm depths compared to 0 and 1 mm for AL10 (Table 4).

Table 3. Knoop Hardness Number for the Hybrid According to Depth

Depth	0 mm ($P = 0.2837$)	1 mm ($P = 0.4008$)	2 mm ($P = 0.0242$)	3 mm ($P = 0.0034$)	4 mm ($P = 0.0001$)
VL40	53.0 (6.5)	52.9 (2.4)	53.6 (4.7)	51.3 (4.7)	49.2 (4.3)
AL30	48.0 (4.3)	51.7 (4.5)	53.5 (7.5)	53.0 (9.1)	49.2 (8.2)
AL20	53.4 (10.1)	49.6 (7.6)	51.3 (8.3)	48.0 (8.1)	40.1 (5.7)
AL10	46.4 (4.5)	46.8 (7.0)	40.6 (6.2)	35.3 (3.4)	23.9 (5.0)

Values connected by lines are not significantly different at $\alpha = 0.05$.

DISCUSSION

Hardness testing, at various depths, is the most common technique used for measuring degree of polymerization for composite resin. This indirect method has been shown to be well correlated with the actual degree of conversion determined from FTIR spectroscopy (DeWald & Ferracane, 1987). The Higher KHN can be translated into a greater degree of conversion or polymerization of resin (Ferracane, 1985). This increase in polymerization may result in a material with improved physical properties (Hansen & Asmussen, 1993). While no direct correlation exists between a single mechanical property and the clinical performance of resin restorative materials, it is accepted that a stronger

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Table 4. Knoop Hardness Number for the Hybrid According to Exposure Source

Depth	VL40 ($P = 0.5882$)	AL30 ($P = 0.6729$)	AL20 ($P = 0.1358$)	AL10 ($P = 0.0001$)
0 mm	53.0 (6.5)	48.0 (4.3)	53.4 (10.1)	46.4 (4.5)
1 mm	52.9 (2.4)	51.7 (4.5)	49.6 (7.6)	46.8 (7.0)
2 mm	53.6 (4.7)	53.5 (7.5)	51.3 (8.3)	40.6 (6.2)
3 mm	51.3 (4.7)	53.0 (9.1)	48.0 (8.1)	35.5 (3.4)
4 mm	49.2 (4.3)	49.2 (8.2)	40.1 (5.7)	23.9 (5.0)

Values connected by lines are not significantly different at $\alpha = 0.05$.

composite should be more resistant to stress (Lambrechts, 1983).

Several factors influence the degree of polymerization and depth of cure of composite resins. These include light intensity, exposure duration, a composite resin's transmission coefficient, the refractive indices of the filler and matrix, particle type, size and loading, opacity and shade (Rueggeberg & others, 1993; Admatja & Bryant, 1990; Kawaguchi, Fukushima & Miyazaki, 1993; Bayne, Heymann & Swift, 1994; Sakaguchi, Douglas & Peters, 1992). It is interesting to note that at various depths, these factors may play different roles in influencing resin cure (Rueggeberg & others, 1993).

In the current study, polymerization (as indicated by microhardness) for the hybrid composite resin was greater than that found for the microfill for any given depth and light source. This is in agreement with findings of other investigators (Phillips, 1991; Sturdevant, 1995). It is believed that the larger particle size and the higher loading percent of the hybrid composite resin compared to that of the microfill contributes to this increase in polymerization (Pilo & Cardash, 1992; Ruyter & Oysted, 1982; Rueggeberg & others, 1993)

For the microfill composite, a 30-second exposure to the argon laser was required to achieve comparable polymerization to that obtained from 40 seconds using the VL to a depth of 3 mm. For the hybrid resin it was found that comparable polymerization (as indicated by microhardness) could be achieved to a 3 mm depth using the argon laser for 20 seconds compared to 40 seconds of exposure with the conventional light. At a depth of 0 and 1 mm, a minimum of 10 seconds of exposure with the argon laser was comparable to a 40-second exposure using the conventional light source.

In this study, surface KHN values fell into the range previously reported as standard for microfills and hybrid composite resins (Sturdevant, 1995). Within each composite, surface hardness was similar regardless of light source or exposure time, which is in accordance with other studies (Rueggeberg, Caughman & Curtis, 1994).

This study also took into consideration depth of cure as an indicator of the clinical success of a resin restorative material. Since the internal degree of polymerization of light-activated composite resins decreases with increasing depth from the exposed surface, surface hardness may not be an adequate indicator of the degree of polymerization (Hansen & Asmussen, 1993; ADA Council of Dental Materials, 1985).

It is important to achieve adequate polymerization at all depths of the resin restorative material. Underpolymerization of composite resin results in inferior physical and mechanical properties, higher solubility, and less than optimal performance of the restorative material (ADA Council of Dental Materials, 1985).

Theoretically, polymerization of resin at varying depths is considered adequate if the KHN is at least 80% of the surface hardness (Craig, 1993). In the present study, this was achieved for all exposure sources except AL10 up to a depth of 3 mm for both the microfill and hybrid composite. In addition, for the hybrid composite, at least 80% of the surface hardness was obtained with AL30 and VL, up to a 4 mm depth.

While greater hardness, (i e, increased polymerization) is considered desirable, the elastic modulus of a material is also of concern. A higher degree of conversion presumably results in a higher elastic modulus. This higher modulus may be a disadvantage in certain situations, such as a class 5 restoration, where a material with a low elastic modulus is desirable to accommodate flexural tooth forces that may cause debonding of the restoration (Sturdevant, 1995). Therefore, it is important that a material's physical properties meet the restorative demands of a given clinical situation.

Energy density is an important determinant of the total light energy of an exposed resin material. It is defined as power density over time, and expressed in joules per spot size area (cm^2). Although power output, spot size, and power densities differed in the present study for the laser and conventional light source, energy densities can be compared. The energy density for the argon laser at 10 seconds was 9.37 Joules/cm^2 (power density of .937 W/cm^2 x 10 seconds), 18.74 Joules/cm^2 for 20 seconds and 28 Joules/cm^2 for 30 seconds compared to 14.16 Joules/cm^2 using the VLC system at 40 seconds (power

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density of .354 W x 40 seconds/cm^2). Apparently, in this study, higher energy densities did not correlate with significantly greater hardness for either the hybrid or microfill composite. For the hybrid composite resin, hardness at 2 mm was comparable at 18.74 Joules/cm^2 using the argon laser compared to 14.16 Joules/cm^2 with the conventional light. However, for the microfill, an energy density of at least 28 Joules/cm^2 was required to comparably polymerize composite resin to a depth of 2 mm.

In addition to energy density, the wavelengths of the emitted light should be considered in determining a light source's efficiency for polymerization of composite resin. Conventional light sources emit a broader range of wavelengths between 400-520 nm compared to the argon laser, a small portion of which are effective for resin polymerization. The argon laser used in this study had a bandwidth of 47.1 nm with emission lines at wavelengths of 454.6 nm, 457.9 nm, 465.8 nm, 447.2 nm, 476.5 nm, 488 nm, 496.5 nm, and 501.7 nm. Theoretically the greater portion of energy in effective wavelengths for absorption by camphoroquinone should make the argon laser a more efficient light source for the photoinitiation of resin polymerization. The present study, however, did not substantiate this hypothesis.

Other factors affecting the depth of cure of light-activated composite resins may have overshadowed the wavelength specificity, light intensity, and exposure time. As stated previously, these factors include filler type (particle size and loading), the composite resin's light transmission coefficient, thickness of the restorative material, the photochemistry of the resin system, and shade (Bayne & others, 1994; Sakaguchi & others, 1992). Since both the speed and depth of polymerization can be affected by the characteristics of the material, exposure times are material specific, and the results of studies should be considered based on the specific materials and conditions used in testing.

Results of this in vitro study yielded relevant clinical implications, which indicated that the argon laser is a viable alternative to conventional visible light for polymerization of both hybrid and microfill composite resins.

CONCLUSION

Results of this study suggest comparable polymerization using the argon laser versus a conventional visible light to polymerize light-activated composite resins. Hybrid resins polymerize more completely and to a greater depth than do microfill resins, with any light source. Resin polymerization was accomplished using the argon laser at reduced exposure times. Conventional light at 40 seconds produced comparable polymerization to the argon laser at 30 seconds for the microfill and at 20 seconds for the hybrid composite resins. This represents a 30-50% savings in time required to polymerize resin restorative materials to a depth of 2 mm. This time savings has clinical importance for practitioners in that, if the argon laser can adequately polymerize composite more rapidly compared to a conventional unit, it may be a desirable alternative for polymerizing composite resin restorations.

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The Effect of Amalgam Overhangs on Alveolar Bone Height as a Function of Patient Age and Overhang Width

D E PARSELL • C F STRECKFUS
B M STEWART • W T BUCHANAN

Clinical Relevance
Any radiographically visible overhanging amalgam creates an unacceptable oral situation.

SUMMARY

The purpose of this study was to compare the effects of amalgam restorations with and without overhangs on alveolar bone loss via digitized radiographs for subjects of varying ages and overhang widths. The first phase of this study compared the alveolar bone loss among teeth with clinically acceptable two-surface amalgam restorations with a control surface on the same tooth. The second phase was similar to the first phase with the exception that it compared defective amalgam restorations (those containing amalgam overhanging approximal margins) with the control surface on the same tooth. The collected data showed a significant loss of alveolar bone as a result of amalgam overhang presence ($P < 0.02$). However, overhang width and patient age did not affect the significance of the detrimental effects of the amalgam overhangs. Overall alveolar bone height was seen to decrease with patient age, independent of amalgam restorations. Digital radiography was seen to be an accurate method for evaluating alveolar bone height changes due to the local environment created by overhanging amalgam margins.

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INTRODUCTION

There is a dynamic relationship between the periodontium and the tooth. Much attention has been given to this relationship in the literature (Thomas, 1949; Carranza & Newman, 1996; Genco, Goldman & Cohen, 1990). The periodontal attachment apparatus consisting of the periodontal ligament, alveolar bone, cementum, and supracrestal connective tissue

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provide protection and support to the dentition, while the surface of the tooth provides protection to the periodontium. The presence of overhanging amalgam margins in interproximal locations is thought to disturb this relationship and result in loss of alveolar bone height.

The presence of amalgam overhangs within given patient populations has been investigated by several authors. Percent overhang occurrence ranged from 25% (Kells & Linden, 1992) to 60% (Than, Duguid & McKendrick, 1982). This broad range was partly a result of the overhang detection method. The two most often used methods were bitewing radiographs and clinical probing. Pack, Coxhead, and McDonald (1990) found that only 35% of mesial and distal overhangs were detected by both methods, 74% were found radiographically and 62% were found clinically. Regardless of the study or the detection technique, the number of existing amalgam overhangs is astonishingly large. Therefore, the relationship between overhang presence and the loss of alveolar bone is of great significance.

Published results are divided as to an amalgam overhang's influence on underlying alveolar bone height; however, the majority opinion indicated a positive correlation between overhangs and bone loss. Kells and Linden (1992) and Arneberg, Silness, and Nordbó (1980) found no significant overhang-related alveolar bone loss. On the other hand, Jeffcoat and Howell (1980), Gorzo, Newman, and Strahan (1979), Claman, Koidis, and Burch (1986), Gilmore and Sheiham (1971), Hakkarainen and Ainamo (1980), Pack and others (1990), and Björn, Halling, and Thyberg (1969) all found significant bone loss associated with the presence of amalgam overhangs. The significance of overhang width and patient age on amalgam overhang-induced bone loss has been noted by few investigators. Jeffcoat and Howell (1980) found that only overhangs of a certain size and larger caused significant bone loss; however, the amount of bone loss could not be correlated with the size of the overhang. Björn and others (1969) also found nonsignificant amounts of bone loss when overhangs were below a critical size. Claman and others (1986) and Hakkarainen and Ainamo (1980) both found no correlation between patient age and an increased occurrence of overhang-induced bone loss.

METHODS AND MATERIALS

A retrospective analysis of bitewing radiographs from patient records of the University of Mississippi Medical Center School of Dentistry (UMMC) was performed. Fifty-two restored teeth with two-surface amalgams and 51 teeth with defective amalgam restorations (overhangs) were selected through examination of random radiographs from the dental records department at UMMC. All selected sites were in approximal contact, and the presence of amalgam was verified via patient records. The age of the amalgams in the restored teeth when the radiographs were taken was not known. It could be assumed that on average a significant period of time had elapsed between amalgam placement and admittance of the patient to the University dental program. Therefore, the biological response of the affected bone to the placement of the amalgam (with or without an overhang) was assumed to have occurred to a measurable degree when the radiographs were taken. The investigators assumed that the age of each restoration was randomly distributed among the various groups.

Cementoenamel junction (CEJ)/bone height distances and amalgam overhang widths were measured by digitizing a video image of each radiograph and importing the data into an image analysis program (Periovis, Birmingham, AL 35201) (Jeffcoat, Jeffcoat & Williams, 1984). Radiograph-measured distances were calibrated by referencing to an overlaid gold grid (1 mm x 1 mm) or to the width of the actual negative. Because variation in incident angle of the x-ray beam could account for a measurement error in the CEJ/bone height distance, radiographs were produced using +5° and +10° perpendicular beam incidence on a human skull to assess the significance of the potential error. CEJ/bone height distances were taken at 11 locations on a standard bitewing radiograph with three measurements taken for each location (0°, 5°, and 10° of beam tilt). The effect of incident x-ray beam angle on the apparent CEJ/bone height distance was measured. Ten degrees of incident beam tilt in the plane perpendicular to the facial surface and parallel to the major axis of the tooth produced an average bone height measurement change of 0.38 mm and a standard deviation of 0.31 mm. The significance of the change in measured bone height with beam angulation was lessened, because both the amalgam side and the control side of the tooth should be affected equally. Therefore, the relative difference between the two bone-height measurements should remain valid despite the absolute error introduced, due to possible variation in beam alignment. Horizontal bone loss due to periodontal disease was also subtracted out of the bone height calculation if it was assumed that periodontally caused bone loss would equally affect both the experimental and control sides of the tooth.

The mesial and distal sites of the first and second premolar and first molars of restored teeth were used in this study. The restorations were two-surface amalgams, including the occlusal surface and only the mesial or distal surfaces. The untreated surface of the same tooth was used as a control surface for bone

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height measurement. Figure 1 is a schematic of the measurement methodology used. Absence of caries in the area of the control surface was required. The restored surface (mesial or distal) had to be above the CEJ in order to have an anatomical landmark for bone height measurement. For each case the distance between the CEJ and the uppermost alveolar bone was compared for the restored side (overhang and nonoverhang) and the control side of the tooth. Additional information collected included amalgam overhang width and patient age. Amalgam overhang widths were determined as the perpendicular distance from the surface of the enamel to the outermost extension of the amalgam overhang. It is recognized that distortion in overhang width will occur due to slight differences in x-ray projection. In general, however, the measured overhang width would be a best case scenario (i e, the actual overhang will be that size or larger). Teeth that were malposed were not considered for this study because of the effect of the angulation on the bone height distance measured.

Statistical Analysis

Statistical analyses were performed using a statistical software package (Excel). The first stage of the analyses provided descriptive statistics of the data. Statistical comparison, a pairwise *t*-test, was used to compare the unrestored controlled surface with the restored surface. A Student's *t*-test with unequal variances was used to compare differences in bone height between clinically acceptable and defective restorations. An alpha level of $P < 0.05$ was used to indicate significant differences between groups. Simple regressions were also performed to determine the relationship between various independent and dependent variables.

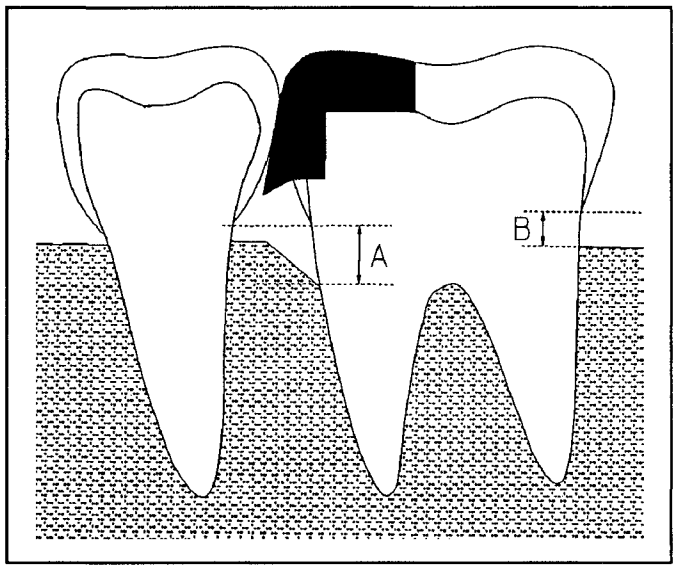

Figure 1. *The change in alveolar bone height is calculated by subtracting length B from length A.*

RESULTS

Nonoverhang Amalgam Bone Height Compared to Control

For the 52 cases of two-surface amalgams that had clinically acceptable restorations, the mean bone height on the restored surface was 1.57 ± 0.84 mm, and the mean bone height on the opposing control tooth surface was 1.48 ± 0.87 mm. Therefore, the difference between the two sides (restoration side bone height minus control side bone height) had a mean of 0.086 ± 0.45 mm. The *t*-test revealed no significant differences between the nonoverhanging restorations and their control surfaces at a 95% significance level.

Amalgam Overhang Bone Height Compared to Control

Statistical comparisons were made between CEJ/bone-height distances for the overhang and the opposing control tooth surfaces. The mean measured distance for the control side was 1.66 ± 0.87 mm and 2.07 ± 0.97 mm for the overhang situation. The difference between the two sides (overhang side bone height minus control side bone height) had a mean of 0.41 ± 0.71 mm. Two-sample, one-tail *t*-test assuming unequal variance showed a significant difference between the overhang and control means at $P < 0.02$.

Effect of Patient Age and Amalgam Overhang Width

The sensitivity of the patient population to bone loss resulting from amalgam overhangs was investigated as a function of patient age and overhang width. Figure 2 plots relative bone loss (overhang CEJ/bone height distance minus control side CEJ/bone height distance) versus patient age. There was no apparent correlation between the age of the patients and their sensitivity to bone loss due to the presence of an amalgam overhang ($R^2 = 0.0059$). Figure 3 plots relative bone loss versus amalgam overhang width. Again, there is no observed correlation between amalgam overhang width and the resulting susceptibility to bone loss. Linear regression of these data yielded an R^2 value of 0.025. Plotting the control CEJ/bone height distance versus patient age showed a linear trend with a positive slope (Figure 4). Linear regression analysis of these data yielded a R^2 of 0.19.

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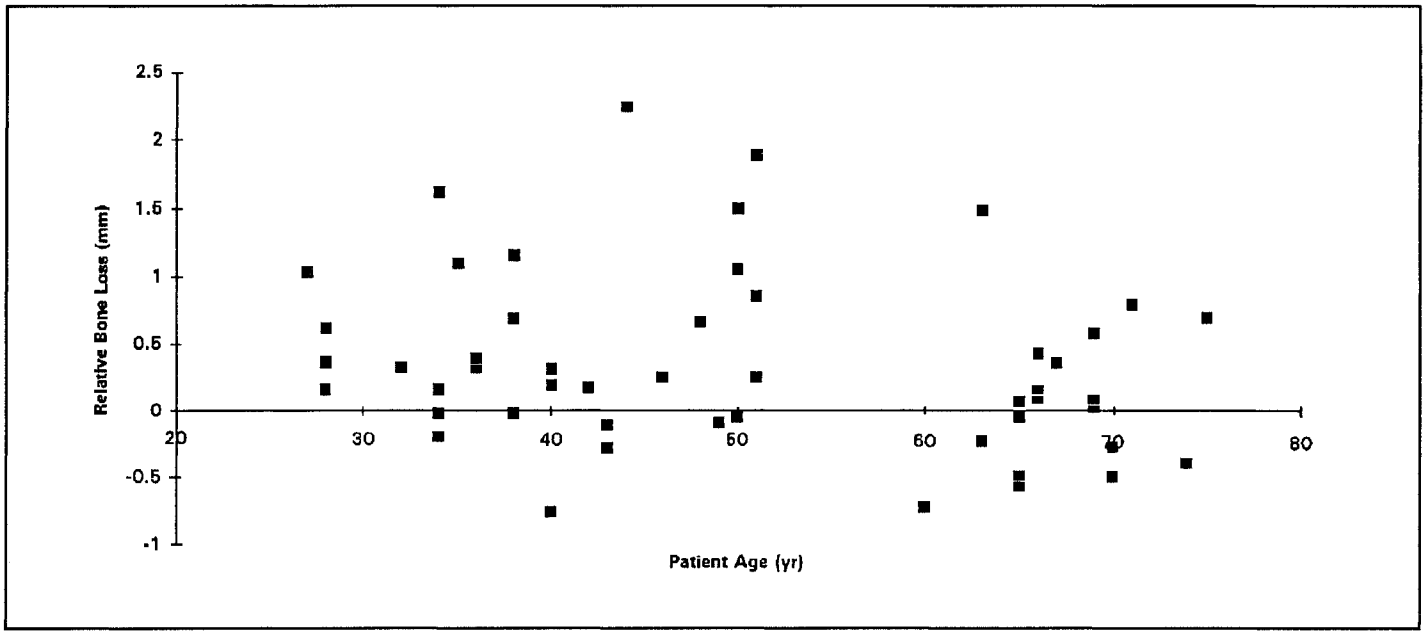

Figure 2. *The lack of significance of patient age on overhang-induced aveolar bone loss is shown by plotting the difference in alveolar bone height between affected sites and their control sites versus patient age.*

DISCUSSION

It has been commonly cited in dental texts that the presence of amalgam overhangs irritates gingival tissue (Sturdevant,1995) and encourages alveolar bone resorption (Grant, Stern & Listgarten, 1988). Data collected from this study tended to support this position. The data also showed that placement of a proper nonoverhanging amalgam restoration did not cause increased bone loss in comparison to the control tooth surface.

Since the height of the alveolar bone prior to amalgam placement was unknown for the cases used in this study, it was uncertain what portion of the final bone height resulted from the presence of the initial caries and/or from the presence of the faulty amalgam margin. However, because it was found that nonoverhanging restorations did not significantly

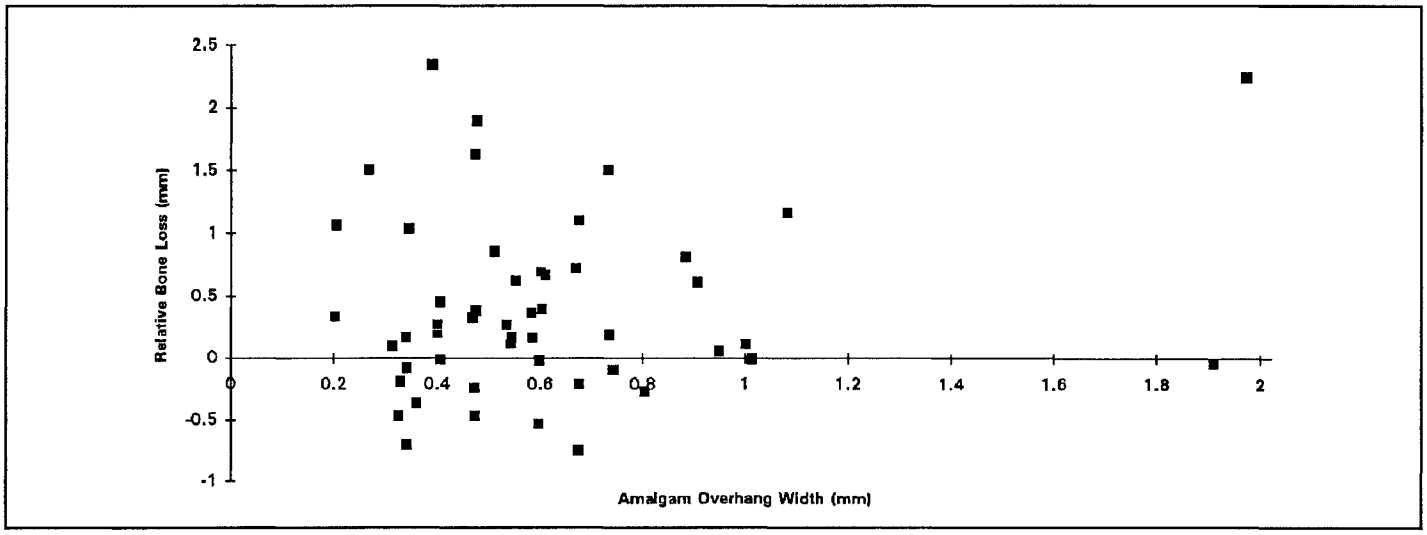

Figure 3. *The effect of perpendicular overhang width on alveolar bone height is shown by plotting the difference in alveolar bone height between affected sites and their control sites versus patient age.*

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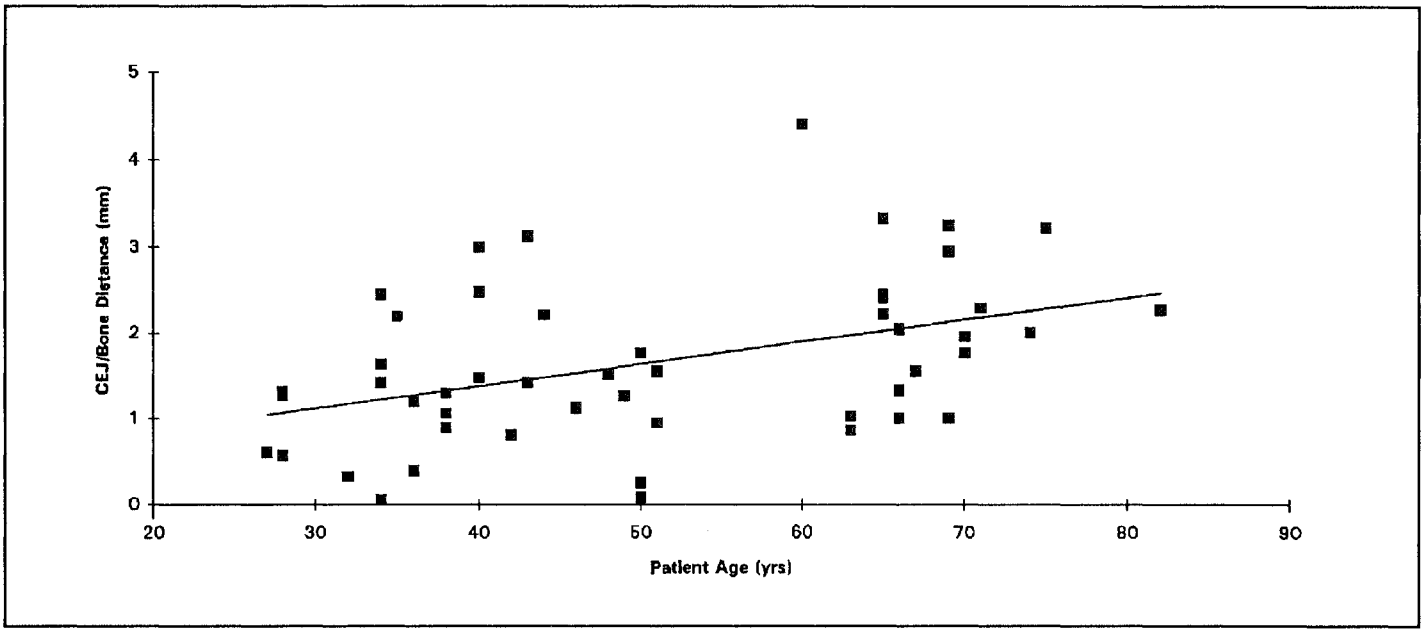

Figure 4. *The influence of patient age on alveolar bone loss is shown by plotting CEJ/alveolar bone crest distances for nonrestored, healthy teeth versus patient age.*

affect bone height, it could be concluded that the majority of bone loss measured was a result of the overhanging margins, not from the initial caries.

Data collected in this study showed no statistical relationship between bone loss as a result of amalgam overhang presence and patient age. Recently several publications (Burt, 1994; Papapanou & others, 1991) concluded that patient age was not a significant factor in assessing one's susceptibility to periodontal bone loss. An overhanging amalgam margin created a potential site for periodontitis and bone loss, but present data also concluded that the overhang was equally damaging to young and old. A possible mechanism to explain the zero-slope relationship between age and overhang-induced bone loss could be the combination of two opposing factors: immune response and salivary function. Overhang-caused bone loss could be due to a hypersensitive autoimmune response (Nolte, 1982). As such, elderly patients might be less sensitive to overhang-generated bone loss due to decreased T-cell function (Song & others, 1993). On the other hand, a more youthful patient with superior salivary function and/or composition should be able to more effectively reduce the bacteria action at the overhang site and therefore reduce the subsequent bone loss.

The lack of correlation between the width of the amalgam overhang and the measured bone loss (i e, one side of the tooth versus the other side of the tooth) can be explained by assuming that only a limited area beyond the tooth/amalgam contact area acted as a site for bacterial proliferation and subsequent gingival irritation. Because the major microbial contributors to periodontal disease and subsequent alveolar bone loss were anaerobic (Grant & others, 1988), only this limited section of the total overhang environment had a low enough partial pressure of oxygen to foster anaerobic growth. Therefore, the overall amalgam width was not a predictor of resultant bone loss as long as the tooth/amalgam contact area was properly configured to avoid food entrapment. The minimal geometrical requirements necessary for food entrapment and significantly harmful bacterial action will vary from individual to individual, but general guidelines would be an asset to clinical dentistry.

CONCLUSIONS

The database generated by this study supported the general clinical guideline that any overhanging amalgam margin that can be radiographically observed created an unacceptable oral situation. The presence of the class 2 amalgam restorations did not result in any measurably significant alveolar bone loss when margins were correctly contoured. Bone loss was found to be statistically significant ($P < 0.02$) in the presence of overhanging amalgam margins. Bone loss was also found to be independent of the width of the amalgam overhang and the patient's age. The independence of this site-specific periodontal bone loss modality with age correlates with recent

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conclusions that patient age is not a significant factor in predicting tendencies for severe periodontitis (Burt, 1994).

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The authors would like to express their appreciation to the dental record-keeping staff of the University of Mississippi School of Dentistry. The authors would also like to thank Dr Marjorie Jeffcoat for the software utilized in this project.

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Clinician of the Year Award

The Clinician of the Year Award was donated by Vic Williams on behalf of the Ivoclar/Williams Company to recognize annually one of the Academy's younger members for his/her outstanding contributions to dentistry. The recipient of this year's American Academy of Gold Foil Operators Clinician of the Year Award is Dr Ronald Zokol.

Ron is a graduate of the University of British Columbia and a long-time member of this Academy, the Vancouver Ferrier Gold Foil Study Club, and the Associated Gold Foil Study Clubs. He has also served on committees of this Academy and operated at many of its annual meetings. Ron exemplifies how this Academy can mold the philosophy, motivations, and skills of a clinician. The heart of this organization is in its study clubs, and this is where Ron has made his largest contribution. He has been an active member and leader in several gold foil and casting study clubs. He has proven himself as an excellent clinician and teacher, eagerly passing on his skills and knowledge through the many local courses he has participated in, and by teaching at the University of British Columbia. He has operated numerous times before this Academy, demonstrating his commitment and dedication to excellence.

Most importantly, Ron has now accomplished what this Academy truly stands for. He has taken the skills and philosophy of this organization and applied them to the entire practice of dentistry. As Ron now moves from the world of mallets and condensers to a practice filled with torque wrenches and superstructures, we can feel confident that he will apply the same level of skill and excellence that he has demonstrated to this Academy. We will probably be seeing less of Ron at our annual meetings from here on, but we wish him the best in his new endeavors into implant dentistry. We also wish to remind him to remember his roots; and we aren't referring to those made of titanium.

Ronald Zokol

It is with a great deal of pride and honor that we present the Clinician of the Year Award on behalf of this Academy to Dr Ronald Zokol. We would also like to thank the people at Ivoclar/Williams for continuing their support of this award.

FREDERICK EICHMILLER

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Distinguished Member Award

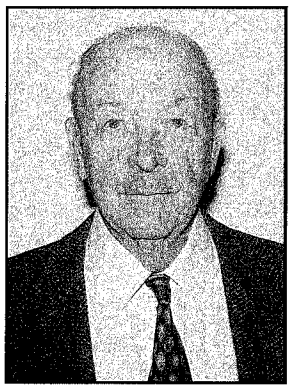
It is a real pleasure to represent the officers and members of the American Academy of Gold Foil Operators in honoring one of our oldest and most distinguished members. Ludlow William Beamish, "Beam," as he is usually known, has served this organization since its inception, and has served the profession of dentistry since his graduation in 1944, and is still serving in several capacities.

Beam was born in Boston, Massachusetts, on 25 March 1914, into a prominent Anglo-Irish family. He was raised and educated in British Columbia, obtaining a degree in arts and education from the University of British Columbia in 1938. He then taught high-school English and history until he decided to change to a dental career, enrolling in North Pacific College of Oregon, the precursor to the Oregon Health Sciences University, in 1941. He graduated from the accelerated wartime program in June 1944, leading his class.

In July 1944, he enlisted in the Canadian Dental Corps of the Canadian Army, and was attached to the Royal Canadian Air Force until he was discharged in 1946. Beam's teenage experience as a King's Scout and his service as a reserve officer while at the University of British Columbia stood him in good stead in the service, and he attained the rank of captain in 1945.

In 1946 Beam began a solo practice in New Westminster, British Columbia, from which he retired at the age of 76 in 1990. During his years of practice, he served almost all the dental organizations in his area, including the Vancouver and District Dental Society and the British Columbia Dental Association; he served as president for both organizations. He also served on the council of the College of Dental Surgeons of British Columbia, our governing body.

He also found time to be an officer of his church, a member of the Burnaby School trustees, and a member of several charitable and fraternal organizations. He has acted as a dental historian and has presented many papers on excellence in dentistry, as well as some 25 clinics on a worldwide basis. Beam has also taught part-time at the University of British Columbia and has presented remedial courses for the College of Dental Surgeons.



Ludlow W Beamish

Probably Beam's chief claim to honor is his constant civility to everyone, and his obvious sincerity and integrity. These qualities have led many to request his help as an arbitrator of conflicts with the College and with fellow professionals. In all cases, his honesty and goodwill have resolved the conflict, usually to the agreement of all concerned.

It is in recognition of Beam's technical skills, his depth of knowledge, and more importantly his innate humanity, that we honor ourselves by honoring him. The officers and members of the American Academy of Gold Foil Operators are proud to present our 1997 Distinguished Member Award to Ludlow W Beamish.

NORM FERGUSON

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DEPARTMENTS

LETTER

TRENDS IN CLINICAL DENTISTRY SKILLS

The study "Trends in Clinical Dentistry Skills Observed by Board Examiners: a 15-Year Comparison" is seriously flawed. The article published in the September-October 1997 issue of *Operative Dentistry* bases its findings on the clinical abilities of recent graduates on an opinion questionnaire of board examiners. "Opinionaires" are an unreliable method on which to base the conclusion that skills in restorative dentistry have decreased over the 15-year time period studied. The discussion attempts to finesse the fact that the findings are based on opinions rather than reliable data by talking about "perceptions" that skills have increased in some subject areas while decreasing in others, namely, basic operative dentistry. The field of evaluation has moved beyond perceptions. It is unfortunate that the journal would choose to publish an article on such a serious matter as recent graduates' clinical skills based on perceptions. During a time of great controversy on the subject of licensure examinations and their meaning, this article confuses the issues rather than helps to clarify them. In the discussion, the authors further confuse the readers into thinking the results are scientific by stating that the "study was carefully controlled for respondent collaboration and instruction... " However, this study is no more than opinions without controls or methods to determine the accuracy of those opinions.

In both the discussion and the conclusion the authors leave the impression that the clinical curriculum has changed in favor of such subjects as "basic sciences, oral and general medicine, pharmacological agents and dental materials ... [which] results in reduced exposure to basic procedures and techniques for the student dentist." In fact, the ADA curriculum survey shows that between 1981-1982 and 1995-1996, the similar 15-year time period that this paper covers, mean basic science hours decreased by over 100 hours (from 932 hours to 829 hours) while clinical science hours increased by 441 hours (from 3480 hours to 3921 hours) and behavioral science hours decreased from 224 hours to 143 hours. The 1995-1996 curriculum survey showed that the lion's share of the clinical curriculum, or 41% of the clinical curriculum hours (687 hours operative dentistry, 807 hours prosthodontics), is still devoted to restorative dentistry (operative, fixed and removable). The almost 1500 hours spent on restorative dentistry pales in comparison to the 80 hours devoted to pharmacology, the 73 hours on physical diagnosis, and the 72 hours spent on dental materials. Let's move beyond perceptions. We do concur with the authors, however, that "new evaluation methods that are highly reliable should be developed for evaluating clinical competence of candidates for licensure." Such examinations will move us from perception to reality.

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UNIVERSITY OF MARYLAND

The University of Maryland Dental School, Department of Restorative Dentistry is seeking applicants for a full-time, nontenure-track position at the rank of assistant professor. The appointment involves teaching dental anatomy/occlusion and operative dentistry in the preclinical and clinical DDS programs. The successful candidate will be expected to participate in clinic and/or basic research projects. Requirements for the position include a DDS/DMD or equivalent and eligibility for Maryland state licensure. Additionally, previous teaching experience and the potential to conduct clinical research are highly desirable. Salary is commensurate with experience and credentials. Intramural practice opportunities are available. The University of Maryland is an AA/EOE/ADA employer and is committed to diversity in all areas. For best consideration, please submit by 1 May 1998, a letter of interest, curriculum vita, and names and addresses of three (3) references to:

Dr Morton Wood
University of Maryland Dental School
Department of Restorative Dentistry
666 West Baltimore Street
Baltimore, MD 21201
Tel: (410) 706-7047

INDIANA UNIVERSITY

Indiana University School of Dentistry is seeking applications for a full-time tenure-track position available July 1998 as chair of the Department of Restorative Dentistry. This department includes the disciplines of operative dentistry, prosthodontics, dental materials, and endodontics. Responsibilities include coordination of departmental predoctoral and postdoctoral instruction, research, and service activities, including the continued development and implementation of a new predoctoral curriculum involving problem-based learning and clinical competencies; leadership activities to support and further enhance the international reputation of existing advanced education programs in all departmental divisions; faculty recruitment and mentoring, and faculty development (including needs analysis and progress assessment). The successful candidate must be a recognized leader in one of the departmental disciplines and have substantial experience in teaching, research, and management as well as strategic planning and program implementation in current issues within dental education. He/she should also have experience in budgeting, finance, and information management. The candidate must be committed to, and capable of, development of the mission of the school through strong leadership within the department as well as close cooperation with other departments. Candidates must be eligible for licensure within the state of Indiana and hold advanced training in at least one of the disciplines. Salary and rank will be commensurate with qualifications and experience. Indiana University is an EEO/AA employer and applications from women and minorities are strongly encouraged. Send applications, including curriculum vitae and the names of at least three references, to:

Dr E Brady Hancock, Chair
Indiana University School of Dentistry
Department of Periodontics and Allied Programs
1121 W Michigan Street
Indianapolis, IN 46202-5186

UNIVERSITY OF TEXAS--HOUSTON

The University of Texas--Houston Health Science Center Dental Branch seeks applicants for a full-time, tenure-track position in the Department of General Dentistry. Responsibilities include section head of Operative Dentistry, teaching operative and general dentistry, and research. Applicants must have a DDS/DMD degree and prior teaching experience/private practice. Credentials such as a Master's degree in operative/restorative dentistry or advanced training in prosthodontics are preferred. The position will be available 1 June 1998. Academic rank and salary are commensurate with qualifications and experience. The University of Texas--Houston Health Science Center is an EEO/AA employer. Send letters of application and curriculum vitae to:

Dr Rudolph S Fulton, Chair
University of Texas Dental Branch
Department of General Dentistry
6516 John Freeman Avenue
Houston, TX 77030
FAX: (713) 500-4108
E-mail: rfulton@bite.db.uth.tmc.edu

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UNIVERSITY OF TEXAS
HEALTH SCIENCE CENTER AT SAN ANTONIO

The University of Texas Health Science Center Dental School at San Antonio seeks applicants for a full-time, tenure-track position at the assistant/associate professor level in the Department of Restorative Dentistry. Applicants must have a DDS, DMD, or foreign equivalent. An MS degree with research experience is desirable. Primary teaching responsibilities in operative dentistry include didactic and clinical instruction predominantly at the pre-doctoral level with some postdoctoral contact, as well as continued development of an independent research program. Candidates with a demonstrated record in research and directing students and faculty in biomaterials, operative dentistry, and other funded research programs will be given strong preference. Salary is commensurate with experience and credentials. Intramural practice available for faculty licensed in Texas. Preference given to those eligible for dental licensure in Texas. Deadline for application is 15 April 1998. Position is available starting 1 September 1998. The University of Texas Health Science Center at San Antonio is an EEO/AA employer. Send applications and current curriculum vitae to:

Dr Karen Troendle
University of Texas Health Science Center
Department of Restorative Dentistry
7703 Floyd Curl Drive
San Antonio, TX 78284-7890
Tel: (201) 567-3690
E-mail: troendle@uthscsa.edu

ANNOUNCEMENTS

BOUND ISSUES OF *OPERATIVE DENTISTRY* AVAILABLE

Volume 21 of *Operative Dentistry* (1996, six issues) has been bound and is available for purchase from the Editorial Office in Seattle. Individual volumes sell for $35.00 each plus postage. The entire set of 21 volumes sells for $480.00 plus postage. Checks or money orders should be made payable to Operative Dentistry and sent to:

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

INAUGURAL MEETING EUROPEAN SECTION OF THE ACADEMY OF OPERATIVE DENTISTRY

30 April - 2 May 1998
Hotel du Lac et du Parc, Riva del Garda, Italy

This meeting is being held in association with the 1998 Annual Meeting of the Accademia Italiana di Conservativa. The speakers are Michael Degrange, Burkhard Hugo, Heinrich Kappert, Francesco Mangani, John McLean, Michael Noack, Massimo Nuvina, Cesare Robello, Richard Simonsen, and Nairn Wilson. Information may be obtained by contacting:

Dr Margaret A Wilson, Honorary Secretary, ESAOD
University Dental Hospital of Manchester
Restorative Dentistry
Higher Cambridge Street, Manchester M15 6FH, UK
Tel: 44 (0)161 275 6660/6619; FAX: 44 (0)161 275 6710
E-mail: WilsonM@man.ac.uk

THE TUCKER INSTITUTE

A course on cast gold restorations mentored by Richard V Tucker will be held at the University of Washington in Seattle on 22-26 June 1998. During this five-day clinical course each clinician will prepare and seat at least four castings and will be assisted in doing the laboratory procedures for at least one case.

The fee for the course is $2000.00; a deposit of $400.00 is required to hold a position, and the balance will be due by 25 May. Make checks payable to the Academy of R V Tucker Study Clubs and send in care of:

Dennis Miya, DDS
14027 Ambaum Blvd SW
Seattle, WA 98166
Tel: (206) 244-1618; FAX: (206) 431-9800

OPERATIVE DENTISTRY ARTICLES AVAILABLE ON MICROFICHE, MICROFILM

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Send manuscripts and correspondence regarding manuscripts to the Editor, Richard B McCoy, at the editorial office: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457; (206) 543-5913, FAX (206) 543-7783; URL: http://weber.u.washington.edu/~opdent/.

Exclusive Publication

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

Manuscripts

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

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

Illustrations

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

Tables

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

References

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

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