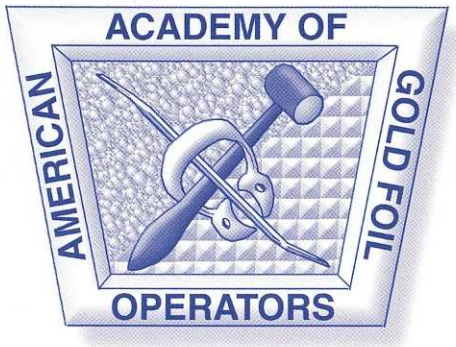
OPERATIVE DENTISTRY



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

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Guest Editorial

MB Chenoweth was right!!

Eighteen years ago, the *Annual Review of Pharmacology and Toxicology* published an article (Chenoweth, 1985) on perspectives in toxicology and discussed its major social value as a predictive science. Dr Chenoweth stated that the current difficulties in the field of toxicology are not technical, but political, psychological and sociological. This article is particularly pertinent today with regard to dentistry's amalgam conflict.

We have been amazed at what is going on in this arena. First, many articles discussing the dental amalgam issue ignore the fact that mercury is a part of the environment. Yet, we eat, drink and breathe mercury continuously. If the anti-amalgamists were to be believed, one would have to think that the only source of mercury is from dental restorations. But, the body's burden of mercury comes from numerous external sources and is best predicted by the amount of fish consumed in the diet. Someone who eats little fish and does not have any other exposure to an external mercury source would need 120 or more amalgam restorations in his or her mouth to have a mercury level that is considered above normal.

Second, the social and psychological aspects of the amalgam issue have been extensively studied, with dozens of papers published. Medical studies have not found an association between dental amalgam and any disease. Data from more than 25 multidisciplinary studies indicate mercury levels found in the hundreds of patients studied to be too low to cause any medical problem and, invariably, to be within normal limits. Although many anti-amalgam groups have claimed an association between amalgam restorations and a variety of diseases, these claims have been consistently refuted. Interestingly, the majority of individuals with increased levels of mercury, as compared to mercury levels in the general population, are dentists. If the effects of mercury in the body were what the anti-amalgamists claim them to be, we dentists should have many more health problems than the general population. However, dentistry is one of the safest professions, with no verifiable health problems related to mercury.

Psychological profiles of individuals who have "amalgam disease" have been extensively studied. They indicate that these individuals show signs of inappropriate and faulty reasoning. Their psychological profiles often include psychosomatic disorders, anxiety, depression, panic disorder, an inability to perceive threatening situations and antisocial behaviors. Because there has been no valid evidence that medical problems have been caused by amalgam restorations, treatment for patients claiming their amalgam fillings to be the cause of their woes should focus on changing their coping and attribution styles.

Politicians have now become influenced by the anti-amalgamists. Some want to ban amalgam. For them the issue of dental amalgam is that it contains mercury, which is a biocumulitive toxin. Because of the emotional issues created by special interest groups, these politicians have reacted without studying the scientific evidence and have, in some cases, initiated misguided legislation.

As a restoration, dental amalgam is very stable. It would take about 10,000 years for an amalgam restoration to release all of its mercury into the mouth. During removal of dental amalgam, the bur, rotating up to 400,000-rpm, generates heat and causes catastrophic breakup of the restoration. The removal produces mercury vapor along with small particles of dental amalgam and results in a solution containing these particles and a colloidal suspension of mercury in coolant water and saliva. These small particles of amalgam are readily separated by gravity from a solution. The mercury vapor generated is minimal, and 90% can be removed by continuing high volume aspiration for an addition 20-30 seconds after cutting ceases. Recovery of the mercury from the colloidal suspension requires a special system. The development and improvement of mercury recovery systems is ongoing.

The technology used to remove mercury is neither difficult nor excessively expensive. The mercury recovery systems for dental facilities have the potential to render the effluent coming from an office to be lower in mercury content than the water that comes into the same office.

Banning amalgam is not the answer. In fact, dentists who are placing the most mercury into the environment are those who have the so-called mercury-free practices in which amalgam restorations are routinely removed. The profession should be moving toward the universal installation of mercury recovery systems in dental offices. These systems should remove the colloidal suspension of mercury and the amalgam particles. Obtaining discharge water with low levels of mercury from the dental office will place dentistry in compliance with federal guidelines. Legislating the stopping of placement of amalgam restorations will not curtail the discharge of mercury from dental offices since removal of these restorations is the primary source. The use of dental amalgam should decline because of improved tooth-colored restorative materials that are easier to place and more conservative of tooth structure, not because of unfounded fears of adverse effects of the material.

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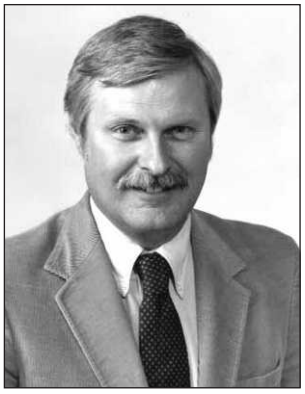

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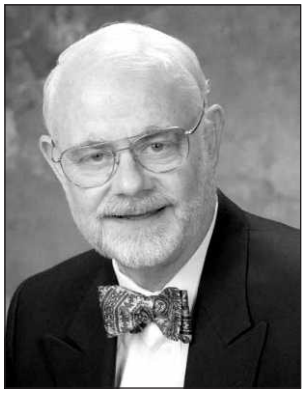

James Summitt, DDS, MSD

Whether you advocate amalgam restorations or alternative materials does not affect the issue of mercury control from dental discharge water. We need to effectively reduce the bioincompatible mercury that comes from our offices.

This is our opinion:

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Clinical Research

Short- and Long-Term Clinical Evaluation of Post-Operative Sensitivity of a New Resin-Based Restorative Material and Self-Etching Primer

VV Gordan • IA Mjör

Clinical Relevance

Beautifil resin-based system does not result in long-term post-operative sensitivity when placed in posterior restorations within the parameters of this study.

SUMMARY

This study evaluated the post-operative sensitivity of posterior restorations restored with a resin-based restorative material and a self-etching primer. Forty-six restorations, 28 Class I and 18 Class II were placed by two clinicians in 25 patients. After cavity preparations were completed under rubber dam isolation, they were restored using a self-etching primer (Fluorobond, Shofu Inc, Kyoto, Japan) and a resin-based restorative material (Beautifil, Shofu Inc, Kyoto, Japan). Patients were contacted on days 2 and 7 post-operatively and questioned regarding the presence of sensitivity, the stimuli that created sensitivity, the length of time the sensitivity lasted and its intensity using a rating scale from slight to severe. If sensitivity was experienced on day 7, patients were also contacted on days 14, 30 and 90 to assess the degree of sensitivity. All patients were recalled after 6-, 12- and 24-months for further evaluation of any sensitivity experienced. Chi-Square and Fisher's Exact Test were used for statistical analysis. At day 2, six restorations were sensitive to cold with no statistical difference ($p>0.05$) from the restorations that were not sensitive. At day 7, only two restorations were sensitive. No sensitivity was present after day 14, which was also confirmed at the six-month recall. No correlation could be established among the duration of the sensitivity, the degree of pain and the causes that initiated sensitivity ($p>0.05$). At one–year recall, one restoration was replaced due to post-operative sensitivity that started after the six-month recall. No sensitivity was noted at the 24-month recall. No correlation ($p>0.05$) was found between sensitive restorations and those with a normal response throughout the study. The study showed that Fluorobond

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self-etching primer and Beautifil resin-based restorative material, when placed in posterior restorations, do not result in long-term post-operative sensitivity.

INTRODUCTION

New resin-based bonding materials and composite restorative systems are regularly introduced for use in the esthetic restoration of posterior cavities. These materials have two main characteristics, they are tooth-colored and they can bond to tooth structure. The use of resin-based composite (RBC) materials became more popular as studies reported good durability when they were placed in small cavities and under ideal conditions (Letzel, 1989; Wilson, Mandradjieff & Brindock, 1990; van Dijken, 1994).

Long-term bonding of dental materials to dentin has been controversial and the results of *in vitro* testing does not always reflect those found *in vivo* (Roulet, 1987). RBC materials and adhesive technology have rapidly advanced; however, polymerization shrinkage and post-operative sensitivity still remain a challenge to practitioners.

Clinical studies have also indicated that up to 30% of the study populations have reported post-operative sensitivity following application of a posterior composite resin restoration (Wilson & others, 1991; Wendt & Leinfelder, 1992; Letzel, 1989; Stangel & Barolet, 1990; Brunson & others, 1989).

Sensitivity can be related to preparation trauma and leakage of the restoration with the ingress of bacteria (Brännström, 1987). Sensitivity may also result from polymerization shrinkage (Eick & Welch, 1986) and deformation of the restoration under occlusal stress which transmits hydraulic pressure to the odontoblastic processes (Suzuki, Jordan & Boksman, 1985).

Several studies have shown that cavity preparation depth has a significant impact on the response of underlying pulp to materials or procedures (El-Kafrawy & Mitchell, 1963; Stanley, 1968; El-Kafrawy & others, 1974; Wennberg, Mjör & Heide, 1982; Plamondon & others, 1990). In contrast, other studies have indicated that cavity depth does not significantly affect pulp reactions (Dowden, 1970; Plant & Anderson, 1978). Theoretically, the thicker the remaining dentin in the floor of a cavity preparation, the lower the concentration of the substance diffusing into the pulp (Pashley, 1985). The degree of obturation of the tubules by precipitation of mineral salts (sclerosis) will also affect the sensitivity (Duke & Lindemuth, 1990).

This study evaluated short- and long-term post-operative sensitivity of a new self-etching primer and a resin-based restorative material when placed in Class I and Class II cavities in premolar and permanent molar teeth.

METHODS AND MATERIALS

Forty-six restorations, 28 Class I and 18 Class II, were included in a study on short- and long-term post-operative sensitivity. The restorations were placed by two clinicians in 25 patients ranging in age from 21 to 62 years (mean age 38). Patients were informed about the study and signed a consent form approved by the Institutional Review Board at the University of Florida.

Clinical criteria included patients with a molar-supported permanent dentition free of any edentulous spaces and occlusal interference of clinical significance, and one-to-three first and second permanent molars or premolars requiring new or replacement of Class I or Class II restorations. Specific criteria included vital teeth and sound occlusal and proximal contact with adjacent teeth. Teeth with a previous history of sensitivity were excluded from the study. Patients taking analgesics that could alter their normal pain perception were not included in the study. The oral hygiene of the patients was recorded according to the clinical criteria described (Ryge, 1980).

After cavity preparations were completed, the depth of each cavity preparation was evaluated clinically: 20 teeth had the cavity preparation located on the inner one-third of dentin, 24 were located on the middle-third of dentin and two were located in the outer-third of dentin. The preparations were then restored according to the manufacturer's instructions under rubber dam isolation. The resin-based material was applied incrementally and polymerized with a visible light-curing unit (Demetron, a Division of Kerr Corporation, Danbury, CT 06810, USA). Appropriate occlusion and proximal contact points were restored. No base or cavity liners were employed. The restorations were finished under water-cooling with fine and super-fine diamond points (Hybrid Points Kit, Shofu Inc, Kyoto, Japan) and polished with diamond impregnated rubber points (CompoSite Fine, Shofu Inc, Kyoto, Japan).

The study design for short-term sensitivity was based on previously published post-operative studies (Gordan & others, 1999; Gordan, Mjör & Moorhead, 1999). All patients were contacted on day 2 and day 7 post-operatively by a clinician. They were questioned regarding the presence of sensitivity. If sensitivity and/or discomfort was experienced, the stimuli, duration and intensity were reported using a rating 1-3 scale: 1) for sensitivity described as slight, 2) for sensitivity described as moderate and 3) for sensitivity described as severe. Dentin sensitivity stimuli included cold (ice cream, cold drinks), hot (coffee or tea), chewing and spontaneous sensitivity. If discomfort was experienced on day 7, patients were also contacted on days 14, 30 and 90 to assess the sensitivity. All patients, including those with no positive sensitivity record on day 2 and 7, were told to report to the principal

Table 1: *Criteria for Oral Hygiene and Long-Term Post-Operative Clinical Assessment (Ryge, 1980)*

	Oral Hygiene	Post-Operative Sensitivity
Alpha	Healthy, pink, no bleeding when the probe is placed 1 mm below the tissue at one side of the proximal tooth and moved laterally to the opposite side.	No sensitivity when an air syringe is activated for two seconds at a distance of half an inch from the restoration with the facial surface of the proximal teeth covered with gauze.
Bravo	Red, but no bleeding when the probe is placed 1 mm below the tissue at one side of the proximal tooth and moved laterally to the opposite side.	Sensitivity is present when an air syringe is activated for two seconds at a distance of half an inch from the restoration with the facial surface of the proximal teeth covered with gauze and ceases when the stimulus is removed.
Charlie	Bleeding when the probe is placed 1 mm below the tissue at one side of the proximal tooth and moved laterally to the opposite side.	Sensitivity is present when an air syringe is activated for two seconds at a distance of half an inch from the restoration with the facial surface of the proximal teeth covered with gauze and does not cease when the stimulus is removed.

Table 2: *Composition of Fluorobond Self-Etching Primer and Beautifil Resin Based Restorative Material*

FL Primer A	FL Primer B	FL Bond	Beautifil
Distilled water, Initiators Acetone	2-HEMA, 4-Acryloxyethyltrimellitic acid. 4-Acryloxyethyltrimellitate anhydride, Urethane-triacrylate, Triethyleneglycol dimethacrylate, Acetone, Initiators, Stabilizers, Pigment	Distilled water, 2-HEMA, 4-Acryloxyethyltrimellitate acid, 4-Acryloxyethyltrimellitate anhydride, TEGDMA, Urethane dimethacrylate, Pre-reacted glass-ionomer filler, DL-Camphorquinone, Initiators	BIS-GMA, Triethyleneglycoldimethacrylate, Inorganic glass filler, Aluminuoxide, Silica, Pre-reacted glass-ionomer filler, DL-Camphorquinone,

investigator if any sensitivity or any other discomfort was experienced during the study.

Long-term post-operative sensitivity was assessed through an oral examination according to the clinical criteria described in Table 1 (Ryge, 1980). All patients were examined at 6-, 12- and 24-month recall examination of the restorations. Clinicians other than those who placed the restorations evaluated the restorations at these observation periods.

Data management and analysis was done using the Statistical Analysis System (SAS). Chi-Square and Fisher's Exact Test were used for statistical analysis ($p<0.05$).

RESULTS

At day 2, six restorations were sensitive. Two restorations were located in the middle-third of dentin and four were located in the inner-third of dentin with no statistical difference ($p>0.05$) based on cavity depth. A significant correlation difference was found for oral hygiene and sensitivity at day 1. Patients with oral hygiene classified as "Bravo" were more sensitive than patients with "Alpha" oral hygiene.

At day 7, only two restorations remained sensitive. One restoration was located in the middle-third of dentin and one was located in the inner-third of dentin.

No sensitivity was present after day 14, which was also confirmed at the six-month recall. There was no correlation among the duration of the sensitivity, the degree of pain, the causes that initiated sensitivity and cavity depth ($p>0.05$). The stimulus that initiated the sensitivity reactions was predominantly cold.

At the 12-month recall, one restoration was replaced by a primary care dentist due to post-operative sensitivity. This sensitivity started after the six-month recall exam. No sensitivity was noted at the 24-month recall.

No statistical difference ($p>0.05$) was found between restorations that were sensitive and those with a normal sensitivity response in the study.

DISCUSSION

Post-operative sensitivity following application of a posterior composite resin restoration is reported as a common problem by private practitioners. It is generally found that post-operative sensitivity diminishes during the first few weeks after restoration placement, but it sometimes persists for a longer period (Letzel, 1989; Stangel & Barolet, 1990; Brunson & others, 1989).

To avoid post-operative sensitivity, the quality of the adhesive system is important, including good adaptation of the composite to the cavity wall. The box-shaped configuration of the cavity, especially in Class I restorations, may lead to considerable polymerization shrinkage stress and, therefore, to an increased gap formation (Feilzer, de Gee & Davidson, 1987). Polymerization shrinkage stress can be reduced by applying the composite resin incrementally (Eick & Welch, 1986). The current study used the incremental technique.

The importance of the smear layer on dentin permeability has been indicated (Pashley, 1985; Pashley & Matthews, 1993). *In vitro* studies have reported different responses in dentin permeability with and without removal of the smear layer (Pashley & others, 1978; Pashley, Michelich & Kehl, 1981). Self-etching primers make the smear layer part of the hybrid layer, as it dissolves the smear layer, incorporating it into the mixture of collagen fibers and resin monomers. Since the smear layer becomes an integral part of the hybrid layer, this may explain the low sensitivity response presented in this study.

Similarly, previous clinical studies have reported low incidence of post-operative sensitivity with self-etching primers when compared to conventional three step bonding systems (Opdam & others, 1998a). These systems, theoretically, provide better penetration of the monomers into the collagen fibers of demineralized dentin. This complete penetration should also enhance marginal integrity wherever the cavosurface margin is in dentin (Gordan & others, 1997; 1998). Furthermore, studies indicate that resin-based agents may provide pulp protection as long as the dentin is sealed by hydrophilic resins (Pashley & others, 1978; Pashley, 1992). This sealing of the dentinal tubules is a factor in the prevention of post-operative sensitivity.

In resin-based systems, concerns have been expressed that the resin adhesion can deteriorate after long-term immersion in water (Nakabayashi, Ashizawa & Nakamura, 1992). If such deterioration leads to the seal being broken, it may result in the exposure of collagen that lies between the hybrid layer and the unaltered dentin. In a conventional multi-step bonding system, an excessive demineralization from etching may occur, therefore, the chances for an incomplete monomer impregnation into the demineralized dentin may follow (Van Meerbeek & others, 1992). This incomplete penetration may leave an unprotected band of dentin that can be accessible to degradation of exposed peptides (Nakabayashi & others, 1992). Self-etching primers have the advantage of demineralizing the dentin surface and penetrating it with the monomer at the same time. Previous studies observing the monomer penetration of acidic primers containing Phenyl-P have reported a resin impregnation zone of about 2 μm (Watanabe, Nakabayashi & Pashley, 1994; Nakajima & others, 1999). Similarly, a study using Laser Raman Microscopy found resin depth impregnation into demineralized dentin of 1-2 μm for Fluorobond bonding system (Miyazaki & Onose, 2001). This system contains 4-AET, which has have been shown to interact with hydroxy apatite to form 4-AETCa. It has been speculated that 4-AET could penetrate and interact with the Ca cations derived from hydroxy apatite to form relatively insoluble calcium salts that resulted in the improved durability of the self-etching adhesive (Ikemura & others, 2002).

In an *in vivo* study, SEM observations indicated that the gaps under a conventional multi-step bonding system were located between the adhesive and the dentin, whereas gaps in the self-etching primer restorations were located between the composite resin and the adhesive layer, indicating that the dentin remained protected by the resin monomers in the self-etching process (Opdam & others, 1998b).

Brännström & Åström (1972) stated that dentin sensitivity is mediated by fluid movement through dentinal tubules. Whereas this movement could be induced by numerous stimuli causing changes in hydrostatic pressure, others believe that the dental pain is primarily due to evaporation of water from the dentinal fluid (Matthews, Showman & Pashley, 1993). Therefore, dentin permeability can significantly affect the pain response.

Studies have shown that age is an important factor, since, in older patients, partial or complete obturation of tubules may occur resulting in growth of the peritubular dentin (Azaz, Michaeli & Nitzan, 1977; Stanley & others, 1983). Patients who have participated in this study ranged from 21 to 62 years of age with a mean age of 38 years. No significant correlation was observed with age as a variable.

One important consideration in this study is that some of the cavity preparations were placed as a result of previous restoration failures. The sensitivity response of teeth receiving restorations due to primary caries can be different from those receiving replacement restorations. Caries may result in the localized formation of irregular secondary/tertiary dentin in the formation of sclerotic dentin through the formation of crystallite deposits within the dentinal tubules (Frank, Wolff & Gutmann, 1964) that will affect the sensitivity reaction of teeth (Mjör, 1985). The restorative treatment will also induce changes in the primary dentin, facilitating the formation of tertiary dentin (Mjör & Ferrari, 2002). In the case of restoration replacement, the tertiary dentin formation that may markedly change the dentin permeability may have already occurred (Pashley, 1996; Mjör & Ferrari, 2002).

CONCLUSIONS

The study showed that the experimental resin-based restorative material and self-etching primer did not result in significant short- or long-term post-operative sensitivity when used in posterior restorations at 24-month recall.

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The Effectiveness of Four-Cavity Treatment Systems in Sealing Amalgam Restorations

LA Morrow • NHF Wilson

Clinical Relevance

None of the materials investigated consistently prevented leakage and there was considerable variation in leakage scores within and between teeth and groups. However, some of the materials tested, notably Copaliner Dentin Varnish and Sealant, were found to offer certain advantages in terms of limiting leakage in the short-term.

SUMMARY

Amalgam does not bond to tooth tissue; therefore, restorations using such material are prone to leakage despite the deposition of corrosion products. This study evaluated the effectiveness of four cavity treatment systems placed in vivo **in sealing restorations of amalgam. Four cavity treatment systems were investigated in this study: Cervitec, Gluma One Bond, Panavia 21 and Copaliner Dentin Varnish and Sealant. No cavity treatment was placed in an additional group to serve as a control. The teeth were extracted within 15 minutes of restoration placement. The specimens were thermocycled (5-55 ± 2°C, 500 cycles), immersed in a dye solution, sectioned and scored for leakage. Scanning electron microscopy also examined features of the tooth/restoration interfaces. There were statistically significant differences among the groups regarding leakage scores (**p**=0.00). None of the materials tested consistently prevented leakage; however, use of Copaliner Dentin Varnish and Sealant resulted in less overall, occlusal and cervical microleakage than any other systems tested. Significantly more leakage was observed in relation to the cervical portions of the cavities (**p**=0.00). No significant differences were identified between the leakage scores obtained for the buccal and palatal (lingual) cavities and the different tooth types (**p**=0.52 and 0.83, respectively). A level of significance of 0.05 was selected in all cases. The benefits of the materials tested in this study need to be evaluated using robust, long-term clinical studies. Further work should continue to develop laboratory tests that predict the behavior and performance of cavity sealants in clinical service.**

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INTRODUCTION

Dental amalgam remains a commonly used restorative material despite considerable controversy concerning its efficacy and safety (Eley, 1998). The two major disadvantages of amalgam as a restorative material are that it is not tooth-colored and it does not bond to tooth tissues. The need to create retentive cavity designs for restorations of amalgam often results in the excessive removal of sound tooth tissue. Following amalgam placement, the tooth-restoration interface remains vulnerable to microleakage: a term used for the passing of fluids, micro-organisms or ions between the restoration and the adjacent cavity walls (*Heinemann Dental*

Dictionary, 1990). Amalgam restorations tend to exhibit significantly greater leakage than restorations of other materials (Setcos, Staninec & Wilson, 2000). Possible reasons may include its lack of adhesion to tooth tissue, differences in thermal expansion compared with tooth tissue, dimensional changes during setting, incorrect selection or handling of the material, dissolution of the lining material and occlusal loading (Ben-Amar, 1989). Such leakage provides a path for the ingress of bacteria and bacterial products around restorations. This potential for leakage may contribute to a variety of clinical conditions such as marginal discoloration, pulpal irritation and subsequent necrosis, postoperative sensitivity, recurrent caries and the eventual failure of restorations (Bergenholtz & others, 1982; Brännström, 1986; Going, 1972; Kidd, 1976).

The methods used to treat cavity surfaces prior to amalgam restoration placement have changed over the years. This may be considered a direct response to better understanding of the cause of pulpal damage, the hydrodynamic theory of pulpal pain (Brännström, 1986; Brännström, Linden & Astrom, 1967) and the development of new dental materials. Traditional teaching encourages the generous use of liners and bases under amalgam restorations to limit post-operative sensitivity and to provide thermal insulation. Such teaching is founded on the outdated belief that the primary cause of pulpal inflammation relates to the cytotoxic effects of restorative materials and that variations in oral temperature are transmitted to, and have adverse effects on, the pulp (Hilton, 1996). Most authorities now recognize that the presence of bacteria is the most important determinant factor of pulp inflammation (Brännström, 1986). Bacterial contamination may be derived from caries, exposure of dentin to saliva, cavity preparation, the smear layer, restoration placement or leakage.

In traditional thinking, it has been considered appropriate to apply two coats of cavity varnish to cavity walls and margins prior to amalgam restoration placement. This is said to act as a temporary sealer, minimizing leakage until the deposition of corrosion products that seal the gap (Grossman & Matejka, 1993; Schwartz, Conn & Haveman, 1998; Sneed, Hembree & Welsh, 1984; Murray, Yates & Williams, 1983). For many years, however, there has been considerable doubt regarding the effectiveness of copalite varnish in providing a seal before high copper amalgam restoration corrosion products are deposited at the interface (Fitchie & others, 1990).

Many different techniques for cavity treatment prior to amalgam placement have been reported in the literature. More recent techniques, typically involving some form of liner, have been known to overcome the limitations of amalgam by sealing the dentinal tubules and, in certain circumstances, concurrently bond the restoration to the remaining tooth tissues (Gwinnett & others, 1994; Hilton 1996; Setcos, Staninec & Wilson, 1999). Hilton (1996), however, concluded that endorsing the use of dentin bonding agents under amalgam restorations was premature, and warned that caution should be exercised until controlled clinical studies provide evidence of the effectiveness and long-term sequelae of using such materials. If such caution is exercised, an alternative to the treatment of cavity surfaces prior to amalgam placement may be found in the use of desensitizing agents. Such agents are reported to be effective through a reduction in the diameter of the dentinal tubules and thereby limiting fluid movement (Trowbridge & Silver, 1990). It has been postulated that desensitizing agents through the same mechanism may be equally effective in preventing postoperative sensitivity with amalgam restorations (Schwartz & others, 1998).

This study evaluated the effectiveness of four different types of cavity treatment when used clinically to seal amalgam restorations.

METHODS AND MATERIALS

Leakage Study

Thirty-three intact premolars and third molars listed for extraction under local anaesthetic for orthodontic crowding or dental impaction were included in the study. Following administration of a local anaesthetic, a Class V cavity (5 mm wide x 3 mm high x 2 mm deep) was prepared through enamel on the buccal and, where access permitted, on the palatal (lingual) surface of each tooth. There were slight variations in the number of teeth and cavity position in each group, however, there were a total of nine cavities in each group (Table 1). The cavosurface margins of each cavity lay entirely within enamel; the cervical margin of each cavity having been placed 2 mm above the cemento-enamel junction. A #565, tungsten carbide pear-shaped bur (Ash Instrument, Dentsply Ltd Surrey, UK) in an air turbine handpiece with copious water coolant was used to prepare the cavities. The bur was replaced after preparing up to five cavities. All the cavities were prepared by the principal author to ensure standardization in cavity preparation. The prepared teeth were allocated at

Table 1: *Numbers and Distribution of Teeth and Cavities Position for Each Group*

Group	Number of Teeth	Cavity Position	
		Buccal	Palatal (lingual)
1	6	5	4
2	7	5	4
3	8	4	5
4	7	4	5
5	6	5	4

random to one of five test groups immediately following cavity preparation. Table 2 lists the materials selected for investigation. The materials were used according to the relevant directions for use and predetermined clinical protocols that principally relied on selecting an envelope containing the name of the material to be used in each preparation. Rubber dam isolation was not used during cavity preparation or restoration placement.

Immediately following application of the cavity treatment according to the test grouping and prior to the atraumatic extraction of each tooth, the amalgam restoration was placed in the cavity using conventional instruments and techniques. Tytin FC precapsulated, firm condensation, regular set, high copper amalgam (Kerr Corporation, Orange, CA 92867, USA) was selected for use in this study. After the initial set, the amalgam was carved flush with the cavity margins using a Wards carver (Ash Instrument, No 3c, Dentsply Ltd, Surrey, UK) lightly burnished and left to set undisturbed for 10 minutes. No further finishing was undertaken. When using Panavia 21, the excess paste was removed following condensation of the amalgam using a brush. Oxyguard II was then applied to all restoration margins and left for four minutes prior to its removal with water spray. To obtain a control, a group of nine teeth were restored with only amalgam; the cavity surfaces were washed with water and dried with air prior to the restoration placement.

Dental elevators were employed circumferentially to free the epithelial attachment, achieve mobility and deliver the teeth. Forceps were occasionally used to pick the tooth out of the socket. Great care was taken to avoid any disruption of the restorations, let alone cause damage to the crown of the tooth. In each case the extraction was completed within 15 minutes of placement of the restoration. These arrangements were a requirement of the Local Research Ethical Committee which also stipulated that all the patients be given an information leaflet explaining the nature of the study prior to their recruitment, and written informed consent was requied from each patient prior to commencing treatment.

Following extraction, the teeth were cleaned of soft tissue, washed under running water, examined under an illuminated magnifier (x 2.0 magnification) to exclude any teeth with a displaced restoration or adjacent enamel cracking and stored in tap water at room temperature (23-27°C) for three months. The teeth were subsequently stored in tap water at room temperature throughout the duration of the study, except during the thermocycling and dye fixation stages.

All specimens were placed in a thermocycling apparatus at the same time and subjected to 500 cycles. This was to ensure that all specimens were subjected to exactly the same thermal challenge. The temperature of the water baths was maintained at 5 ± 2°C and 55 ± 2°C. There was 30-second dwell time in each bath and

Table 1: *Materials Used in the Study (manufacturer, batch number and clinical procedure)*

Group (tested material)	Manufacturer (batch #)	Chemical Composition	Clinical Procedure
Group 1 (Cervitec)	Vivadent Ets, Schaan, Liechtenstein (A22060)	1% chlorhexidine, 1% thymol, ethanol, ethyl acetate, polyvinylbutyrol varnish	• two separate coats applied • each coat air dried for 40 seconds • amalgam restoration placed
Group 2 (Gluma One Bond)	Heraeus Kulzer, Dormagen, Germany (096907)	Conditioner; (20% phosphoric acid, pyrogenic silica) Bond; (4-META, UDMA, HEMA, acetone)	• conditioner applied to cavity for 20 seconds, washed and dried • 2 coats applied and dried with air syringe • light cured for 20 seconds • amalgam restoration placed
Group 3 (Panavia 21)	Kuraray Dental Co Ltd, Osaka, Japan (41139) comonomer, initiators)	ED Primer; (MDP, HEMA, water) Paste; (MDP, inorganic fillers,	• ED Primer applied for 60 seconds, dried with air syringe • thin layer of paste applied and left "wet" • amalgam restoration placed • Oxyguard II applied to margins for four minutes prior to washing with water
Group 4 (Copaliner Dentin Varnish & Sealant)	H J Bosworth Company Skokie, Illinois, USA (0921526)	Natural resins, chloroform, ethyl ether anydrous	• two separate coats applied • first layer dried with air syringe and second air dried • amalgam restoration placed
Group 5 (Control)	-	-	• cavity washed with water and dried with air syringe • amalgam restoration placed

(4-META) 4-methacryloxyethyl- trimellitate-anhydride; (MDP) 10-methacryloyloxydecyl dihydrogen phosphate; (UDMA) Urethane dimethacrylate; (HEMA) Hydroxy-ethyl-methacrylate.

an approximate 10 second transfer time from one bath to the other (International Organization for Standardization ISO Technical Report 11405 1994).

Following thermocycling, all specimens were aged for one week in tap water at room temperature. The apexes were resectioned and sealed with a high strength glass-ionomer restorative material (ChemFlex Dentsply, Surrey, UK) to prevent unwanted ingress of tracer. Two layers of nail varnish were then applied to the sealed apex and tooth surfaces to within 1 mm of the tooth-restoration interface, thus ensuring that the cemento-enamel junction was covered with nail varnish in all cases.

The teeth were immersed in 2% rhodamine B solution for 24 hours at room temperature, rinsed under running water, then allowed to air dry to secure dye fixation and allow embedding in an epoxy resin block (Araldite, Ciba Specialty Chemicals, Cambridge, UK LB001073/17703455). The embedded specimens were longitudinally sectioned using an EXAKT 300 standard band system (Mederex, Bath, UK) to produce at least four 1 mm-thick sections through each restoration. Each section was examined under a stereo zoom microscope (x 2.5 magnification), photographed and scored blind using a modified version of the Chan & Jones (1992) and Staninec & Holt (1988) scoring systems. To minimize bias, the sections were labeled with random numbers that were decoded after the scoring was complete.

Leakage scores were based on the degree of dye penetration according to the following scale:

0—no marginal penetration or penetration just into enamel

1—penetration up to half the length of the cavity wall

2—penetration of greater length than score 1 but not including the floor of the cavity

3—penetration involving the floor of the cavity

4—diffusion into surrounding dentin

The occlusal and cervical margins included in each section were scored separately, giving eight scores for each restoration. From these scores the maximum leakage, maximum occlusal and cervical wall scores for each restoration, were identified. The principal author performed all the assessments on three separate occasions, with five days between each assessment. When there was an inconsistency among the three scores, the most frequent score was recorded.

Data Analysis

The results were analyzed using SPSS for Windows (8.0 version). The tooth was considered to be the independent variable for statistical analysis, not the cavity or the individual leakage readings. Distribution of the degree of leakage within and between the teeth investigated was initially recorded and tabulated. The maximum (overall) leakage score for each tooth, along with the maximum occlusal and cervical wall scores, were identified. The median scores for overall, occlusal and cervical wall leakage were subsequently calculated using the previously obtained maximum leakage scores for each tooth.

A comparison of the median scores of the maximum overall, occlusal and cervical leakage was made among the groups using the Kruskal-Wallis test. This test also ranked the groups with respect to their overall, occlusal and cervical wall leakage scores. The Wilcoxon signed rank test was used as the pairwise comparison analysis to compare the median scores between the occlusal and cervical wall leakage, the median leakage scores between cavity site (buccal and palatal) and the median leakage scores between the different tooth types (premolar and molar). A level of significance of 0.05 was selected in all cases.

Interface Study

This part of the study used scanning electron microscopy (SEM) to investigate features of the tooth/restoration interfaces. A representative random sample (n=10) of the epoxy resin embedded tooth sections from each group of teeth was examined by (SEM). The embedded tooth sections were mounted on stubs using a silver and butyl acetone solution. All specimens were sputter coated with gold under vacuum for four minutes (Emscope SC500, Metallic Constructs, UK). Following gold sputtering, the specimens were examined using a Cambridge 360 Scanning Electron Microscope (Cambridge Instruments, UK). Magnifications ranging from x26.8 to x192 were employed. Images were captured and stored for future reference.

RESULTS

Leakage Study

Thirty-three teeth were included in the study, 24 premolars and nine third molars. There was a slight variation in the number of teeth within each group; however, a minimum of nine restorations were in each group. Some teeth were excluded following examination under magnification because they included minor enamel cracks that may have occurred during the extraction process. One restoration from Group 2 (Gluma One Bond) was lost during the thermocycling process.

Distribution of the degree of leakage associated with sections from individual teeth in the five test groups ranged from 0-4. The maximum leakage scores for the teeth in each group ranged from 3-4 in Group 1, 1-4 in Group 2, 3-4 in Group 3, 1-3 in Group 4 and 1-3 in Group 5. Table 3 shows the median scores for the maximum overall occlusal and cervical wall leakage for each group. The Kruskal-Wallis test showed a statistically significant difference among groups for the overall

Table 3: *The Median and Ranking of Groups According to the Overall, Occlusal and Cervical Wall Leakage Scores for Each Group*

			Mean Ranking		
Group	**Median**	**Leakage**	**Overall**	**Occlusal Wall**	**Gingival Wall**
1	1	1	Group 1	Group 3	Group 3
2	2	2	Group 3	Group 2	Group 1
3	2	3	Group 2	Group 1	Group 2
4	0	4	Group 5	Group 5	Group 5
5	1	5	Group 4	Group 4	Group 4

Group 1, Cervitec; 2, Gluma One Bond; 3, Panavia 21; 4, Copaliner; 5, Control
Mean ranking 1 = most leakage and 5 = least leakage

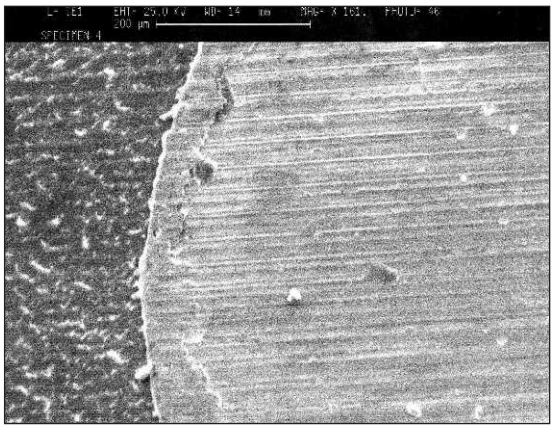

Figure 1. *SEM image (x161 magnification), Cervitec: Interface between amalgam (right) and dentin (left).*

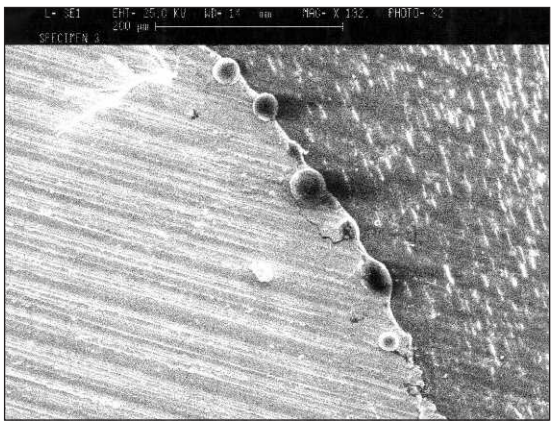

Figure 2. *SEM image (x192 magnification), Gluma One Bond: Interface between amalgam (left) and dentin (right).*

(p=0.00), occlusal (p=0.00) and cervical wall (p=0.01) leakage scores. Group 4 (Copaliner Dentin Varnish and Sealant) statistically had significantly less overall leakage than the other three test groups (p=0.01). The control group (Group 5) statistically had significantly less overall leakage than Group 1 (Cervitec) and Group 3 (Panavia 21). Group 4 (Copaliner Dentin Varnish and Sealant) statistically showed significantly less leakage at the occlusal and cervical walls than the other three test groups (Groups 1, 2 and 3). There was no statistically significant difference between the overall, occlusal and cervical wall leakage scores for test Groups 1, 2 and 3.

The mean ranking of the overall leakage scores using the Kruskal-Wallis test revealed that Group 1 (Cervitec) demonstrated the most leakage, followed by Group 3 (Panavia 21), Group 2 (Gluma One Bond), Group 5 (Control), while Group 4 (Copaliner Dentin Varnish and Sealant) showed the least leakage. There was a slight variation in the ranking of the occlusal and gingival wall scores (Table 3).

The Wilcoxon signed rank test confirmed that the cervical wall scores were significantly greater (p=0.00) than the occlusal wall scores and that there was no statistically significant difference between the leakage scores obtained for the buccal and palatal/lingual cavities (p=0.52) or the leakage scores obtained for the different tooth types (p=0.83).

Interfacial Study

SEM confirmed that none of the tooth sections examined demonstrated a hermetic seal between the restoration and tooth tissues. Variations in the width of the gap between the tooth tissues and restoration were considered to be directly related to the leakage dye penetration scores. On examination of the specimens, different types of localized interface appearances were noted within and between tooth and group sections. A pattern of failure within any of the test groups could not be determined given the small sample sizes. Several different interface morphologies tended to be observed within the same restoration.

Examination of Group 1 (Cervitec), Group 2 (Gluma One Bond) and Group 3 (Panavia 21) specimens revealed evidence of micromechanical retention. Group 1 (Cervitec) revealed a distinct but irregular interfacial layer between the amalgam and dentin (Figure 1). Group 2 (Gluma One Bond) also demonstrated an interfacial layer between the amalgam and dentin. Discrete spherical structures were visible along the amalgam dentin interface in parts of some of these sections (Figure 2). These structures, given their shape and size, were considered to be some form of air or fluid entrapment. Group 3 (Panavia 21) demonstrated irregular islands of resin spreading out into the amalgam from the interface (Figure 3).

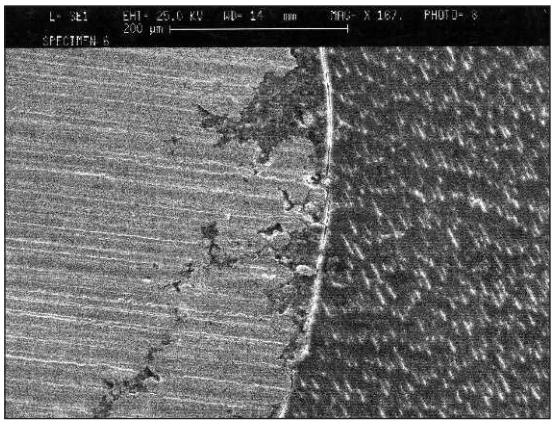

Figure 3*: SEM image (x167 magnification), Panavia 21: Interface between amalgam (left) and dentin (right).*

DISCUSSION

The leakage associated with four different cavity treatment systems placed clinically when used in conjunction with amalgam in Class V cavities has been investigated. Traditionally, laboratory leakage studies are considered valuable in helping to rank and aid selection of materials for subsequent clinical investigations. Studies involving the clinical placement of restorations tend to be time consuming, expensive, rely on patient cooperation, may contain many uncontrollable variables and are operationally difficult (Wilson, 1990). This study intended to extend existing knowledge and understanding of the effectiveness of various cavity treatments. In planning for the study, it was decided that this was best achieved by placing the restorations in patients, with the Local Research Ethical Committee insisting that the teeth be extracted immediately after placement of the restorations rather than by letting the restorations age in clinical service, necessitating the patients returning for their extraction as a second operative procedure. Not withstanding this limitation and the need to limit the investigations to Class V restorations rather than typical Class II restorations, this study, which is considered one of a small number involving the clinical placement of restorations tested for leakage, is considered to have advantages over a laboratory-based investigation.

Regarding possible differences in leakage among different liner systems, Gordan & others (1999) evaluated post-operative sensitivity experienced following placement of Class I and II amalgam restorations with one of three different liner treatments. No significant difference was found among the groups following two days. However, almost one-third of the teeth restored with dentin adhesive resin liner or copal varnish exhibited sensitivity. In some cases, this sensitivity lasted up to 30 days. Given such findings, further clinical comparisons of the effectiveness of cavity treatment systems would appear to be indicated. Studies of the type reported are intended to help target the cavity treatment systems most worthy of clinical testing.

Leakage studies have been criticized because the temperatures employed in thermocycling still need to be substantiated by intraoral temperature studies that report considerable variations in findings (Gale & Darvell, 1999). Leakage, however, tends to increase with thermal stress. As a result, leakage studies without thermal cycling may be open to particular criticism. In contrast, no significant differences in leakage were demonstrated by Wendt, McInnes & Dickinson (1992) between thermocycled and non-thermocycled composite restorations, indicating that the lack of thermal stressing may not be associated with misleading findings. This may result from slow rates of thermal diffusion through composite restorations (Harper & others, 1980). As a consequence, there are no generally accepted standard leakage experiment parameters, including temperatures, the number of thermal cycles, dwell time in each water bath, the type of disclosing solution, storage criteria and the scoring scheme (Chan & Jones, 1992; Goodis, Marshall & White, 1991). Notwithstanding the above, it is acknowledged that different leakage studies often yield conflicting results (Dejou, Sindres & Camps, 1996). This invariably makes it extremely difficult to compare findings between studies. Standardization of leakage testing could possibly help to make meaningful comparisons of different studies and thereby improve the clinical significance of such testing (Chan & Jones, 1992). In the absence of standardization, studies such as this investigation should be considered of value in ranking the materials under investigation in terms of their ability to form a seal between amalgam and remaining tooth tissues.

Difficulties in recruiting patients to participate in investigations involving the placement of otherwise unnecessary restorations limited the number of teeth included in this study. For statistical analysis purposes, the individual tooth was considered as the independent variable, not cavities or tooth sections. This has not always been the case in previous studies with small sample sizes. Dejou & others (1996) demonstrated how leakage results could be presented differently depending on the criteria selected for evaluation. The maximum dye penetration scores measured for each tooth, as used in this study, are considered the best evaluation criterion to enhance the power of the statistical analysis. To achieve this power, multiple sections were prepared from each tooth and scored independently, thus ensuring the recording of the maximum leakage score. As anticipated, a wide variation in leakage scores was observed within each tooth and group. The majority of reported leakage studies involved sectioning the tooth once through the center of the restoration. Such sectioning is unlikely to consistently coincide with the area of maximum leakage.

In view of the recent controversies regarding amalgam restorations (Eley, 1998), local Research Ethical Committee approval could not be obtained for a long-term clinical follow-up of the restorations investigated. This limited study does, however, take into account the influence of pulpal pressure, dentinal fluid, oral temperatures, oral humidity and tooth dynamics during restoration placement, which could not be simulated in many laboratory studies.

By way of a further and final limitation of leakage studies, it should be remembered that restorations are usually placed in intact teeth rather than diseased teeth. The effects of placing restorations in tooth tissue that has not been subjected principally to caries are unknown.

Regarding the cavity treatment systems selected for investigation, the four materials were chosen because Cervitec and Gluma One Bond have been advocated for their ability to seal dentinal tubules and their placement under amalgam restorations is listed as an indication for their use; Panavia 21 is frequently used by many dental practitioners to reduce leakage and/or bond the restoration to the adjacent tooth tissue and Copaliner Dentin Varnish and Sealant has been used prior to amalgam restoration placement for many years despite its use being questioned in recent years.

The results revealed a statistically significant difference among groups. Group 4 (Copaliner Dentin Varnish and Sealant) statistically had significantly less overall leakage than the other three test groups (Group 1, 2 and 3) (Table 3). The control group (Group 5) showed statistically significant less overall leakage than that found in Group 1 (Cervitec), and Group 3 (Panavia 21). Clinical studies of the systems investigated in this study have not been reported in the literature when used with amalgam restorations; therefore, the findings of this study cannot be compared. No explanation can be advanced for the performance of the test materials in this clinical situation, except that the three test materials are highly technique sensitive and may have been adversely affected by the moisture of the dentin and oral environment.

The cervical walls of the preparations exhibited statistically significant additional leakage than the occlusal walls (p=0.01). The restorations in this study were placed entirely within enamel in order to limit confounding variables such as those that might have existed if the restorations had been placed crossing the cemento-enamel junction. Previous studies have reported no significant differences in leakage at the occlusal and gingival walls of enamel restorations (Swift, Perdigão & Heymann, 1995). The present findings may be considered indicative that enamel prism angulations may influence the degree of leakage. There was no statistically significant difference between the leakage scores obtained for the buccal and palatal (lingual) cavities (p=0.52), indicating that cavity position in this particular study had no adverse effect on the overall results. Multiple cavities in one tooth have been used in laboratory studies (Chan & Jones, 1992) and could justifiably be used in future investigations, helping to alleviate difficulties in obtaining sufficient numbers of teeth.

There was no statistically significant difference between the leakage scores obtained for the different tooth types (p=0.83). This may assist in future studies enabling a variety of teeth to be used for laboratory studies provided they have been erupted in the mouth for a similar length of time and are intact. The restorations in this study were not subjected to occlusal loading; it is, therefore, inappropriate to speculate at this level how the different teeth would perform in clinical service.

Group 4 (Copaliner Dentin Varnish and Sealant) demonstrated the least leakage when compared to the other test materials. This finding is of clinical interest as contemporary textbooks suggest that the clinical use of cavity varnish under amalgam is diminishing and is superseded by using newer cavity treatment systems. This study's findings could not lend support to these views. However, the short clinical exposure of the restorations in this study must be examined when considering the findings.

The main reasons for amalgam restoration failure include secondary caries as diagnosed clinically, retentive failure, marginal breakdown, fracture of the tooth or restoration, sensitivity and pulpal damage (Harris, 1992; Mjör, 1981; Mjör & Toffenetti, 2000). Harris (1992) stated that the materials themselves are least often the problem and that most failures can be attributed to the lack of attention to cavity preparation and handling. Results of scanning electron microscopy revealed a variety of different leakage patterns both within and between the different test groups. This is of concern because in some instances the dentin is sealed, therefore, providing some form of protection even if leakage around the amalgam were to occur. However, this was not consistent within groups and a combination of leakage pathways types were observed within individual sections.

CONCLUSIONS

None of the materials tested consistently prevented leakage; wide variations in leakage scores existed within and between the teeth and groups investigated. Copaliner Dentin Varnish and Sealant showed significantly less overall, occlusal and gingival leakage scores compared to the other three test materials. The cervical walls exhibited significantly more leakage than the occlusal walls. There was no statistically significant difference between the leakage scores obtained for the different cavity sites and tooth types.

Notwithstanding the limitations of the study and the debate regarding the significance of leakage, further investigations would be required to verify the findings of this investigation, notably long-term clinical evaluations of the effects and cost benefits of the materials tested. Concurrent work should continue to develop laboratory tests that may give insight into the performance of restorative materials in clinical service.

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Laboratory Research

Effect of Light Curing Modes and Filling Techniques on Microleakage of Posterior Resin Composite Restorations

FHB Aguiar • KF Ajudarte • JR Lovadino

Clinical Relevance

Bulk filled restorations, light cured with initial low-intensity light, presented the lowest leakage means. The initial low intensity with soft-start and a 1.3 cm distanced light tip polymerizations presented no significant difference between each other.

SUMMARY

This in vitro **study evaluated the microleakage of a posterior resin composite restoration (P60–3M ESPE) filled with two techniques and light cured with three different modes. Standardized Class V cavities were prepared on the enamel buccal surface of freshly extracted inferior bovine incisors. Teeth were randomly divided into six experimental groups: two filling techniques (bulk and incremental filling) and three polymerization methods (conventional–680 mW/cm²/30 seconds; soft-start—380mW/cm²/10 seconds + 680 mW/cm²/20 seconds; 1.3 cm light tip distanced –200mW/cm²/10 seconds + 680 mW/cm²/20 seconds). All specimens were thermocycled for 3,000 cycles at 5°C and 55°C before immersion in a 2% methylene blue solution for 12 hours. Specimens were then washed and prepared for spectrophotometric analysis in order to quantify the dye infiltration around each restoration. Results showed that three polymerization modes presented no statistically significant differences for the incremental filling groups, whereas for the bulk filling group, conventional polymerization presented the highest leakage means that was statistically different from the other two polymerization modes. It was concluded that even though polymerization with initial low intensity light and bulk filling resulted in lower leakage means, no polymerization or filling techniques avoided microleakage.**

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INTRODUCTION

Dental resin composite is the most frequently used direct tooth-colored restorative material (Applequist & Meiers, 1996). Improvements in composite mechanical properties have permitted their use in posterior teeth with greater reliability today (Leinfelder, Bayne & Swift Jr, 1999; Manhart & others, 2000). However, polymerization shrinkage is a major concern among dental practitioners and researches (Lambrechts, Braem & Vanherle, 1987). Such contraction creates mechanical stresses in the resin composite, which can disrupt the marginal seal between the composite restoration and dentin or enamel (Koran & Kürschner, 1998). Polymerization shrinkage may lead to clinical problems, such as marginal fading, restoration or tooth fractures, solubility of the bonding system and marginal leakage. Microleakage is characterized by the invasion

of acids, enzymes, ions, bacteria and bacterial products into the margins of the restoration (Kidd, 1976; Going, 1972), causing post-operative sensitivity, recurrent caries, inflammation or even pulp necrosis (Gordon & others, 1986; Jedrychowski, Bleier & Caputo, 1998; Tarle & others, 1998).

Adhesive bond strength, restorative materials modulus of elasticity, cavity design, light intensity and curing time are some of the factors that influence the marginal quality of composite restorations (Unterbrink & Muessner, 1995; Friedl & others, 2000). Some polymerization and filling techniques have been proposed in an attempt to reduce stress caused by polymerization shrinkage. Incremental layering of composites has been suggested to counteract shrinkage and its stress on the bonded interface (Lutz, Krejci & Oldenburg, 1986; Full & Hollander, 1993). However, several authors have challenged the concept of incremental layering due to its claimed advantages over shrinkage reduction (Versluis & others, 1996; Köprülü, Gürgan & Önen, 1995; Mangun & others, 1994; Puckett & others, 1992). On the other hand, incremental filling techniques improve other aspects such as density, adaptation, thoroughness of cure and hardness of the composite (Yap, 2000; Versluis & others, 1996; Tjan, Bergh & Lidner, 1992). Despite this, polymerization of thick composite increments (5 mm) has been advocated by some packable composite manufacturers who claim that no reduction in physical properties occurs.

Initial polymerization with low-intensity light followed by a final cure at high-intensity light may result in improved marginal integrity and good mechanical properties (Uno & Asmussen, 1991; Mehl, Hickel & Kunzelmann, 1997). The aim of this technique is to prolong the time it takes before reaching the gel point by low light curing intensities, increasing the flow capacity of the material (Friedl & others, 2000). High light intensities are then necessary for complete polymerization and optimal mechanical properties (Uno & Asmussen, 1991; Friedl & others, 2000).

Initial low-light intensity polymerization can be achieved with specific light curing units (Friedl & others, 2000) or by distancing the light source from the resin composite surface (Mehl & others, 1997; Dennison & others, 2000). Therefore, the marginal adaptation of the composite restoration is strongly dependent on the initial curing intensity and the relationship between initial and final curing intensity (Friedl & others, 2000). Higher initial curing intensities do not allow enough flow to reduce internal stress (Mehl & others, 1997), whereas a lower intensity cannot activate enough initiator molecules to start an adequate reaction, thus, the final cure of this nearly unpolymerized material corresponds to an immediate full intensity curing (Mehl & others, 1997; Price & others, 2000).

This *in vitro* study evaluated the marginal leakage of a posterior resin composite using two filling techniques (horizontal and bulk filling) and three light curing modes (conventional, soft-start technique and distanced light tip technique).

METHODS AND MATERIALS

One week after extraction, 60 sound, inferior bovine incisors were cleaned, polished and examined under a light microscope (x4) in order to exclude damaged teeth. Teeth were stored in distilled water at 5°C for less than one month before conducting the restorative procedures. Cubic blocks of 5 mm size were obtained from the buccal surfaces. The crown of each tooth was set in acrylic plaques that were fixed in a precision low speed water cooled diamond saw (Imptech PC10–Equilam Lab Equip–Diadema-SP Brazil 09960-500) with two parallel disks distanced 5 mm from each other and perpendicular to the buccal surface of the tooth. Each tooth was cut in the incisal-gingival and in the mesial-distal direction, resulting in a 5 x 5 mm block.

These dental blocks were included in epoxy resin to facilitate handling (Figure 1). A plastic matrix was placed over a wax plaque and the block was positioned in the center of the matrix, with the buccal enamel surface in contact with the wax. The epoxy resin was poured into the matrix, and after eight hours, the epoxy resin cylinder was removed from the matrix and superficial enamel was wet polished with silicon carbide (SiC) paper #600 and 1,200 grit.

Cylindrical cavities of 2.0 ± 0.05 mm diameter by 4.0 mm depth were prepared on the central part of the block with a special diamond bur (KG Sorensen Ind Com Ltda–Barueri–São Paulo, Brazil). All the cavities were prepared with a water-cooled high-speed turbine. A new bur was used for every five preparations. Cavity preparations were rinsed for 10 seconds with air/water spray and air dried for 10 seconds. The same investigator restored all cavities.

Each tooth was acid etched with 35% phosphoric acid (Scotchbond-3M Dental Products, St Paul, MN 55144,

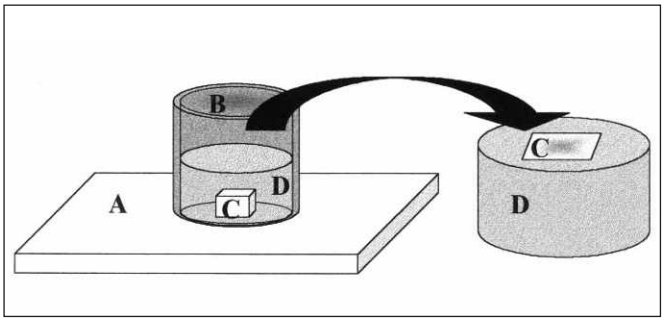

Figure 1. *Dental blocks included in epoxy resin. A—dentistry wax; B—plastic matrix, C—dental blocks (with the enamel surface in contact with the wax); D—epoxy resin.*

USA) for 15 seconds. The cavities were rinsed for 15 seconds and gently air dried for 10 seconds. Two layers of adhesive system (Single Bond–3M-Dental Products) were applied and the second layer light cured for 20 seconds following the manufacturer's instructions. The teeth were then restored with P60 resin composite (3M Dental Products), filled in one (bulk) increment of 4 mm or in three increments (pulpal-cavosurface) of 1.5 mm (first two increments) and 1 mm (last increment). Each increment was light cured according to three polymerization methods: 1-conventional polymerization at 680 mW/cm²/30 seconds, 2-soft-start polymerization at 380 mW/cm²/10 seconds + 680 mW/cm²/20 seconds; and 3-polymerization with a 1.3 cm-distanced light tip (controlled by an electronic digital caliper) at 200 mW/cm²/10 seconds + 680 mW/cm²/20 seconds. A Degulux Soft-start Curing Light device (Degussa–Hüls AG–Hanau, Germany 1364) was used for the three techniques.

After restoration, all samples were stored in distilled water at 37°C for 24 hours and polished with flexible aluminum oxide disks (Sof-Lex Pop-on, 3M ESPE) under water spray. All samples were maintained in water at 37°C for 24 hours. They were then thermocycled 3,000 times (5 ± 2°C and 55 ± 2°C) with a dwell time of one minute at each temperature.

The interface between the block and the epoxy resin of all samples was then protected with a cyanoacrylate adhesive Superbond (Henkel Loctite Adhesives, LTDA, Itapevi-SP, Brazil 06690-111). The blocks were immersed in a 2% methylene blue solution for 12 hours at 37°C and the samples were rinsed in tap water and dried. A surface layer of the composite restorations was abraded with aluminum oxide disks (Sof-Lex) to remove any superficial dye absorption by the resin composite.

Dental blocks were removed from the resin cylinders and each block was weighed before and after being ground into powder in a mill for hard tissues (Marconi Equip Ltda, Piracicaba—SP, Brazil, 13400). If the difference between the initial and final weight was greater than 10%, the specimens were to be discarded. No specimens were discarded in this study. The powder of each block was individually immersed in a glass tube containing 4 ml of absolute alcohol PA for 24 hours in order to dilute the methylene blue. After that, the solutions were centrifuged (Tomy–IC 15AN– Tomy Ind, Tokyo, Japan) at 3,000 rpm for three minutes. The supernatant (floating solution) was analyzed through a spectrophotometer (Beckman DU-65–Instruments, Inc, Fullerton, CA 92834, USA) adjusted with a wavelength of 668 nm.

To determine absorbance, the spectrophotometer was adjusted to an appropriate wavelength for the methylene blue that corresponded to the maximum absorbency for the dye. To calibrate the spectrophotometer, the absorbance of standard solutions (0.1; 0.2; 0.3; 0.5; 1; 2; 4; 6 µg/mL) was determined at wavelengths ranging from 400 to 700 nm, and the maximum value was obtained at 668 nm. In this wavelength, the absorbances for the standard solutions were obtained. With these values, a coefficient of linear correlation (r=0.9998) and a straight-line equation (y=a + bx) were determined. The following relation was obtained: Absorbance = 0.2716 x (Dye concentration)–0.0075. To quantify the dye concentration (µg/mL) infiltrated between the tooth and the restoration, the "y" was changed for the absorbancy value of each sample.

One-way ANOVA and Tukey-Kramer tests were performed on the data at 0.05 confidence level.

RESULTS

Table 1 presents the results of the leakage test. ANOVA revealed significant differences among the groups and a double interaction between the two factors: photo curing and filling technique. Tukey-Kramer's test ($p<0.01$) was applied to individual comparisons between factors ($p<0.01$). For the incremental filling technique, the three polymerization modes presented no significant differences (Figure 2). For the bulk filling technique, the test showed that conventional light curing presented the highest leakage means, which was statistically different from the other two techniques. The Soft-Start and the 1.3 cm-distanced light tip light curing techniques presented no significant differences (Figure 3). Regarding the filling technique, the incremental technique presented the highest leakage means that was statistically different from the bulk filling technique (Figure 4).

DISCUSSION

One of the most destructive forces of the resin composite/tooth structure bond is the stress produced by curing shrinkage (Lambrechts & others, 1987). Polymerization shrinkage is a complex process that

Table 1: *Experimental Groups and Marginal Leakage Values (CV=10.66)*

Groups	Number of Increments	Light Curing Intensity	Marginal Leakage Means (µm/ml)
Group 1	3	380mW/cm²/10 seconds + 680mW/cm²/20 seconds	0.0596 ± 0.0067
Group 2	3	200mW/cm²/10 seconds + 680mW/cm²/20 seconds	0.0560 ± 0.0055
Group 3	3	680mW/cm²/30 seconds	0.0578 ± 0.0060
Group 4	1	380mW/cm²/10 seconds + 680mW/cm²/20 seconds	0.0387 ± 0.0055
Group 5	1	200mW/cm²/10 seconds + 680mW/cm²/20 seconds	0.0369 ± 0.0033
Group 6	1	680mW/cm²/30 seconds	0.0497 ± 0.0039

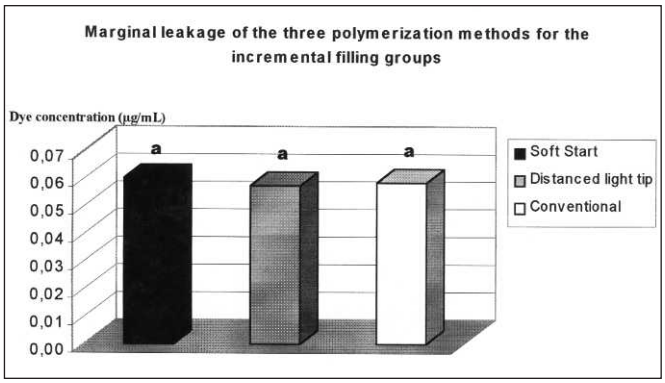

Figure 2. *Results of microleakage for the incremental filling groups. Groups with the same lower case letter were not statistically different.*

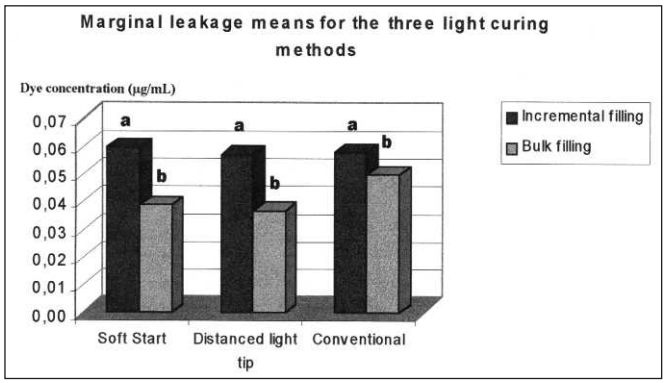

Figure 4. *Results of microleakage for the three light curing methods. Same lower case letters were not statistically different for the same light curing method.*

depends on several factors (Friedl & others, 2000). The cavity configuration (C-factor), which is a ratio between bonded and unbonded (free) surfaces (Feilzer, de Gee & Davidson, 1987), plays an important role in this process. Lower unbonded area means a lesser ability of the resin composite to flow, and therefore, results in greater contraction stress in the bonded surfaces (Carvalho & others, 1996; Burgess & others, 1999).

The major concern when restoring Class I, II and V with resin composite refers to the high "C-factor" of those cavities, that is, what increases the stress caused in the tooth-restoration interface during polymerization shrinkage (Feilzer, de Gee & Davidson, 1990; Carvalho & others, 1996). Carvalho & others (1996) described the ideal C-Factor as being lower than 1, and when the C-Factor is greater than 1, the results are unexpected. Feilzer & others (1987) stated that the C-Factor is approximately 1-2 in Class II preparations and can increase to more than five in Class I preparations. Therefore, elevated stress verified in high C-factor cavities can cause adhesion breakdown between the restorative system and cavity wall (Feilzer & others, 1990), creating a gap in the tooth composite interface that is responsible for microleakage (Fisbein & others,

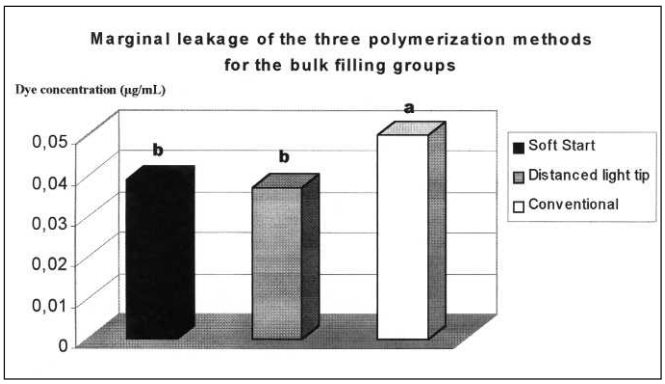

Figure 3. *Results of microleakage for the bulk filling groups. Groups with the same lower case letter were not statistically different.*

1988; Jedrychowsky & others 1998; Burgess & others, 1999).

Under the experimental conditions of this study, the results showed that the incremental filling technique presented the highest microleakage means, which was statistically different from the bulk filling, for the three polymerization techniques tested. These results can be attributed to the cavity design that was of 2.0 ± 0.05 mm diameter by 4.0 mm depth. This cavity design was performed in an attempt to simulate a clinical situation of posterior restoration with a high "C Factor." Thus, the resin composite situated at the bottom of the cavity may not have been completely cured. Yap (2000) demonstrated that resin composite increments could not be greater than 2 mm to obtain uniform and maximum cure, and increments of 3 mm or more presented a significant decrease in the effectiveness of polymerization. Inadequate polymerization affects physical properties and causes some clinical problems that include solubility in the oral environment, postoperative sensitivity, secondary caries and even pulp necrosis (Cobb, Vargas & Rundle, 1996; Yap, 2000). A high degree of polymerization results in high mechanical strength, low amounts of residual monomers and large polymerization shrinkage (Althoff & Hartung, 2000). If the deeper layer of the bulk filling groups does not polymerize completely, it will present lower shrinkage (Hassan & others, 1987) and cause lower stress on the bonded interface. Furthermore, this less polymerized layer creates a free surface and can provide a zone of stress relief for the shallower layer that presents higher conversion rates (Yap, 2000) and, consequently, higher shrinkage. However, bulk filling can decrease the resistance of the cusps to fracture (Wieczkowski & others, 1988) probably due to the uncured deeper layer, while the incremental filling improves some aspects, such as density, adaptation, less residual monomers, thoroughness of cure, resistance to cuspal fracture and hardness of the composite (Wieczkowski & others, 1988; Tjan & others, 1992; Versluis & others, 1996; Yap, 2000). The bulk filling technique should only be used in

cavities 2 mm-deep or less (Fisbein & others, 1988; Jedrychowsky & others 1998; Neiva & others, 1998; Yap, 2000).

In relation to the polymerization technique, soft-start polymerization and polymerization with 1.3 cm distanced light tip presented the lower leakage means that are statistically different from conventional light curing only for the bulk filling groups. A low intensity light can prolong the flow time of the composite, decreasing stress during polymerization (Friedl & others, 2000). However, a high intensity light is necessary for complete polymerization and optimal mechanical properties (Friedl & others, 2000). Burgess & others (1999) demonstrated that polymerization with a low initial intensity light, followed by a high intensity light, does not reduce the mechanical properties of the resin composite. Therefore, in this study, the high intensity light was used for at least 20 seconds, which followed the composite manufacturer's instructions.

The marginal adaptation of the restoration strongly depends on the initial curing intensity and the relationship between the initial and final curing intensity (Friedl & others, 2000). Mehl & others (1997) showed that a lower light intensity cannot activate enough initiator molecules to start an adequate reaction and the final cure of this nearly unpolymerized material then corresponds to an immediate full intensity curing. The results of this study show that a low intensity at 200mW/cm^2 presented no statistical differences from a low intensity at 380mW/cm^2. These two intensities performed for 10 seconds, followed by 20 seconds at 680mW/cm^2, decreased leakage when compared with a conventional polymerization for 30 seconds at 680mW/cm^2 for the bulk filling technique. Thus, it is not necessary to invest in a specific soft-start light. The initial intensity on the curing light can be reduced with a conventional light curing unit by distancing the tip of the light source. For the incremental filling technique, there was no statistical difference among the three-polymerization methods. The incremental method provides a better degree of polymerization, increasing the physical properties (Yap, 2000). However, the polymerization shrinkage is higher than in a bulk-filled restoration (Versluis & others, 1996; Jedrychowsky & others, 1998). Not one of the three methods relieved stress during curing of the material.

This study suggests that the best way to decrease polymerization shrinkage stress without decreasing physical properties is by using a restorative material with a low elasticity modulus (Unterbrink & Muessner, 1995) in the deeper layer, which will acts like the resin composite that was not completely polymerized in this study. Perhaps, in this way, it can be used as an incremental layer associated with a low initial intensity of the polymerization technique, thus, decreasing leakage in resin composite restorations.

CONCLUSIONS

Within the limits of this study, it can be concluded that:

1. No light curing technique or filling technique avoided leakage;
2. Soft-start polymerization and polymerization with the distanced 1.3 cm light tip presented the lowest leakage means, which was statistically different from conventional light curing for the bulk filling groups.
3. The incremental filling technique groups presented higher leakage means, which was statistically different from the bulk filling technique groups.

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Effect of Residual Water on Dentin Bond Strength and Hybridization of a One-Bottle Adhesive System

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MF Burrow • J Tagami

Clinical Relevance

Wet bonding should be considered to be a very sensitive technique, as demonstrated by the large coefficients of variation of bond strengths.

SUMMARY

This research investigated the effects of wet and dry conditions of phosphoric acid etched dentin on resin bonding and determined the optimum moisture condition for resin bonding using an ethanol-based one-bottle adhesive system. Bovine dentin surfaces were etched with 35% phosphoric acid and rinsed with water. Under four wet and dry conditions (overwet, blot dry, one-second dry and desiccated), resin composite was bonded using Single Bond. Tensile bond strength was measured and the results analyzed by one-way ANOVA and Fisher's PLSD test at the 5% level. The resin-dentin interfaces of bonded specimens were observed with SEM. The bond strength of overwet, blot dry, one-second dry and desiccated groups were 5.2 MPa, 12.6 MPa, 11.9 MPa and 4.4 Mpa, respectively. The blot dry group and one-second dry groups revealed significantly higher bond strengths than the desiccated and overwet groups ($p<0.05$). The formation of hybrid layers approximately 5 µm thick (overwet and blot dry), 2 µm (one-second dry) and 3 µm (desiccated) were observed. The coefficient of variation in the blot dry group was very high, even though a higher mean was observed. In the one-second dry group, the moisture content of the collagen network was possibly too low, such that hybrid layer formation was not as good even though the bond strength was high.

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INTRODUCTION

For the last several years, one-bottle adhesive systems have become widely used in resin-dentin bonding. They consist of an etchant and bonding agent that contain a volatile solvent that is utilized for "the wet-bonding technique" (Gwinnett, 1992; Kanca, 1992). The main concept of this technique is to demineralize the dentin surface with phosphoric acid, then maintain the demineralized dentin in a moist state to prevent shrinkage prior to and during application of the bonding agent. The water miscible solvents in the bonding agent, ace-

tone or ethanol, behave like a water chaser and facilitate resin monomer penetration into the collagen network. Monomer infiltration and polymerization in demineralized dentin is essential for the formation of a hybrid layer (Nakabayashi, 1982). One-bottle adhesive systems provide bond strengths of resin to dentin that minimally differ from conventional systems (Gwinnett, 1994b; Kanca, 1996; Kanca, 1997; Swift & Bayne, 1997). However, technique error can easily affect the bond strength of materials reliant on total etching/wet bonding compared with self-etching systems (Frankenberger, Krämer & Petschelt, 2000).

The loss of water causes collapse of the demineralized dentin. The morphological change of the etched dentin surface with water has been confirmed using an atomic force microscope (Marshall & others, 1993), an environmental scanning microscope (Gwinnett, 1994a; Inokoshi & others, 1996) and a laser scanning microscope (Urabe & others, 1997; Nakaoki & others, 2000) which has clarified that the degree of moisture will influence the bond strength to dentin (Gwinnett, 1994b; Kanca, 1996; Kanca, 1997; Swift & Bayne, 1997). It became clear that the degree of collapse of demineralized dentin depends on the severity of air drying and the water content of primers or adhesives (Nakaoki & others, 2000).

For the wet bonding technique, a "visibly moist condition" is required to maintain demineralized dentin in its original state. There is a great degree of variability in interpreting the term "moist dentin," which has been described as three seconds air-blow dry, one second air-blow dry or blot dry (Gwinnett, Tay & Wei, 1995; Tay, Gwinnett & Wei, 1998). It has not been confirmed whether these moisture conditions will lead to the same efficacy of the resin-dentin bond. In addition, the relationship among the degree of water saturation, bond strength and hybrid-layer formation is still not well established. In this study, the tensile bond strength and SEM observation of the resin-dentin interface were compared under four moisture states. This research investigated the effect of wet and dry conditions of phosphoric acid etched dentin on resin bonding and determined the optimum moisture condition for resin bonding using an ethanol-based one-bottle adhesive system. The null hypothesis of this study is that the wet bonding system is not a strongly technique-sensitive method such that demineralized dentin surfaces do not collapse after one second of air drying.

METHODS AND MATERIALS

Bonding to Bovine Dentin

Four groups, each containing 10 bovine teeth stored frozen after extraction, were established. The central portion of the labial dentin surface was ground with silicon carbide paper from #280 to #600-grit under running water, exposing superficial dentin. The dentin surface was covered with a piece of vinyl tape in which a 4 mm-diameter hole had been punched and was etched with 35% phosphoric acid (Single Bond Etchant, 3M Dental Products, St Paul, MN 55144, USA, Lot #7423) for 15 seconds and rinsed with water for 10 seconds. The etched dentin surfaces were prepared for each group as follows:

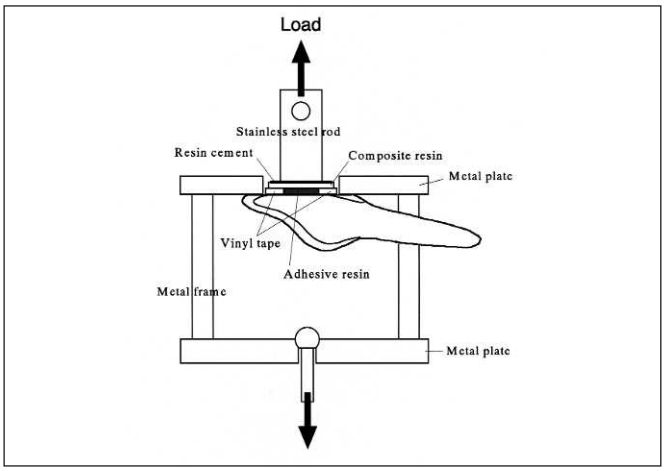

Figure 1. *Schematic illustration of the sample configuration and the tensile bond test.*

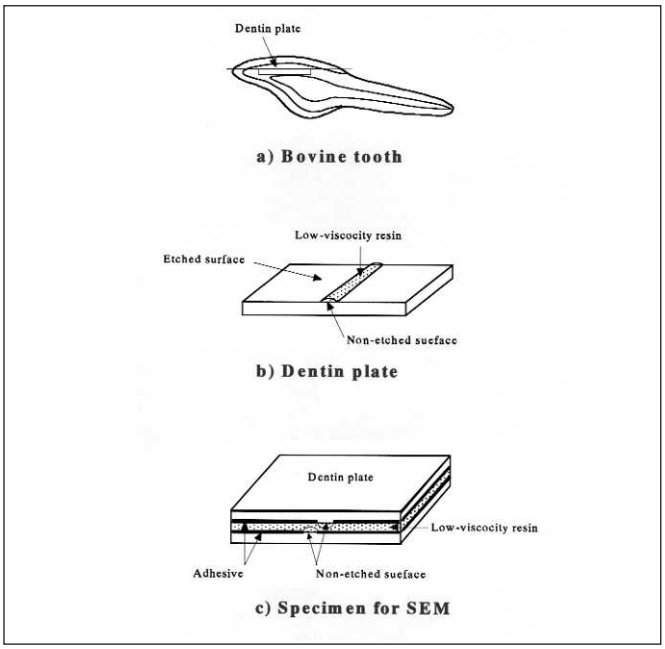

Figure 2. *Preparation of specimens for SEM observation.*
a) Bovine tooth: A rectangular shape was cut out from a bovine tooth.
b) Dentin plate: A dentin plate with low-viscosity resin to preserve the non-etched dentin surface.
c) Specimen for SEM: Two dentin plates were stuck together with low-viscosity resin and light-cured for 60 seconds.

Group 1: Excess water remained on the demineralized dentin surface (overwet);

Group 2: Excess water was blotted with tissue paper (Kimwipe, CRECIA Co, Tokyo, Japan), maintaining a moist dentin surface (blot dry);

Group 3: The etched dentin surface was air dried for one second using compressed oil-free air (Air Cleaner, Sekisei, Tokyo, Japan) at an approximate distance of 2.5 cm from the surface (one-second dry);

Group 4: The etched dentin surface was air dried for 30 seconds using compressed oil-free air (Air Cleaner, Sekisei, Tokyo, Japan) approximately 2.5 cm from the surface (desiccated).

Under these conditions, Single Bond Adhesive (3M Dental Products, St Paul, MN 55144, USA, Lot #3411) was applied twice to the demineralized dentin, then mildly air dried and light cured for 10 seconds. A resin composite (Clearfil AP-X A3, Kuraray, Osaka, Japan, Lot #0532) was placed, pressed flat by a slide glass and light cured for 40 seconds. A stainless steel rod was attached to the resin by a resin cement (Panavia 21, Kuraray, Osaka, Japan, Lot #0499AN) for the tensile bond test. Specimens were immersed in water for 24 hours, and as illustrated in Figure 1, tensile bond strength was then measured using a universal-testing machine, Autograph AG500B (Shimadzu, Kyoto, Japan) at a crosshead speed of 2 mm/minute. The results were analyzed by one-way ANOVA and Fisher's PLSD test at the 5% level. The fracture modes after tensile testing were classified into the following categories by visual inspection: A: adhesive failure and M: mixed failure that consisted of adhesive failure between the dentin surface and resin combined with cohesive failure of the bonding resin or dentin.

Specimen Preparation for SEM Observation

Figure 2 illustrates specimen preparation for the SEM observation. Labial bovine dentin was ground with #600-grit silicon carbide paper and cut into a rectangular shape. A strip of low-viscosity microfilled resin (Protect Liner-F, Kuraray, Osaka, Japan, Lot #0021) was placed on the center of the dentin surface to preserve the original non-etched surface. The dentin surface was then etched with 35% phosphoric acid (Single Bond Etchant, 3M Dental Products, Lot #7423) for 15 seconds and rinsed with water. The four conditions for the dentin surfaces (overwet, blot dry, one-second dry and desiccated) were prepared in the same manner as the bond test specimens.

Following this, Single Bond Adhesive (3M Dental Products, Lot #3411) was applied twice to the conditioned dentin, mildly air dried and light cured for 10 seconds. Two dentin specimens were stuck together with Protect Liner-F (Kuraray, Osaka, Japan, Lot #0021) and light cured for 60 seconds. Inokoshi & others (1993) describes this method as the "sandwich technique." In this study, two specimens of sandwiched samples were made under the same wet or dry condition to obtain eight locations that contained an etched surface and a non-etched surface. After the specimen was immersed in 10% formaldehyde for 24 hours, each specimen was sectioned vertically at the center and polished with diamond pastes down to 0.25 µm–grit size, then etched with an argon-ion beam for three minutes. Specimens were gold-sputter coated for SEM observation (Inokoshi & others, 1993) and observed under SEM (JSM-5310LV, JEOL, Tokyo, Japan).

Table 1: *Tensile Bond Strengths and Fracture Mode of Single Bond to Bovine Dentin*

Wet/Dry Condition	Tensile Bond Strength (MPA	Coefficient of Variation	Fracture Mode
Overwet	5.2 (4.1)[A]	79%	A(70%) M(30%)
Blot Dry	12.6 (7.7)[B]	61%	A(20%) M(80%)
One Second Dry	11.9 (3.6)[B]	30%	A(20%) M(80%)
Desiccated	4.4 (2.1)[A]	48%	A(100%)

Mean (SD)
Values designed with the same superscript letter are not statistically different p<0.05)

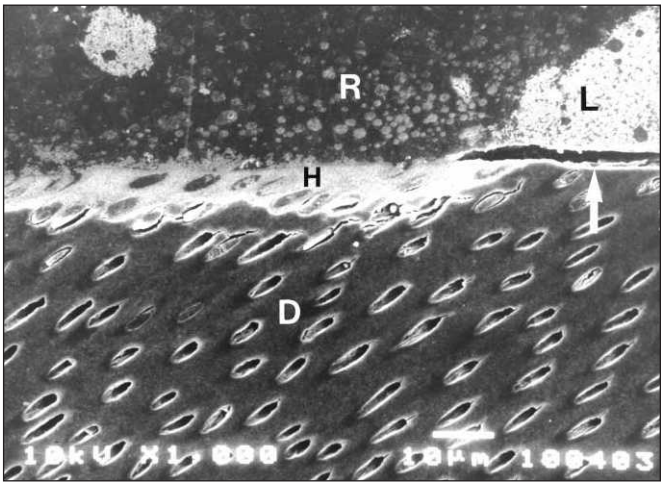

Figure 3a. *Cross-sectional SEM view of resin-dentin interface of Single Bond to etched dentin under overwet condition. One side of a dentin surface was protected with low-viscosity resin against demineralization. The thickness of hybrid layer is 5 µm. The top of the hybrid layer was at the same level as the original dentin surface.*
Arrow: Unetched dentin surface, D: Dentin, H: Hybrid layer, R: Bonding resin, L: Low-viscosity resin.

RESULTS

Tensile Bond Test

Table 1 summarizes the tensile bond strengths of Single Bond to bovine dentin.

Group 1 (overwet) showed a mean bond strength of 5.2 MPa, which was statistically no different from the

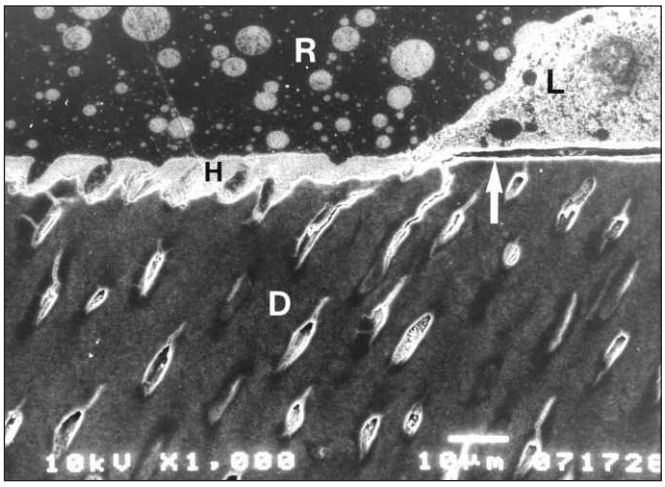

Figure 3b. *SEM view of resin-dentin interface of Single Bond to etched dentin under blot dry condition. Hybrid layer is 5 µm thick, with the hybrid layer surface at the same level as the non-etched dentin.*
Arrow: Unetched dentin surface, D: Dentin, H: Hybrid layer, R: Bonding resin, L: Low-viscosity resin.

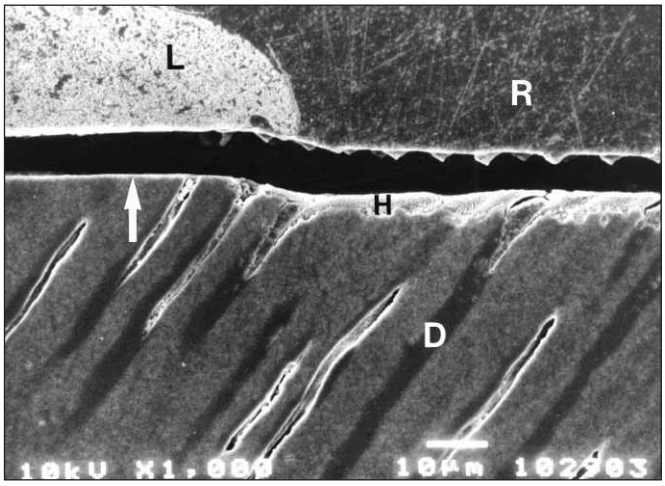

Figure 3d. *SEM view of resin-dentin interface of Single Bond to etched dentin under desiccated condition. The polymerized resin had pulled away from the dentin surface. The thickness of hybrid layer is 3 µm. The collapse of the demineralized collagen surface from the original level is about 3 µm.*
Arrow: Unetched dentin surface, D: Dentin, H: Hybrid layer, R: Bonding resin, L: Low-viscosity resin.

desiccated group at 4.4 MPa ($p>0.05$). The coefficient of variation of Group 1 was 79%, whereas Group 4 was 48%. Seventy percent of the specimens exhibited adhesive failure. The others showed cohesive failure in dentin or bonding resin. In Group 4, all specimens exhibited adhesive failure.

Group 2 (blot dry) showed a mean bond strength of 12.6 MPa, which was significantly greater than the desiccated and overwet groups ($p<0.05$). There was no significant difference in bond strength between the blot

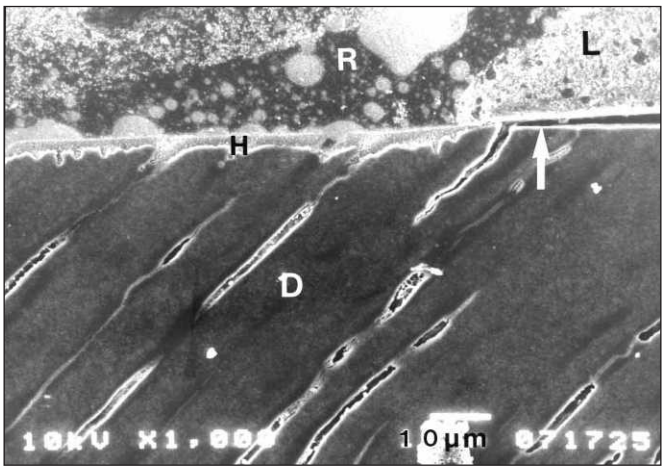

Figure 3c. *SEM view of resin-dentin interface of Single Bond to etched dentin under one-second dry condition. The slight collapse of adhesive interface is identified. The thickness of hybrid layer was approximately 2 µm. Arrow: Unetched dentin surface, D: Dentin, H: Hybrid layer, R: Bonding resin, L: Low-viscosity resin.*

dry and the one-second dry group at 11.9 MPa ($p>0.05$). The blot dry group showed a coefficient of variation of 61%, whereas the one-second dry group showed 30%. The fracture mode was mixed failure, including cohesive failures in dentin, with few specimens showing adhesive failure for both groups.

SEM Observation of Bonded Specimens

Figure 3 shows the SEM views of bonded specimens.

Figure 3a shows a specimen bonded under the overwet condition. The thickness of the hybrid layer was approximately 5 µm. The top of the hybrid layer was at the same level as the original dentin surface. In the polymerized bonding agent, many small globules were observed above the resin-dentin interface. Fine globules (less than 1 µm diameter) were noted in great numbers just above the resin-dentin interface.

In Figure 3b, the hybrid layer created under the blot dry condition was 5 µm thick, with the hybrid layer surface at the same level as the non-etched dentin. Some globules that contained a solid material were observed in the bonding agent.

In the one-second dry specimen (Figure 3c), the level of the resin-dentin interface was a little lower than that of the original dentin surface. The thickness of the hybrid layer was approximately 2 µm. The bonding resin also exhibited solid globules.

In the desiccated specimen (Figure 3d), the resin had pulled away from the dentin surface. The thickness of the hybrid layer was 3 µm. The collapse of the demineralized collagen surface from the original level was about 3 µm. No globules were observed in the bonding resin of this specimen. However, in some specimens, a few voids (10-20 µm diameter) were observed in the bonding resin.

DISCUSSION

The relation between bond strengths and hybrid layer formation for each moisture condition is one clue to a better understanding of resin-dentin bonding of one-bottle adhesive systems.

Among the four wet/dry conditions, the blot dry group was statistically the same strength as the one-second dry group. Fracture mode of both groups was similar at 80% mixed failure. In the SEM pictures, the blot dried demineralized dentin did not shrink during the bonding procedure, while the one-second dry group showed collapse of the demineralized dentin surface. In the case of blot drying, after etching and blotting, most of the water in the interfibrillar spaces remained to support the collagen network (Carvalho & others, 1996; Maciel & others, 1996). During application of the adhesive, the ethanol solvent could drive water away sufficiently to allow penetration of the monomers (Nishiyama & others, 1995; Xu & others, 1997; Pashley & others, 1998). Thus, the monomers infiltrated into the demineralized dentin, polymerize and produce a hybrid layer without collapse of the collagen network or separation of the resin from the dentin. In the case of one-second dry, the level of the resin-dentin interface was a little lower than the non-etched surface. In addition, the hybrid layer was much thinner than the blot dry specimens. This indicates that one-second air drying caused some shrinkage of demineralized dentin due to a loss of water support in the collagen fibrils (Nikaido, Antonucci & Tagami, 1997; Nakaoki & others, 2000). Therefore, collapse of the collagen network and lack of water made resin infiltration into the demineralized dentin less effective, producing a thinner hybrid layer.

On the other hand, the coefficient of variation of the blot dry group was large at 61%. This value is believed to result from overwet patches causing a poor bond. In the one-second dry group, the coefficient of variation was smaller at 30%. These results indicated that the blot dry method is more technique-sensitive than the one-second dry method and may possibly affect the long-term durability of resin-dentin bonding.

The tensile bond strength of the overwet group was 5.2 MPa, which was significantly lower than the blot dry and one-second dry groups. Collapse of the dentin surface was not observed under SEM. However, the fracture mode after tensile bond testing showed 70% adhesive failure. Because of the excess water on the dentin surface, separation between the bonding resin and resin-reinforced dentin occurred, even in the case where the collagen network was infiltrated by monomers from the bonding agent. The high value of the coefficient of variation (79%) was possibly due to the volume of residual water on demineralized dentin causing variation among specimens.

On SEM views of these three groups (blot dry, one-second dry and overwet), the polymerized resin exhibited globules that are characteristic for the wet bonding technique (Tay & others, 1996b). The mechanism of their formation is not clear. However, phase separation of the more hydrophilic monomer components of the bonding agent might have occurred in the presence of excess water (Tay, Gwinnett & Wei, 1996a; Tay, Gwinnett & Wei, 1996c).

In the desiccated group, the tensile bond strength was significantly reduced compared with the blot dry and one-second dry groups. The SEM view shows separation between resin and dentin, a thin hybrid layer and collapse of the demineralized dentin surface compared with the original level. The significant shrinkage of the collagen network after removing water was believed to lead to inadequate diffusion of monomers into the demineralized dentin. Globules in the polymerized resin did not appear in this group probably due to the lack of water. Voids observed in some specimens may be formed when applying the adhesive using a brush.

Spencer & others (2000) reported the results of micro-Raman spectroscopic analysis, stating that the relative percent of Single Bond adhesive penetration was ~55 % approximately 2 μm into demineralized dentin. The decreasing percentage of resin infiltration into deeper zones may be an inevitable phenomenon on phosphoric acid etched dentin (Sano & others, 1995; Han & others, 2000). Further investigation regarding long-term durability of such adhesive systems is needed (Kato & Nakabayashi, 1998).

There are numerous choices of adhesive materials for restorations, such as conventional three-step bonding systems, two-step bonding systems (wet bonding system and self-etching priming system), all-in-one bonding systems and glass-ionomer cements. In this study using wet bonding, the blot dry and one-second dry groups showed higher bond strengths than the other two groups. However, the coefficient of variation of the blot dry group was very high. In the one-second dry group, the moisture content of the collagen network was possibly too dry such that hybrid layer formation was not as good even though the bond strength was high. Thus, from the clinical standpoint, wet bonding is believed to be a very technique-sensitive method.

CONCLUSIONS

The effect of residual water on dentin bond strengths and hybrid layer formation of a one-bottle adhesive system was investigated. The blot dry and one-second dry groups showed higher bond strengths than the other two groups. However, the coefficient of variation of the blot dry group was very high. In the one-second dry group, hybrid layer formation was not as good even though the bond strength was high. Thus, from the

clinical standpoint, wet bonding is believed to be a very technique-sensitive method.

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Composite Restorations: Influence of Flowable and Self-Curing Resin Composite Linings on Microleakage *In Vitro*

A Peutzfeldt • E Asmussen

Clinical Relevance

The use of flowable resin composite as first increment in the proximal boxes of MOD cavities decreased microleakage as compared to the use of hybrid composite alone. Using a self-cured composite as first increment did not reduce microleakage.

SUMMARY

This in vitro **study evaluated the microleakage at enamel (occlusal) and dentin (gingival) margins of MOD resin composite restorations made with different incremental insertion techniques. MOD cavities were prepared on 60 extracted human molars with the proximal margins placed 1 mm below the cemento-enamel junction. All teeth were acid-etched and treated with One-Step adhesive, then restored with a hybrid resin composite (Renew) with and without a flowable composite (Æliteflo) or a self-curing composite (Bisfil 2B) as the first increment in the proximal boxes. The time of placement of the second increment in relation to curing of the first increment was also varied. After polishing, the teeth were soaked in 0.5% basic fuchsin for 24 hours, sectioned and evaluated for dye penetration. None of the restorative techniques prevented microleakage at the enamel and dentin margins. However, microleakage at dentin margins were significantly reduced by the use of a flowable composite as the first increment in the proximal boxes. Time of placement in relation to curing had no influence on microleakage. Microleakage was lower at enamel margins than at dentin margins; however, besides microleakage at the enamel-restoration interface, 37 of the 60 restored teeth (62%) displayed at least one white line in enamel adjacent to the composite restoration.**

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INTRODUCTION

The use of resin composites as posterior restoratives has markedly increased over the past decade as a result of material improvements and disfavor of amalgam. Even though some of the problems of resin composites, for example, unacceptably low wear resistance, have been overcome, today's composites still shrink 2-to-4% upon polymerization (Soltész, 1998; Watts & al Hindi, 1999; Park, Krejci & Lutz, 1999; Cook, Forrest & Goodwin, 1999). Polymerization shrinkage may cause polymerization stress and/or gap formation and microleakage depending on the strength with which the composite is bonded to the tooth surfaces (Davidson, de Gee & Feilzer, 1984; Davidson & de Gee, 1984). These phenomena may lead to postoperative sensitivity, sec-

ondary caries and pulpal inflammation. As these factors may shorten the longevity of a restoration, they should be minimized or, preferably, eliminated (Cox, 1992; Bergenholtz & others, 1982).

Several attempts have been made to synthesize novel monomers that would result in non-shrinking or even expanding resin composites (Stansbury, 1990; Stansbury, 1992; Byerley & others, 1992; Stansbury, Dickens & Liu, 1995). Unfortunately, this work has not yet materialized in a commercial product, partly due to problems regarding compatibility of the new types of monomers with conventional dental monomers and initiator systems. In the meantime, painstaking efforts are made during the restorative procedure to alleviate the adverse effects of polymerization shrinkage. Thus, the use of bonding agents and incremental insertion techniques have been routine for several years. Recently, different "soft-start" curing techniques and curing units have been introduced that intend to prolong the compensating flow of the composite during polymerization and thus counteract the negative effects of shrinkage (Uno & Asmussen, 1991; Goracci, Mori & Casa de Martinis, 1996; Mehl, Hickel & Kunzelmann, 1997; Kanca & Suh, 1999).

Moreover, new incremental techniques have emerged that make use of different types of composites. For example, one idea is to use a flowable composite, as the first increment of the proximal boxes of direct Class II restorations. The reduced filler loading of flowable composites compared with their hybrid analogs leads to enhanced flow and reduced elastic modulus (Bayne & others, 1998; Peutzfeldt & Asmussen, unpublished results). These two characteristics have been speculated to counteract microleakage by increasing adaptation and by forming a stress-absorbing layer (Bayne & others, 1998; Kemp-Scholte & Davidson, 1990a). Several recent *in vitro* studies have investigated the influence of a flowable composite on marginal sealing of Class II composite restorations. The results of these studies are conflicting; whereas, some studies found the use of a flowable composite as first increment to improve marginal sealing (Estafan, Estafan & Leinfelder, 2000; Leevailoj & others, 2001; Belli & others, 2001), other studies found no effect of such an increment (Jain & Belcher, 2000; Chuang, Liu & Jin, 2001; Chuang & others, 2001; Beznos, 2001). Alomari, Reinhardt & Boyer (2001) also found no reduction in gap formation but did find a flowable liner to reduce cusp deflection.

In another version of the incremental insertion technique, self-curing composite is used as the first increment in Class II restorations. It has been hypothesized that the warmth of the tooth will enhance polymerization of the self-curing composite closest to the tooth and thus inhibit the tendency of the composite to shrink towards the center of its mass and to pull away from the gingival wall (Bertolotti, 1991; Fusayama, 1992). The use of a self-cured adhesive has been proposed to have the same effect by accelerating polymerization of the self-curing composite in contact with the adhesive, thereby directing shrinkage toward the gingival wall. It has also been suggested that the slower polymerization and delayed development of stiffness of self-curing composites allow for increased flow of these materials to counteract polymerization stress and gap formation (Kemp-Scholte & Davidson, 1990b; Feilzer, de Gee & Davidson, 1993).

Subsequently, one study comprising zero controls found excellent marginal seal of certain combinations of adhesive and self-curing resin composite when using the self-curing composite as a first increment between adhesive and light-curing composite in Class II restorations (Garberoglio, Coli & Brännström, 1995). Several other studies have failed to show any effect of a self-curing first increment (Miller & others, 1996; Hilton, Schwartz & Ferracane, 1997; van Dijken, Hörstedt & Waern, 1998; Beznos, 2001).

Feilzer, de Gee & Davidson (1987, 1993) have shown that during polymerization, shrinkage stress is built-up in the composite to a degree that varies with the so-called configuration factor of the restoration, that is, the ratio of bonded to unbonded composite surfaces. All but one of the above-mentioned studies of incremental insertion techniques used Class II cavities or Class II slot cavities. However, many MOD amalgam restorations are being replaced by composite restorations, and since a large MOD restoration has a different configuration factor than a small Class II restoration, the effect of variations in the insertion technique may be expected to depend on the type of cavity in question.

This study tested the hypothesis that a first, gingival increment of either flowable or self-curing composite reduces microleakage at the gingival margin of otherwise light-curing composite MOD restorations.

METHODS AND MATERIALS

Sixty extracted human molars stored in 0.5% chloramine since extraction were free of caries. The restorations were scaled and cleaned. MOD cavity preparations were prepared by an experienced operator using medium diamond burs (Komet 848 018, Gebr Brasseler, Lemgo, Germany) in a water-cooled high-speed turbine. The cavities were approximately 4 mm in width and 4 mm in depth in the occlusal part of the preparation and had a gingival wall of 1 mm. The proximal margins were located 1 mm below the cemento-enamel junction. The cavosurface margins were prepared at 90°, and all internal line angles were rounded. The teeth were randomly divided into six groups of 10 teeth.

All cavities were etched for 15 seconds with 32% phosphoric acid (Table 1), washed for 10 seconds and the

Table 1: *Materials Used in This Study*

Material	Type	Lot #	Manufacturer
Uni-Etch	32% Phosphoric acid	0100000900	BISCO, Inc, Schaumburg, IL, USA
One-Step	Dental adhesive	0100000596	BISCO, Inc, Schaumburg, IL, USA
Æliteflo LV	Flowable composite	0100000562	BISCO, Inc, Schaumburg, IL, USA
Renew	Hybrid composite	0100001126	BISCO, Inc, Schaumburg, IL, USA
Bisfil 2B	Self-curing composite	0100001098	BISCO, Inc, Schaumburg, IL, USA

Table 2: *Restorative Techniques Studied*

Group	Technique
A	Renew: Three increments in each proximal box—one horizontal + two oblique. Two oblique increments in the occlusal cavity. Each increment cured for 20 seconds.
B	Æliteflo, light-curing, Renew, light-curing: First, horizontal increment in the proximal boxes restored with Æliteflo. Otherwise, the restorative procedure was identical to that of Group A.
C	Æliteflo, Renew, light-curing: As Group B except that Æliteflo was not light-cured before application and light curing of the subsequent layer of Renew.
D	Bisfil 2B, five-minute self-curing, Renew, light-curing: First, horizontal increment in the proximal boxes restored with Bisfil 2B which was allowed to cure for five minutes before application of the first oblique increment of Renew. Otherwise, the restorative procedure was identical to that of Group A.
E	Bisfil 2B, Renew, five-minute self-curing, light-curing: As D except Bisfil 2B was not left to cure before application of the first oblique increment of Renew. This increment was not light-cured until after Bisfil 2B had been left to cure for five minutes.
F	Bisfil 2B, Renew, light-curing, self-curing: As E except the restoration proceeded with out consideration for the curing of Bisfil 2B.

excess was very briefly blown away, leaving a moist surface. The cavity was then covered with two consecutive layers of One-Step adhesive (Table 1). The excess solvent was evaporated by air drying for 10 seconds. The adhesive was light cured for 10 seconds with an XL 3000 light-curing unit (3M, St Paul, MN 55144, USA) having a light intensity of 450 mW/cm^2 (Optilux Radiometer, Model 100, Demetron Research Corp, Danbury, CT 06810, USA). A steel matrix (Hawe Neos Dental, Bioggio, Switzerland) was applied with a Nyström retainer (Dentatus, Stockholm, Sweden), and each tooth was mounted in a clamp.

The teeth were restored with the materials listed in Table 1 according to the six different techniques described in Table 2. Maximal care was taken during placement of the composite to keep finishing to a minimum. The occlusal surfaces were finished with fine diamond burs (Komet) and polished with rubber points (Identoflex, Buchs, Switzerland). Proximal margins were finished with Sof-Lex discs (3M). Finishing was checked in a stereo-microscope.

The apices of the teeth were sealed with resin composite and the tooth surfaces were covered with a layer of light-curing resin with the exception of 1 mm around the tooth-restoration interface. The teeth were then immersed in 0.5% basic fuchsin dye for 24 hours. They were removed, washed, dried and embedded in self-curing acrylic resin. Each tooth was then sectioned in the buccolingual direction through the center of the Class I part of the restoration with an Accutom diamond saw of thickness 0.5 mm (Struers, Copenhagen, Denmark) at low speed using copious amounts of water. Both hemi-sections were evaluated at 18x with a stereomicroscope (Leitz, Wetzlar, Germany) for penetration of the dye at the buccal and lingual enamel margin of the Class I part of the MOD restoration (Figure 1A). The following scoring criteria were used:

0 = No dye penetration

1 = Penetration along the buccal/lingual wall up to the pulpal wall

2 = Penetration along the pulpal wall

The presence of enamel cracks, so-called white lines within the enamel adjacent to the restoration was also noted (Staninec & others, 1986; Belli & others, 2001).

Each hemi-section was then ground on wet silicon-carbide paper grit #1000 in the mesial-distal direction from the lingual surface in two stages corresponding to one-third and two-thirds through the restoration, respectively. After each grinding stage, the extent of dye penetration of the mesial or distal Class II part of the MOD restoration (Figure 1B) was determined using the following scoring criteria:

0 = No dye penetration

1 = Penetration along the gingival wall up to the axial wall

2 = Penetration along the axial wall

Consequently, for each restoration, dye penetration was evaluated at four geographic points along the enamel margin (a-d in Figure 1A) and four geographic points along the dentin margin (e-h in Figure 1B). The highest of the four enamel scores and the four dentin scores, respectively, were used to characterize a given restoration. The number of teeth with one or more white lines was registered for each of the six groups. The Kruskal-Wallis test and the Mann-Whitney U-test were used for statistical analysis and comparison of dye penetration scores between groups with p=0.05 as the level of significance. Comparisons between white line

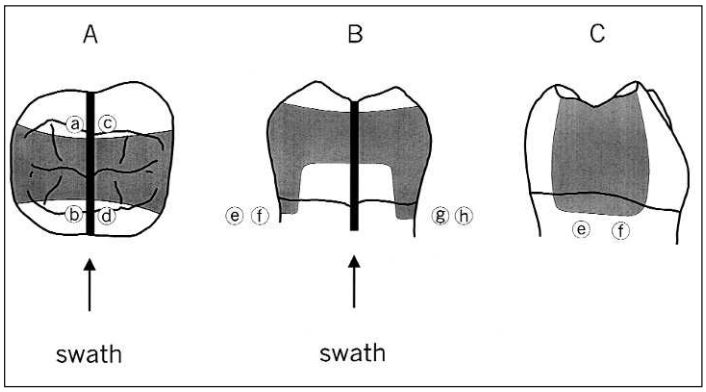

Figure 1: *Schematic drawing of a restored tooth showing the dye penetration evaluation sites.*
A. Occlusal view showing that each restored tooth was sectioned in buccolingual direction. For each hemisection, dye penetration was then evaluated at the buccal (a and c) and lingual margin (b and d).
B. Buccal view again showing the sectioning of the tooth. Each of the hemisections was ground in mesial-distal direction corresponding first to one-third through the restoration allowing evaluation of dye penetration at sites e and g, and then corresponding to two-thirds through the restoration allowing evaluation at sites f and h.
C. Proximal view of the mesial box showing the two sites where dye penetration was evaluated.

Table 3: *Distribution of Microleakage Scores at Enamel Margins*

Group	0	1	2
A	1	7	2
B	0	10	0
C	1	9	0
D	0	9	1
E	1	7	2
F	0	8	2

Table 4: *Distribution of Microleakage Scores at Dentin Margins*

Group	0	1	2
A	0	3	7
B	0	8	2
C	0	7	3
D	0	7	3
E	0	6	4
F	0	5	5

frequencies were made by the Fisher exact probability test.

RESULTS

At enamel margins, only three of the 60 restorations were totally free of microleakage, and the majority of the restorations showed dye penetration along the buccal/lingual wall corresponding to a score of 1 (Table 3). There was no significant difference in microleakage among the six restorative techniques.

At the dentin margins, none of the restorations were without leakage and more restorations were designated the maximal leakage score of 2 (Table 4) than at the enamel margins. Technique B, which used a separately cured gingival increment of flowable composite, had significantly less leakage than did technique A, the control. The combination of results obtained with techniques B and C (the two techniques in which a flowable composite was used) demonstrated significantly less microleakage for these techniques than for technique A.

When testing each technique separately, dentin margins showed statistically significant greater microleakage than enamel margins for technique A, whereas there was no difference in leakage at enamel and dentin margins for techniques B-F. However, when microleakage was combined for techniques B and C (flowable composite) and for techniques D, E and F (self-curing composite), or for all five techniques B-F, dentin margins also showed statistically significantly greater microleakage than did enamel margins for these five techniques.

Pair-wise comparisons between technique A and each of the five experimental groups showed that technique E had significantly more white lines than technique A (Table 5). When combining the results of the five experimental techniques (B-F), these techniques had statistically significantly more white lines than did technique A.

DISCUSSION

This study agrees with other studies on microleakage in relation to resin composite restorations in that it found leakage to be the rule rather than the exception. Also, in keeping with previous work, microleakage could not be totally eliminated by variations in the insertion technique. However, in this study, using a flowable composite as the first increment significantly reduced microleakage at the dentin margins. As noted in the introduction, at least two factors resulting from the reduced filler content of flowable composites may account for this favorable effect: the improved flow is likely to facilitate adaptation, and the reduced elastic modulus may provide the material with a certain stress-absorbing ability. On the other hand, reduced filler content also leads to increased polymerization shrinkage, a factor that tends to aggravate microleakage. In this study, enhanced polymerization shrinkage may have had a negative effect on microleakage and a limiting effect on the microleakage-reducing capacity of the flowable composite. However, the net result of the counteracting effects was a positive one, a reduction in gingival microleakage. Thus, this study, which involved large MOD restorations, corroborates the findings of previous studies on Class II restorations that reported a positive effect of flowable composites (Estafan & oth-

Table 5: *No. of Teeth Out of 10 with White Lines*

Group	No
A	3
B	6
C	7
D	6
E	8
F	7

ers, 2000; Leevailoj & others, 2001; Belli & others, 2001).

According to technique B, the flowable composite was light cured prior to application of the following increment, whereas in technique C, the flowable composite was cured together with the following, first increment of hybrid composite. Co-curing may be speculated to maximize the stress-absorbing ability of the flowable composite as the elastic modulus develops concomitantly with the curing of both increments and is, therefore, not already high when curing of the hybrid composite is initiated. On the other hand, polymerization shrinkage may, to a higher degree, lead to microleakage when both increments are cured simultaneously because of the increased polymerization stress created in a bigger volume of polymerizing material. In this study, the two opposing effects seem to counterbalance each other, as no differences in microleakage were found between the two different techniques. The choice of technique may therefore be made on the basis of practical considerations, and in this regard, separate curing of the flowable composite seems preferable.

The slower polymerization of self-curing composites compared to light-curing composites may imply the same advantages as those advanced for the soft-start curing techniques introduced for light-curing composites: increased flow and delayed development of stiffness and, thereby, reduced polymerization stress, gap formation and microleakage. Furthermore, porosity incorporated during mixing of composites has been found to reduce polymerization shrinkage stress. The effect has been attributed to increased flow caused by delayed setting due to oxygen inhibition and/or by increased free surface area formed by the pores (Alster & others, 1992; Feilzer & others, 1993; Bouschlicher, Vargas & Boyer, 1997). However, under the conditions of this study, these mechanisms were not manifested in significantly reduced microleakage. Consequently, the findings of previous studies were corroborated (Miller & others, 1996; Hilton & others, 1997; van Dijken & others, 1998; Beznos, 2001).

Three different sequences of application and curing of the second increment in relation to the first increment in self-curing composite were examined. According to technique D, the self-curing composite was allowed to harden before application and curing of the light-curing hybrid composite. As recommended by Bertolotti (1991), technique E applied the hybrid composite immediately after application of the self-curing composite but did not light cure until after initial cure of the self-curing composite. The idea is that application of the second increment will force air bubbles out of the self-curing composite and, as mentioned in the introduction, that shrinkage will be directed towards the gingival wall so that this first increment may resist being "lifted off" when the second increment is cured. In technique F, the light-curing composite was cured immediately after application and before initial cure of the self-curing composite. This sequence may be speculated to give the poorest result of these three techniques as practically no compensating flow may take place during curing of the first increment from the already cured and fixed second increment. Despite these reflections, this study found no differences among the three self-curing composite techniques, and as discussed above, none of these techniques were found to significantly reduce microleakage. A possible explanation for this may be that the polymerization of the self-cured composite was insufficiently slow.

Leakage at the enamel margins was less than leakage at the dentin margins when the different insertion techniques were pooled into relevant groups. This is in keeping with the results reported by others (Hilton & others, 1997; Leevailoj & others, 2001; Beznos, 2001). The difference between enamel and dentin has been attributed to the higher bond strengths obtainable to enamel. Since One-Step, the adhesive used in this study, has been found to promote higher bond strength to enamel than to dentin, this explanation seems likely (Asmussen & Peutzfeldt, 2001). However, some of the newer adhesive systems promote a bond to dentin that is as high in strength as that promoted to enamel (Van Meerbeek & others, 2001; Asmussen & Peutzfeldt, 2001), and for these materials it may be that there would be no difference in microleakage at enamel and dentin margins.

In some teeth, white lines of varying depths were observed some microns from the enamel-restoration interface. These white lines are probably the result of fractures within the enamel caused by polymerization shrinkage stress. Enamel is weaker than dentin, and because of the strong bond between enamel and resin composite mediated by phosphoric acid etching, polymerization shrinkage has been suggested to express itself as a gap within the enamel instead of a gap between enamel and composite restoration as forms at dentin margins (Jörgensen, Asmussen & Shimokobe, 1975). It follows that determination of microleakage at enamel-restoration interfaces may be an insufficient measure of the marginal quality and that the presence of white lines should also be considered. In this study,

the number of teeth with white lines was higher for the experimental insertion techniques than for the control technique. This result was unexpected as only variations in the gingival increment were tested. It seems that the experimental insertion techniques altered the polymerization shrinkage pattern also in the subsequent increments of composite.

Furthermore, it would appear that the problems of gap formation and microleakage may not be solved by using adhesives that promote even stronger bonds than present-day adhesives. If the bond strength is very high, it is possible that the shrinkage forces will result in pronounced post-operative symptoms and even fractures of the restored teeth. Instead, efforts to compensate for polymerization shrinkage should concentrate on the slow polymerization procedures and the stress-absorbing layer techniques.

CONCLUSIONS

The hypothesis tested was partly confirmed. Only when a flowable composite, and not a self-curing composite was used for the first gingival increment was microleakage at the gingival margins of MOD composite restorations reduced.

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Effects of Professionally Applied Topical Fluorides on Surface Hardness of Composite-Based Restoratives

AUJ Yap • BYY Mok

Clinical Relevance

The use of acidulated fluoride gel and foam may be detrimental to the long-term durability of composites, compomers and giomers. Compomer restorations may also be degraded by treatment with 0.9% neutral fluoride foam.

SUMMARY

This study investigated the effects of professionally applied topical fluorides on the surface hardness of a composite (Spectrum TPH), a compomer (Dyract AP) and a giomer (Reactmer). Thirty specimens of each material were fabricated and stored in distilled water at 37ºC for one week. These specimens were then randomly divided into five groups of six and treated for 36 hours at 37ºC with one of the following: distilled water (control), 1.23% acidulated phosphate fluoride (APF) foam, 0.9% neutral foam, 1.23% APF gel and 0.4% stannous fluoride gel. The treated specimens were subsequently subjected to microhardness testing (load = 500gf; dwell time = 15 seconds). Results were analyzed using ANOVA/Scheffe's test ($p<0.05$). The effects of topical fluoride application on surface hardness was material dependent. For all materials, treatment with APF gel and foam significantly reduced surface hardness when compared to the control. KHN values after exposure to APF gel were consistently the lowest and ranged from 4.53 to 15.97. Control KHN values were higher, ranging from 32.88 to 47.47. The surface hardness of the compomer was also significantly reduced after exposure to neutral foam. Therefore, the use of professionally applied topical fluorides, especially APF gel and foam, may be detrimental to the long-term durability of composite-based restoratives.

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INTRODUCTION

Fluoride acts in several different ways to prevent caries. Once teeth have erupted, it inhibits demineralization and promotes remineralization, thus encouraging repair or arrest of carious lesions. Depending on its concentration and pH, fluoride can also exert a bactericidal or anti-enzymic effect (Joyston-Bechal & Kidd, 1994). Topical fluorides can be professionally applied "in-office" by clinicians or at home by patients. Topical fluoride treatments are recommended for children and adolescents who are at risk for dental caries. In addition, daily topical fluoride gels are used to control decalcification, rampant dental caries and plaque accumulation. Composite restoratives and adhesive techniques have

become the foundation of modern dentistry. Clinical usage of composites and compomers have increased substantially due to improvements in formulation, simplification of bonding procedures, increased aesthetic demands by patients and the decline in amalgam usage arising from the fear of mercury toxicity and changes in government regulations. The composition and surface integrity of composites and other glass-containing restoratives can be significantly changed when exposed to strong acids (El-Badrawy, McComb & Wood, 1993; Diaz-Arnold, Wistrom & Swift, 1995; Papagiannoulis, Tzoutzas & Eliades, 1997). This is clinically significant as topical acidulated phosphate fluoride (APF) gels, recommended as a preventive strategy in dentistry, contain strong acids.

Topical APF gels can cause surface damage, weight loss and decreased wear resistance in composites (Kula, McKinney & Kula, 1997; Papagiannoulis & others, 1997). The amount of weight loss and surface damage appear related to the type of filler particles in the composite (Kula & others, 1986; Papagiannoulis & others, 1997) and the topical fluoride that is applied (El-Badrawy & others, 1993; Kula, Webb & Kula, 1996). Composite resins containing barium boroalumino-silicate glass particles are among the most susceptible to surface changes caused by APF. Although the effects of professionally applied fluorides on composites has been widely reported, minimal literature regarding their effects on compomers and giomers is available. The latter, also known as PRG composites, is a new class of hybrid composite restorative that employs pre-reacted glass ionomer (PRG) technology. Unlike compomers, the fluoroalumino silicate glass is reacted with polyacrylic acid prior to inclusion into the urethane resin. The manufacturer's claims include fluoride release, fluoride recharge, biocompatibility, smooth surface finish, excellent aesthetics and clinical stability. Like compomers, giomers are light polymerized and require bonding systems for adhesion to tooth structure.

This study investigated the effects of professionally applied topical fluorides on the surface hardness of three different composite-based restoratives. Hardness deterioration associated with gel and foam presentation was also compared.

METHODS AND MATERIALS

Materials selected for this study included a composite (Spectrum TPH, Dentsply-De Trey, Konstanz, Germany), a compomer (Dyract AP, Dentsply-De Trey, Konstanz, Germany) and a giomer (Reactmer, Shofu Inc, Kyoto, Japan). The restoratives were placed in the rectangular recesses (4 mm long x 3 mm wide x 2 mm deep) of customized acrylic molds and were covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over the mold and pressure was applied to extrude excess material. The restoratives were light-polymerized according to manufacturers' cure times (20, 30 and 40 seconds for Spectrum, Reactmer and Dyract, respectively) through the glass slide using a Spectrum curing light (Dentsply Inc, Milford, DE 19963, USA). The intensity of the light source was checked with a radiometer (CureRite, EFOS Inc, Ontario Canada) before starting the experiment. The mean output was 515 ± 2 mW/cm^2 and the output was not affected by illumination through the glass slide and acetate strip. Immediately after light polymerization, the acetate strips were discarded and the composites stored in distilled water at 37ºC for one week. Thirty specimens were made for each material.

After one week, the 30 specimens of each material were randomly divided into five groups of six and treated for 36 hours at 37ºC with one of the following: Distilled water; 1.23% APF foam (Butler Fluoride Foam); 0.9% neutral fluoride foam (Butler Neutral Fluoride Foam); 1.23% APF gel (Butler APF Fluoride Gel) and 0.4% stannous fluoride gel (Stop). The latter patient-applied gel was included for comparison and storage in distilled water was used as control. Table 1 lists the topical fluoride agents used, the active ingredients, the mode of usage and the manufacturer. Specimens of the different composites were placed in the same plastic container and treated with 20 ml of gel, foam or water. At the end of 36 hours, the specimens were removed, rinsed under

Table 1: *Topical Fluoride Agents Used, Active Ingredients, Mode of Use and Manufacturers*

Fluoride Agent	Active Ingredients	Suggested Mode of Use	Manufacturer
1.23% APF Foam (Butler Fluoride Foam)	1.23% (w/w) fluoride ion from sodium fluoride and hydrofluoric acid in 0.1M phosphoric acid base (pH 3.0-4.0)	One-to-four minutes tray minutes tray application application after prophylaxis. 30 minutes contact time	John O Butler Company, Chicago, IL 60630
0.9% Neutral Foam (Butler Neutral Fluoride Foam)	0.9% (w/w) fluoride ions from sodium fluoride in a pH neutral base	One-to-four minutes tray application after prophylaxis. 30 minutes contact time	John O Butler Company, Chicago IL 60630
1.23% APF Gel (Butler APF Fluoride Gel)	1.23% (w/w) fluoride ons from sodium fluoride and hydrogen fluoride in 0.1M phosphoric acid gel (pH 3.5–4.0)	One-minute tray application after prophylaxis. 30 minutes contact time	John O Butler Company, Chicago IL 60630
0.4% Stannous Fluoride Gel (Stop)	0.4% stannous fluoride, glycerin, silica, flavor, hydroxyethylcellulose	One-minute application with soft toothbrush after brushing teeth. 30 minutes contact time	Oral B Laboratories, Belmont, CA 94002

Table 2: *Mean KHN of the Materials After the Various Fluoride Treatments*

Material	Spectrum TPH	Dyract AP	Reactmer
Distilled water	47.47 (4.09)	33.25 (2.98)	32.88 (5.87)
1.23% APF Foam	27.43 (8.15)	26.92 (2.97)	11.08 (1.97)
0.9% Neutral Foam	44.78 (4.89)	19.08 (2.43)	33.78 (1.87)
1.23% APF Gel	10.22 (1.89)	15.97 (2.39)	4.53 (0.63)
0.4% Stannous Fluoride Gel	36.45 (8.11)	30.42 (2.14)	34.90 (4.57)

Standard deviation in parenthesis.

Table 3: *Results of Statistical Analysis*

Variables		Significance
Materials	Spectrum TPH	Control, Neutral Foam > APF Foam, APF Gel APF Foam, Stannous Fluoride Gel > APF Gel
	Dyract AP	Control > APF Foam, Neutral Foam, APF Gel
	Reactmer	Control, Neutral Foam, Stannous Fluoride Gel > APF Foam, APF Gel
Fluoride Agents	Distilled water (control)	Spectrum > Dyract, Reactmer
	1.23% APF Foam	Spectrum, Dyract > Reactmer
	0.9% Neutral Foam	Spectrum > Dyract, Reactmer Reactmer > Dyract
	1.23% APF Gel	Spectrum, Dyract > Reactmer Dyract > Spectrum
	0.4% Stannous Fluoride Gel	NS

Standard deviation in parenthesis.

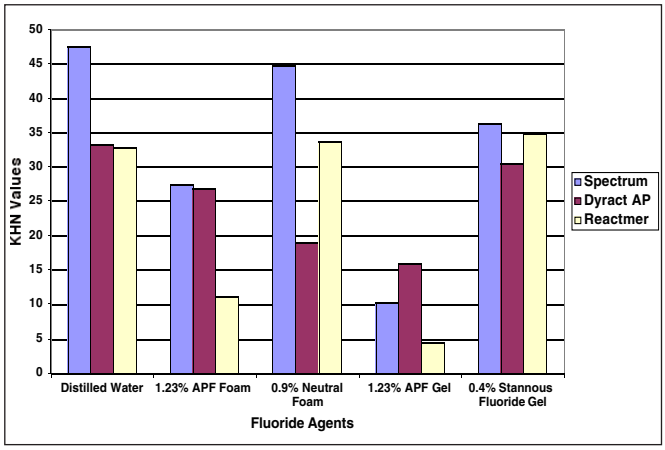

Figure 1. *KHN of the composites after treatment with the different fluoride agents.*

running water and blotted dry. The composite specimens were then placed centrally beneath the indenter of a digital microhardness tester (FM7, Future-Tech Corp, Tokyo, Japan) and a 500g load was applied through the indenter with a dwell time of 15 seconds. The Knoops Hardness Number (KHN) corresponding to each indentation was computed by measuring the dimensions of the indentations and using the formula KHN = 1.451 x (F/d^2), where F is the test load in Newtons and d is the longer diagonal length of an indentation in millimeters. Three readings were taken for each specimen and averaged to form a single value for each specimen.

All statistical analysis was conducted at a significance level of $p<0.05$. Two-way analysis of variance (ANOVA) was performed on hardness data with restorative materials and fluoride agents as main effects. One-way ANOVA and Scheffe's post-hoc tests were also performed with materials and fluoride agents as independent variables to determine the effects of topical fluoride application and to compare the hardness of the different composites, respectively.

RESULTS

Table 2 and Figure 1 show the mean KHN of the materials after the various fluoride treatments; whereas, Table 3 reflects the results of statistical analysis.

Two-way ANOVA of hardness data showed significant interaction between materials and fluoride treatments. The effects of professionally applied topical fluorides on surface hardness were therefore material dependent. For Spectrum, KHN values after treatment with distilled water and neutral foam were significantly greater than after treatment with APF foam and gel. In addition, hardness after treatment with APF gel was significantly lower than with APF foam and stannous fluoride gel. For Dyract, the control specimens were significantly harder than specimens treated with APF foam, neutral foam and APF gel. For Reactmer, KHN values obtained with distilled water, neutral foam and stannous fluoride gel were significantly greater than with APF foam and gel. Hardness after exposure to APF gel was consistently the lowest and ranged from 4.53 to 15.97. Table 2 demonstrates that the control KHN values were much higher and ranged from 32.88 to 47.47.

In the control group (distilled water), Spectrum was significantly harder than Dyract and Reactmer (Figure 1). After exposure to APF gel and foam, Spectrum and Dyract were significantly harder than Reactmer. Dyract, however, was significantly harder than Spectrum after treatment with APF Gel. When treated with neutral foam, Spectrum was significantly harder than Dyract and Reactmer, and Reactmer was signifi-

cantly harder than Dyract (Figure 1). No significant difference in hardness was observed among the three materials when treated with stannous fluoride gel.

DISCUSSION

Hardness may be defined as the resistance of a material to indentation or penetration (O'Brien, 1997). It is, however, difficult to formulate a definition that is completely acceptable, as the indentation produced results from the interaction of numerous properties. Among the properties related to the hardness of a material are strength, proportional limit and its ability to abrade or be abraded by opposing dental structures and materials (Anusavice, 1996). Therefore, any hardness deterioration observed with the use of professionally applied topical fluorides has implications on the clinical durability of restorations. The materials were stored for one week in distilled water at 37ºC prior to fluoride treatment to allow for post-polymerization (Chadwick & others, 1990), which affects hardness reading. The fluoride treatment regimen (36 hours at 37ºC) employed was that advocated by Diaz-Arnold & others (1995). Their regimen was based upon a commonly used fluoride regimen for caries-susceptible individuals that involves the nightly use of a fluoride gel placed in a tray and applied for six minutes (American Dental Association, 1986). The total exposure time with each professionally applied topical fluoride ranges from 31 to 34 minutes (one-to-four minute tray application and 30 minutes of contact prior to eating, drinking or rinsing). Thirty-six hours would simulate about 60 sessions or five years of monthly topical fluoride application. Although the fluoride exposure time utilized may appear excessive, it may actually occur clinically, as fluoride gels are rather tenacious and may accumulate in the interproximal areas and at the margins of restorations for more than a day.

The effect of professionally applied topical fluorides on surface hardness was found to be material dependent. This finding corroborates that of Abate & others (2001), who also found the effects of topical fluoride on hardness to be material dependent. For all materials, treatment with APF gel and foam significantly reduced surface hardness when compared to the control. The decrease in hardness may result from a difference in the pH or fluoride concentration (Kula & others, 1986; Kula & others, 1992). A 1.23% APF gel and foam with greater fluoride and hydrogen ion concentration are expected to be more reactive than 0.9% neutral foam and 0.4% stannous fluoride. Three major interaction pathways among the materials and fluoride agents may be identified. Interactions exist with organic matrix, filler-matrix coupling agents and/or reinforcing fillers. The organic matrixes of the composites evaluated are all organic esters of methyl methacrylate derivatives. Organic esters undergo hydrolytic cleavage of the ester group in low pH. This reaction is acid-catalyzed and is pH-dependent (Roberts & Caserio, 1965). As both APF gel and foam are acidic (pH 3 to 4), the amount of water bound to the organic matrixes is increased (Papagiannoulis & others, 1997), resulting in the decreased hardness that is observed. The decreased hardness after treatment with APF gel and foam could also be attributed to the presence of hydrofluoric acid (Cehreli, Yazici & García-Godoy, 2000). Hydrofluoric acid, a well-known glass etchant, dissolves composite filler particles and fluorosilicate glass particles that contribute to surface hardness. It may also cause dissolution of the siliceous hydrogel layer and ionic matrix around the fluorosilicate glass particles in the giomer (Diaz-Arnold & others, 1995; El-Badrawy & McComb, 1998). Increased filler dissolution may result in increased exposure of the organic matrix and, consequently, an accelerated hydrolytic effect. Fluoride ion has been implicated in depolymerization reactions of the matrix-filler interface (Bowen & Cleek, 1983). Fluoride may cause rearrangement of the water monolayer absorbed on filler where silanols form hydrogen bonds. It may also hydrolyze the organosilicon ester group and cause disorganization of the siloxane network formed from the condensation of intramolecular silanol groups that stabilize the interface (Plueddemann, 1970). All these mechanisms might weaken the filler-matrix interface, resulting in filler loss and decreased hardness.

The greatest hardness deterioration for all materials resulted from treatment with 1.23% APF gel. The differences in KHN values (ΔKHN) among the control and APF gel treatment were 37.25, 17.28 and 28.35 for Spectrum, Dyract and Reactmer, respectively. The ΔKHN obtained with 1.23% APF foam was lower at 20.04 for Spectrum, 6.33 for Dyract and 21.8 for Reactmer. Thus, APF in foam presentation is less damaging than in gel presentation. This finding agrees with a recent study by García-Godoy, García-Godoy & García-Godoy (2000), which showed that the effects of APF foam on several glass-ionomers and compomers were not as pronounced when compared to results obtained after using APF gel. Significant differences in hardness between specimens treated with APF gel and foam was, however, only observed with the composite (Spectrum).

For the composite and giomer, no significant difference in hardness was observed between treatment with 0.9 % neutral fluoride foam and distilled water/0.4% stannous fluoride. Hardness after treatment with neutral foam was significantly greater than with APF gel and foam. Therefore, 0.9% neutral foam is the professionally applied topical fluoride of choice if these materials are present intra-orally. Exposure to neutral foam, however, significantly decreased hardness of the compomer evaluated (Dyract). As pH of the stannous fluo-

ride evaluated (4.5) is lower than the neutral fluoride foam (Papagiannoulis & others, 1997), the aforementioned observation could be ascribed to the higher fluoride concentration in the neutral foam. The concentration of fluoride in the neutral foam may be sufficient to cause depolymerization reactions of the matrix-filler interface as mentioned earlier. Etching of unreacted fluoroalumino silicate glass particles in the compomer may also occur (El-Badrawy & others, 1993). This study cannot confirm the exact mechanism and warrants further investigation. Patients with multiple compomer restorations should avoid professionally applied topical fluoride agents. If topical fluoride therapy is required, the home-use, patient-applied stannous fluoride gel is recommended.

In the control group, the composite was significantly harder than the compomer and giomer (Figure 1). This was consistent with other studies that compared the mechanical properties of composites and compomers (Yap, Low & Ong, 2000; Yap & others, 2000). However, no significant difference in hardness was observed between the composite (Spectrum) and compomer (Dyract) after exposure to 1.23% APF gel and foam. The hardness deterioration of Spectrum after treatment with these fluoride agents was greater than Dyract. This may be attributed to using barium boroaluminosilicate glass particles in addition to colloidal silica in Spectrum. Composites containing these fillers are most susceptible to damage caused by APF fluoride application (Kula & others, 1997). The fillers used in Dyract are strontium fluorosilicate glass and silica. No significant difference in hardness was observed among the three materials after treatment with 0.4% stannous fluoride. This may be accounted for by the greater hardness deterioration observed with Spectrum and Reactmer's high resistance to the effects of stannous fluoride.

CONCLUSIONS

1. Using 1.23% APF gel and foam significantly decreased hardness of the composite, compomer and giomer evaluated.
2. Compomer hardness was also significantly reduced by treatment with 0.9% neutral fluoride foam.
3. Hardness deterioration associated with APF foam was less than with APF gel.
4. Composites containing barium boroalumino-silicate glass particles appear more susceptible to the effects of APF fluoride treatment.

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Evaluation of Microleakage Using Different Bonding Agents

RM Gagliardi • RP Avelar

Clinical Relevance

The use of a resin-modified glass ionomer or a glass ionomer as a base should be recommended since no adhesive systems were found to eliminate microleakage at dentin margins.

SUMMARY

This study evaluated microleakage in vitro **using different bonding agents. Forty-two freshly extracted caries-free human teeth were randomly divided into seven groups of six teeth and restored with different adhesive systems: Single Bond, Prime&Bond NT, Excite, Durafill Bond, Etch&Prime 3.0, Prompt L-Pop and Vitremer as the control group. All groups were treated according to manufacturers' instructions. Class V cavities were prepared on buccal and lingual surfaces (3 x 2.5 x 1.5 mm) of each tooth (12 restorations per group), with gingival margins in dentin. The teeth were restored with Charisma resin composite. After finishing and polishing with Denco-Flex disks, the teeth were thermocycled for 200 cycles (5°C-55°C ± 2°C, 60-second dwell time). Apical foramina and surfaces around restorations were coated with nail varnish, stained in 50% $AgNO_3$ solution for 12 hours and longitudinally sectioned. Microleakage was evaluated with a stereomicroscope. Marginal penetration was scored on a 0-4 scale. Statistical analysis using the Kruskal-Wallis test revealed significant ($p \leq 0.05$) leakage at dentin margins for all adhesive systems when compared to the control. Except for Durafill Bond, no significant difference was found between the self-etching adhesives and one-bottle adhesives.**

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INTRODUCTION

The satisfactory adhesion of bonding agents and their longevity are of interest to dentistry. Several studies evaluating the microleakage of dentin bond systems show that no system can block microleakage, which increases significantly in cementum areas (Retief, 1994). The hybrid layer has been suggested as the main mechanism of adhesion between the adhesive system and conditioned dentin (Walshaw & McComb, 1996), where the collagen network is infiltrated by monomers that are polymerized and capable of reinforcing demineralized dentin (Sano & others, 1994). The leakage pathway allows oral fluid and bacteria to permeate the resin/dentin interface and can cause degradation of the bond area and pulp inflammation. The bacterium at the restoration/dental interface is the main cause of pulpal irritation from dental restorative materials (Brännström, Vojinovic & Nordenvall, 1979; Qvist, 1980; Cox & others, 1987).

To reduce microleakage, certain procedures, such as maintaining a wet dentin, applying the adhesive according to manufacturers' instructions and restoring with resin composite by an incremental technique, should be adopted. The characteristic of the adhesives is also important, where an efficient adhesive system depends on polymerization, penetration capacity and its reaction to surface dentin (Eick & others, 1993). Furthermore, efficient diffusion of primers and saturation of spaces around collagen fibers is essential (Suzuki, Takahashi &

Nakai, 1990; Manabe & others, 1991). Thus, treating dentin with acids can cause a collapse of exposed collagen fibers by removing the hydroxyapatite and/or denaturing the collagen (Nakabayashi & Takarada, 1992; Pashley & others, 1993; Gwinnett, 1994). Self-etching adhesive systems were thus proposed to solve this problem. Recently, many new adhesive systems have been developed and their pre-treatment and adhesion-promoters are being studied to improve clinical results.

This study evaluated *in vitro* microleakage using different bonding agents.

METHODS AND MATERIALS

Forty-two freshly extracted caries-free human molars and premolars were used. The teeth were randomly divided into seven groups of six each, where two cavities were prepared (12 restorations for each group) and restored with different bonding agents according to manufacturers' instructions (Table 1).

After mechanical debridment and enamel integrity evaluation using a magnifying glass (4x), all the teeth were cleaned with pumice-water slurry (SSWhite, Rio de Janeiro, RJ 20921-430, Brazil) before starting restoration procedures. Class V cavities, 3 mm wide, 2.5 mm high and 1.5 mm in depth were prepared with a cylindrical diamond bur (#1093, KG Sorensen LTDA, Barueri, SP 06465-130, Brazil), under copious water on buccal and lingual surfaces with gingival margins in dentin. Each bur was replaced every five cavity preparations.

A total etch condition was performed with phosphoric acid 37% (Acigel, SSWhite) for a minimum of 15 seconds in enamel and a maximum of 15 seconds in dentin, when one-bottle adhesive systems were used. The self-etching adhesive Etch&Prime 3.0 was used by mixing an equal portion of the Universal with the Catalyst. This was applied to the cavity for 30 seconds (Table 1). Prompt L-Pop was activated per manufacturers' instructions and applied to the cavity, agitating for 15 seconds. A new blister pack was used for each sample. The modified glass ionomer Vitremer (3M, St Paul, MN 55144, USA) was used as control (Table 1).

All groups, except for the control, were restored with a Charisma microhybrid resin composite (Heraeus Külzer, D-61269 Wehrheim, TS/Germany) by an incremental oblique technique (Hansen, 1986). Each resin increment was light cured for 20 seconds using an Optilux 401 visible-light cure unit (Demetron-Kerr, Danbury, CT 06810, USA). All restorations were polished with Denco-Flex disks (DFL LTDA, Rio de Janeiro, RJ 22713-001, Brazil).

Between procedures, the teeth were stored in distilled water at 37°C for at least 24 hours. They were thermocycled for 200 cycles at 5°C-55°C (±2°C), 60 seconds dwell time. Apical foramina was sealed with Araldite (mercaptan polymer, aliphatics amines and epoxy resin; Ciba-Geigy Química SA, S Bernardo do Campo, SP 09892-110, Brazil). Tooth surfaces were sealed with two coats of nail varnish, except for 1 mm around restorations (Niasi SA, T da Serra, SP 06751-970, Brazil). After 24 hours, the teeth were stained in 50% $AgNO_3$ solution (Vetec Química Final LTDA, Rio de Janeiro, RJ 25250-000, Brazil) for 12 hours, washed for 15 minutes in run-

Table 1: *Restorative Materials Used*
*Procedures: a1, etch enamel for at least 15' and dentin for at most 15'; a2, apply self-etching adhesive without agitation; a3, apply self-etching adhesive with agitation; b, apply adhesive; c, gently air dry; d, light-cure; e, place restoration**

Gps	Material	Lot #	System	Procedures
SB	Single Bond (3M, St. Paul, MN 55144, USA)	1105	One-bottle	a1; b (15'); c; d(20'); e
PB	Prime&Bond NT (Dentsply De Trey, D-78467 Konstanz, Germany)	9811001112	One-bottle	a1; b (20'); c;† d (10'); e †repeat b and c if necessary
EX	Excite (Vivadent Ets, FL-9494 Schaan Liechtenstein)	B29610	One-bottle	a1; b (10'); c; d (20'); e
DB	Durafill Bond (Heraeus Külzer, D-61269 Wehrheim/Ts, Germany)	010188	One-bottle	a1; b
EP	Etch&Prime 3.0 (Degussa AG, D-63403 Hanau, Germany)		Self-etching	a_2 (30'); c; d (10'); e repeat the steps
	Universal	099812		
	Catalyst	129817		
PP	Prompt L-Pop (ESPE Dental AG, Seefeld 82229, Germany)	51578	Self-etching	a_3 (15'); c; d (10'); e
VM	Vitremer (3M, St Paul, MN 55144, USA)		Modified Glass Ionomer (color B-20)	primer (30'); c (15'); d (20'); powder + liquid (mixing within 45'); d (40'); polish; rinse; c; finishing gloss; d (20')
	Primer	733		
	Powder	745		
	Liquid	320		
	Finishing gloss	7H		

**Charisma Color B-20 (Lot #49)*

Table 2: *Microleakage Data of All Groups*

Scores	Single Bond	Prime&Bond NT	Excite	Durafill Bond	Etch&Prime 3.0	Prompt L-Pop	Vitremer
0	-	-	-	-	-	-	9
1	1	-	-	-	1	3	3
2	2	3	1	1	2	5	-
3	5	5	9	1	5	-	-
4	4	4	2	10	4	4	-
Total	12	12	12	12	12	12	12

ning water and placed in a photographic developing solution (Kodak Brasileira LTDA, S José dos Campos, SP 12240-420, Brazil) under a fluorescent light overnight. They were then rinsed under water and cut using a water-cooled diamond disk (KG Sorensen LTDA) in an elaborated machine (University of Brasília, Brasília, DF 70910-900, Brazil) in a mesio-distal, then buccal-lingual longitudinal section through the center of both restorations of each tooth.

Microleakage at dentin margins was evaluated with a low-power stereomicroscope (Carl Zeiss, Jena 07740, Germany). Marginal penetration was scored on a 0-4 rank scale as follows: 0 = no evidence of silver nitrate penetration at tooth/restoration interface; 1 = dye penetration along the interface to half of the cavity depth; 2 = penetration greater than half, but not including the axial wall; 3 = penetration involving the axial wall, but not the pulp; 4 = penetration involving the pulp.

The Kruskal-Wallis test was used to detect differences in microleakage among the groups. The level of significance was set at $p \leq 0.05$.

RESULTS

Table 2 lists all sample scores. Statistically significant leakage ($p \leq 0.05$) was found at dentin/cementum margins for all bonding agents when compared to the modified glass ionomer control (Table 3). Durafill Bond showed the highest leakage scores ($p<0.01$) shown in Table 3. There was no significant difference between self-etching adhesives and one-bottle adhesives, except for Durafill Bond. Prompt L-Pop was similar to Etch & Prime 3.0, however, it produced the lowest scores among adhesive systems (Table 3). Single Bond, Prime&Bond NT and Excite were not significantly different (Table 3).

DISCUSSION

This study evaluated the microleakage of six different bonding agents, all of which exhibited significant ($p \leq 0.05$) leakage at dentin margins. Another study that evaluated three recent dentin-bonding agents documented the same results (Santini & Mitchell, 1998). The self-etching adhesives revealed similar leakage scores in dentin when compared to one-bottle systems and were similar to a previous *in vitro* microleakage experiment (Cardoso & others, 1999).

Despite this study being conducted *in vitro*, it can predict *in vivo* behavior. Schneider & others (2000) demonstrated that during the formation of a hybrid layer, peri and intratubular adhesive penetration and nanoleakage did not differ in vital and non-vital dentin.

Microleakage failure at the tooth/restoration interface observed in this study may be caused by tensile stresses of the light-cure composite, which is principally a resin-cohesive failure within the collagen-rich hybrid layer (Santini & Mitchell, 1998). Since the hybrid layer morphology was not evaluated, the kind of failure that could occur is not known. The resin-cohesive failure may affect the longevity of bonded resin restorations. This is especially true at dentin margins and can be caused by chemical, mechanical and thermal factors (Crim, 1993). At these areas, bonding agents cannot form a stable hybrid layer and block microleakage, as demonstrated in this study. Inadequate marginal adaptation (Crim, 1993) also accounts for clinical failure, and it has been also speculated that areas with unpolymerized resin may cause leakage (Grossman & Sparrius, 1990). To minimize these problems in this study, all cavities were restored in three increments with the first two increments placed obliquely against the gingival, then the occlusal walls. The last increment was built-up flush with the tooth (Hansen, 1986). Each increment was adequately polymerized with a calibrated Optilux 401 light-curing unit. Leakage could also result from the effects of thermocycling (Grossman & Sparrius, 1990). To simulate the oral cavity conditions, the thermocycled test was performed and the teeth kept at 37°C and 100% humidity during procedures. However, another study demonstrated no significant difference between thermocycled and non-thermocycled specimens in cervical microleakage (Sidhu & Henderson, 1992).

Prompt L-Pop showed the lowest infiltration among bonding agents (Table 3) but showed no significant difference from the other agents except Durafill Bond. One explanation is that self-etching adhesives are less sensitive to water, but water is an essential component of these adhesive systems. Prompt L-Pop has phosphoric acid esters and water in a 4:1 ratio. The water may improve the Prompt L-Pop adhesive behavior. Another explanation is that the lower pKa of Prompt L-Pop is sufficient to etch beyond the smear layer and demineralize the underlying intact dentin with the formation of

Table 3: *Microleakage Means, Kruskal-Wallis Test (means with the same letter are not significantly different,* p*>0.05)*

Groups	Mean Post	Mean Score	Grouping
DB	64.45	3.75	A
SB	47.04	3.0	B
PB	47.95	3.08	B
EX	46.79	3.08	B
EP	47.04	3.0	B
PP	37.08	2.41	B
VM	7.12	0.25	C

an authentic hybrid layer (Tay & Pashley, 2001). Prompt adhesive can be light cured for 10 seconds before or after placing the resin composite, so photocuring for 10 seconds prior to placing the resin was done to standardize the groups. The other self-etching bond agent, Etch&Prime 3.0, was similar to the other one-bottle adhesives, except for Durafill Bond. However, Etch&Prime 3.0 bond agent was not as efficient as Prompt L-Pop in preventing microleakage. It had a greater mean post but was not significantly different (Table 3). One explanation is that the layers of this adhesive that were not covered with composite lost contact with enamel just a few hours after water storage, although Etch&Prime 3.0 showed cohesive failure (Hannig, Reinhardt & Bott, 1999). Single Bond also showed cohesive failure (Prati, Chersoni & Pashley, 1999). It was demonstrated that Single Bond adhesive penetrated the collagen network and showed great immediate bond strength. Etch&Prime 3.0 had the same mean post as Single Bond, with the same leakage scores (Table 2), and both had alcohol and water as solvents and 2-hydroxyethyl methacrylate (HEMA) in their composition. This hydrophilic monomer can dramatically lower the vapor pressure of water by an inverse relation (Pashley & others, 1998). Excite was similar to Single Bond and Etch&Prime 3.0 in spite of only having alcohol as its solvent. Excite could be more sensible to air dry procedures, but this study showed that these procedures are not critical.

Despite Durafill Bond being fabricated by the same resin composite manufacturer, it shows the highest microleakage with a greater mean post (Table 3) and the most infiltrations on the 4 score (Table 2). Its bond strength could be lower than the minimum to resist the contraction forces of resin composite, failing to adhere in enamel/dentin surface.

Prime&Bond NT showed the same mean score as Excite (Table 3) but a greater mean post. Prime&Bond NT adhesive has acetone as a solvent and nanofillers with a particle size of 7 nm, which could infiltrate the interfibrillar spaces of demineralized dentin (20 nm). Using acetone as a solvent is more critical than alcohol or water. After demineralization, channels are filled with water where resin monomers should infiltrate. If the diffusion gradient occurs between the adhesive monomers and polymers with higher molecular weights (Eick & others, 1995), the nanofillers may not infiltrate within the hybrid layer (Tay, Moulding & Pashley, 1999). Tay & others (1999) hypothesized that aggregation of the nanofillers in one-bottle adhesive resulted in filler clusters that are too large to infiltrate the interfibrillar spaces of the hybrid layer. Moreover, retention of ground substance within the demineralized intertubular matrix may also prevent infiltration of the nanofillers. Although one-bottle agents can also form an authentic hybrid layer, they could demineralize dentin deeper than they can infiltrate.

Results of this study showed minimal microleakage at the dentin margin with the Vitremer resin-modified glass ionomer group (Table 2 and 3). This material was chosen as control because of its chemical bond to enamel and dentin, its reduced polymerization contraction and its increased penetration through the smear layer compared to chemically-cured glass ionomers (Lin, McIntyre & Davidson, 1992).

Fifty percent silver nitrate solution was used to evaluate the extent of microleakage because of its particulate form and minute size. The authors were better able to visualize the infiltration and score the maximum dye penetration, which is considered the best evaluation criterion available (Dejou, Sindres & Camps, 1996). Using labeled adhesives was not considered because they could interfere with adhesion (Gagliardi, De Paula & Avelar, 1999).

Compared to conventional acid-etching techniques, self-etching adhesives achieve similar marginal integrity in dentin. The advantage of self-etching systems is their simple application procedure. Since *in vitro* studies have limitations, further *in vivo* investigations should be conducted to evaluate microleakage, bonding strength and marginal adaptation of conventional and self-etching bonding agents. Therefore, the mode of adhesion seems integral to a better dentinal bonding agent.

CONCLUSIONS

This *in vitro* study concluded that:

1. Self-etching bonding agents could provide similar marginal seal to one-bottle adhesives;
2. The two self-etching adhesives tested in this study, Etch&Prime 3.0 and Prompt L-Pop, can equally prevent microleakage as did Single Bond, Prime&Bond NT and Excite one-bottle adhesives;
3. Durafill Bond had significantly more microleakage compared all the other adhesives tested;
4. Vitremer modified glass ionomer material used as a control demonstrated significantly less microleakage compared to any of the adhesives tested;

5. None of the materials used eliminated microleakage.

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Dentin Sealers' Effect on the Diameter of Pulpal Microvessels: A Comparative Vitalmicroscopic Study

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L Rosivall • I Nyárasdy

Clinical Relevance

Dentin sealers applied on a very thin layer of dentin may influence pulpal circulation during clinical restorative procedures.

SUMMARY

After crown preparation, exposed and untreated dentinal tubules can result in bacterial penetration into pulp. Treating the exposed dentin involves closing the tubules. Dentin sealers are often applied on a very thin dentin layer that covers the pulp chamber. In these cases, the sealers may have some effect on local micro-circulation through dentin. This study examined the acute effects of different dentin sealers on the vascular-diameter of pulpal vessels measured by vitalmicroscopic technique in rats.

Gluma Desensitizer in Group 1 (n=10), Seal & Protect with acid etching in Group 2 (n=10) and Seal & Protect without acid etching in Group 3 (n=10) were applied on a very thin layer of dentin in the left lower incisor of male Sprague-Dawley rats weighing 336 ± 93SE/g. Saline served as the untreated control. After one-hour equilibration time, changes in vessel diameter were recorded with a digital camera connected to a microscope at baseline and at 5, 15, 30 and 60 minutes after the investigated materials were administered on dentin. The results were evaluated by ANOVA. In each group, diameter changes were averaged (compared to the baseline diameters) and standard errors of the mean were calculated for each examined time.

The results suggest that Gluma Desensitizer caused the most severe pulpal vessel-diameter changes, followed by Seal & Protect with acid etching, while the least change was recorded in Seal & Protect without acid etching.

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INTRODUCTION

The growing need for high quality aesthetics has led to the extensive use of tooth-colored, full-coverage crown restorations. For an average complete crown preparation, 1.2 to 1.5 mm of tooth structure is removed (Schillinburg, Hobo & Whitsett, 1981). According to Richardson, Tao & Pashley (1991), approximately one-

to-two million dentinal tubules are exposed during this preparation. Thus, preparing deeper into the dentin and exposing more tubules endangers the health of the pulp. In fact, as the pulp is approached during crown preparation, the number and diameter of dentinal tubules increases as does the permeability to the pulp (Pashley, 1985). Thus, techniques that go deeper into the dentin, exposing more tubules, may endanger the health of the pulp. Through these exposed dentin tubules, diffusion in two directions is possible: on one hand, the oral fluid and some other substances (bacterial products) penetrate to the pulp, whereas on the other, dentinal fluid moves from the pulp to the open surface of the tubules.

Numerous experiments have demonstrated that bacterial infection and microleakage are the main causes of pulpal damage, not toxicity of restorative materials (Brännström & Nyborg, 1971, 1973). After crown preparation, using dentin sealers may provide pulp-protection by blocking the penetrability of bacteria from oral plaque through the opened tubules. In dental practice, these dentin sealers are frequently applied on a very thin dentin layer over the pulp. Therefore, the sealer may alter the local blood circulation due to its close proximity to pulpal microvessels.

This study investigated the immediate vascular effects of a new polymerizable dentin sealer material, Seal & Protect, with and without acid etching and a typical non-polymerizable sealer, Gluma Desensitizer, on the pulp microvessels of the rat. The results of this vitalmicroscopic examination may provide additional information about the biocompatibility of these materials.

METHODS AND MATERIALS

Materials

Gluma Desensitizer (Heraeus Kulzer, D-41538 Dormagen) containing (2-hydroxyethyl) methacrylate, glutardialdehyde and purified water.

Seal & Protect (DeTrey, Dentsply, D-78467 Konstanz) containing dipentaerythritolpentacrylate—monophosphate (PENTA), methacrylate resins (MA), nanofillers, acetone and triclosan.

Conditioner 36 (DeTrey, Dentsply, D-78467 Konstanz) containing 36% o-phosphoric acid.

The application of physiological saline (0.9% NaCl) served as the sham-treated control.

Animal Preparation

This study examined six groups of 10 male Sprague-Dawley rats (weighing 336 ± 93/SE/g) using the vitalmicroscopic technique (Figure 1). The rats were anaesthetized with pentobarbitone sodium (Nembutal 35 mg/kg, ip, supplemented, as required). Breathing was supported by tracheal cannulation. The right femoral artery was cannulated with a heparinized (1500 IU/ml) polyethylene catheter and connected with an electro-manometer to measure and register systemic blood pressure. The body temperature was kept constant at 37°C using a heating lamp (150 W). The skin was removed from the lower jaw of the rat. From the left part of the lower jaw, the mucous membrane was retracted and the jaws separated by transsecting the connective ligaments between the lower jaws. The left part of the lower jaw was fixed with a circular polyester strip to position the incisor for further preparation. With the teeth firmly held, the mesial and distal surfaces of the incisor and some part of the alveolar bone were ground away with a dental bur. The excavation was made on the mesial and distal surfaces from the labial to the lingual margins and from the alveolar bone to the incisal edge. Grinding

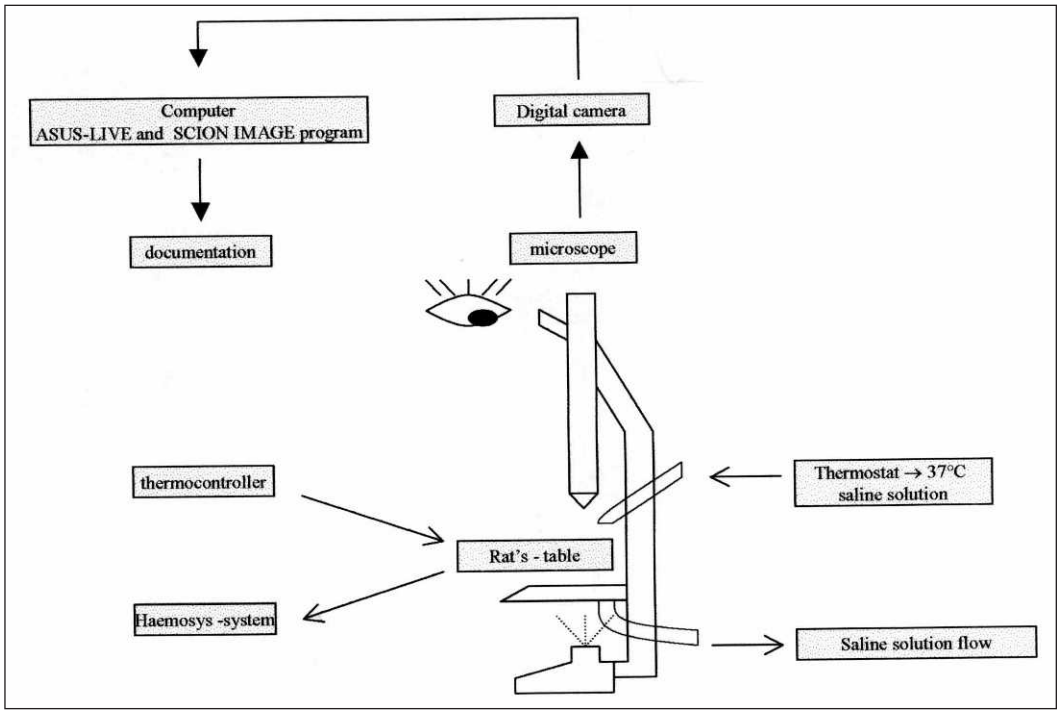

Figure 1. *Experimental set-up of vitalmicroscopy.*

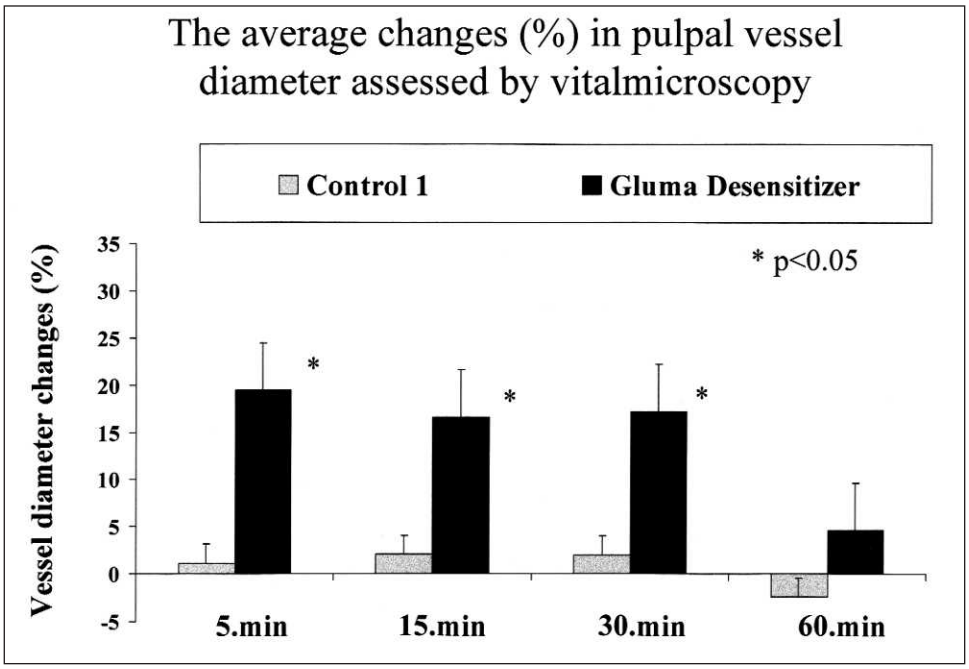

Figure 2. *Each column represents a mean value (+ SE) expressed as % changes of the baseline vessel diameter.*

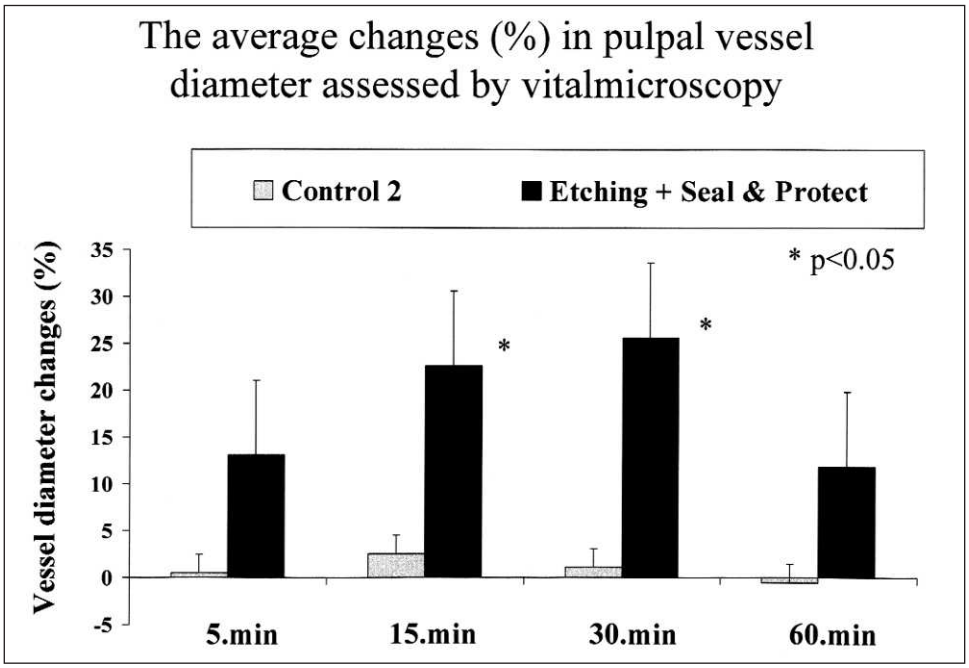

Figure 3. *Each column represents a mean value (+ SE) expressed as % changes of the baseline vessel diameter.*

was conducted at about 15,000 rpm with a diamond fissure bur and the applied pressure was kept minimal. The tooth was sprayed with physiological saline solution (37°C) to avoid heat damage during preparation and exsiccation of the tooth. After removing the enamel and the alveolar bone, preparation continued under a dissecting binocular microscope (1.6 x 6.3 Nikon, Japan) until the pulpal vessels became clearly visible through the dentinal wall and only a very thin plate of dentin covered the intact pulp tissue. After preparation, the rat was placed on its right side on a suitable animal board attached to the stage of a Nikon stereo light microscope (10x0.255 + 1x16) equipped with a digital camera (Nikon Coolpix 990) connected to a computer (IBM-compatible). The prepared tooth was kept wet with the saline solution (37°C by means of a peristalic pump) to guarantee a standard, permanent temperature. After one-hour equilibration time, a suitable arteriole was chosen for the measurement of its inner diameter. The vessel diameter was measured before (baseline value) and after applying test materials on the monitor via image analyzing software (Scion Image, Scion Corporation). The placement of test materials—on the prepared surface—was distal from the observed pulp-area to assure that the sealers would not interfere with visualization of the microvessels.

Test 1: With a small piece of absorbent paper, the tooth was dried until it remained "visibly moist." The test material—Gluma Desensitizer—was then applied to the prepared surface with an applicator tip according to manufacturer's instructions. The layer was dried with a gentle air steam for about five seconds and allowed to set for 60 seconds.

Test 2: After acid etching the dentin surface with Conditioner 36 for 15 seconds, the dentin surface was rinsed and Seal & Protect was applied with an applicator tip. The layer was dried with a gentle air steam for about five seconds and light cured for 20 seconds.

Test 3: Seal & Protect was applied with an applicator tip according to the manufacturer's instructions. The layer was dried with a gentle air steam for about five seconds and light cured for 20 seconds.

Control 1, 2, and 3: Applying saline served as treated control.

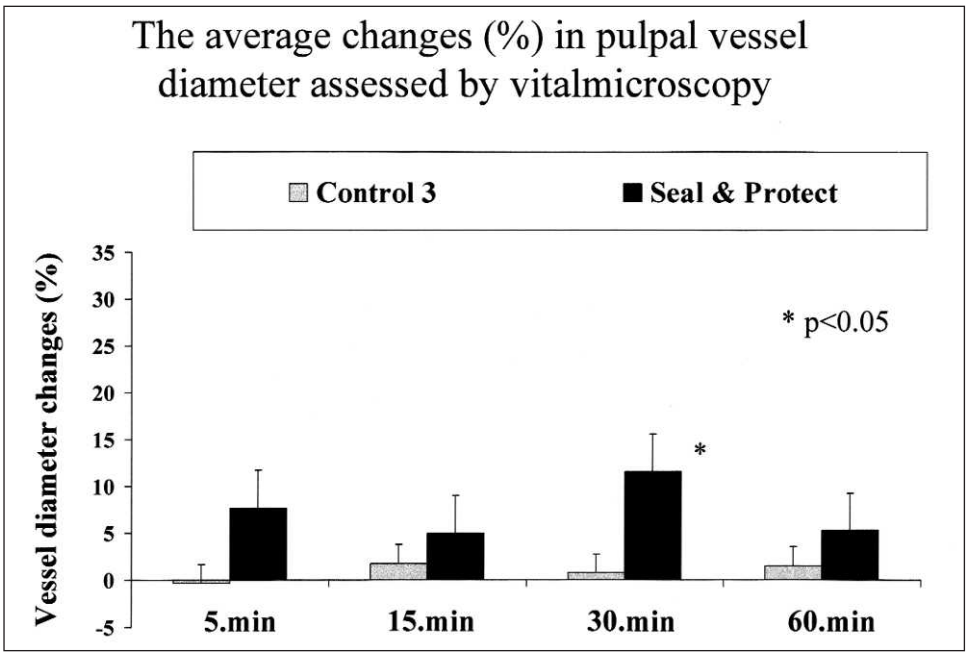

Figure 4. *Each column represents a mean value (+ SE) expressed as % changes of the baseline vessel diameter.*

Diameter changes, compared to their own baseline diameters, were calculated at 5, 15, 30 and 60 minutes after the test materials or saline (control) application. For statistical analysis two-way ANOVA was applied with treatment and time as factors. Normal distribution was tested using the Kolmogorov-Smirnov test. A significant level less than or equal to 0.05 was chosen to indicate statistical significance.

RESULTS

The systemic arterial pressure remained unchanged during the experiments in the control (112 ± 5 mmHg) and in the test animals (116 ± 3 mmHg). In the control groups, no significant changes were observed in the mean vessel diameter. The average of the control measurements at different time periods were used for comparison with experimental data.

In the presence of Gluma Desensitizer (Figure 2), the vessel diameter was increased (20 ± 4%; 17 ± 5%; 17 ± 4%; 5 ± 5%). These changes were significant in 5, 15 and 30 minutes when compared to the control values. In this test group, the vessel diameter changes were significantly different at 5 and 60 minutes only (ANOVA, $p<0.05$).

In the presence of Conditioner 36 and Seal & Protect (Figure 3), the vessel diameter also showed an increasing tendency (13 ± 7%; 23 ± 9%; 26 ± 12%; 12 ± 6%). Vessel diameter changes were significant (ANOVA, $p<0.05$) at 15 and 30 minutes when compared to the control groups change.

In the third test group, where Seal & Protect was applied without acid etching (Figure 4), the smallest vasodilatating effect in pulpal vascular diameter (8 ± 4%; 5 ± 5%; 12 ± 5%; 5 ± 4%) was observed. Changes in vessel diameter were significant (ANOVA, $p<0.05$) at 30 minutes when compared to the control groups change.

There were no signs of stasis or prestasis in the control or the test groups.

DISCUSSION

According to some authors, the possibility of "pulp-survival"—after the trauma of preparation and crown cementation—is based on preventing bacterial microleakage (Bergenholtz & others, 1982; Cox, 1987). The term "microleakage" may be defined as the passage of bacteria, fluids, molecules or ions between the cavity wall and the restorative material applied to it (Kidd, 1976).

A poorly fitted provisional crown is a good opportunity for the bacterial penetration to pulp. Noxious bacterial agents can activate the sensoric nerve fibers at the pulp-dentin area (Brännström, 1966; Lilja, 1980), stimulate the immune system and may cause pain and pulpal inflammation. Pashley & others (1992) found that sealing opened dentinal tubules with sealer material decreased the sensitivity of dentin and reduced the penetrability of bacteria. Thus, the use of sealers is important with frequent intervention. Sealers used in the practice are not toxic *in vitro*, but there is no data that determines whether they have a local effect on pulpal microcirculation *in vivo*. Therefore, this study investigated whether non-resin, non-polymerizable sealer, the glutardialdehyde-containing Gluma Desensitizer had an acute effect on the rat's pulpal microcirculation. The mechanism for its sealing is the precipitation of plasma protein in the dentinal fluid to occlude the tubules (Schüpbach, Lutz & Finger, 1997). Another test material was the Seal & Protect. This is a self-adhesive, polymerizable resin sealer with an improved formula that contains nanofillers with an antimicrobial agent called triclosan, representing a step forward compared to the fourth and fifth generation bond materials of adhesion technique. Nanofillers increase stability and the resistance of sealer against abrasivity. The diameter of the nanofillers is only 7 nanometers, thus, they do not decrease the viscosity of bonding materials and can penetrate deeply into the tubules closing them. The practitioners investigated its pulpal effect without removing the smear layer as recommended by the manufacturer (Test 3).

In another group, the acute effect of Seal & Protect after removing the smear layer with acid etching (Test 2) was examined. The smear layer is a mixture of debris, bacteria and dentin matrix that remains on the dentin surface after preparing the tooth with rotating instruments. The exposed dentin surface represents a physical barrier. Pashley, Michelich & Kehl (1981) reported that removing the smear layer could increase the hydraulic conductance twenty-fold. However, experiments show several possible reasons for removing it. Brännström (1987) demonstrated that bacteria could inhabit the smear layer. Studies have shown significantly less bonding adhesion when the smear layer has covered the dentin surface (Aquilino, Williams & Leary, 1989; Newman, Porter & Szojka, 1989).

In this study, the acidic etching gel and the sealer material are applied on a very thin dentin layer. They may influence the circulation of the pulp through the exposed tubules. Due to increasing concern for the safety and biocompatibility of dental materials, the authors investigated the acute vascular response of these sealer materials on the rat's first incisor with the vitalmicroscopic technique. The advantage of this method is that any material can be locally applied near the pulp without influencing the systemic circulation (Kim & others, 1980). To achieve standardization of the intact systemic circulation, it is essential to monitor the systemic blood pressure and minimize blood loss (Kim & others, 1980). The vascular reaction was examined immediately after applying the dentin sealer because the initial toxicity is highest for the vessels and the toxicity lowers in time (Hamid & Hume, 1996; Palasz, Gerzina & Hume, 1994).

In this study's experimental conditions, the three investigated sealers have a possible reversible vasodilating effect on pulpal circulation without prestasis or stasis. The initial stage of inflammation is vasodilation, which causes an increased blood flow. Increased vascular permeability and the resultant stasis will only occur if the inflammatory process continues and worsens (Kim, 1985). The smallest significant change in pulpal vascular diameter was caused by Seal & Protect without acid etching (Test 3). In this case, the sealer was applied to dentinal tubules covered with smear layer, which blocked the material from penetrating deeply into the tubules but it also penetrated the tubules, preventing them from closing completely. When the smear layer was removed by acid etching (Test 2), the sealer rapidly caused higher, significant vasodilatation, probably because of the deeper, faster penetration of sealer into the tubules and the demineralized dentin surface. Perdigão & others (1996) have shown that the etch-and-rinse procedure results in a 3-5 μm deep demineralization of the dentin surface.

Gluma Desensitizer (Test 1) caused the most pronounced and earliest pulpal vasodilatation. As a fixative material, glutardialdehyde is not an inert substance for biological tissues. Similarly, in the two groups mentioned above, the observed vasodilatation seemed to decrease within the time period of this experiment, indicating a possible reversible effect in non-carious, healthy rat pulp tissue. The observed vasodilatation can be a defense process of the pulp (Pashley, 1996). The elevated rate of pulpal blood flow and the outward fluid flow are basically a washing-out effect of the bond material. This mechanism protects the pulp from the penetrating bond and other chemical factors that could occur to the pulp through the dentinal tubules.

Further investigations should be conducted to examine the extent to which these sealer materials decrease the retention of permanent crowns fixed with various cements.

CONCLUSIONS

Under the conditions of this study, each of the investigated dentin sealers showed varying amounts of acute vasodilatating effects on rats pulpal microvessels but no stasis or prestasis was detected. The sealers seem to have no irreversible, acute effect on microcirculation when applied as recommended by the manufacturers.

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Depths of Cure and Effect of Shade Using Pulse-Delay and Continuous Exposure Photo-Curing Techniques

ST Hackman • RM Pohjola • FA Rueggeberg

Clinical Relevance

Clinicians should minimize contouring and finishing the top composite surface when using pulse-delay to avoid exposing poorly cured material. They should also use a longer exposure than currently advocated for the second exposure.

SUMMARY

This study investigated the extent of cure (monomer conversion into polymer) of a variety of photo-initiated resin composites and different shades. Cure values were measured at the top surface and at simulated lighting conditions 0.5, 1.0 and 2.0 mm below the top. The exposure methods used were continuous output at 600 mW/cm² (10, 20 or 40 seconds), initial component of the pulse-delay technique (pulse) (3 seconds at 200 mW/cm²) and the entire pulse-delay technique (pulse, 3-minute delay, 10 seconds at 600 mW/cm²). The results showed very little difference in conversion values between A2 and D2 shades of the same composite with respect to depth. Conversion values using only the pulse method were remarkably low at the top surface and diminished rapidly at depths. Conversion using the pulse-delay technique produced similar values as that of the continuous 10-second exposure at similar depths but still decreased remarkably at depth. Conversion values using the pulse-delay technique and a 20-second continuous exposure were significantly lower than those obtained using continuous 40-second exposure.

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INTRODUCTION

Clinicians face many choices regarding curing unit selection and exposure technique. The choices involved with contemporary light sources range from quartz-tungsten-halogen units (QTH), short-arc xenon lights (also referred to as the plasma-arc curing lights (PAC), argon-ion lasers and blue light-emitting diodes (LED). The advantages and disadvantages of these sources are still under debate (Rueggeberg, 1999). The central controversy involves the rate at which the composite is cured (Rueggeberg, Caughman & Chan, 1999) and the development of stresses arising from this rate (Uno & Asmussen, 1991; Bouschlicher, Vargas & Boyer, 1997; Kinomoto & others, 1999).

As monomers in an uncured composite begin to form polymer chains, the stiffness (modulus) of the forming

polymer begins to increase. During this time, the polymer shrinks as a result of the joining together of individual monomer units. During this early phase in the conversion process, stresses developed from a monomer reaction in this low modulus material are released as flow from the unbonded surface (Davidson & de Gee, 1984). As the polymer continues to incorporate more monomer into the growing polymer chain, the modulus of the mass increases. Polymer deformation in response to continued stress will continue to a point where the modulus becomes high enough that further shrinkage stress is transmitted through the restoration and is applied to the bonded surface interface. This stage of polymerization is commonly referred to as the gel point (Versluis, Tantbirojn & Douglas, 1998). The polymer may continue to shrink in response to further conversion after reaching the gel point, but stress resulting from this continued cure develops elsewhere. If the strength of the polymer at the bonded interface is weak, a gap will develop between the restorative material and the tooth. However, if the bonding agent has adequate physical properties, stress from further conversion will be transmitted to tooth structure (enamel or dentin). The modulus of dentin (18.3 GPa) is much lower than that of enamel (84.1 GPa) (Craig, 1997). Because of these differences, dentin can actually distort in reaction to additional stress, whereas enamel, being a brittle material, may overtly crack.

Evidence exists for gap formation or overt enamel cracking associated with continuous, high level exposure (Suh & others, 1999). To reduce the development of curing stress, the conversion rate should be reduced (Kinomoto & others, 1999). Such a reduction would delay the onset of the gel point, allowing the composite to deform from the unbonded surface. Various techniques exist for slowing the rate of conversion. This slow reaction rate was seen in the first generation of composites: the chemically-cured or self-curing materials. These systems utilized two separate pastes, each having similar monomeric content, but each having two separate components for creating free radicals (Cook & Standish, 1983a). Once the pastes were mixed, free radicals formed but were hindered in their reaction with monomers by adding an inhibitor agent. This agent delayed the onset of reaction of monomer with free radicals. When the inhibitor was depleted, the radicals that formed would develop polymer chains (Cook & Standish, 1983a). This slow process extended the overall rate at which the composite cured, delaying the gel point and permitting the composite to deform at the unbonded surface as a reaction to curing stresses. With the development of visible light curing, the rate at which radicals form was greatly increased with respect to the chemically cured systems (Cook & Standish, 1983b). This increased rate did not permit a delay of the gel phase; instead, it tended to develop interfacial stresses (Feilzer & others, 1995; Sakaguchi & Berge, 1998).

Recently, manufacturers introduced methods for reducing the rate at which conversion of visible light-initiated composites polymerize. These methods use low light levels during the initial exposure segment and are often referred to as "soft-start" techniques (Mehl, Hickel & Kunzelmann, 1997). Curing units are marketed using these different methods. Some units utilize a stepped increase in light intensity, providing a discrete, low level of light for a specified time, after which the full intensity is emitted for the duration of the exposure. Ramped curing units initiate output at a very low intensity, then continually increase this value until maximal intensity is reached. Once this level is achieved, the remainder of the exposure is maintained at maximal output (Rueggeberg, 1999).

A newer technique, the "pulse-delay" technique, has recently been introduced (Suh & others, 1999). It is advocated only for the last composite increment that will be bonded to enamel. In this method, the last 1.5 to 2.0 mm of composite is placed and contoured. A low light intensity (200 mW/cm^2) is delivered for three seconds. It is then recommended that the dentist start initial contouring and polishing of the restoration, as the conversion level at the top surface is considered adequate to withstand this mechanical stress. After three minutes from the initial three-second exposure, a higher intensity exposure is provided (600 mW/cm^2) for 10 seconds only when a Class I restoration is placed. If the restoration involves proximal surfaces, a series of 10-second exposures at this higher intensity is delivered through tooth structure (buccal and lingual) and ends with direct exposure from the occlusal direction. Evidence exists that indicates this technique significantly reduces polymerization stress and incidence of circumferential, cavosurface gap formation and enamel fracture (Koran & Kurschner, 1998; Kanca, 1999; Kanca & Suh, 1999). These decreases are thought to be associated with a decrease in formation of high stress levels at the cavosurface margin. This technique is thought to significantly delay gel point formation, allowing the composite to cure at a low rate under the top surface.

This paper examined monomer conversion values for a variety of composites when the pulse-delay technique (PD) was used compared to using conventional, continuous output exposure. In addition, the conversion of composite at various depths from the top surface of this last increment was examined along with the influence of composite shade.

The first hypothesis tested is that, for a given brand of composite and at similar depths from the top surface, the conversion value using the PD technique will be equal to that when applying a continuous, 10-second

exposure, but less than when 20- or 40-second exposures are used. It is further hypothesized that darker shade composites will have lower conversion values when using the PD technique compared to continuous exposure.

METHODS AND MATERIALS

Table 1 lists the composites used in this study. These materials were chosen for specific purposes. Pyramid, manufactured by the developer of the pulse-delay technique and the curing light (Variable Intensity Polymerizer, VIP), is specifically designed for this polymerization method. Herculite was chosen because it is a commonly used hybrid composite of medium curing "speed" (Clinical Research Associates Newsletter, 1999). Z-100 was selected because of its high modulus and ease of cure with visible light (*Clinical Research Associates Newsletter*, 1999). Because the pulse-delay technique advocates polishing and finishing of composite surfaces that have yet to reach full conversion, use of a high modulus composite would seem appropriate. At similar degrees of conversion, the higher modulus product would be stiffer than a composite of lower modulus. The curing source used in the study was a quartz-tungsten-halogen unit (VIP, BISCO, Inc, Schamburg, IL 60193, USA). This unit allows for the selection of specific output intensity values for predefined exposure duration values (200 to 600 mW/cm^2 in 100 mW/cm^2 increments). The unit is capable of self-calibration of the desired intensity levels.

Specimen Fabrication and Monomer Conversion Measurement

A small amount of composite was placed on the flat face of an attenuated total internal reflecting element (ATR) (KRS-5, 45-degree, 10x5x1 mm, item #545G1, Buck Scientific, E Norwalk, CT 06855, USA). This element transfers infrared energy into an opaque composite material, allowing for the conversion measurement at the interface of the crystal and composite. After composite placement, a small Mylar strip (0.08 mm, Type D Mylar, Du Pont, Wilmington, DE 19898, USA) was placed and the composite flattened into a uniform thickness approximately 50 to 70 µm using hand pressure and a microscope slide. This thickness was not continually measured from specimen to specimen, as variation in thickness did not affect conversion values in these thin films. The infrared spectrum of the uncured paste film was obtained by placing the ATR element in a holder positioned in a beam condensing unit (model 4XV-CLO, Harrick Scientific, Ossining, NY 10562, USA) in the sample compartment of a Fourier transform infrared spectrometer (FTIR) (FTS-40, Digilab Division, Bio-Rad Corporation, Cambridge, MA 02139, USA). Sixteen scans were obtained at a resolution of 2 cm^{-1}. The specimen still in the holder was removed, then treated in different ways. The composite was exposed to the curing source in a continuous manner at 600 mW/cm^2 for a duration of 10, 20 or 40 seconds. Also, the pulse-delay (PD) technique was used. In this method, the composite was exposed through the Mylar strip to an intensity of 200 mW/cm^2 for three seconds (pulse). All light-exposed specimens were placed in the dark for a period of five minutes. Composite conversion was then measured by taking another infrared scan. For the PD technique, a second exposure was not applied or was applied for 10 seconds at an intensity of 600 mW/cm^2 prior to the second infrared scan. Specimens were made in the above manner at simulated depths of 0, 0.5, 1 and 2 mm below the top surface of the composite. For this simulation, pre-cured composite wafers of the same lot as the test specimen were made in thicknesses of 0.5, 1 and 2 mm. The cured overlays were positioned between the Mylar, covering the composite specimen and the distal end of the light-curing tip. For simulation of light conditions at the top surface, no pre-cured overlay was used.

Three specimens were made for each testing condition, resulting in 240 specimens. Conversion values at similar depths from the top surface for each brand of composite were analyzed statistically using a one-way ANOVA. Dunnett's 2-tailed *t*-test compared the conversion value of the PD technique (acting as control) to that of the other curing methods. To test the effect of shade, two-tailed, unpaired student's *t*-tests were performed between equivalent curing conditions of Herculite A2 and D2 at similar depths from the top surface. All statistical testing was performed at a pre-set alpha level of 0.05.

RESULTS

Figure 1 shows the Herculite A2 results. A significant difference in conversion values was found ($p<0.0001$) at all depths from the top surface. At the top surface, conversion using PD was significantly greater than with the pulse only, but less than that when using a 40-

Table 1

Brand Name	Shade	Manufacturer	Address	Lot #
Herculite XRV	A2	Kerr Corporation	Orange, CA 92867	803869 exp 1/3
Herculite XRV	D2	Kerr Corporation	Orange, CA 92867	711316 exp 11/00
Pyramid	Enamel A1	BISCO, Inc	Schamburg, IL 60193	9900006375 exp 6/02
Z-100	A2	3M Dental Products	St Paul, MN 55144-1000	exp 6/02

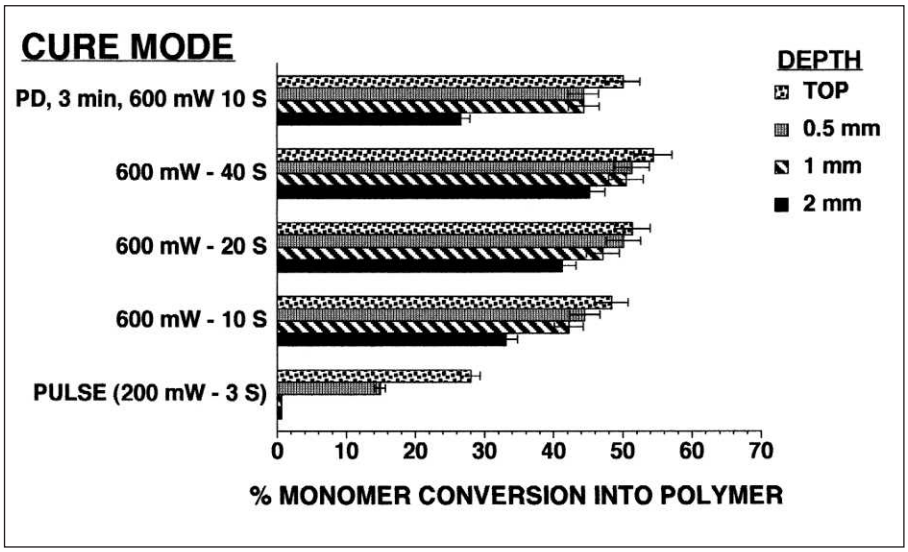

Figure 1. *Conversion values of Herculite XRV (A2) using the various exposure techniques.*
PD = pulse-delay technique
horizontal bar = ± 1 standard deviation
n = 3 specimens per test group

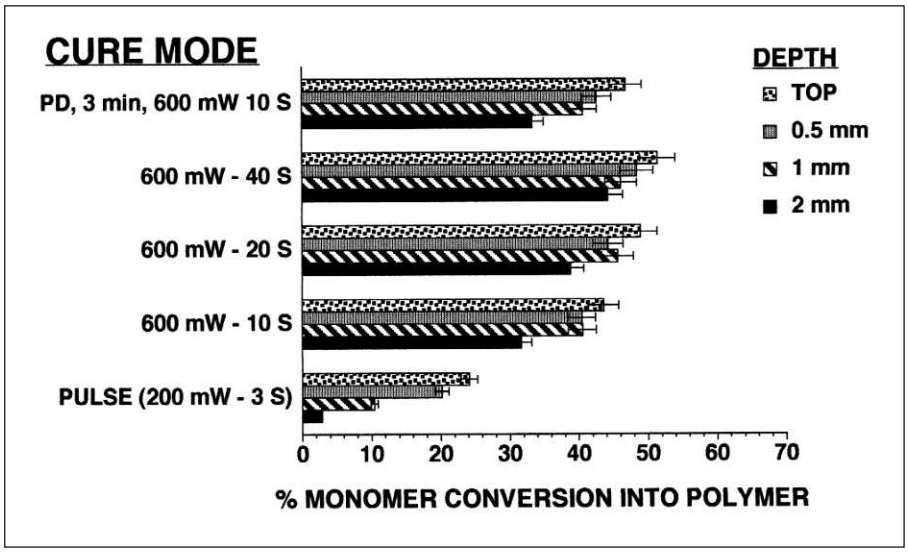

Figure 2. *Conversion values of Z-100 (A2) using the various exposure techniques.*
PD = pulse-delay technique
horizontal bar = ± 1 standard deviation
n = 3 specimens per test group

second conventional cure. One-half mm below the top surface, the cure values using PD were greater than those of the pulse only, equivalent to the 10-second continuous exposure, but less than the 20- and 40-second continuous methods. At a 1 mm depth, the pulse technique alone produced no detectable conversion value. Conversion using PD was equivalent to that using the 10- and 20-second continuous modes, but less than that using 40 seconds. At a 2-mm depth, the pulse-only method again showed no detectable conversion. Conversion using PD yielded significantly lower values than with any of the continuous exposure methods.

The trends of conversion differences using Z-100 were different from those noted in Herculite A2 (Figure 2). Conversion using the pulse-only technique was significantly lower than PD at every depth. Also, at every depth, conversion values using the 40-second continuous exposure were greater than using PD. At a 1-mm depth, conversion using 20 seconds of continuous exposure was greater than using PD.

When using Pyramid, the conversion value at each depth using pulse only was lower then that when PD was used (Figure 3). For all depths except the top surface, conversion using PD was significantly lower than when using continuous 20- or 40-second exposures but equivalent to the value using the 10-second continuous exposure. At the top surface, conversion values were equivalent between the PD technique and 20-second continuous exposure.

Figure 4 shows the conversion values for the dark shade of Herculite (D2). Compared to values using the A2 shade (Figure 1), the following differences were noted: 0.5 mm pulse conversion was greater for A2 than for D2 (14.9% vs 10.2%, p=0.0208); for 600 mW/cm^2 continuous 10 second exposure, the conversion of A2 was significantly lower than for D2 at the top surface (48.4 vs 50.1, p=0.0139), and at 0.5 mm depth, conversion of A2 was less than for D2 (44.5 vs 46.5, p=0.0061); for 600 mW/cm^2 continuous 40-second exposure, conversion at 0.5 mm depth for A2 was less than for D2 (51.2 vs 53.3, p=0.0093) and conversion of A2 was greater than D2 at 2 mm depth (45.2 vs 44.4, p=0.0281).

DISCUSSION

The first hypothesis proved true for most cases. For all conditions except Herculite A2 at 2.0-mm depth, conversion values resulting from the pulse-delay technique were equal to those that used a continuous 10-second exposure. Conversion at all depths when using the combined pulse and subsequent 600 mW/cm^2 10-second exposure (the PD technique) proved greater than using the pulse exposure, alone. At the top surfaces, conver-

sion values for all tested composites using the PD technique were equivalent to that of the continuous 10- or 20-second exposure but less than when using the 40-second exposure. At a depth of 0.5 mm, the lighter shade of Herculite (A2) yielded similar conversion trends as did using Pyramid A1: PD conversion was only equivalent to the 10-second continuous exposure (Figures 1 and 3). However, for the darker shade of Herculite (D2) and Z-100, conversion using the PD technique was equivalent to both the 10- and 20-second continuous values (Figures 2 and 4). At a 1-mm depth, the groups demonstrating similar equivalent groupings changed. Herculite D2 and A2 indicated similar conversion values between the PD technique and the 10- and 20-second continuous exposures (Figures 1 and 4). With Pyramid and Z-100, only the conversion using 10-second exposure was equivalent to the PD technique (Figures 2 and 3). For all composites except Herculite A2, the conversion value using the PD technique was equivalent to that using a 10-second continuous exposure at a 2-mm depth. For Herculite A2, conversion using the PD at a 2-mm depth was significantly different from all other treatments (Figure 1).

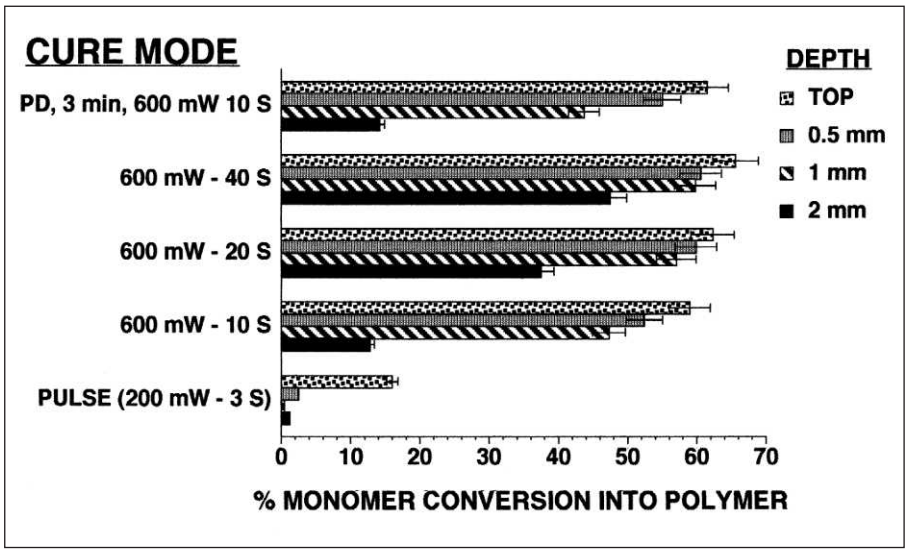

Figure 3. *Conversion values of Pyramid (A1, enamel) using the various exposure techniques.*
PD = pulse-delay technique
horizontal bar = ± 1 standard deviation
n = 3 specimens per test group

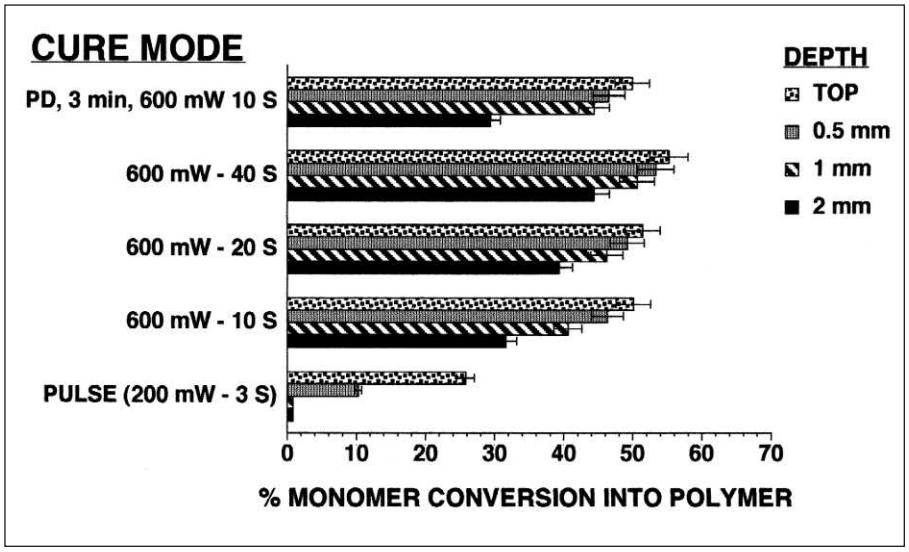

Figure 4. *Conversion values of Herculite XRV (D2) using the various exposure techniques.*
PD = pulse-delay technique
horizontal bar = ± 1 standard deviation
n = 3 specimens per test group

The second hypothesis was that there would be significantly lower conversion values using the darker shade of composite compared to using the lighter one at similar depths and curing conditions when using the PD technique. This hypothesis was generally disproved. Only a few differences were noted and, overall, these differences were very small. Thus, clinicians can be assured that at least similar conversion values can be attained when using light or dark shades when the PD technique is used.

The clinical significance of these results draw attention to the relatively low conversion levels attained when using the PD technique compared to longer duration, continuous exposures. After the initial three-second pulse exposure, the dentist is instructed to initiate finishing and polishing procedures to the top surface, while the conversion in deeper layers is thought to slowly continue over the three-minute delayed period. When comparing the conversion value of the top surface after the pulse-only exposure to using either the subsequent delayed exposure or continuous exposures, the pulsed value is remarkably lower. The mechanical properties of a resin-based restoration can be directly related to the extent of conversion of the polymer network (Ferracane & others, 1997). Even though this surface may have attained sufficient modulus to impart the sensation of a hard surface, it is still only partially cured compared to its full potential. This surface needs sufficient resistance to flow so that it can be cut into shavings or polished during the initial contouring and

polishing step. Because of the lower conversion values noted, it may be possible that some of this polymer actually flows in reaction to mechanical stress applied during contouring. It is not uncommon that at least 0.5 mm of material could be removed during composite finishing and contouring. When this much material is eliminated, the data from this study indicates that remarkably lower conversion values are noted. Again, the mechanical integrity of composite with such low conversion values is of concern. Should additional gross reduction be necessary when using the PD method and 1 mm is removed from the top surface after the pulse exposure, then, in some instances, no conversion of the material was detected.

Previous research demonstrated lower polymerization stress values using the PD technique over conventional, continuous light output (Suh & others, 1999). In that study, stress measurements were made using both acrylic and glass rings. The deformation of 3 mm-thick rings was measured and stress values calculated accordingly. The results indicated that compared to the continuous application of moderately high intensity (500 mW/cm^2), the curing stress values were less in the pulse-delay method. The longer the delay period, the greater the reduction of stress values, up to a point. However, the results of this study seem to indicate that the lower stress values seen with pulse-delay might be attributed to a lack of homogeneous conversion in the specimen. Conversion values at the top surface using PD and continuous 10-second exposures were equivalent. However, the difference between PD conversion values and those of longer duration continuous exposures increase with depth from the top surface. This phenomenon is emphasized in Pyramid, where below the top surface, the pulse exposure gave little-to-no conversion and continuous exposures greater than 10 seconds demonstrated greater conversion than the PD technique.

The clinical implications of these results indicate that, should the practitioner choose to select the PD technique, it would be better to remove excess composite and contour the material prior to exposure to the curing light. In this case, subsequent to the initial pulse exposure, there would be no need to eliminate excess material and a composite of poor conversion would not have to be subjected to high stresses of mechanical abrasion. The results also indicate that, in general, a more highly converted composite would result if a 20- or 40-second continuous exposure were used instead of the PD technique. Higher conversion values would provide greater, more uniform mechanical properties to the last increment placed.

Ultimately, using the PD technique reduces the incidence of cavosurface marginal gap and enamel fracture. This study did not investigate these factors, but they have been verified in previous studies (Kanca, 1999; Suh & others, 1999; Kanca & Suh, 1999) and have been shown to be effective. This effectiveness comes at a cost, however. The cost seems to be a lower converted restoration with potentially decreased mechanical properties compared to those when continuous exposures of longer duration are used. When using the PD technique on Class II restorations, the second, delayed exposure following the initial pulse should consist of a series of 10-second durations. These exposures are first aimed through the tooth from the facial and lingual, and finally from the occlusal. This increased exposure to curing light may provide additional conversion in Class II restorations. However, it would seem advantageous to perhaps increase the duration of the second exposure of the PD technique to at least 20 seconds instead of the stated 10-second value. At 2 mm depth, conversion values using the 20-second continuous exposure produced greater conversion than the PD technique for all composites except Z-100, where the conversion was equivalent.

CONCLUSIONS

Within the limitations this study, the following conclusions can be drawn:

1. Conversion at the top surface of a photo-polymerized composite restoration using the pulse-delay (PD) technique produced conversion values equivalent to those using 10- and 20-second continuous durations at 600 mW/cm^2.
2. At 0.5, 1.0 and 2.0 mm from the top surface, conversion values using PD were equivalent to those using continuous 10-second exposure.
3. Conversion values using the 40-second exposure were always greater than those using PD at similar depths from the top surface.
4. Conversion values at the top surface using only the pulse technique were very low compared to continuous exposure values, and this difference was even greater at increasing depths from the top surface.
5. In general, study results showed that there were few differences in conversion values between using a light and dark shade of the same composite.

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Microleakage of Class II Packable Resin Composites Lined with Flowables: An *In Vitro* Study

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Clinical Relevance

No consistent reduction in microleakage was demonstrated with the use of a flowable liner beneath the four packable systems tested *in vitro*.

SUMMARY

Flowable resin materials have been suggested as liners beneath packable composites to improve marginal integrity. This investigation evaluated the effect of low-viscosity liners on microleakage in Class II packable composite restorations. Twenty Class II cavities were prepared in extracted third molars for each of four packable composites (Heliomolar HB, Prodigy Condensable, Surefil and Tetric Condense). Ten restorations were placed for each material with their corresponding bonding agent per manufacturer's suggestion; in addition, 10 were placed with the flowable liner recommended by the manufacturer for that material. Samples were finished, stored in distilled water for at least 24 hours and thermocycled for 1,000 cycles between 5° and 55°C with a one-minute dwell time. Apices were sealed with epoxy cement and the teeth were varnished to within 1 mm of the margins. Samples were placed in 0.5% basic fuschin dye for 24 hours, rinsed, embedded in resin and sectioned to produce multiple sections. Microleakage was rated (0-4 ordinal scale) at both the occlusal and cervical margins. Data were analyzed with Kruskal-Wallis ANOVA for main effect and ranked sum analysis for pairwise testing (α=0.05). All materials, either separately or in combination with a flowable liner, had greater leakage scores at the cervical margin compared to the occlusal margin. All packable systems tested did not yield a reduction in microleakage with the use of a flowable liner in vitro**; however, the packable system with the flowable compomer used as a liner yielded significantly less overall microleakage compared to the three systems that used a resin composite liner.**

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INTRODUCTION

Resin composites, introduced in 1960, now dominate the materials used for direct esthetic restorations. With

increased patient interest in esthetic alternatives to dental amalgam, composites are a popular choice for posterior tooth restoration (Payne, 1999). However, the sticky consistency of many composite materials creates some challenges in manipulation, especially for posterior teeth where access is more difficult.

The importance of the handling characteristics of a restorative material during condensation has long been recognized (Brackett & Covey, 2000). Dental manufacturers have concentrated on improving the handling of dental resins and have made considerable progress. Through extensive research and development, today's resin composites come with a variety of handling characteristics. Condensable (packable) composites have been developed for use in Class I and II cavity preparations. Manufacturers claim that the increased stiffness of packable composites, compared to traditional composites, provides sufficient resistance to condensation forces and facilitates establishing proximal contacts. Also, the mechanical properties and abrasion resistance of resin composites has improved considerably over the years. Still, the posterior composite restoration remains very technique sensitive.

Clinicians are concerned with poor adaptation of the material to tooth structure when placing a posterior restoration. A material's ability to seal a cavity preparation can be influenced by its composition, plastic deformation, flow, coefficient of thermal expansion, modulus of elasticity and the mechanical stresses caused by cavity preparation shape (Schwartz, Summitt & Robbins, 1996). Payne (1999) states that many studies show a variety of possible causes for failure of composite restorations at the cavosurface margin of Class II restorations. Studies that investigate microleakage have shown that selection and handling of materials are the most significant factors to influence marginal adaptation and subsequent microleakage (Mangum & others, 1994).

Flowable resin-based materials have been recommended as liners beneath packable composites due to their low viscosity, increased elasticity and wettability. These handling characteristics and a syringe delivery system make flowable resins an ideal choice for use in a "sandwich" technique where they are placed at the cementum margins of the proximal box of Class II resin composite restorations as a liner. Flowable resin materials have been suggested as liners beneath packable composites assuming that the low-viscosity material will better fill irregular internal surfaces and proximal boxes, thereby, improving final marginal integrity. This seems especially sensible given the difficulty in accessing the gingival margin of the proximal box. This *in vitro* investigation compared the extent of microleakage in Class II packable composite restorations with and without a flowable liner.

METHODS AND MATERIALS

Forty extracted, non-carious third molars stored in 0.2% sodium azide at room temperature for less than one month were used in this study. All teeth were cleaned with a slurry of flour of pumice and water prior to preparation. Samples were stored in distilled water at room temperature following cleaning and throughout the experiment.

Tooth Preparation

Two Class II preparations were made in each tooth, one on the mesial surface and one on the distal surface, with a high-speed handpiece using water spray and a #256 carbide bur (Brasseler USA, Savannah, GE 31419, USA). At least 1.5 mm of sound tooth structure was left occlusally between the two cavities. Pulpal floor depth was 2.0 mm and the proximal boxes were approximately 4.0 mm high, 4.0 mm wide and 1.0 to 1.5 mm deep. The cervical margin was placed on cementum 1.0 to 1.5 mm apical to the CEJ. Forty teeth with two preparations per tooth were randomly assigned to one of eight groups of five teeth (10 preparations) per group.

Restoration Placement

The restorations were placed by a single operator according to manufacturers' instructions. Table 1 lists the restorative materials and manufacturers. Per man-

Table 1: *Materials and Manufacturers*

Group Number (n=10)	Restorative Material	Bonding Agent	Manufacturer
1	Tetric Condense	Excite!	Ivoclar North America, Inc, Amherst, NY 14228
2	Tetric Condense + Tetric Flow	Excite!	Ivoclar North America, Inc, Amherst, NY 14228
3	Heliomolar HB	Excite!	Ivoclar North America, Inc, Amherst, NY 14228
4	Heliomolar HB + Heliomolar flow	Excite!	Ivoclar North America, Inc, Amherst, NY 14228
5	Prodigy Condensable	OptiBond Solo Plus	Kerr Corporation, Orange, CA 92867
6	Prodigy Condensable + Revolution	OptiBond Solo Plus	Kerr Corporation, Orange, CA 92867
7	SureFil	Prime & Bond NT	Dentsply/Caulk, Milford, DE 19963
8	SureFil + Dyract Flow	Prime & Bond NT	Dentsply/Caulk, Milford, DE 19963

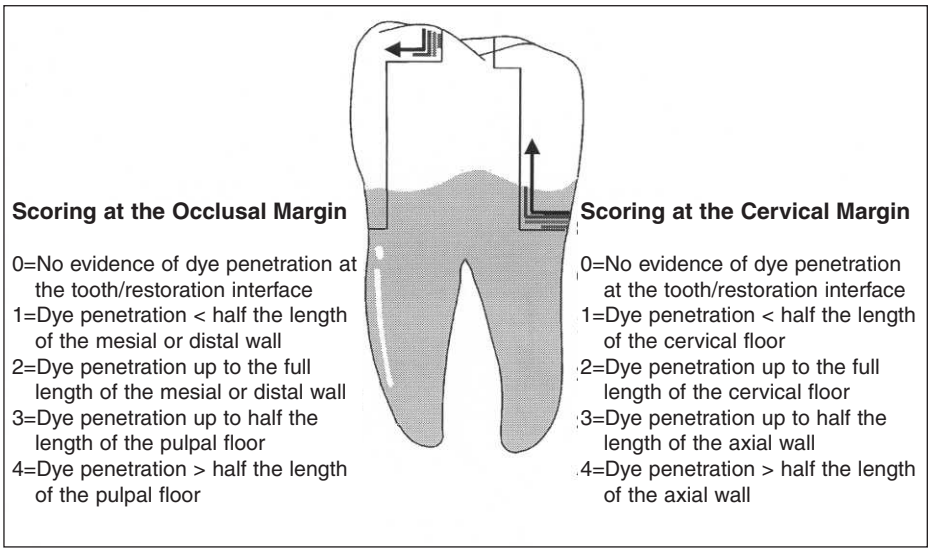

Figure 1.

ufacturers' instructions, each tooth was etched and the recommended bonding agent was applied and light cured. A stainless steel matrix (Tofflemire, Teledyne Water Pik, Ft Collins, CO 80553, USA) was then adapted to the prepared tooth before incremental insertion and light curing of the restorative material. Where a liner application was randomized, it was placed prior to the packable composite and light cured. All materials were light cured per manufacturers' instructions using an Astralis 7 (Ivoclar Vivadent, Austria) light-curing unit. The curing unit was tested per manufacturers' suggestion for light intensity. Within 15 minutes following placement, the occlusal aspect of each restoration was grossly contoured and all cavosurface margins finished flush using a gold-shank football finishing bur (#7406 Brasseler USA). Specific manufacturer's recommendations for each material system follow.

Groups 1 and 2: Samples were restored with Tetric Condense packable composite (Ivoclar North America, Inc, Amherst, NY 14228) as follows:

1. Samples were total etched for 15 seconds with 37.5% phosphoric acid.
2. Preparations were rinsed thoroughly with water and lightly air dried for two seconds.
3. Excite (Ivoclar) bonding agent was applied using a light brushing motion with the applicator tip for 10 seconds, air thinned for three seconds and light cured for 20 seconds.
4. For Group #2, when a liner was randomized for application, a 1-mm increment of Tetric Flow (Ivoclar) was placed in the base of proximal box, axial wall and pulpal floor, then light cured for 40 seconds.
5. Tetric Condense composite was placed in 2-mm increments and polymerized for 40 seconds/increment with a final cure of 40 seconds.

Groups 3 and 4: Samples were restored with Heliomolar HB (Ivoclar) using the same instructions as for Groups 1 and 2 with the exception of using Heliomolar Flow (Ivoclar) as the liner.

Groups 5 and 6: Samples were restored with Prodigy Condensable (Kerr, Corp, Orange, CA 92867, USA) as previously described with the exception of using Optibond Solo Plus (Kerr, Corp) adhesive and Revolution (Kerr, Corp) as the liner. The adhesive was applied using a light brushing motion with the applicator tip for 15 seconds, air thinned for three seconds and light cured for 20 seconds.

Groups 7 and 8: Samples were restored with Surefil (Dentsply/Caulk) as previously described with the exception of using Prime & Bond NT (Dentsply/Caulk) adhesive and Dyract Flow (Dentsply/Caulk, Milford, DE 19963, USA) liner. Prime & Bond NT adhesive was applied to thoroughly wet the surface for 20 seconds. The excess solvent was removed by gently air drying and light curing for 10 seconds.

The restored specimens were stored in distilled water at room temperature for a minimum of 24 hours. The specimens were then thermocycled in 5°C and 55°C water with a one-minute dwell time for 1,000 cycles. Following thermocycling, the apex of each tooth was sealed with epoxy cement and the tooth was painted with two coats of fingernail varnish to within 1 mm of the restoration margins. Specimens were placed in a solution of 0.5% fuschin dye for 24 hours. Following dye exposure, the teeth were rinsed with distilled water and embedded in self-curing clear orthodontic resin (Dentsply/Caulk). Specimens were stored in distilled water until sectioning.

Embedded specimens were sectioned longitudinally through their centers mesial to distal using a water-cooled, slow-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL 60044, USA) to produce multiple sections. Dye penetration was measured at the cervical and occlusal margins of all restorations. The extent of microleakage was determined visually under a light microscope at 40x. Two examiners scored the extent of dye penetration using an ordinal scale (0-4) (Figure 1) by consensus. Examiners were blind to the material and/or technique used. Ranked data were analyzed using the Kruskal-Wallis test for non-parametric data

and the Wilcoxon Signed Rank test for paired non-parametric comparisons (α=0.05).

RESULTS

Table 2 lists median ordinal scores for each material combination. Overall, there was a significant difference in the amount of leakage between the cervical and occlusal margins. Although median occlusal microleakage scores were the same (median = 0) for all eight groups, a statistically significant difference was found overall for occlusal microleakage. Paired comparisons and evaluation of ranked sums identified that microleakage at the occlusal margins for Surefil with a flowable liner was greater than for Heliomolar plus a liner and Prodigy plus a liner.

There was also a statistically significant difference in cervical microleakage among the eight groups. Surefil with a flowable liner demonstrated statistically less microleakage at the cervical margin compared to all other material combinations, including its control (no liner). Tetric Condense also demonstrated less cervical microleakage when its recommended flowable liner was used (Tetric Flow) compared to its control (no liner).

When both cervical and occlusal data were pooled, a statistically significant difference was determined among all groups for overall microleakage. Table 3 lists the results of the Sign Test for paired comparisons of overall microleakage for all groups. Ranked sum values in order of increasing microleakage were: Surefil with liner (15374), Heliomolar (22368), Surefil (24072), Prodigy Condensable with liner (26284), Heliomolar with liner (27138), Tetric Condense with liner (27587), Tetric Condense (28286) and Prodigy Condensable (29650). Surefil with liner yielded statistically less overall microleakage than all other material combinations.

When comparing each material individually with or without liner, there was no significant difference in microleakage in either Heliomolar or Prodigy Condensable. However, the other two tested materials, Surefil and Tetric Condense, demonstrated less overall leakage with the use of their flowable liner compared to their control, no liner.

DISCUSSION

Improved handling characteristics developed for the packable composite materials have made them more suitable for posterior application compared to traditional composites. Due to modification of the filler particle by the manufacturer, they are more viscous and less sticky than traditional resin composites, which allows them to better simulate the behavior of amalgam during condensation. However, for the gingival proximal area of posterior teeth where isolation is difficult and access and visibility are compromised, the technique sensitivity of the material is more likely to put this type of restoration at risk. Therefore, in Class II cavities, it has been suggested that flowable composite materials be used as a liner for the proximal box area. The rationale for using flowable composites in this way is to improve marginal adaptation while decreasing internal voids, ultimately resulting in a reduction in marginal leakage.

"Sandwich" techniques, using alternative materials at the cementum margin of Class II resin composite restorations, have been tested both *in vitro* (Sjödin,

Table 2: *Median Microleakage Scores*

Group	Cervical	Occlusal	Overall
Tetric Condense	4	0	4
Tetric Condense + Tetric flow	3	0	2
Heliomolar HB	3	0	3
Heliomolar HB+ Heliomolar flow	3	0	2
Prodigy Condensable	4	0	3
Prodigy Condensable + Revolution	4	0	3
SureFil	3	0	0
SureFil + Dyract Flow	0	0	0

Table 3: *Sign Test Results for Overall Pairwise Comparison (p-value)*

	Heliomolar	Heliomolar +	Prodigy	Prodigy +	SureFil	SureFil +	Tetric	Tetric +
Heliomolar	1.000							
Heliomolar +	0.824	1.000						
Prodigy	0.078	*0.003*	1.000					
Prodigy +	0.210	*0.021*	1.000	1.000				
SureFil	0.078	0.728	*0.000*	*0.041*	1.000			
SureFil +	*0.001*	*0.038*	*0.002*	*0.009*	*0.007*	1.000		
Tetric	*0.035*	*0.004*	0.332	0.388	*0.000*	*0.000*	1.000	
Tetric +	1.000	1.000	*0.000*	0.000	0.855	*0.000*	*0.002*	1.000+

+ Denotes addition of flowable liner specific for that restorative material.

Uusitalo & van Dijken, 1996; Friedl & others, 1997; Dietrich & others, 1999; Tung, Estafan & Scherer, 2000; Beznos, 2001; Chuang & others, 2001) and *in vivo* (van Dijken 1994; Opdam & others, 1998). Results have varied with materials and techniques. A low-viscosity (flowable) material has been suggested as a liner to fill irregular internal surfaces and proximal boxes before placing the more viscous (packable) material. One argument for using a flowable material is that it can better wet and adapt to the tooth surface, thus sealing it, which may lead to a subsequent reduction in post-operative sensitivity (Payne 1999), an infrequent outcome with this type of restoration. Some have promoted the sandwich-type restoration, using resin-modified glass-ionomer materials to decrease the amount of polymerization shrinkage of large composite fillings, thus reducing the potential for leakage at the tooth restoration interface (Douglas & Lin, 1994; Roulet & Lösche, 1994). Two of the four material combinations tested in this study supports a reduction in microleakage using a flowable liner, while the remaining two systems have demonstrated statistically similar leakage whether or not a flowable liner was placed.

Findings from this study support many previous studies which demonstrate that gingival margins are potentially a greater source of marginal leakage in Class II composite restorations compared to occlusal margins (Derhami, Coli & Brännström, 1995; Hilton, Schwartz & Ferracane, 1997; Demarco & others, 2001). Schuckar & Geurtsen (1997) have suggested that the absence of enamel at the gingival cavosurface margin of the proximal box results in low bond strength between material and substrate. This lack of enamel also requires adhesion of the restorative material to cementum/dentin, a less reliable, more complex substrate than enamel (Coli & Brännström, 1993; Carvalho & others, 1996). A third hypothesis proposed for increased cervical leakage compared to occlusal relates to the distance of the light source from the material at the proximal box base compared to the occlusal surface. It has been hypothesized that the resulting higher polymerization stresses at the cervical margin cause increased dimensional change, leading to gap formation (Demarco & others 2001).

All the liners used in this study were flowable resin composites except for Dyract Flow, which is a flowable compomer. Some researchers hypothesize that the difference in the coefficient of thermal expansion and/or elastic modulus between restorative material and tooth structure may result in stress at the interfacial gap, resulting in microleakage (Demarco & others, 2001). The combination of the packable system with the compomer liner (Surefil plus Dyract Flow) resulted in the least microleakage at the cervical margin and overall, although not at the occlusal margin. The coefficient of thermal expansion for compomers better matches that of tooth structure compared to the resin composite materials. This property may be important for maintaining marginal integrity following thermal stressing such as thermocycling. Toledano & others (1999) recently suggested that the amount of resin content and filler particles of materials placed at the cavosurface margin might influence the degree of microleakage because, as the ratio of resin to filler increases, so does the polymerization shrinkage. The fact that compomers have a smaller resin component than traditional composite materials may contribute to the reduced microleakage scores found in this study with the compomer liner.

Two of the four packable materials tested in this study have demonstrated less microleakage with the recommended flowable liner compared to the control, composite and bonding agent, alone. Since all four materials did not perform in this way, the findings do not support mandatory use of a liner for posterior composite restorations.

Although a consistent reduction in marginal leakage was not found with the use of a flowable liner and packable composite for every material combination in this *in vitro* study, clinical handling characteristics may play a more important role *in vivo*. Samples evaluated in this investigation were prepared on bench top with adequate visualization, moisture control and ideal access. This is not the case in the clinical situation. The ability to place a liner via syringe application prior to "packing" a more viscous material may aid significantly to marginal adaptation *in vivo* regardless of material combinations. However, it should be noted that voids can be introduced during liner placement and leakage can directly result from poorly adapted flowable materials. During the delivery of flowable materials, the practitioner must carefully apply the material at the cervical cavosurface margin in one direction using a gentle releasing motion (Chuang & others, 2001). This will help to reduce the amount of trapped air when the material is expressed and help to eliminate voids from mishandling during syringe application.

Additional *in vitro* testing that could include evaluation of marginal integrity by SEM and clinical evaluation will add further insight into the efficacy of these restorative techniques. An additional technique that has been suggested and should be evaluated is applying a flowable liner followed by placing a small layer of packable composite on top and light curing the two together. For now, based on the results of this *in vitro* investigation, generalizations should not be made regarding reduction in leakage in packable composite restorations with the use of a flowable liner.

CONCLUSIONS

- Results of this *in vitro* study indicate significantly more leakage in cervical margins than occlusal margins for Class II packable resin composite restorations.

- Two of the four packable composite materials tested (SureFil and Tetric Condense) demonstrated a significant reduction in the extent of microleakage when restored with a flowable liner compared to the control (no liner).
- Placement of a flowable compomer as a liner beneath its packable counterpart had resulted in the least amount of overall leakage compared to the other material combinations where a flowable composite was used as a liner.

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Validity of Electrical Conductance Measurements in Evaluating Marginal Leakage Around Resin Composite Restorations

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Clinical Relevance

This study presents a new electrical method for detecting the degree of marginal leakage without the influence of the marginal shapes of restoratives. It offers significant potential for future clinical use.

SUMMARY

This in vitro **study evaluated the influence of the cavity size of restoratives on a new electrical method for detecting marginal leakage. Cavities were prepared on the buccal coronal and root surfaces of 32 extracted non-carious human molars and were divided into four groups having different cavity depths (0.5~4.0mm) or margin sizes (long axis or diameter: 2.0~4.0mm). All cavities were filled with resin composites without a bonding system. After physiological saline was applied, then wiped off, the change in conductance was measured continuously across the margin from the composite surface to the tooth surface. Conductance was measured at the same location after filling and before cavity preparation. In coronal and root surface cavities, the change in conductance after filling increased as the depth of cavity increased. There were significant differences in the change of conductance among the three groups with different cavity depths (p<0.05). The differences between large and small cavity margin groups were not significant for either surface cavities. This method was shown to discriminate between deep and shallow marginal leakage, with the detection of marginal leakage being independent of margin size.**

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INTRODUCTION

The stimulation of cariogenic bacterial leakage is seen as an important cause of pulpal inflammation in restored teeth (Schmeiser & Gülzow, 1999; Camps & others, 2000; Murray & others, 2001). In secondary caries developed from the margins of restoratives, marginal leakage is reported to be one of the important pathways for cariogenic bacteria to reach the pulp (Ben-Amar, Cardash & Judes, 1995; Moreira Jr & others, 1999). However, objective diagnosis of marginal leakage is difficult when there are no subjective symptoms (Merrett & Elderton, 1984; Klausner, Green & Charbeneau, 1987). Since *in vitro* methods to detect

marginal leakage require cutting of the observed surface for evaluation, they are not applied in clinical situations. *In vitro* studies have included using dyes (Brackett & others, 1995; Demarco & others, 2001; Piva, Martos & Demarco, 2001), chemical tracers (Ramos & others, 2000; Tulunoglu & others, 2000) and radioactive isotopes (Powis & others, 1988; Puckett & others, 1995). Previous studies have suggested that measurement of conductance or impedance of the margin of the restorative *in vitro* might be improved and developed into a method for clinical diagnosis (Martinez & Greener, 1976; Nakano, 1985; Verdonschot, Rondel & Huysmans, 1995). Such methods have been used for *in vitro* monitoring of the improvement of the marginal leakage with the passage of time (Momoi & others, 1990; Von Fraunhofer & others, 2000). However, in these *in vitro* methods, the measurement of conductance was dependent on the area of an electrolyte (Hoppenbrouwers, Scholberg & Borggreven, 1986; Huysmans, Verdonschot & Rondel, 1995) and cannot be used for diagnosis in dentin or cementum surfaces with high conductance or low impedance because of measurement errors due to the influence of applied areas or amounts of the electrolyte (Nakano, 1985).

Table 1: *List of Prepared Cavities*

Cavity Location	Group	Margin Size (mm)	Cavity Depth (mm)	Basal Wall
Coronal surface cavity	A	(long axis x short axis)	1.0	enamel
	B		2.0	dentin
	C	4.0 x 3.0	4.0	pulp exposure
	D	3.0 x 2.0	2.0	dentin
Root surface cavity	A	(diameter)	0.5	enamel
	B		1.5	dentin
	C	3.0	3.0	pulp exposure
	D	2.0	1.5	dentin

The authors have proposed a new electrical method for clinical use (Iwami, Yamamoto & Ebisu, 2000). In brief, after electrolyte has been applied to the margin of the restorative, then wiped, leaving only the electrolyte to penetrate the marginal gap, marginal leakage can be detected by measuring the change in conductance across the margin. This new method can detect marginal leakage in both coronal and root surface cavities. However, this new method only demonstrated detecting whether *in vitro* restoratives had marginal leakage. In a clinical situation, the size of marginal shapes of restoratives will vary. Results from tests of methods used to detect marginal leakage should not be influenced by the size of the marginal shape of the evaluated restoratives. Therefore, the influence of the marginal shape to the results of this new method needed to be evaluated to help improve it for use in clinical situations. If the relationship between the extension of marginal leakage and the clinical symptoms of restoratives can be clarified, it may be possible to diagnose restorative prognosis. Accordingly, the ability of this new method to detect the extension of marginal leakage was investigated.

This study evaluated the influence of various extensions of marginal leakage on the results of this new electrical method by using *in vitro* models with a variety of marginal leakages in the direction of the pulp cavity. The influence of the marginal shape of restoratives on the results of this method was also evaluated.

METHODS AND MATERIALS

Preparation of Specimens

Thirty-two extracted, non-carious human maxillary and mandibular permanent molars were prepared. They were stored in physiological saline at 4°C and used within six months of extraction. The specimens were divided into four groups (Group A, B, C and D; each group consisted of eight specimens). Access cavities were prepared with a diamond point on the occlusal surface of the specimens and the pulp tissues were removed using K-files and a reamer. The roots of these teeth were fixed in Teflon tubes with a self-curing acrylic resin (Uni-Fast II, GC Corporation, Tokyo, Japan). After measuring the baseline conductance of these specimens (as described in the next section), cavities on the buccal coronal and root surfaces were prepared using a standardized cavity preparation device (Itoh Engineering Co, Kyoto, Japan) (Iwami & others, 2000). The coronal surface cavities were elliptical and the root surface cavities were circular (Figure 1). Table 1 lists the marginal size and cavity depth of each group. The marginal shapes in both surface cavities of Groups A, B and C were larger than those of Group D. The depth of cavities in Group A were shallow, Groups B and D were deeper and those of Group C were the deepest. The axial walls of the Group B and D cavities were made from dentin, while those of Group A were made from enamel. Those in Group C were made from partially exposed pulp.

A hybrid-type resin composite (Clearfil AP-X, Kuraray Co, Ltd, Osaka, Japan; Lot #735) was used to fill (without a dentin bonding system) both the coronal and root surface cavities of all specimens and was cured in bulk for 40 seconds. The light-curing unit was tested with a radiometer (Shofu Lite-Checker, SLC-I, Shofu Inc, Kyoto, Japan). After the specimens were stored in phys-

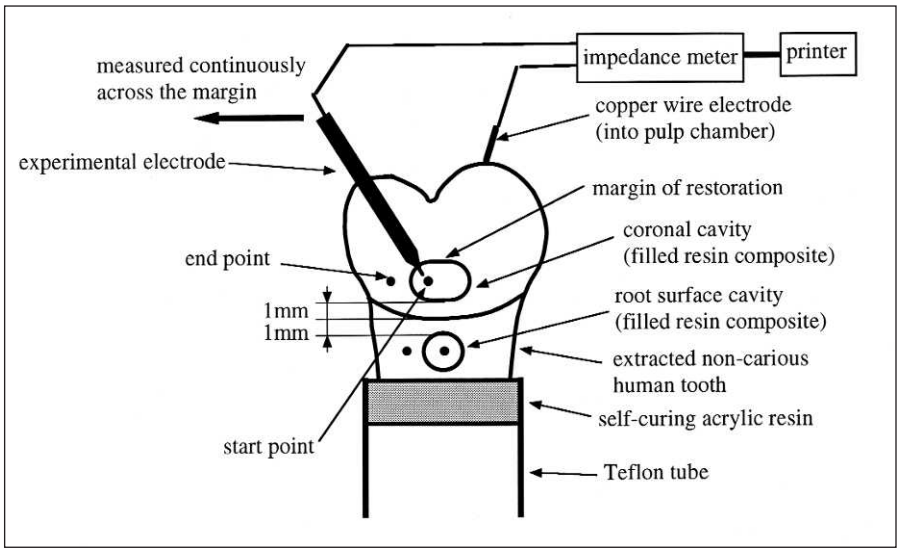

Figure 1. *Prepared cavities and the measurement of conductance. Cavities were prepared on the buccal coronal and root surfaces of 32 extracted non-carious human teeth. Conductance was measured consecutively using the experimental electrode from the starting point (composite surface) to the end point (coronal or root surface), crossing the margin.*

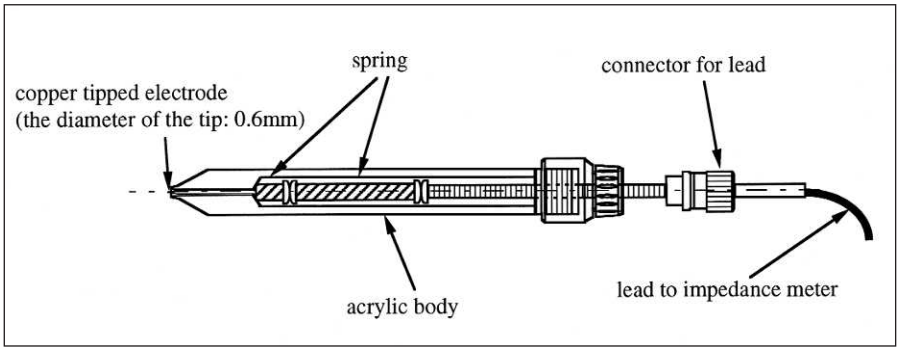

Figure 2. *Experimental electrode. The experimental electrode has a mechanism for measurement under constant pressure, with the contact between specimen and electrode being kept as constant as possible.*

iological saline at 37°C for 24 hours, the restoratives were finished and polished with polishing disks (Sof-lex, 3M Dental Products, St Paul, MN 55144, USA).

Measurement of Conductance

Figure 2 shows the experimental electrode used in these experiments (Iwami & others, 2000). The acrylic body of the sharp tipped (0.6 mm in diameter) experimental electrode was fitted with two springs to assist measurement under constant pressure by keeping the contact between the specimen and the electrode constant. The copper wire electrode and the experimental electrode were connected to an impedance meter (HP4263B, Hewlett-Packard Japan, Ltd, Tokyo, Japan). The pulp chamber of each specimen was filled with physiological saline and the copper wire electrode placed into it from the access cavity on the occlusal surface (Figure 1). The start point of the measurement process was located on the composite surface 1.5 mm from the margin of the restoration. The end point was located on the coronal or root surface 1.5 mm from the margin. Ten µl of physiological saline was applied to the margin of the restorative with a micropipette (Varipette 4710, Eppendorf, Hamburg, Germany) and the excess was wiped off. Once this process was completed, the surface of the margin was not wet to the naked eye. Conductance crossing the margin from the starting point to the end point was continuously measured using the experimental electrode. The start and end points of the measurement process were marked with an oily, fine marker. These marks did not seem to influence the conductivity of the composite or the tooth surface (Iwami & others, 2000). The electrical frequency was 100 kHz and the voltage 20 mV. After filling, the conductance was measured six times on the margin of each specimen. As described in the preceding section, prior to cavity preparation, the conductance of the enamel or root surface at the future cavity location was measured six times. The location of each measurement was the same for each specimen as was the location of each specimen. The measurement of conductance before cavity preparation (baseline) was used as a control for this experiment, as the specimens had no marginal leakage before cavity preparation.

Dye Penetration Test

In this experiment, none of the specimens were treated with a dentin bonding system because a model case was required in which a constant marginal leakage into the basal wall in the cavities was possible. Therefore, after taking all measurements of conductance, a dye penetration test was carried out to confirm the existence of marginal leakage into the axial wall. The access cavity on the occlusal surface of each specimen was blocked with a self-curing acrylic resin to avoid dye penetration. After the tooth surface of the specimen (with the exception of an area 0.5 mm wide around the cavity margin) was coated with nail varnish, each specimen was immersed in 2% wt methylene blue solution at 37°C for 24 hours. The specimens were then removed from the solution and the dye wiped off. Each specimen was then embedded in MMA resin (LEICA HistoDur, Leica Instruments GmbH, Heidelberger, Germany) and sectioned longitudinally across the surface using an auto-sectioning machine (Isomet 2000 Precision Saw, Buehler, Ltd, Lake Bluff, IL 60044, USA). Two sectional parts of each specimen were observed at 40x mag-

nification with a stereoscopic microscope (SMZ-10, Nikon Corporation, Tokyo, Japan) and evaluated using the highest microleakage score of the two parts of each specimen. The scoring used in these experiments was the same as that recommended in a previous study (Iwami & others, 2000). Namely, in both coronal and root surfaces, the degree of marginal leakage was scored 0. Score 0 means no penetration of dye, and the degree of marginal leakage increased as the score increased. In both surfaces, score 3 meant some penetration of dye into the dentin of an axial wall.

Statistical Analysis

The change in conductance (CC value) was defined as the difference between the conductance at the start or the end point of measurement, whichever was larger, and the maximum conductance excluding the start and end points. The mean value of six measurements was calculated and used as the result of each specimen. To enable comparison among Groups A, B and C (each group had different cavity depth), the CC values were analyzed by the Kruskal-Wallis test. When a significant difference was found, a Tukey-Welsch test was performed for nonparametric multiple comparison. For comparison between Groups B and D (each group had different margin sizes), the CC values were analyzed by the Mann-Whitney U test. For comparison of the CC values before cavity preparation and after filling, the changes were analyzed using the Wilcoxon signed-ranks test. Statistical significance was set at the 5% probability level.

RESULTS

Figure 3 shows the CC values in the coronal surface cavities of Groups A (shallow cavities), B (middle cavities) and C (deep cavities). The CC values in the root surface cavities are shown in Figure 4. In both cavities, the CC value after filling significantly increased as the cavity depth increased. In both types of cavity, there were significant differences in the CC values among each group ($p<0.05$). In both types of cavity, the CC values after filling were significantly larger than the changes prior to cavity preparation ($p<0.05$).

Figure 5 shows the CC values in the coronal surface cavities of Groups B (large cavities) and D (small cavities). Figure 6 illustrates the CC values in the root surface cavities. In both cavities, there were no significant differences in the CC values after filling between Groups B and D. In addition, in both types of cavity, the CC values after filling were significantly larger than those before cavity preparation ($p<0.05$).

Results from the dye penetration test showed that the dye penetrated the axial wall of the cavities in all specimens. Therefore, all specimens had marginal leakage into the axial wall after filling.

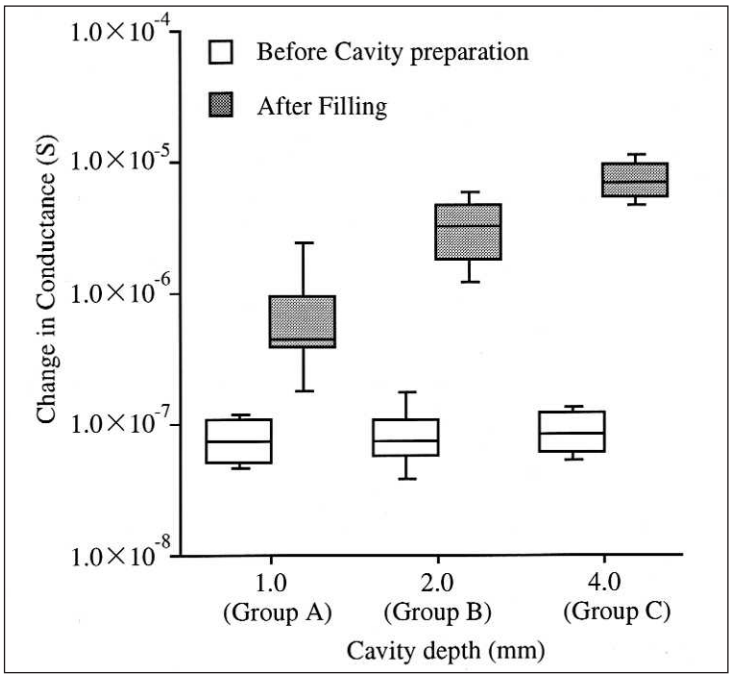

Figure 3. *Relationship between changes in conductance and cavity depth in coronal surface cavities. There were significant differences in the changes in conductance after filling among each of the three groups (p<0.05). In all groups, the changes in conductance after filling were significantly larger than before cavity preparation (p<0.05). Center line of the box: median, Box: 25-75% interval, Error bars: 10-90% interval.*

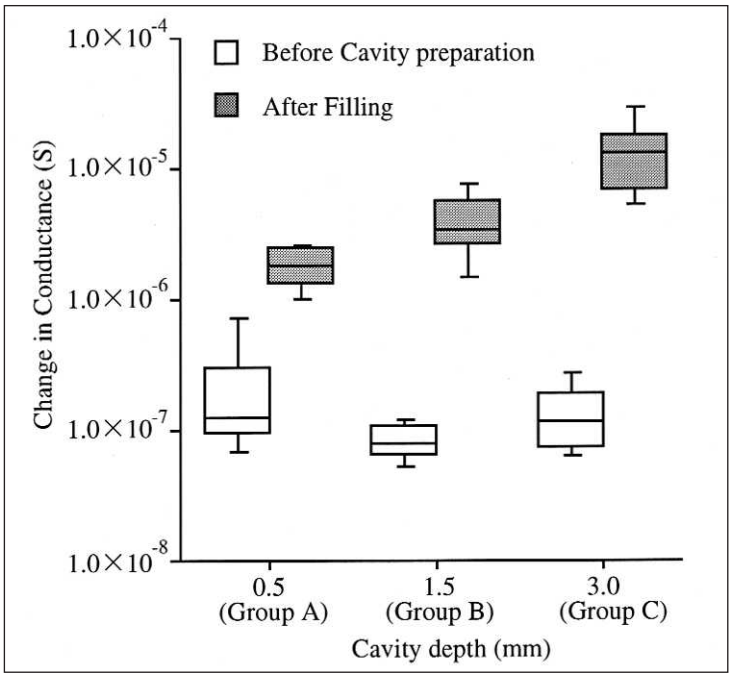

Figure 4. *Relationship between changes in conductance and cavity depth in root surface cavities.There were significant differences in the changes in conductance after filling among each of the three groups (p<0.05). In all groups, the changes in conductance after filling were significantly larger than before cavity preparation (p<0.05). Center line of the box: median, Box: 25-75% interval, Error bars: 10-90% interval.*

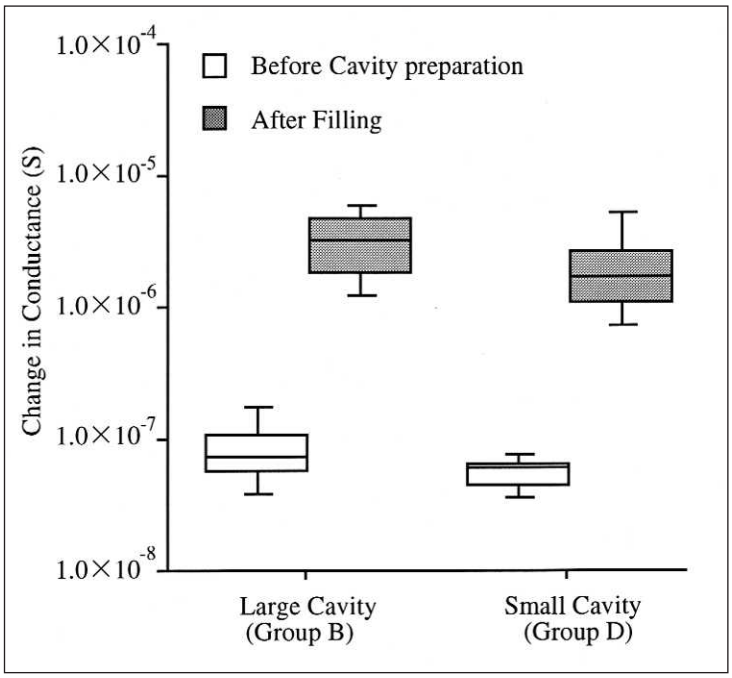

Figure 5. *Relationship between changes in conductance and the marginal shape size in coronal surface cavities. There were no significant differences in the changes in conductance after filling between Groups B and D. In addition, the changes in conductance after filling were significantly larger than those prior to cavity preparation (p<0.05). Center line of the box: median, Box: 25-75% interval, Error bars: 10-90% interval.*

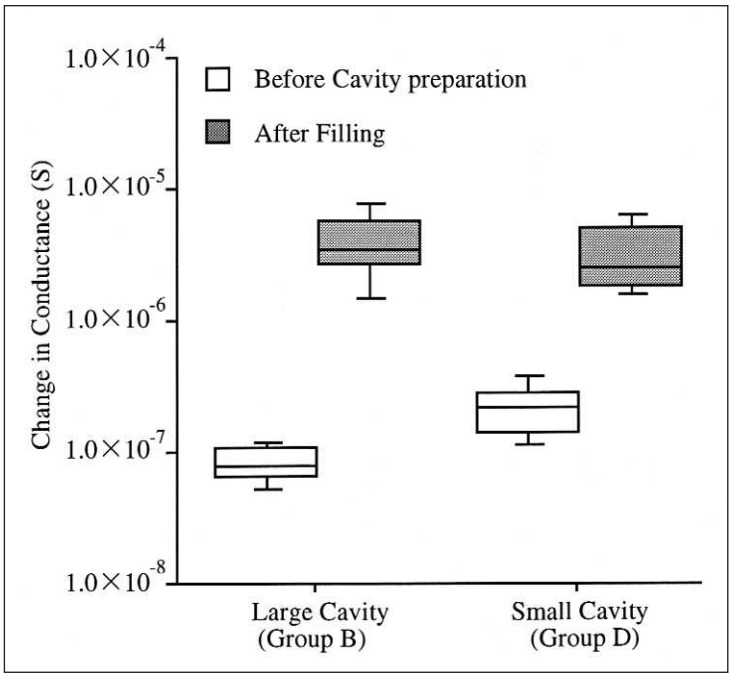

Figure 6. *Relationship between changes in conductance and the marginal shape size in root surface cavities. There were no significant differences in the changes in conductance after filling between Groups B and D. In addition, the changes in conductance after filling were significantly larger than before cavity preparation (p<0.05). Center line of the box: median, Box: 25-75% interval, Error bars: 10-90% interval.*

DISCUSSION

The authors have proposed an electrical method for evaluating marginal leakage (Iwami & others, 2000). It was reported that this new method could detect marginal leakage in coronal and root surface cavities, although marginal leakage in root surface cavities had not been detected by previously reported methods (Jacobsen & Von Fraunhofer, 1975; Martinez & Greener, 1976; Von Fraunhofer & Hammer, 1984; Nakano, 1985; Momoi & others, 1990; Verdonschot & others, 1995). In this study, the influence of restorative depth and marginal size on the results of this new method were evaluated.

Since it was difficult to prepare an experimental group treated with a bonding system that exhibited identical values of marginal leakage, none of the specimens in this model study were treated with a dentin bonding system. Based on the results of dye penetration tests, all specimens were found to exhibit an almost constant degree of marginal leakage as the dye penetrated into the axial wall of the restoratives. Consequently, all specimens were prepared for a model case in which there was marginal leakage into the axial wall. As the cavity depth of the Group B specimens was deeper than that of = Group A, the Group B specimens were established as model cases in which the gap extended in the direction of the pulp chamber. The Group C specimens were established as model cases in which the gap extended into the pulp chamber.

CC values were ascertained by continuous measurement of conductance and analyzed according to the authors' previous report (Iwami & others, 2000). When wiping off the electrolyte (except for the marginal gap) is insufficient to measure conductance, an evaluation of marginal leakage might be difficult. Thus, when the value of conductance at the measurement starting point is greater than the experiential value (about $1.0x10^{-6}$ S in this experiment), and wiping off of the electrolyte has been insufficient, the CC values should be measured again. If the value was smaller than $1.0x10^{-6}$ S, moisture on the surface of the specimens was considered suitable for measurement and marginal leakage had been detected. This procedure might reduce technical sensitivity in the application and wiping off of the electrolyte.

In extracted human teeth, the pulp tissue sometimes incurs dehydration or degeneration, and an air bladder might occur in the pulp chamber. Therefore, several factors in the pulp chamber of extracted teeth are considered as influencing the values of the conductance. In this study and previous ones (Nakano, 1985; Momoi & others, 1990; Iwami & others, 2000), because various factors that influence the results were eliminated (except for the effects of the test con-

ditions), the electrode was placed within the pulp chamber by preparing the access cavities on the occlusal surface and, as far as possible, pulp tissue was removed and filled with physiological saline in the pulp chambers. In the future, if this method is used in a clinical situation, the authors suggest that access cavities not be prepared but rather an electrode resembling a lip clip of an electrical apical locator be placed into the oral cavity. However, before such clinical use, it will be necessary to examine the influence of pulp on evaluations using this method.

In both coronal and root surface cavities, an increase of cavity depth led to an increase in CC values (Figures 3 and 4), so that CC values tended to increase in proportion to the extent of the gap in the direction of the pulp cavity. In contrast, since there were no significant difference between the CC values of large (Group B) and small cavities (Group D) (Figures 5 and 6), the CC values might not have been related to the size of the cavity margin. These experimental results show that this method can detect the extent of marginal leakage towards the pulp chamber without any influence from the size of the cavity margin. The electrical circuit connected the copper wire electrode to the pulp chamber, and finally to the experimental electrode for measurement through the pulp chamber using an impedance meter (Figure 1). Figure 7 shows a simple model of the electric current flow in these experiments. As the distance of the tooth structure (enamel or dentin) that the electric current flows decreases, the extension of electrolyte (saline) in the marginal gap towards the pulp chamber increases. The influence of the distance of tooth structure on the CC values is theoretically greater than that of the extension of electrolyte in the width of gap or along the margins because the electronic resistance of tooth material is considerably larger than that of an electrolyte. In addition, electrical resistance in the following descending order is noted: enamel, dentin and pulp tissue (Mayuzumi, 1964; Nakano, 1985). The CC values of the specimens exhibiting extensions of marginal leakage extended to dentin (low resistance) were therefore considered as having been greater than those exhibiting leakage extended to enamel (high resistance). The results of these experiments reasonably agree with the discussion of the simple model shown in Figure 7.

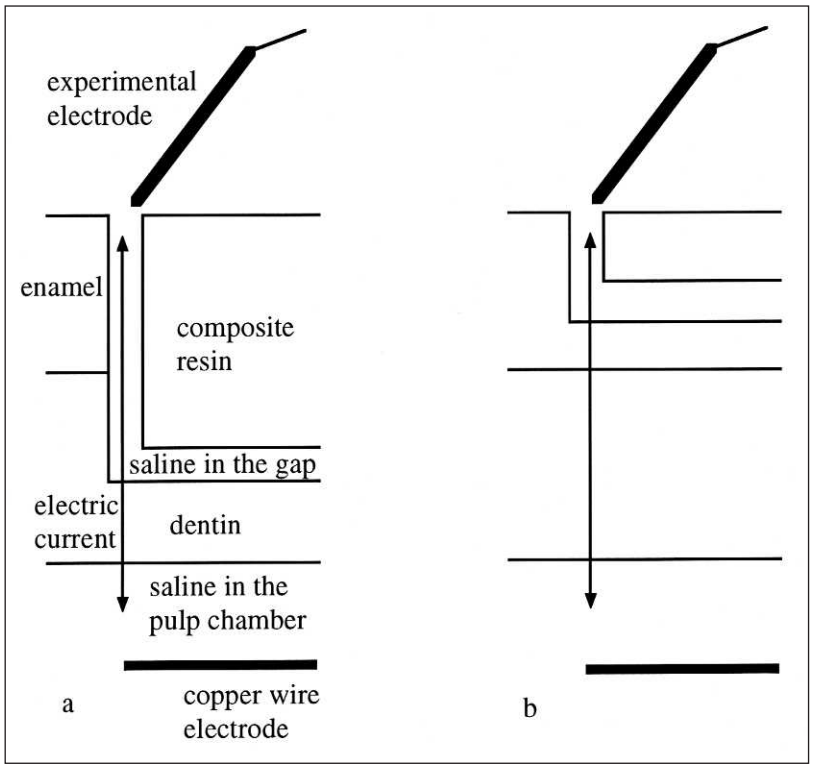

Figure 7. *Simple model of the electric current flow. (a) Model of the gap towards the dentin. (b) Model of the gap towards the enamel. The progress of the gap towards the pulp chamber leads to a decrease in the distance of the tooth structure in which the electric current flows. Theoretically, the distance of the tooth structure (enamel or dentin) had a greater influence on the CC values compared with those of the electrolyte in the width of the gap or along the margins.*

Before this electrical method is used in clinical situations, some factors that influence the results of this method still need to be examined. In previous studies and these experiments (Jacobsen & Von Fraunhofer, 1975; Martinez & Greener, 1976; Von Fraunhofer & Hammer, 1984; Nakano, 1985; Hoppenbrouwers & others, 1986; Momoi & others, 1990; Verdonschot & others, 1995; Huysmans & others, 1995; Iwami & others, 2000; Von Fraunhofer & others, 2000), non-carious extracted teeth were used. Therefore, it will be necessary to further examine measuring conditions, the influence of pulpal pressure, pulpal fluid, pulp tissues and dehydration or degeneration of the dentin. If a dependence on frequency or voltage is found, it will be necessary to examine the optimum measurement conditions. The electromotive force used in this experiment did not lead to irreversible pulpitis or reversible pulpitis with pain (Stark & others, 1977; Ricketts, Kidd & Wilson, 1995; Iwami & others, 2000). However, it may be necessary to use greater voltages because the influence of external noise must be kept to a minimum (Nakano, 1985). According to Nakano (1985), theoretically, the electrical methods themselves may have high sensitivity, for example, the change of marginal gap can be detected after hydroscopic expansion of composites. However, the sensitivity of this method needs to be evaluated; if it is insufficient, some experimental conditions may need to be changed, for example, by investigation of other electrolytes with higher permeability, reduction of measurement time, stabilization of the data by

means of increased frequency or voltage or by reducing the moving speed of the experimental electrode.

CONCLUSIONS

The results of this study suggest that this method can detect extensions of marginal leakage in the direction of the pulp chamber in coronal and root surfaces. The size of the cavity margin did not influence the results. Also, this method does not require cutting the observed surface to evaluate marginal leakage, which is in contrast to the dye penetration test or other *in vitro* tests. Compared to previous electrical methods, this method is straightforward and has significant potential

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Removal of Amalgam, Glass-Ionomer Cement and Compomer Restorations: Changes in Cavity Dimensions and Duration of the Procedure

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D Schmidt • T Gerhardt • D Heidemann

Clinical Relevance

Based on this study, which awaits confirmation *in vivo*, amalgams and glass ionomer cements seem easier to remove without too much loss of sound dentin, while tooth-colored resin bonded systems produce more dentin loss when repaired or removed.

SUMMARY

This study investigated changes in the dimensions of Class II cavities following the removal of amalgam, glass ionomer and compomer restorations. In 30 extracted caries-free human molars, preparation for 60 mesio-occlusal and occluso-distal cavities (two cavities per tooth) occurred. With a CEREC 3 laser triangulation sensor and software-based construction analysis, the dimensions of the cavities at seven defined sites were measured. The cavities were randomized into four groups. Group 1 was restored with Ketac-Fil glass-ionomer cement, Group 2 with amalgam and Group 3 with Compoglass F compomer. In Group 4, Compoglass F was used in combination with photochromic Tetric Flow Chroma as a cavity liner. The completed restorations were then removed using 2x magnification and the cavities were once again controlled using the laser system. The duration of the removal procedure was also recorded.

Changes in cavity dimensions (depth, height and width) following removal of the restorations were significantly smaller in Groups 1 and 2. Groups 3 and 4 were characterized by a significant overextension of the cavities compared to Groups 1 and 2 in all three dimensions. Group 4, with Tetric Flow Chroma as a cavity liner, showed better results than Group 3, but this improvement was not statistically significant. The duration of the removal procedure was significantly shorter in Group 2 than in the other groups.

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INTRODUCTION

The use and development of adhesive restorative materials continues to progress rapidly. As these restorations are continuously optimized in terms of adhesive proper-

ties, marginal seal and shade, they become more durable and gain broader acceptance among dentists and patients.

Recent studies have shown that today's composite restorations outnumber amalgams in Class II cavities (Sundberg & others, 2000) in Scandinavia. The close color match can, however, turn into a disadvantage if the restoration has to be removed, as it may become difficult to distinguish between filling material and prepared tooth structure (Hunter, Treasure & Hunter, 1995; Krejci, Lieber & Lutz, 1995). Failure to revisit the original cavity dimensions carries a high risk that restorative material may be overlooked and left behind or that cavities will become overextended (Krejci & others, 1995).

Direct visual inspection and orientation deep into the cavity is facilitated by materials such as amalgam or zinc phosphate cement, as their color stands out against the tooth structures. Compared to inherently adhesive materials, however, they offer far less adhesion to enamel and dentin (Smith, 1997). Glass-ionomer cements and compomers will adhere to prepared tooth structures at a strength of 4–18 MPa. Removal of dentin-bonded fillings, such as composites, glass ionomer cements and ceramic restorations, have been described as being associated with massive cavity overextensions (Krejci & others, 1995). Novel "photochromic" composites offer a promising method of solving this problem: they are flow-composites used as a cavity liner underneath composite restorations and acquire a dark-green color when exposed to polymerization devices, so that the cavity outlines can be visualized when the restoration is removed.

In this study, the dimensions of Class II cavity preparations were compared prior to placement and after removal of amalgam, glass ionomer cement and compomer restorations. The compomer was used either alone or in combination with a photochromic cavity liner. The changes in cavity height, width and depth among the various groups were measured with a laser triangulation sensor. Changes in cavity dimensions and the time involved in removing the amalgam were measured, keeping in mind that using photochromic materials is an advantage in removing restorations.

METHODS AND MATERIALS

Thirty extracted, caries-free human molars were selected. They were stored in 0.1% thymol solution and, after cleaning with ultrasound and scaling, their occlusal structures were ground flat using a model trimmer (Adeb, Degussa, Hanau, Germany). For technical reasons related to scanning in the model holder, the roots had to be shortened to a maximum tooth length of 1.8 cm. With the help of magnifying glasses (magnification 2x, Zeiss, Oberkochen, Germany), each tooth was prepared with both a mesial and distal box using a conic diamond bur (Brasseler, Lemgo, Germany) and a high-speed handpiece (at 160,000 rpm) with water spray. To ensure that the inner walls of the cavities could be scanned, the opening angle of the cavity was at least 6 degrees in conicity. Each cavity was prepared to external dimensions of 3 x 3 x 3 mm, finished with Arkansas stones (#653, Busch, Engelskirchen, Germany) and on the occlusal surface with fine (600-grit) emery paper followed by cleaning with 3% H_2O_2.

The teeth were placed on a CEREC model holder (Scanhalter, Sirona, Bensheim, Germany) so that they

Table 1: *Materials Used and Their Composition According to Manufacturers*

Material (Manufacturer)	Batch	Composition
Total Etch (Vivadent, Ellwangen)	12515	Phosphoric acid (37%)
Excite (Vivadent, Ellwangen)	28725	Phosphoric acid acrylate, HEMA, BisGMA, silicium dioxide ethanol, catalysts, stabilizers
Compoglass F (Vivadent, Ellwangen)	546987	UDMA (11.5%), polyethylene glycol dimethacrylaet (4.6%), cyclo-aliphatic dicarbonic acid dimethacrylate (6.6%), mixed oxides (5.9%) ytterbium trifluoride (11.5%), Ba-Al-fluorosilicate glass (59.6%)
Tetric Flow Chroma (Vivadent, Ellwangen)	9005	BisGMA (13.8%), UDMA (12.2%), barium glass (46%), tri-methylene glycol dimethacrylate (6,6%), ytterbium trifluoride (12%), pigments (0.03%), stabilizers (0.4%)
Vivacap (Vivadent, Ellwangen)	6456	Non-gamma-2 amalgam (sliver, tin, copper, mercury)
Ketac-Fil (ESPE, Seefeld)	23/009	Calcium-sodium-fluoride-phosphorus-aluminum silicate (11:2:13:2:16:56), polyacrylic acid, maleic acid, tartaric acid

(BisGMA = Bisphenol A diglycidyl ether dimethacrylate, HEMA = 2-hydroxyethyl methacrylate, UDMA = urethane dimethacrylate)

were anchored in a plastic frame (Technovit 4004, Kulzer, Hanau, Germany) 1 mm below the cavity floor. In addition, standardized metal planes (Elastic, Mainz, Germany) designed to simulate the presence of neighboring teeth were embedded mesially and distally to facilitate the correlation of data in the subsequent scanning procedure. After being covered occlusally with a scanning powder (Scan'Spray, Dentaco, Bad Hamburg, Germany) to prevent the laser beams from being reflected, the teeth were mounted in the CEREC 3 CAD/CAM unit (Sirona, Bensheim, Germany). They were scanned by the laser system from two angles with the spot sensor in correlation mode. The result was saved as "preparation image." The internal line angles of the metal plane were highlighted for the scanned data for accurate attribution and correlation after removing the restoration. The teeth were taken out of the chamber, the powder was sprayed off and the cavity thoroughly cleaned again with 3% H_2O_2.

The teeth were randomly placed into four groups of 15 cavities each. Table 1 shows the materials used. The various groups were defined by restorative approaches as follows:

Group 1: Cavities were filled with Ketac-Fil (ESPE, Seefeld, Germany) using a dental shade guide (VITA, Bad Säckingen, Germany), striving for an ideal color match. No trimming was performed, as this would have changed the cavity and filling margins, distorting the recorded dimensions after removing the restoration.

Group 2: Cavities were filled using Vivacap (Vivadent, Ellwangen, Germany) without lining and condensed with a spherical plugger, and the margins trimmed using a Wiland carver. The restorations were finished, as in Group 1, using no cutting tools.

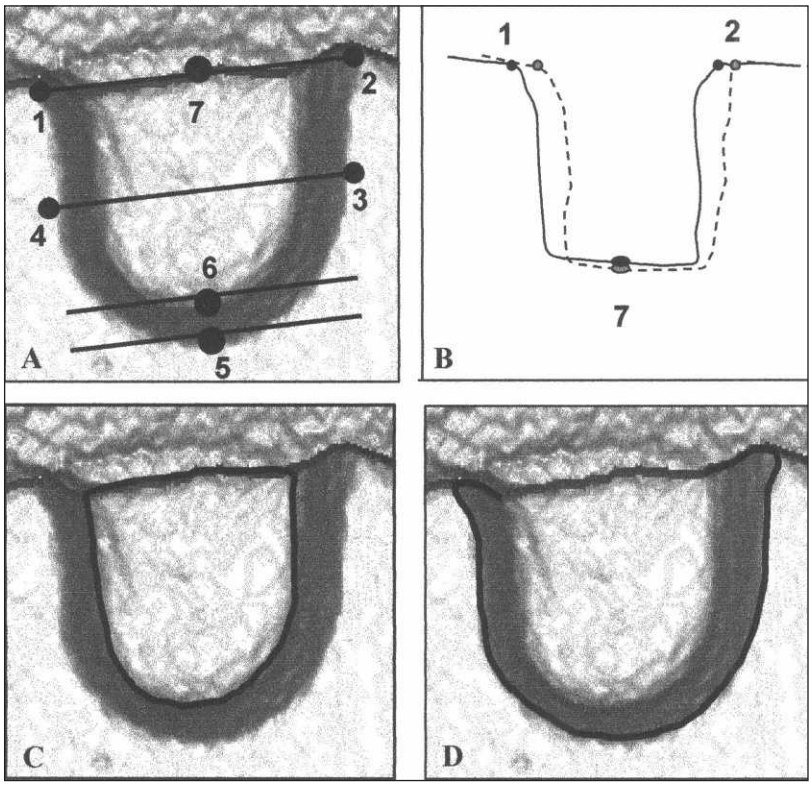

Figure 1. *Outline of the used measurement technique.*
A = Example of a mesial cavity with seven defined reference sites for measurement: tangent drawn between points 1–2 (extreme occlusal locations at the cavity margins of the extension surfaces orally and buccally of the cavity); tangent drawn between points 3–4 (extreme occlusal locations at the oral and vestibular margin in the center of the cavity); 5 (center of the cavity margin occlusally at the interface with the pulp-axial wall); 6 (center of the interface between cavity floor and pulp-axial wall); 7 (extreme cervical location at the mesial or distal margin in the center of the cavity floor).
B = Example of a cross-section from the correlation software with tangent 1–2 and point 7 being traced before placement (continuous line) and after removal (broken line) of the restoration.
C = Tracing of cavity floor (thick continuous line)
D = Tracing of cavity margins (thick continuous line)

Group 3: Cavities were conditioned according to manufacturers' instructions. All cavities were pre-treated using Total Etch (Vivadent, Ellwangen, Germany) with 37% phosphoric acid for 30 seconds in enamel and for 15 seconds in dentin. The gel was sprayed off for 30 seconds and dried with oil-free air for an additional 30 seconds. The specimens were coated with Excite dentin adhesive (Vivadent, Ellwangen, Germany), dried and polymerized with a curing unit (Elipar Highlight, ESPE, Seefeld, Germany). The shade was taken and several 1.5 mm layers of Compoglass F (Vivadent, Ellwangen, Germany) were applied into the cavities using a spatula and spherical plugger. The margins were adapted with brushes, followed by polymerization for 40 seconds. A glycerine gel (Airbloc, Dentsply, Konstanz, Germany) was applied on the surface of the restoration before the last polymerization step to prevent the formation of an oxygen inhibited layer.

Group 4: In Group 4, the cavities were also lined with Tetric Flow Chroma under the compomer restoration, that is, the material was applied to the floor and the margins of the cavity. Tetric Flow Chroma contains a chromogenic dye that acquires a dark green color when illuminated by a curing lamp. After removing the light source, the material returns to its original color. The restoration using Compoglass F was performed as described above for Group 3.

Subsequently, all restorations in Groups 1 through 4 were removed by practitioners using magnifying glasses (magnification 2x, Zeiss, Oberkochen, Germany) and had not been involved in preparing and filling the cavities to exclude any visual notion of the cavity dimensions. The sequence in which the various restorations

were removed was randomized. In the first step, an ISO-Size 10 diamond- bur (Brasseler, Lemgo, Germany) was used in the high-speed handpiece under spray cooling to remove most of the restorative material. The cavity was then blown dry, and a medium-sized round bur (Brasseler, Lemgo, Germany) was used in the low-speed handpiece to remove residual material.

A mirror and probe were used together with a curing lamp for illumination to distinguish between tooth structures and restorative material. In Group 4 cavities, the polymerization light also reactivated the dark-green color of the Tetric Flow Chroma material that proved helpful even as it shined through the restoration. The removal procedure continued until all residual restorative material had been eliminated. The procedure time then was recorded.

The cavity was thoroughly cleaned, dried, covered with scan powder and mounted again under the scanner of the CEREC 3 laser system. The scanned image was saved as an "occlusion image," which could now be directly compared to the "preparation image" obtained before placement of the restoration. Using the "cross section" icon, the second image could be superimposed over the first, and any differences in dimensions were directly quantified by tracing the contours with the cursor (Figure 1B). After rescanning the tooth to calculate the inner surfaces of the cavities, the following parameters could be evaluated:

(1) Internal Surfaces of the Cavity (mm^3)—The inner surfaces of the cavities were determined before placing and after removing the restoration using the function for adhesion surface calculation included in the CEREC 3 software. After highlighting the margins (Figure 1D) and the floor (Figure 1C) of the cavity on the scanned image, the surface was calculated automatically.

(2) Width (X values in pixels)—Points 1–4 (Figure 1A) could be read as X values for the width of the cavity after drawing a line directly on the cross-section diagram (Figure 1B). The cursor values in pixels were converted to mm as follows: 1 pixel = 25 µm x 0.001 = mm

(3) Height (Z values in mm)—Points 6-7 (Figure 1A) could be read as Z values for the width of the cavity after drawing a line directly on the cross-section diagram (Figure 1B).

(4) Depth (Y values)—Points 5–6 (Figure 1A) could be read as Y values for the depth of the cavity after drawing a line directly on the occlusion and preparation images.

(5) Total change in cavity dimensions—Finally, all converted findings were summarized to obtain the total metric dimensions before placement and after removal of the restoration.

(6) Duration of removal (minutes)—The time required to remove and review the removal of each restoration.

Mean values, standard deviations, min-max values and medians were gained from 15 specimens in each group. Explorative data analysis was based on the Skewness normality of residuals test. Kruskal-Wallis multiple comparison Z value test (NCSS 6.0.2.1) with the corrected significance level µ=0.05 was used to test the null hypothesis that there are no differences in the removal parameters among the various groups.

RESULTS

Explorative data analysis using the Skewness normality of residuals test showed that no normal distribution of the data was found. The difference hypothesis was therefore done with a non-parametric test. The findings for the various parameters, including the comparative statistical data, are compiled in Tables 2 to 7.

(1) Differences in cavity inner surfaces—Group 3 showed the greatest (2.34 mm^2), Group 2 the smallest (–0.03 mm^2) mean difference in terms of cavity inner surfaces before placement as compared to after removal of the restorations (Table 2). (Positive values indicate an over-extension of cavities, negative values indicate an under-extension or the presence of residual filling material.)

(2) Differences in cavity width—Group 4 showed the greatest (0.50 mm), Group 2 the smallest (0.02 mm) mean difference in cavity width before placement as compared to the situation after removing the restorations (Table 3).

(3) Differences in cavity height—Group 6 showed the greatest (0.55 mm), Group 2 the smallest (0.09 mm) mean difference in cavity height before placement compared to after removing the restorations (Table 4).

(4) Differences in cavity depth—Group 3 showed the greatest (0.41 mm), Group 2 showed the smallest (0.01 mm) mean difference in cavity depth before placement as compared to after removing the restorations (Table 5).

(5) Total changes in cavity dimensions—Group 4 showed the greatest (1.24 mm), Group 2 showed the smallest (0.11 mm) total changes in cavity dimensions before placement compared to after removing the restorations (Table 6).

(6) Time needed to remove fillings—Group 4 showed the longest (5.89 min), Group 2 showed the shortest (0.71 min) mean duration of removal procedures (Table 7).

DISCUSSION

The figures available from the literature on the life of dental restorations range between five and eight years for composites, 12 and 14 years for amalgams and more than three years for glass ionomer cements (Jokstad, Mjör & Qvist, 1994; Mjör & Moorhead, 1998; Mjör 1997; Pink, Minden & Simmonds, 1994). Common reasons for placing, replacing and repairing restorations

include primary caries (41–56%) and other reasons, such as secondary caries (22%), tooth fracture (6%) and fracture or degradation of the primary filling material (5–6%); however, aesthetic considerations related to the color of the filling also play a role (20%), altogether 53-54% (Wilson, Burke & Mjör, 1997; Burke & others, 1999; Franco & Pascotto, 1990; Friedl, Hiller & Schmalz, 1995), so that every second filling is to be removed once at minimum.

Today, a number of authors have reported that Class II cavities are more frequently restored with composites than with amalgams (Sundberg & others, 2000). In a German study, 47.1– 49.5% of the restorations in the dental office were performed to correct previous fillings, of which 50.6–52.9% were primary restorations (Friedl & others, 1995; Friedl, Hiller & Schmalz, 1994). According to the same source, 10.9% of restorations were performed to replace primary amalgams with composites, a trend that has been confirmed by other authors who pointed out that this approach is more costly than replacing amalgams with amalgams (Tobi & others, 1999). It was also reported that 91.4% of removed composites were replaced with

Table 2: *Mean Value, Standard Deviation, Minimum (Min)-Maximum (Max) Values and Medians of Recorded Differences in Cavity Inner Surfaces (mm^3)*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	-0.04	1.75	-3.20	4.10	0	4
Amalgam	2	-0.03	1.19	-1.80	2.00	-0.30	3,4
Compoglass	3	2.34	3.73	-3.90	8.60	2.50	2
Compoglass/ Tetric Flow Chroma	4	1.27	3.82	-8.30	9.40	2.00	1,2

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

Table 3: *Mean, Standard Deviation (SD), Minimum (Min), Maximum (Max) and Median of the Width Changes Found. All Values in mm*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	0.05	0.08	0.05	0.23	0.05	3
Amalgam	2	0.02	0.02	0	0.05	0	3
Compoglass	3	0.10	0.33	-0.48	0.83	0.03	1,2,4
Compoglass/ Tetric Flow Chroma	4	0.50	0.40	0	1.43	0.48	3

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

Table 4: *Mean, Standard Deviation (SD), Minimum (Min), Maximum (Max), and Median of the Height Changes Found. All Values in mm*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	0.19	0.17	0.01	0.73	0.17	3,4
Amalgam	2	0.09	0.09	-0.07	0.30	0.08	3,4
Compoglass	3	0.53	0.45	0.10	1.93	0.45	1,2
Compoglass/ Tetric Flow Chroma	4	0.55	0.31	0.05	1.05	0.58	1,2

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

Table 5: *Mean, Standard Deviation (SD), Minimum (Min), Maximum (Max) and Median of the Depth Changes Found. All Values in mm*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	0.15	0.19	-0.08	0.55	0.05	2,4
Amalgam	2	0.01	0.09	-0.13	0.23	0	1,3,4
Compoglass	3	0.41	0.38	0.05	1.45	0.30	2
Compoglass/ Tetric Flow Chroma	4	0.19	0.20	-0.13	0.58	0.18	1,2

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

Table 6: *Mean, Standard Deviation (SD), Minimum (Min), Maximum (Max) and Median of the Total Changes Found. All Values in mm*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	0.39	0.34	-0.01	1.26	0.27	3,4
Amalgam	2	0.11	0.16	-0.17	0.58	0.08	3,4
Compoglass	3	1.03	0.75	-0.08	2.73	1.10	1,2
Compoglass/ Tetric Flow Chroma	4	1.24	0.80	-0.01	2.75	1.16	1,2

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

Table 7: *Mean, Standard Deviation (SD), Minimum (Min), Maximum (Max) and Median of Recorded Time Needed to Remove Restorations. All Values in Minutes*

Group	#	Mean	SD	Min	Max	Median	Significance Relative to #
Ketac-Fil	1	2.48	1.65	0.24	6.00	2.40	2-4
Amalgam	2	0.71	0.44	0.25	1.50	0.43	1,3,4
Compoglass	3	5.14	1.42	3.07	8.15	5.05	1,2
Compoglass/ Tetric Flow Chroma	4	5.89	1.76	4.10	10.15	5.15	1,2

*Paired comparisons of values. Figures indicate to which group a statistically significant difference was found. (alpha = 0.05, Kruskal-Wallis multiple comparison Z value test with corrected significance level).

composites, whereas amalgams were only used 6.5% to replace composite restorations (Friedl & others, 1995).

Several authors have reported on structural loss associated with filling replacement (Hunter & others, 1995; Krejci & others, 1995; Millar, Robinson & Davies, 1992). They found that the time required to remove the first restoration and the hard-tissue loss involved in the procedure depended heavily on the filling materials used. Yet, while the methods for assessing the removal time were relatively straightforward, experimental designs to determine changes in cavity dimensions after removal have varied due to the greater procedural complexities involved. They were either based on volumetric evaluation of silicone elastic impressions taken before and after removal or photographic images analyzed by superimposition (Hunter & others, 1995; Krejci & others, 1995; Millar & others, 1992). The results on changes in cavity height, width and depth drawn from these approaches are relatively inaccurate.

In 1998, a procedure was introduced that measured anatomical structures of the mandible by computerized tomography (Mozzo & others, 1998). Again, this method was relatively inaccurate and very expensive. In 1990, a laser-based method of measuring tooth dimensions in X- and Y-coordinates was described, which fell short of giving a three-dimensional representation (Kimura, Sohmura & Watanabe, 1990). In 1996, a three-dimensional measurement technique was introduced based on orthodontic plaster models and laser sensoring in combination with two video cameras (Kuroda & others, 1996). These authors described a method of assessing data along the X, Y and Z coordinates at a resolution of 0.05 mm in a procedure that took approximately 40 minutes. By comparison, the CEREC 3 system offers a resolution of ± 25 µm and an average scanning time of seven minutes.

This experimental study measured dental cavities *in vitro* at defined sites before placement and after removal of various filling materials using a laser scanner and CEREC 3 construction software. With the triangulation sensor, the specimens could be scanned in all three dimensions (Mörmann & Bindl, 2000). The specimens were accurately positioned for the scanning procedure using a mounting plate according to the scanner so that the relevant XYZ coordinates for any position on the scanned image could be read and converted into mm. The seven reference sites for measurement were specifically selected to outline changes in three dimensions: width (X), depth (Y) and height (Z). In this way, it was possible, for the first time, to assess cavity size changes in all dimensions based on direct measurement rather than volume behavior. The disadvantage of this procedure was that only specimens diverging in the occlusal direction could be accurately scanned, whereas undercuts were outside the scope of exact metric assessment.

Several authors have indicated that removing composite restorations involves substantially greater structural loss (41.8 mm^3) than amalgam (17.6 mm^3) or glass ionomer cement (19.6 mm^3) (Krejci & others, 1995). They suggested that color indicators should be used to visualize the borderlines of the filling material to be removed (Krejci & others, 1995). In another study, cavities were shown to be enlarged by up to 37% following removal of direct composite restorations (Millar & others, 1992), and similar observations have been made by other groups (Hunter & others, 1995), as well. This

study adds to the growing evidence of overextended cavities following removal of composite restorations. The cavities occupied by the metallic amalgams in Group 2 showed significantly more favorable dimensions of the cavity inner surfaces once the restoration was removed than the cavities in Groups 3 and 4 that had been occupied by tooth-colored materials. The amalgam restorations resulted in slightly under-extended, the tooth-colored compomer restorations in massively overextended cavities. The good visible amalgam was easily identified within the cavity and could be removed with almost flawless perfection. By contrast, the poorly distinguishable compomers (Group 3) were completely removed, but they resulted in overextended cavities. The Ketac-Fil glass ionomer cement used in Group 1 showed similar behavior to the amalgam in Group 2 and was significantly different from Group 4. Although the authors strove to achieve an ideal color match in Group 1, just as was done in the compomer groups, the borders of the material were more easily discernible with Ketac-Fil than with the compomers, one explanation was that a perfect color match could not be achieved with Ketac-Fil due to the porosity of the surface. Although no trimming was performed with any of the restorations because this would have changed the previously recorded cavity dimensions, the additional use of Tetric Flow Chroma as a cavity liner in Group 3 improved the values obtained with the regular compomer group without Chroma lining. This difference, however, fell short of statistical significance, which is confirmed by the absence of a statistically significant difference between Groups 3 and 4 based on total changes in cavity dimensions.

Overall, an over-extension of cavities following removal of restorations was seen with all materials used, while amalgam and glass ionomer cement yielded significantly better results than the compomer. It appears that the photochromic cavity liner must have influenced the various cavity dimensions in different ways.

The changes in cavity depth led to over-extension with all materials used, while the results obtained with amalgam were significantly better than the rest. There were no significant differences between the glass ionomer (Group 1) and the compomer (Group 3). When the photochromic material was used with the compomer (Group 4), the over-extension was reduced by half compared to Group 3. While this improvement was not statistically significant, it might nevertheless substantially reduce the risk of injury to the pulp when removing compomer restorations in a real-life situation.

The changes in cavity height also led to over-extension with all materials used, while the results for amalgam were significantly better than for compomer (Group 3), but not for the glass ionomer (Group 1). This can be explained by the color dissimilarity between tooth structures and material. Additional use of the photochromic cavity liner (Group 4) did not significantly improve the values obtained with the compomer alone (Group 3). In other words, Tetric Flow Chroma did not make a difference as far as changes in cavity height were concerned.

The changes in cavity width again led to over-extension with all materials used. The greatest changes in width were seen with the compomer, with the surprising facet that the changes in Group 4 were significantly higher than in Group 3. There is no good explanation for this unexpected finding. One hypothesis would be that the randomized sequence of removal procedures might have played a role, as Group 4 was the last group. Although the treating dentist had no knowledge of the dimensions of the cavity, he expected a change in the combination of materials, which may conceivably have led to a more aggressive approach.

While previous investigators reporting on changes in cavity dimensions have removed dental restorations without magnification (Krejci & others, 1995; Hunter & others, 1995), this study shows that overextended cavities could not be avoided even with a 2x magnification factor entering the equation. Whether the results would have been worse if no magnification had been used remains unclear, as a control group without magnification was not included in the study design.

A study by Krejci & others, 1995 indicated significant differences in the time needed to remove amalgam (15.2 minutes), glass-ionomer cement (11.9 minutes) or composite (24.9 minutes) restorations. Other authors reported a mean removal time of seven minutes for direct composite restorations (Millar & others, 1992). The significantly shortest mean removal time in this study was obtained with amalgam (0.71 minutes), while the compomer with photochromic lining took the longest time to be removed (mean: 5.89 minutes). Given the different restoration volumes removed in previous studies (mesial cavities of 3.2 x 2.8 x 5.0 mm), these results are not surprising (Krejci & others, 1995).

The cavity volumes in other reports were not specified (Millar & others, 1992). The brief removal time obtained in this study seems to be a factor of color contrast among other possible reasons. Considering the known adhesive properties of the materials used in this study, it is by no means surprising that amalgam, which does not, per se, adhere to tooth structures, took the shortest time to be removed. Glass ionomer cements are known to adhere to tooth structures with an adhesive strength up to 4 MPa. Accordingly, the removal times in Group 1 were significantly longer than in Group 2. The adhesiveness of compomers against tooth structures is established with the help of a dentin adhesive and previous etching with phosphoric acid, which increases the adhesive strength up to 16 MPa. The time needed to remove these restorations was accordingly

longer, in addition to the fact that removal times are already considerably extended by the high color match of these materials. Using photochromic material did not significantly influence the time needed to remove restorations.

CONCLUSIONS

The results of this experimental study show that removing restorations *in vitro* invariably resulted in an over-extension of cavities regardless of the type of filling material removed and despite the use of 2x magnifying glasses or photochromic agents.

Based on all investigated parameters, the most favorable results were obtained with amalgam.

Using Tetric Flow Chroma as a photochromic cavity liner in combination with a compomer failed to significantly reduce the over-extension compared to the compomer, alone. Indeed, in terms of cavity width, the group that used the photochromic liner showed significantly less favorable results than the group in which the compomer was used without a photochromic liner. Therefore, more data on its material properties are needed before photochromic liners can be recommended for clinical application.

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Re-Attachment of Anterior Fractured Teeth: Fracture Strength Using Different Materials

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Clinical Relevance

Different material combinations used to bond tooth fragments to the remaining crown were found to have no influence on fracture strength after bonding. The resin composite restoration can restore the original tooth fracture strength. The chamfer technique provided better strength recovery than the simple reattachment, but both were inferior to the resin composite restoration.

SUMMARY

This study compared the fracture strength of two different techniques (bonded only and buccal chamfer) and different material combinations used to reattach tooth fragments. An axial load applied to the buccal area fractured 110 sound permanent lower incisors. Fifty teeth were designated for the bonded only group (no additional preparation) and 50 teeth were designated for a buccal chamfer group. For each group teeth were subdivided into five subgroups (n=10) according to the restorative material combinations used: 1) adhesive system (A); 2) A + light cured luting cement; 3) A + dual cured luting cement; 4) A + flowable resin and 5) A + hybrid resin. In a control group (resin composite build-up), in the remaining 10 teeth, the crown portion was rebuilt with adhesive and resin composite. Restored teeth were subjected to the same loading in the same buccal area. Fracture strength after restorative procedures for all groups was expressed as a percentage of the original fracture strength and the results were analyzed by two-way ANOVA and Tukey's test for pair-wise comparison. The interaction and the material factor were not statistically significant ($p=0.140$ and $p=0.943$, respectively). The chamfer group showed higher fracture strength recovery (67.9%) than the bonded only group (41.1%), and both were statistically lower than the resin composite build-up (103.2%). It was concluded that the material used to reattach the fragment is less important than the chosen technique.

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INTRODUCTION

Recent studies on the incidence of dental trauma, mainly among children and teenagers, have shown that trauma affects up to 25% of patients at this age (Murchison, Burke & Worthington, 1999).

Reattachment of a tooth fragment should be preferable to restoring fractured teeth since the fragment is available. Several advantages in this treatment are responsible for its widespread use. It is a conservative procedure; it maintains the original tooth contours and translucence, the color match to remaining crown portion and its color stability over time (Busato & others, 1998). Therefore, less chair time is required, which reduces the cost of the treatment. Many techniques have been proposed for reattaching the fragment to the remaining tooth: using a circumferential bevel before reattaching (Simonsen, 1979; Amir, Bar-Gil & Sarnat, 1986; Burke, 1991; Walker, 1996), placing a chamfer at the fracture line after bonding (Davis, Roth & Levi, 1983; Franco & others, 1985; Andreasen & others, 1995), using a V-shaped enamel notch (Simonsen, 1982), placing an internal groove (Baratieri & others, 1994; Walker, 1996) or a superficial overcontour over the fracture line (Reis & others, 2001). Some authors have also indicated bonding with no additional preparation (Osborne & Lambert, 1985; Martens & others, 1988; Dickerson, 1994).

A recently published article compared the fracture strength of different reattachment techniques (Reis & others, 2001). It showed that using a superficial overcontour over the fracture line, placing an internal groove and the resin composite restoration provided fracture strength as high as the ones observed in sound teeth. However, simple reattachment with no additional preparation or using a buccal chamfer over the fracture line only recovered 37% and 60% of the intact tooth fracture strength, respectively, when a dual cure luting cement was used.

Another source of variation found among published articles relating to this subject were the materials used to reattach the fragment. Using bonding agents only (Munksgaard & others, 1991; Andreasen & others, 1993; Badami, Dunne & Scheer, 1995; Kanca, 1996; Pagliarini & others, 2000); associating bonding agents with flowable resins (Small, 1996; Farik & Munksgaard, 1999; Farik & others, 1999; Farik, Munksgaard & Andreasen, 2000), dual or self-cured luting cements (Dickerson, 1994; Reis & others, 2001) or light cured luting cements (Dean, Avery & Swartz, 1986) have been extensively reported. Associating bonding agents with hybrid or microfill resin composites has also been used by others (Simonsen, 1982; Martens & others, 1988; Burke, 1991; Diangelis & Jungbluth, 1992; Baratieri & others, 1994).

Thus, it seems that this is not the only technique used to bond the fragment to the fractured tooth. The kind of material or its association may also play an important role in the fracture strength of fragment-bonded teeth. By merely varying the kind of adhesive system used, different fracture strength recoveries can be obtained (Badami & others, 1995; Pagliarini & others, 2000), although this finding was not observed in other studies (Farik & others, 1998a; 1998b; Farik & Munksgaard, 1999; Farik & others, 1999). Despite the relevance of this subject, no *in vitro* study has been published that compared the different material combinations used by several authors to reattach tooth fragments. Therefore, this study evaluated the fracture strength of two techniques (bonding only and buccal chamfer), varying the materials used to bond the fragment to the remaining tooth.

METHODS AND MATERIALS

Reis & others (2001) have already used the methodology applied in this study. One hundred and eighty sound human lower incisors extracted due to periodontal disease were selected under optical magnification (x2). Only teeth free from cracks or other kinds of structural defect were selected. The teeth were disinfected in 0.5% chloramina for 15 days and stored for less than six months in 0.9% saline solution (DeWald, 1997). The test basically consisted of three procedures: (1) fracture of the sound teeth; (2) restoration of the fractured teeth using different techniques and materials associations; (3) fracture of the restored teeth, as in procedure 1.

Fracture of the Sound Teeth

The buccal surface of each tooth was divided in transversal and longitudinal thirds. Figure 1 shows the area (point) for application of the perpendicular loading. The roots were confined in a special device (holder) and adapted in a universal testing machine (RIEHLE Testing Machine, FS-5, IL, USA).

The load was applied to each tooth in a buccal-to-lingual direction by means of a small stainless steel ball (2 mm^2) inserted at the end of a pin held in the crosshead of the universal testing machine at a speed of 1.0 mm/minute. The force required to fracture the teeth was recorded.

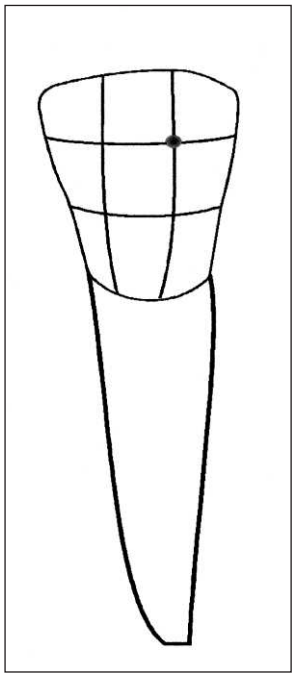

Figure 1. *Tooth divided into transversal and longitudinal thirds to standardize the area for the perpendicular load application.*

Table 1: *Composition of the Materials Used*

Code	Material (*)	Composition	Mode of Use	Batch
A	Excite Adhesive System "One-Bottle"	- Total-Etch 37% phosphoric acid gel - Adhesive HEMA, dimethacrylates, phosphonic acid acrylat, highly dispensed silicon dioxide, initiators and stabilizers in an alcohol solution	1. Acid etching – 15 seconds 2. Rinse –15 seconds 3. Blot dry 4. Apply two coats of adhesive for 10 seconds 5. Air-drying for three seconds 6. Light-curing for 40 seconds (each side)	C33179
B	Variolink II Dual Resin Luting cement (**)	- Catalyst (low viscosity) and base BIS-GMA urethane dimethacrylate and triethylene glycol dimethacrylate. The inorganic fillers: barium glass, yterbium tifluoride, Ba-Al-fluorosilicate glass, and spheroid mixed oxide. The range of particle size is 0.04-3.0 mm with a mean of 0.7 mm. Additional contents: stabilizers, catalysts, and pigments Catalyst has 71.2% and base has 73.4% wt filler load	1. Similar increments of base and catalyst past (1:1) 2. Mixing for 10 seconds 3. Light-curing for 40 seconds (each side)	A23654 (Base) A23650 (Catalyst)
C	Tetric Flow Flow Resin	- BIS-GMA, urethane dimethacrylate and triethylene glycol dimethacrylate. The inorganic fillers are barium glass, yterbium tifluoride, Ba-Al-fluorosilicate glass, highly dispensed silicon dioxide, and spheroid mixed oxide. The particle size is 0.04-3.0 mm with a mean of 0.7 mm. Additional contents: stabilizers, catalysts, and pigments. The syringe has 64.62% wt filler load	1. Incremental placement(<2 mm) 2. Light-curing for 40 seconds (each side)	B21015
D	Tetric Ceram Resin Composite	- Barium glass, silica, spherical silicate and yterbium trifluoride High filler content (+ 80% wt) with mean particle size smaller than 1 mm -Organic Matrix: Bis-GMA, Urethane dimethacrylate, Polyalkylenogalycol Dimetacrilate and Aminoalkyl Metacrylate	1. Incremental placement(<2 mm) 2. Light-curing for 40 seconds	903309

(*) Vivadent, Schaan/Liechtenstein, Germany. (**) When the light cured version was used, only base past was placed.

Restoration of the Fractured Teeth

Only 110 of the 180 teeth were chosen for this *in vitro* study because only 110 teeth showed a Class II Ellis fracture type (Ellis & Davey, 1970), the pattern chosen for this *in vitro* study. They were kept in 0.9% saline solution until the restoration procedure was performed (Farik & others, 1998b; 1999).

Two reattachment techniques—bonded only and buccal chamfer—were tested. They were divided into five subgroups according to the material combinations used to do the reattachament (Tables 1 and 2). A control group (resin composite build-up) was also tested. Ten specimens were used in each subgroup.

In subgroup 1, the fragments were reattached using only an adhesive system (Excite, Vivadent, Schaan/Liechtenstein, Germany). The adhesive system was applied on the remaining teeth and on the fragments following the manufacturer's instructions (Table 1). Only after the fragment was reattached to the remaining teeth was light curing performed on the buccal and lingual surface for 40 seconds each.

In subgroups 2, 3, 4 and 5 only after applying the adhesive system without light curing were the other materials handled according to the manufacturers' instructions (Table 1 and 2) and placed on the fragment that was, in turn, reattached to the remaining tooth under some hand pressure. The excess material was removed using a micro-brush and each side (buccal and lingual) was light-cured for 40 seconds

The same procedures were performed for the chamfer group. After re-attachment using the same material combinations described above, a 1.0 mm depth chamfer was placed in the fracture line in the buccal surface with a diamond round bur (ref #1016, KG Sorensen, São Paulo, Brazil). One increment of resin composite (shade A2 dentin—Tetric Ceram, Vivadent) was used to restore the buccal surface after applying the Excite adhesive system (Vivadent).

In the resin composite restoration group, no re-attachment technique was used in the fractured teeth. A 45º bevel extending 1 mm on the buccal surface was prepared using a cylindrical diamond finishing bur (ref #2135F, KG Sorensen) and a resin composite build-up

Table 2: *Technique Description and Sequence Materials*

Groups (*)/ Subgroups	Bonded Only Technique		Chamfer Technique	
1	Excite	A	Excite + Tetric Ceram	A + D
2	Excite + Variolink II	A + B (light-cured)	Excite + Variolink II + Tetric Ceram	A + B (light-cured) + D
3	Excite + Variolink II	A + B (dual-cured)	Excite + Variolink II + Tetric Ceram	A + B (dual-cured)+ D
4	Excite + Tetric Flow	A + C	Excite + Tetric Flow + + Tetric Ceram	A + C + D
5	Excite + Tetric Ceram	A + D	Excite + Tetric Ceram + Tetric Ceram	A + D + D

(*) Control group—Composite build-up with adhesive and resin composite (after beveling the enamel).

Table 3: *Mean Fracture Strength (Kgf) and Standard Deviation of Sound and Restored Teeth and Strength Recovery (%)*

Technique	Bonded Only				Chamfer			
Subgroups	Sound Teeth	Restored Teeth	Recovery (%)	(*)	Sound Teeth	Restored Teeth	Recovery (%)	(*)
1	26.7 (7.3)	7.8 (2.3)	32.1 (16.0)	A	24.3 (7.1)	16.3 (6.5)	70.4 (30.6)	B
2	23.9 (6.9)	9.6 (4.1)	42.1 (15.9)	A	22.3 (6.0)	13.9 (3.8)	67.6 (28.4)	B
3	28.1 8.0)	10.2 (4.6)	36.6 (12.7)	A	23.3 (3.2)	15.8 (6.6)	69.8 (32.8)	B
4	28.6 (8.3)	10.8 (6.0)	38.0 (18.8)	A	22.8 (7.0)	14.9 (6.2)	72.6 (34.0)	B
5	31.0 (7.9)	14.3 (4.4)	58.3 (19.5)	A	26.2 (7.9)	17.5 (6.4)	57.5 (18.5)	B

(*) Similar letters mean statistical similarity.

Table 4: *Mean Fracture Strength (Kgf) and Standard Deviation and Strength Recovery (%) of Restored Teeth for Each Technique Employed Compared to the Composite Resin Build-Up Group*

	Bonded Only			Chamfer			Composite Build-Up		
Technique	Restored Teeth	Recovery (%)	(*)	Restored Teeth	Recovery (%)	(*)	Restored Teeth	Recovery (%)	(*)
	11.2 (5.8)	41.1 (18.1)	A	15.1 (5.5)	67.9 (28.9)	B	23.8 (5.4)	103.2 (37.7)	C

(*) Similar letters mean statistical similarity.

(Tetric Ceram, Vivadent) was performed after adhesive application (Excite, Vivadent). The restorations were made following the incremental technique (approximately 3 increments). Each increment was light cured for 40 seconds.

For polymerization, a light-curing unit VIP (BISCO Inc, Itasca, IL 60193, USA), at 600 mW/cm^2, was used. The teeth were finished and polished with flexible discs (Sof-Lex Pop On polishing discs, 3M ESPE, St Paul, MN 55144, USA).

Fracture of the Restored Teeth

After 24 hours, the specimens were loaded in the same pre-determined area used in the first procedure until failure. The force required to detach each fragment was recorded. For each tooth, the fracture strength was expressed as a percentage of the load required to fracture the sound tooth so that it established a relation between the fracture strength of an intact tooth and the fracture strength obtained by the restorative procedures described previously. A two-way ANOVA was performed on the recorded data (α=0.5%).

RESULTS

The mean force (standard deviation) required to fracture the sound teeth was 25.67 ± 7.36 Kgf. Mean fracture resistance and standard deviation (Kgf) of sound and restored teeth and the strength recovery (%) for each group is presented in Tables 3 and 4.

The statistical analysis showed that the interaction of the factors and the material factor were not statistically significant (p=0.140 and p=0.943, respectively). However, a significant difference was found among the techniques tested (p<0.001). The results were significantly lower than the mean fracture strength found in the bonded only technique in relation to the chamfer technique (p<0.001). When these two reattachment techniques were compared to the resin composite

restoration, it was observed that the latter showed the highest fracture strength recovery (%) (Table 4). The fracture path of the restored teeth followed the bonded interface in all specimens.

DISCUSSION

The authors have employed the same experimental design in a previous publication (Reis & others, 2001). The analysis of the mean force that required the fracture of sound teeth in both studies showed very similar values. This fact demonstrates the reproducibility of this set-up.

Different methodologies have been employed in laboratory articles. For instance, among several sources of variation found in these methodologies, it has been demonstrated that the crosshead speed might alter the results obtained. Farik & Munksgaard (1999) have shown that the fracture strength of fragment-bonded teeth and intact teeth tend to decrease when high crosshead speeds are employed. Other studies confirm this (Andreasen & others, 1993; Pagliarini & others, 2000).

The studies also differ in the way that tooth fragments are obtained. Some authors have sectioned the incisal edge of teeth (Farik & others, 1998a; 1998b; 1999; Farik & Munksgaard, 1999; Worthington, Murchinson & Vandewalle, 1999). Others have placed small notches on the two proximal surfaces and fractured the teeth by using narrow forceps (Munksgaard & others, 1991; Andreassen & others, 1993) or by using a blunt instrument without making any notches (Dean, Avery & Swartz, 1986).

None of the above methodologies allow for measuring the fracture strength of each tooth before the reattachment procedure. This information is valuable since each fragment-bonded tooth can have its own control as performed in this study and in a study by Pagliarini & others, 2000. All the variations presented make comparison among the results published very difficult.

As reported earlier, case reports and laboratory studies have described many clinical approaches using different materials and techniques for reattachment. Developing these adhesive systems has encouraged some authors to employ an adhesive system to bond fragments to the remaining teeth (Munksgaard & others, 1991; Andreasen & others, 1993; Badami & others, 1995; Kanca, 1996; Pagliarini & others, 2000). The results of this study show no significant difference among materials used. However, Table 3 shows that in the bonded only groups, using an adhesive system plus the hybrid resin composite showed a trend towards achieving higher fracture strength. This may result from hybrid resins presenting higher mechanical properties compared to flowable resins and luting resin cements.

It is well documented that light intensity decreases when light-activation is performed through dental tissues (Losche, 1999). Thus, concerns about the possible detrimental effect on the degree of conversion of luting cements may lead clinicians to choose a dual version of a resin luting cement. However, the results of this study suggest that both the dual or the light cured version of the same luting cement had a similar performance. This could be attributed to using a higher light intensity and a higher exposure time. It has already been demonstrated that these two factors might compensate for the decrease in light intensity through dental structures (Rueggeberg, Caughman & Curtis, 1994). Dean, Avery & Swartz (1986) also found similar results when light cured or chemically cured cement was used for reattachment.

The amine accelerator necessary for dual polymerization can cause the color of the luting agent to change over time (Rosenstiel, Land & Crispin, 1998). Therefore, light cured resin cements should be preferable since they are more color stable and may provide teeth with enhanced esthetics over the time. This is ideal for clinicians who prefer not to use any additional preparation on the buccal fractured line. Also, some authors have shown that there might be an incompatibility between single-component adhesive systems and chemically cured resins due to the acidity of some systems (Sanares & others, 2001). Another study that used dual-cured resin cement on simplified-step systems further showed that shear bond strength of the tested assembly was inversely related to the time interval between placement of the dual-cured resin cement and light-activation (Schiltz & others, 2000). Furthermore, using dual-cured resin cement presents some inconvenience to the clinical procedure: it requires mixing two pastes that lead to air incorporation and is more time consuming.

In this study, there was only one preparation design; therefore, there could be no conclusion about the type of preparation design based upon the study. However, these results are in accordance with Reis & others (2001), which showed that only the placement of chamfer improved the fracture recovery compared to the bonded only group. These authors have concluded that some preparation designs could improve fracture strength.

This finding does not agree with the study by Worthington, Murchinson & Vandewalle (1999), who showed that placement of any kind of preparation did not improve the fracture strength of fragment-bonded teeth compared to preparationless reattachment. They observed that incisal edge reattachment restored approximately half the fracture resistance of sound teeth. The findings of Munksgaard & others (1991) also differ from the authors of this study. Munksgaard & others (1991) included one group that received a 0.5-mm

double chamfer preparation prior to reattachment. The fracture strength of this group did not differ statistically from that of 13 other groups without additional preparation.

In these studies, incisors were "fractured" by sectioning rather than fracturing. As already pointed out by Badami & others (1995), the surface anatomy produced by sectioning is likely to differ from that produced as a result of fracture. A fractured surface tends to run parallel to the main direction of the enamel prisms, while the orientation of the sectioned surface is dictated by alignment of the diamond saw used to section the incisal edge. The fit between the fragment and the remaining teeth is lost when sectioning is performed. The authors of this study believe that this fit also plays an important role in the fracture strength of fragment-bonded teeth.

Despite the higher fracture strength of the chamfer groups, this technique presents some inconveniences as well as the resin composite build-up. Greater exposure of a resin composite to the oral environment will diminish the long-term esthetics due to the process of abrasion and discoloration that occurs to composites with time (Peumans & others, 1997; Millar, Robinson & Inglis, 1997).

Resin composite buildup (Table 4) was the most satisfactory technique regarding fracture strength. This finding also agrees with Reis & others (2001). However, this technique should not be preferable when the fragment is available. Although Andreasen & others (1995) have shown similar survival time of resin composite build-up and reattachment of the fragment, the authors raised questions about esthetics problems in the short-term. Besides, low wear resistance, achieving the correct contours and establishing interproximal contacts are more complex, requiring longer chair time. Also, the high toughness of the resin composite is likely to be responsible for absorbing the load used to fracture the tooth before its failure, which may explain the good results obtained in this group.

CONCLUSIONS

According to the methodology used, it was concluded that the material combination used to reattach the fragments does not play an important role in the fracture strength of reattached teeth. The chamfer technique can provide better strength recovery than simple reattachment; both are inferior to the resin composite restoration that is able to restore the original tooth fracture strength.

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Comparison of Two Methods of Measuring Dye Penetration in Restoration Microleakage Studies

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Clinical Relevance

Microleakage tests that use slices to create the surfaces to be examined may seriously underestimate the actual restoration leakage.

SUMMARY

This study compared the slice method of measuring microleakage to the whole-wall method. Forty-eight Class V direct metal restorations were placed in the buccal and lingual surfaces of 24 human molars. Following thermocycling and storage in 2% methylene blue stain for 12 hours, the teeth were sectioned and the restorations removed to expose the intact occlusal and gingival cavity walls. Maximum dye penetration axially was determined along either one or two imaginary slices or over the whole wall. Data were statistically evaluated by ANOVA and Tukey's test.

Non-uniform staining occurred with 38 of the 96 walls available for evaluation. The average maximum dye penetration depth of the 38 walls was 0.61 mm and 0.70 mm for the slice method using one slice or two, respectively, and 1.29 mm for the whole-wall method. About half of these walls had leakage depths that were more than twice as great as when measured by the slice methods. All 12 of the 38 walls with no leakage when measured by the slice method, showed leakage at least somewhere along the margin when measured by the whole-wall method.

This study shows that the whole-wall method detects significantly more leakage than does the slice method ($p<0.0001$) and that using two rather than one slice does not improve the detection of leakage ($p<0.1534$). Slicing the tooth restoration interface into only two or three sections may seriously underestimate the degree of leakage.

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INTRODUCTION

Although the contribution that microleakage makes to restoration failure remains controversial (Mjör & Toffenetti, 2000; Camps & others, 2000), microleakage tests continue to be a popular method of predicting their performance (Taylor & Lynch, 1992; Gwinnett & others, 1995; Alani & Toh, 1997). Since practitioners are exposed to so many articles that have used microleakage tests to evaluate a material, they must ask themselves whether the studies reveal the true extent of the leakage. Although many methods have been used to measure microleakage along the restoration-tooth interface, immersion in a dye followed by slicing the sample to create two-to-six surfaces for measurement is the most commonly used technique (Taylor & Lynch,

1992; Alani & Toh, 1997). A major drawback to this method is that the extent of the microleakage is only revealed along the paths uncovered by the slices. If leakage has penetrated deeply into a region not exposed by the slice, then the leakage results would be misleadingly low.

Several researchers have demonstrated that increasing the number of slices results in a marked increase in the measured leakage. Gwinnett & others (1995) used a serial grinding method that exposed the surface to be evaluated in 80-micrometer increments. They found that the median leakage detected was twice that found when one slice through a buccal Class V restoration's midline was used. Mixsom & others (1991) sliced their restored teeth to create eight surfaces for evaluation. They found that leakage near the proximals of resin composite Class V restorations were greater than that at the other locations. They concluded that not including data from the more extreme ends of the restoration might result in underestimating the leakage. An *in-vitro* evaluation by Roydhouse (1968) of 500 restorations found a highly variable pattern of leakage. His study concluded that the only way to accurately determine the extent of leakage is by removing the restorations so that the entire cavity wall can be examined.

In spite of the many papers documenting the inherent inaccuracy of the slice method, recent publications continue to report leakage results based on this method. A manual review of one popular journal for the year 2000 revealed 12 articles (Abdalla & Davidson, 2000; Santini, Plasschaert & Mitchell, 2000; Brackett, Haisch & Covey, 2000; Hoelscher & others, 2000; Estafan, Estafan & Leinfelder, 2000; Gallo, Bates & Burgess, 2000; Jain & Belcher, 2000; Winkler & others, 2000; Spahr Schon & Haller, 2000; Roebuck, Saunders & Whitters, 2000; Kuramoto & others, 2000; Ferrari & others, 2000) that used three or fewer slices to evaluate microleakage.

Any method that relies on slices is inherently flawed because it assumes that at least one of the slices will traverse the region of greatest dye penetration. When only a few slices are utilized, the probability of the region of greatest dye penetration being missed is very high. In contrast, a method that examines the entire surface avoids this source of error and should result in a much more accurate determination of microleakage.

The samples used in this research were obtained from an unpublished microleakage study completed in 1998. During that study, the restorations, even though bonded, could be easily removed using only slight pressure from a spoon excavator if the cavities were prepared to assure that no mechanical locks remained following sectioning of the restored tooth. Furthermore, it became evident that the leakage varied widely across the cavity wall and had slices been used, the deepest part of the leakage would have often been missed. This observation initiated both the current study and a unique leakage study that used a computerized method of the whole wall analysis concept. The latter study was published recently (Wibowo & Stockton, 2001).

This paper reports on research designed to document the advantages of analyzing the whole cavity wall rather than the surfaces of only a few sections through it.

METHODS AND MATERIALS

The samples used in this study were obtained from an unpublished leakage study that had evaluated the leakage of resin-bonded high copper dispersed-phase amalgam (Dispersalloy, LD Caulk Division, Milford, DE 19963, USA) and a resin-bonded gallium-based direct restorative alloy (Galloy plus PAAMA 2, Southern Dental Industries, San Francisco, CA 94105, USA). The restorations were placed in 24 recently extracted human molars that had been cleaned of soft tissue and stored for two to four months in distilled water at 4°C following the protocol in ISO/TR 11405 (1994). Forty-eight Class V cavity preparations were made on the buccal and lingual surfaces. The teeth were randomly divided into two groups of 12 each. The buccal cavities of the first group were restored with bonded amalgam and the lingual cavities were restored with bonded gallium alloy. The buccal cavities of the remaining group of 12 teeth were restored with bonded gallium alloy and the lingual cavities were restored with bonded amalgam. This assured that each tooth received one of each type of restoration and there were 12 buccal and 12 lingual amalgam restorations with an identical number of gallium alloy restorations. The cavities were approximately 2-mm high and 2-mm deep. The cavity widths were determined by the width of the buccal or lingual surface and varied in size between 4 mm and 8 mm.

The restored teeth were stored for 24 hours in water at 37°C to allow the materials to set completely. Once set, the restored teeth were thermocycled for 25 cycles between water baths at approximately 3°C and 55°C. Dwell time in each bath was about 30 seconds.

Prior to staining, all surfaces of the thermocyled samples were coated with nail polish to within 1 mm of the restoration margins and the apices of the teeth were sealed with wax. The samples were immersed in 2% methylene blue stain for 12 hours at room temperature. Following staining, the samples were thoroughly washed in cool water and the root removed. The crown was sectioned in the occlusal plane through the center of the restorations using a water-cooled #169 bur (Brasseler, Savannah, GA 31419, USA) in a high-speed handpiece. The 48 sectioned restorations were carefully removed from the occlusal and gingival crown halves to expose the intact occlusal and gingival cavity walls.

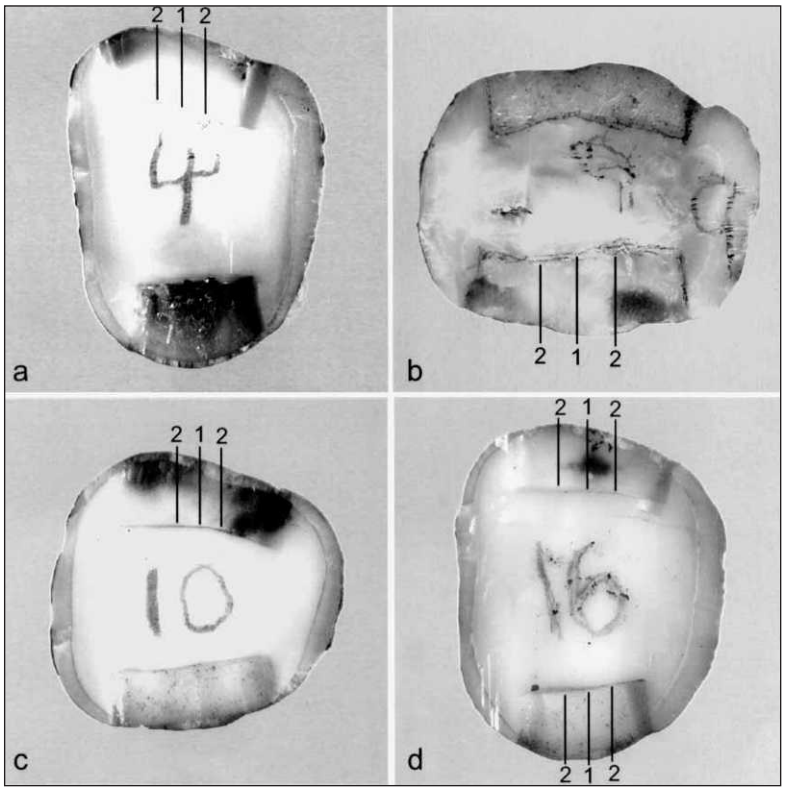

Figure 1a-d. *Composite photograph of four different tooth sections following staining and restoration removal. Figure 1b is a photograph of an occlusal section. The remaining photographs are of gingival sections. The sections are oriented so that the buccal cavities are at the top. Uniform staining involving the entire surface of the gingival-lingual wall and only the enamel of the buccal wall can be seen in Figures 1a and 1b, respectively. The remaining four cavity walls reveal non-uniform staining. The slicing planes have been superimposed over these walls. The slicing planes often fail to intersect the stained region and when they do, they often fail to intersect the region of maximum dye penetration axially. Original magnification 5x.*

Since each restoration had an occlusal and gingival wall, 96 walls were available for evaluation.

To compare the traditional slice method of evaluating microleakage to the whole-wall method, all 96 cavity walls were visually examined with a binocular microscope at magnifications up to 10x. Leakage was determined to have occurred if the wall surface was stained to a greater intensity than the sectioned enamel surrounding the cavity preparation. The samples were oriented under a binocular microscope equipped with a measuring micrometer eyepiece (Bleeker, Zeist, Holland) and a mechanical stage. The fixed eyepiece crosshair was oriented to intersect the cavosurface margin at right angles. The entire wall surface was scanned, and the adjustable eyepiece cursor was used to measure the maximum extent of stain penetration.

To compare the whole-wall method to the slice method, the length of the cavo-surface margin was measured using the mechanical micrometer stage. The typical location of the slicing planes when a single slice was used was determined to be equal to one-half of the way along the cavo-surface margin. When two slices were used, the locations were determined to be one-third and two-thirds of the way along the cavo-surface margin. These imaginary slicing planes have been superimposed over five of the eight cavity walls shown in Figure 1. To measure the depth of stain penetration along each of the slicing planes, the stage was moved so that the eyepiece crosshair intersected the cavosurface margin at a right-angle and 0.25 mm to the left of the slicing plane. The maximum extent of stain penetration axially was measured and recorded. The microscope stage was adjusted to move the sample 0.5 mm to the right (the approximate thickness of a cutting wheel), and a second reading of the stain penetration axially at this location was made and recorded. The process was repeated with the other two locations to give a total of six readings.

To determine whether the whole-wall method revealed a greater depth of dye penetration than the slice method, the largest values from the one slice readings and the largest values from the two slice readings were compared to the largest values from the whole-wall measurement (ANOVA plus Tukey's test and ANOVA plus Least Square Means test). All 96 cavity walls were included in the statistical analysis.

Two comparisons were done. First, the whole-wall method was compared to the slice method to determine whether it revealed a greater depth of leakage than the slice method. Then, in order to gain an understanding of the magnitude of the differences in the methods, the authors calculated how many walls had 100% or greater leakage depth when measured by the whole-wall method rather than the slice method. The 100% value was arbitrarily chosen, as it was large enough to emphasize the difference in leakage depth identified by the two methods.

RESULTS

Most restorations could be removed by gently prying them free with a spoon excavator. A few had spontaneously debonded, while some required considerable force to remove. Figure 1 shows photographs of the occlusal (Figure 1b) or gingival cavity walls (Figures 1a, c, d) of four different restorations. The occlusal wall corresponds with wall 18 in Table 1, and the gingival walls correspond to walls 10, 20, 28 and 30. The photographs are oriented so that the buccal cavities are located at the top of the figure. Uniform staining is shown in Figures 1a and 1b. In Figure 1a, staining occurs across the entire gingival floor and in Figure 1b, very little staining is seen and is confined to the enamel of the buccal floor. Fifty-eight walls (60.4% of the total) were so uniformly stained that the results of the slice method

Table 1: *Comparison of the Whole-Wall Method to the Slice Methods*

		Maximum Depth of Leakage Axially (mm)			Whole Wall Greater Than		Whole Wall 100% Greater Than	
Wall #	Wall Type	One Slice	Two Slice	Whole Wall	One Slice Yes or No	Two Slice Yes or No	One Slice Yes or No	Two Slice Yes or No
1	LO	1.35	2.22	2.27	Y	Y	N	N
2	BG	0	1.37	1.37	Y	N	Y	N
3	LG	0	0	0.35	Y	Y	Y	Y
4	BO	0.35	0.43	0.43	Y	N	N	N
5	LO	1.58	1.93	1.93	Y	N	N	N
6	BG	0	0	0.40	Y	Y	Y	Y
7	LG	0.14	0.52	2.38	Y	Y	Y	Y
8	BO	0.05	0.09	1.05	Y	Y	Y	Y
9	LO	0.38	0.12	1.46	Y	Y	Y	Y
10*	BG	0	0	1.43	Y	Y	Y	Y
11	BO	0.98	0.97	0.98	N	N	N	N
12	BO	2.45	0.38	2.45	N	Y	N	Y
13	BG	0	69	1.03	Y	Y	Y	N
14	LG	1	0.89	1.02	Y	Y	N	N
15	BO	1.17	1.17	1.67	Y	Y	N	N
16	LO	0	0	1.01	Y	Y	Y	Y
17	LO	0.92	0.85	1.44	Y	Y	N	N
18*	LO	0	1.85	1.98	Y	Y	Y	N
19	BO	1.58	1.67	1.82	Y	Y	N	N
20*	BG	1.18	1.23	2.18	Y	Y	N	N
21	LG	0.21	0.25	0.78	Y	Y	Y	Y
22	LG	0.92	0.63	1.33	Y	Y	N	Y
23	BO	0.58	0.5	0.58	N	Y	N	N
24	BG	0.88	0.5	0.92	Y	Y	N	N
25	BO	0.83	0.5	0.87	Y	Y	N	N
26	LO	0 0.	0.08	0.83	Y	Y	Y	Y
27	BO	0	0	0.68	Y	Y	Y	Y
28*	BG	0.75	0	0.93	Y	Y	N	Y
29	LO	1.61	1.61	1.61	N	N	N	N
30*	LG	10	0	0.73	Y	Y	Y	Y
31	BO	0.15	1.27	1.32	Y	Y	Y	N
32	BO	0.62	1.32	1.55	Y	Y	Y	N
33	BG	1.32	1.66	1.77	Y	Y	N	N
34	BG	0	0	1.00	Y	Y	Y	Y
35	LO	0.27	0.46	0.96	Y	Y	Y	Y
36	BO	1.12	0	1.43	Y	Y	N	Y
37	BO	0	0.58	1.73	Y	Y	Y	Y
38	LO	0.52	0.48	0.77	Y	Y	N	N
AVERAGE		0.61	0.70	1.29	Total 34 Y	Total 33 Y	Total 19 Y	Total 18 Y
STAN DEV		0.63	0.66	0.56	4 N	5 N	19 N	20 N

*these walls are shown in Figure 1

and the whole-wall method were essentially the same. Fifteen of the 58 uniformly stained walls (15.6% of total) had no visible stain on their surface. Thirty walls (31.4% of the total) and 13 walls (13.5% of the total), respectively, had complete staining of the enamel only and the enamel plus dentin. In most samples, the uniform

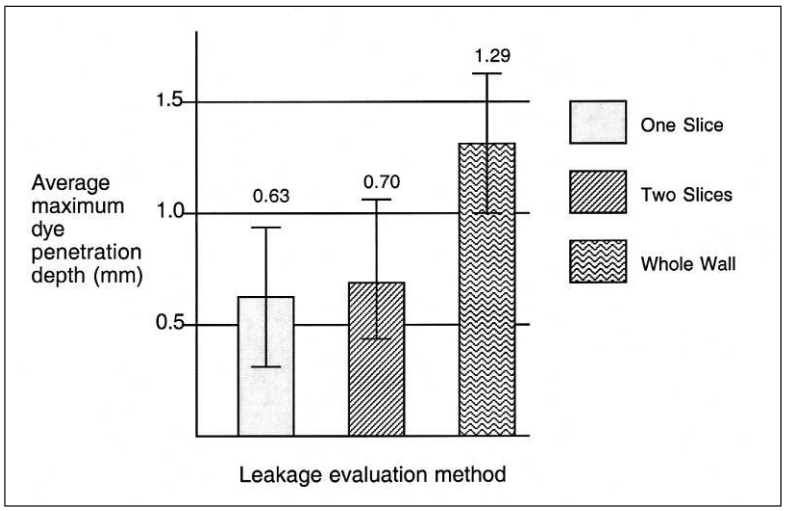

Figure 2. *The average of the maximum depths of dye penetration for each of the three measuring methods. The whole-wall method detected a maximum average depth that was twice as deep as that obtained using one slice and was 80% greater than that obtained using two slices.*

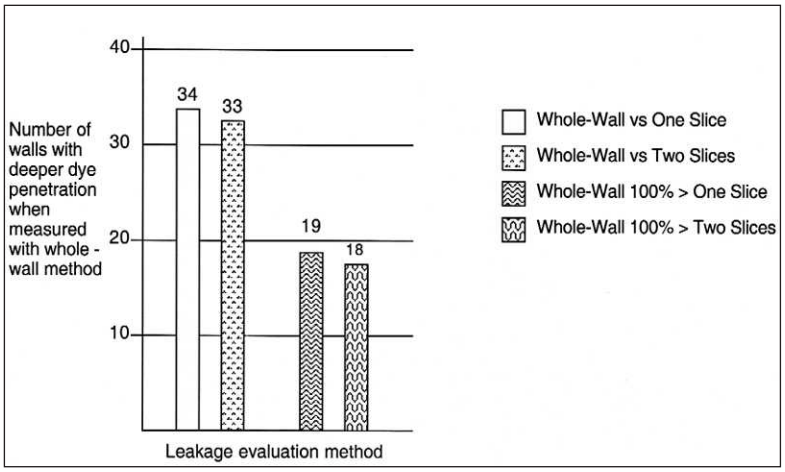

Figure 3. *The vertical bars show the number of walls whose dye penetration depth, when measured by the whole-wall method, was either simply greater or greater by 100% than when measured by using either one or two slices.*

enamel staining extended entirely through the enamel. The average depth of enamel staining was 0.2 mm and 2.1 mm for enamel plus dentin.

In Figure 1a, the stained region had penetrated more than one-third to the axial wall of the buccal cavity. All slicing planes failed to intersect the stained region. In Figure 1b, the staining had penetrated more than half the distance to the axial wall of the lingual cavity. Two of the slicing planes failed to intersect the stained region. The remaining slicing plane barely intersects the staining. In Figure 1c, all three slicing planes failed to intersect the deepest region of staining present in the buccal cavity.

In Figure 1d, although the single slicing plane had intersected the region of deepest stain penetration in the buccal cavity, when two slices are used, both slicing planes failed to intersect the staining. Stain had penetrated for a short distance into the dentin across nearly half of the lingual cavity's margin. The single slice fails to intersect the stained region, and when two slices are used, only one intersects the stained region.

Table 1 shows data for the 38 cavity walls with variable staining. The walls consisted of six lingual-gingival walls, nine buccal-gingival walls, 10 lingual-occlusal walls and 13 buccal-occlusal walls. When the whole-wall method was compared to the slice method, 34 of 38 walls revealed a greater depth of leakage when one slice was used, and 33 of the 38 walls revealed a greater depth of microleakage when two slices were used. When one slice or two were used, the average depth of maximum dye penetration axially was 0.61 mm and 0.70 mm, respectively, compared to 1.29 mm when the whole-wall method was used (Figure 2). The statistical analyses revealed that the whole-wall method gave readings that were very different from the slice method ($p<0.0001$). In contrast, using two slices did not significantly improve the ability to detect leakage ($p<0.1534$). When measured using one slice, 12 walls had no leakage. When measured using two slices, nine walls had no leakage. When measured by the whole-wall method, all the "non-leaking" walls leaked. Dye penetration ranged between 0.35 mm and 1.98 mm for those samples identified as having no leakage when using one slice and between 0.35 mm and 1.43 mm for those samples identified as having no leakage when using two slices.

When the whole-wall method was compared to the slice method, nearly 50% of the walls had leakage depths greater than 100% compared to those obtained using one or two slices. Figure 3 graphically shows these relationships.

DISCUSSION

Identifying restorative materials that most effectively seal the cavity would help the clinician to select materials that reduce the incidence of margin staining, decay and tooth sensitivity. Unfortunately, most restorations leak shortly after their insertion (Thoneman & others, 1999; Prati & others, 1994; Derhami, Coli & Brännström, 1995; Mazer, Leinfelder & Russell, 1992; Duncalf & Wilson, 2001; Lutz & Krejci, 2000). Although some researchers (Mjör & Tofflenetti, 2000) found that a defective seal does not contribute to tooth sensitivity and recurrent decay, others believe that it does (Taylor & Lynch, 1992; Murray & others, 2001). Camps & others (2000) in an *in-vivo* study using 317 Class V restorations concluded that although cytotoxicity of the restorative materials and the release of

inflammatory mediators by the cutting procedures contributed to an adverse pulp response, the greatest contributor was bacterial colonization of the cavity walls associated with microleakage. Most early microleakage research was done on amalgam restorations, which are known to be self-sealing and cariostatic. In contrast, resin composite restorations neither self-seal nor posses anticariogenicity, and according to some (Kawai & Tsuchitani, 2000), they promote caries. Although the importance of leakage to restoration longevity is not known, good clinical practice favors using materials that create non-leaking restorations.

Most studies (Thonemann & others, 1999; Geiger Gulayev & Weiss, 2000; Toledano & others, 2000; Nozaka, Suruga & Amari, 1999; Fu & Hannig, 1999; Helvatjoglou-Antoniades & others, 2000) divide the samples into two and four sections by making one, two or less frequently, three equally spaced slices across the cavity wall. Since each slice creates two surfaces, the researcher has between two and six surfaces for examination. These surfaces are usually separated by the thickness of the cutting wheel or by the thickness of the section. As a result, most studies examine only a very small amount of the cavity wall. Any of the areas not observed could contain a narrow but deep zone of leakage that would not be detected by the slice methods. Figure 1 illustrates and Table 1 describes in its results section that the slice method has often failed to reveal staining when staining has existed, and when detected, the depth of dye penetration was often seriously understated when compared to the whole-wall method.

In addition to the study reported in this paper, the whole-wall technique has been successfully used in studies that evaluate bonded resin composite restorations (Wibowo & Stockton, 2001; Tulunoglu & others, 2000). In these studies, the teeth were sectioned through the restoration, and the bonded composite restoration was removed from the cavities to expose the dye stained cavity walls. The resin that remained on the cavity wall was so thin that the staining, if present, could be readily viewed through it. In other studies (Gwinnett & others, 1995; Hilton & Ferracane, 1998), the stained teeth were decalcified to render them transparent. The staining was viewed directly through the transparent tooth structure and the depth of stain penetration measured.

Since the whole-wall method revealed that all restorations leaked, the slice method that records the lowest value of walls with no leakage would be the most accurate. Statistically, using two slices rather than one does not identify deeper penetration. In absolute terms, when two slices were used, the average leakage depth for the 38 cavity walls with non-uniform leakage was only slightly greater than when one slice was used (0.61 vs 0.70 mm). When measured by the whole-wall method, about half of the walls had a dye penetration depth that was twice as great as the slice method. When these walls were measured using two slices, they had penetration depths that again were only marginally greater than when one slice was used (0.10 vs 0.13 mm). When the slice methods are compared based on how many walls had 100% deeper dye penetration when measured by the whole-wall method, using one or two slices gave almost identical results (Figure 3). Two slices were only marginally better than one slice when compared on the basis of the number of walls with no leakage (one slice 12 walls vs two slices nine walls). The slice technique's accuracy could approach that of the whole-wall method by increasing the number of slices sufficiently. Gwinnett & others (1995) found that using a technique that examined the interface in 80 µm increments gave an average leakage depth that was twice that of a single slice. Their result is the same as that found in this research (0.61 mm when using one slice vs 1.29 mm for the whole-wall method). However, such an approach is very labor intensive compared to the whole-wall method. The decalcification approach to achieving a whole-wall analysis is not suitable for full coverage restorations (Gwinnett & others, 1995). In contrast, the whole-wall method described in this paper requires a minimum of sample preparation following staining. It is simple, fast and suitable for all cavity preparations including full coverage restorations.

Disadvantages of the whole-wall method include the following. The restorative material must not bond strongly to the tooth structure. Many of today's restorative materials meet this condition, including some bonded resin composite restorations (Wibowo & Stockton, 2001; Tulunoglu & others, 2000). The cavity preparation must be done so that following slicing, the restoration is free of mechanical locks and can be removed. Complex restorations may require several slices to achieve the lock-free state. The slices must be done to create sections that expose the stained interfaces in a manner that allows viewing the surface at ideally, right angles. A slice that requires viewing at an angle introduces reading errors. Finally, slices that traverse a surface of interest destroy a part of it.

Unless large numbers of slices are done, restoration leakage studies that use the slice method are likely to report values that are much less than they should be. In contrast, the whole-wall method allows the entire surface to be examined, which results in a better understanding of the amount and nature of the leakage. The researcher must use techniques that truly reveal the leakage pattern. The practitioner must read the literature carefully in order to determine which method was used and rely on this knowledge to decide whether the product provides the degree of protection implied from the research results.

CONCLUSIONS

The whole-wall method is superior to that of the slice method. Using two slices rather than one does not statistically improve the ability to detect leakage. Since the slice method reveals staining only along the path that the slices traverse, the maximum depth of dye penetration across the cavity wall may be missed and the degree of leakage seriously understated. In contrast, the whole-wall method assures that the complete microleakage history of the wall can be assessed.

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Invited Paper

Shedding New Light on Composite Polymerization

WF Caughman • FA Rueggeberg

Clinical Relevance

The light curing protocol from 10 years ago may not be valid today. Today's clinician must choose among several types of curing lights and select from numerous composite systems that were not available when earlier protocols were published. Today's curing lights vary in their spectral emission and power density and modern composites differ greatly in their ease of polymerization. Therefore, to optimize clinical success, the polymerization protocol must be appropriate for a given light and composite system. This manuscript outlines potential curing light/composite choices and supplies a clinical protocol to ensure adequate polymerization.

When we began studying light polymerization 10 years ago, the vast majority of clinicians were using quartz-tungsten-halogen (QTH) lights with power densities (PD) less than 1,000 mW/cm^2 and the clinical parameters were clear. The only requirements necessary to achieve adequate polymerization were that the output be greater than 300 mW/cm^2 and that 2 mm increments be polymerized for 40 seconds (Caughman, Rueggeberg & Curtis, 1995). Today, the clinical protocol for light polymerization of composites is much less defined. While conventional QTH lights are still being used, there are also programmable high intensity QTH models (PD greater than 1,200 mW/cm^2), as well as very high intensity Plasma-arc curing lights (greater than 2,000 mW/cm^2). Lights utilizing light emitting diodes (LED) are now available and have gained in popularity because of their portability, low heat generating features and camphoquinone-specific emission spectrum. In addition, improvements in filler technology and activation chemistry of some newer composite formulations require that the light-polymerization process be reexamined.

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Modifications to QTH Lights

Some of the newer QTH lights offer two clinical options. When used in combination with a light concentration tip (Turbo Tip), several of the new lights produce power densities of up to 1,200 mW/cm^2. In certain clinical conditions, this higher intensity can shorten the required exposure time, but not to the same degree as that with a PAC light. Also, enhanced depths of cure are not truly attainable merely by substituting this tip (Curtis, Rueggeberg & Lee, 1995).

The second option available is the ability to program the rate at which the light's power density changes during exposure: the "soft start" technique. These lights begin an exposure with a low intensity value, and after a few seconds, increase the output. This intensity

increase can be accomplished through a "step-wise" or "ramped" program. A typical "stepped" program light emits a low power density (100mW/cm^2) for 10 seconds, then increases immediately to a maximum value for the duration of the exposure. In the "ramped-cure" light, the power density gradually increases from a low value (100 mW/cm^2) to maximum intensity over a 10-second period, after which it remains constant for the duration of the exposure.

The rationale for this programmed curing is to control composite shrinkage forces by slowing the rate of cure (Rueggeberg, Caughman & Chan, 1999) and extending the viscoelastic phase of the composite. If slowing is accomplished, a greater amount of shrinkage will take place at the unbonded restoration surfaces, resulting in less stress build-up at the bonded interfaces. While *in vitro* research suggests that exposure protocols utilizing programmed curing produce restorations with better tooth adaptation (Uno & Asmussen, 1991; Mehl, Hickel & Kunzelmann, 1997), clinical data is lacking.

Plasma-Arc Lights

Plasma-arc lights (PAC) function differently from QTH sources. Instead of a filament, these lights contain two tungsten electrodes separated by a small gap, between which a high voltage is generated. The resulting spark ionizes the gaseous environment (Xenon) and creates a conductive gas known as plasma. These lights produce large amounts of electromagnetic energy, and the units must contain extensive filtering to remove harmful or unusable wavelengths. The most effective filter in this type of unit is the liquid-filled light guide that transmits light from the base unit to the curing tip. This cord is more durable than conventional glass-fibered cords that may break if the cord is twisted or bent sharply. PAC units typically produce power densities greater than 2,000 mW/cm^2, and have been shown to polymerize composite in the least amount of time (Rueggeberg, Ergle & Mettenberg, 2000). Potential negative clinical aspects of the use of this type light are the intrapulpal temperature rises of the restored teeth (Caughman, Rueggeberg & Moss, 2002) and increases in polymerization shrinkage forces exerted on the restoration/tooth complex (Bouschlicher & Heiner, 2001).

Extended tooth exposure to PAC lights can produce a significant increase in pulpal temperature. However, a 10-second PAC exposure is the maximum time necessary to adequately polymerize a 2-mm increment of composite, and the pulpal temperature rise associated with this scenario is comparable to that observed with a QTH 40-second exposure (Caughman & others 2002). When curing bonding resin with a PAC light in an unfilled preparation, the maximum exposure time should be reduced to three seconds because of the lack of dentin insulation to the pulp and the fact that this thin layer does not require an extended exposure.

Since the PAC light polymerizes composite much faster than other types of curing lights, it seems logical that this activation method would produce increased shrinkage forces. As a result, some manufactures have produced PAC lights with ramped curing modes. However, our laboratory research suggests that the initial ramped output power density must be less than 100 mW/cm^2 to be effective, and the initial output delivered by PAC lights at their lowest possible emission value is much higher than this.

Light-Emitting Diode Lights (LED)

Blue LEDs emit a narrow wavelength of light (455 nm-486 nm) that correlates very well with the spectral absorbance range of camphoquinone, the photo initiator found in most composites (Parr & Rueggeberg, 2002). Therefore, these light types are the only sources that do not require a filter. Other advantages of LED lights are that they are small, portable, most are battery operated and very quiet because they contain no fan.

The output of first generation LEDs is limited. These units utilize individual LED elements arranged in an array, but the total number of LEDs that can be applied to each tip is limited by surface area. Also, there are wide variations in the power densities among LED brands. The more powerful LED lights require exposures similar to conventional QTH lights to adequately cure a range of composites.

Newer LEDs, now being marketed, have substituted conventional LED elements with small chips that contain very large-surfaced emitting LED chips. This design produces much more output than that of earlier lights and may result in shorter exposure times. However, along with increased power output comes an increase in internal heat production during the light's operation. Therefore, future models may require internal cooling fans to dissipate this heat so that the LED source itself does not fail. The addition of fans may increase the size, noise level, weight and power consumption of future LED units.

There are two potential disadvantages to using LEDs as the primary curing source. First, since the spectral profile of all currently available LEDs is narrow, they will polymerize only products utilizing camphoquinone as the photoinitiator. This scenario is much like the early PAC-lights that were very highly filtered. Some composites and dentin bonding agents will not polymerize with such a narrow spectral range. Another limitation that was observed with all LED lights, regardless of output, was that they are less effective in polymerizing darker shades of many microfilled composites. Even when the exposure time was extended, these composites never reached the conversion achieved when using other types of curing lights. These problems may be corrected when more powerful

Table 1

	Conventional QTH	High Intensity QTH	PAC-Light	LED Lights
Traditional cure	40 seconds	20 seconds	10 seconds	20-40 seconds*
Fast cure	20 seconds	10 seconds	6 seconds	20 seconds
Difficult cure	40 seconds	30 seconds	10 seconds	40 + seconds#

** Based on the power density of the LED unit. Units with lower power densities require longer exposure times.*
 # could not achieve comparable cure with darker shades

LED lights are introduced, and when LEDs with different spectral outputs are added to the LEDs currently used in dentistry.

Clinical Protocols

Since the possible combinations of composite systems and curing lights are almost limitless, it would be impossible to test every potential clinical scenario. A more workable protocol is to divide composites into three broad groups based on their ease of cure. Using this designation, composites could be classified based on their photochemistries as "fast cure," "traditional cure" or "difficult cure." Table 1 gives the curing protocol for these three composite classes when activated by either conventional or high intensity QTH lights, PAC-lights and LED lights (Rueggeberg & Moss, 2002). Ease of "photocurablity" is equally influential to the curing time of a composite.

SUMMARY

Life usually gets simpler, but in the case of photocuring dental restorative materials, just the opposite is true. Confusing and contradictory barrages of clinical claims have been made with the ever-growing variety of light-curing sources available today. Often, laboratory research or clinical studies related to these systems are lacking prior to their being introduced to the market, leaving the clinician to become the "testing ground." Manufacturers prefer to market the newest technology available, yet, depending on the type of practice and composite system in use, such "state-of-the-art" devices may offer no advantage. For some clinicians, changing to a "fast cure" composite in combination with a traditional QTH light, instead of purchasing a $4,000 PAC light, may be the only improvement in efficiency needed. However, others may want to spend as little time as possible per procedure and do not mind investing in the newest, yet "unproven" technology.

Either way, today's clinician needs to be wary of the many claims made by manufacturers of all light-curing units. It is prudent that the clinician, prior to selecting a device, aggressively ask questions and dig for the truth before "buying into" a particular unit or system philosophy. At stake are the durability of restorations, the satisfaction of the patient and the well-earned reputation of the operator.

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Clinical Technique/Case Report

Case Report of a 40-Year, Five Surface Complex Amalgam Restoration

DCN Chan • K Grubbs • JW Osborne

SUMMARY

Reports of longevity for multi-surface amalgam restoration have been limited. This paper reports a case where a five-surface complex amalgam restoration has been followed and documented for 40 years. The pictorial series will help to identify some of the factors a dentist should consider before replacing the restoration.

INTRODUCTION

It is important for dental practitioners to know how long dental restorations could last before they propose the treatment option to their patient (Shugars & Bader, 1992; Bader & Shugars, 1995). With regard to amalgam restorations, the majority of studies reported a median survival time of 6 to 10 years, while a few reported a median survival time in the range of 11 to 20 years (Downer & others, 1999). This case report follows a complex amalgam restoration for 40 years in a private practice. In addition, this report will also define terminology related to longevity studies and propose a guideline for amalgam restoration replacement.

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Terminology

Currently, there seems to be confusion in the dental literature regarding the definition of restoration *longevity*. *Longevity* of dental restorations is usually assessed by the method of *life table analysis*. When applying the method of *Life Table Analysis (Survival Analysis)* for dental studies, *Survival Time (Longevity, Durability)* is defined as the time duration between the service of a restoration and its end point. *Failure* can be due to a variety of reasons; when such failures dictate the replacement of a restoration or the extraction of the tooth bearing the restoration, it denotes the end point. *Median survival time (Half Life)* is defined as the time taken for 50% of restorations to fail. The most commonly quoted statistics for *life table analysis* are *median survival time* and the survival rate after a certain number of years (often the five-year survival rate).

One major disadvantage of the life table analysis method is that it is only a prediction of longevity or survival based on selected findings from short-term clinical studies. Even the best estimate or prediction may not be an accurate representation of what occurs in the clinical practice of an individual dentist. Geographical variation (Elderton, 1983; Hawthorne & Smales, 1996; Mjör & Toffenetti, 1992; Mjör & Moorhead, 1998), prac-

tice setting variation (Clarkson, Worthington & Davies 2000; Drake, Maryniuk & Bentley, 1990; Mjör, 1997) and operator variation (Mahler & Marantz, 1979; Smales, 1991) have been reported.

CASE REPORT

This paper reports the case of a male patient, GB, who attended a private dental office since 1960, when he was 14 years old. At that time, the patient presented with a lost restoration on tooth #30 with recurrent decay. A MODBL five-surface complex amalgam restoration was placed with auxiliary amalgam slot retention. Mechanical anchoring elements such as pins were not employed. Moisture control was achieved by cotton rolls and high volume evacuation. Rubber dam was not utilized. The amalgam alloy employed was Aristalloy (Baker Dental, Carteret, NJ 07008, USA) and mixed with an 8/5 mercury alloy ratio. The squeeze cloth technique was employed to express excess mercury. Following completion of the restoration, clinical pictures were taken immediately post-operation, then at 13 subsequent follow-ups spanning 40 years. (Figures 1-15).

DISCUSSION

Longevity of restorative materials has been reported in many journals but reports of longevity for multi-surface amalgam restorations have been limited. In a survey of 171 complex amalgam restorations, Robbins & Summitt (1988) reported a 75% survival rate of 5.7 years; the 50% survival rate is estimated to be 11.5 years and the 25% survival rate is estimated to be 16 years. The percentage of restorations surviving for 10 years was 54%, for 15 years 36% and for 20 years 19%. Downer & others (1999) conducted a systematic review of the literature on the longevity of routine dental restorations. They suggested that 50% of all restorations last 10 to 20 years, although both higher and lower median survival times were reported. The findings were supported by the totality of studies reviewed.

The alloy used to restore #30 in this case was Aristalloy, a low-copper lathe-cut amalgam very popular in the 1950-60 era. The trituration of amalgam was routinely mixed with excess mercury. The Eames technique was not published until 1959 and manufacturers took a couple years to change. In addition, Markley's pin technique for gaining retention was yet to be commercialized.

In spite of these shortfalls, the Aristalloy restoration on #30 in this particular patient held up well for the first 14 years. Lost of surface anatomy became evident and the surface showed slight pitting. The restoration had been polished at each recall visit, tarnish was easily removed and a high shine returned. Oleinisky & others (1996) reported that proper polishing of servicing amalgam restorations might delay a dentist's decision to replace the restoration.

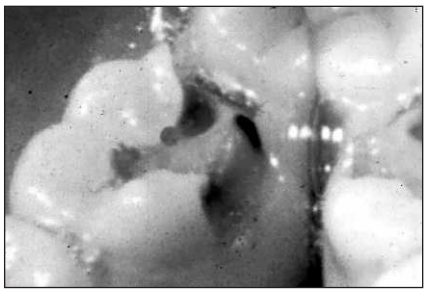

Figure 1. *Tooth # 30 with fractured disto-lingual cusp and recurrent caries.*

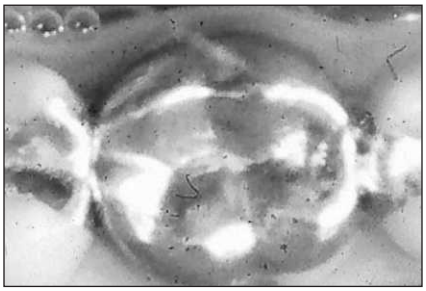

Figure 2. *Immediate post-op.*

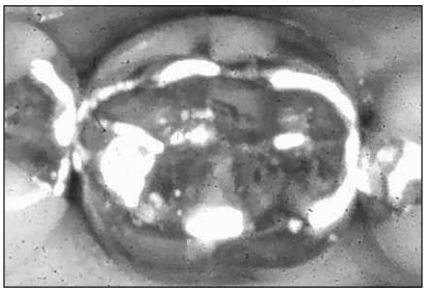

Figure 3. *Two-year post op. Notice the restoration has been polished at this and every subsequent recall appointment.*

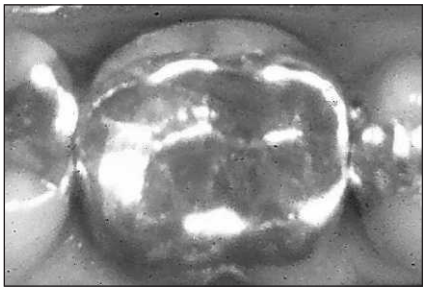

Figure 4. *Five-year post-op.*

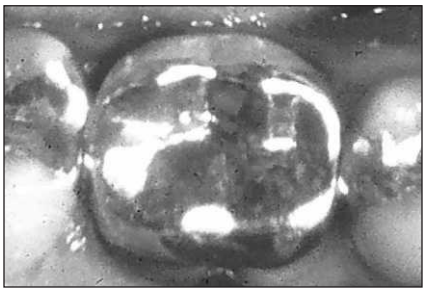

Figure 5. *Seven-year post-op.*

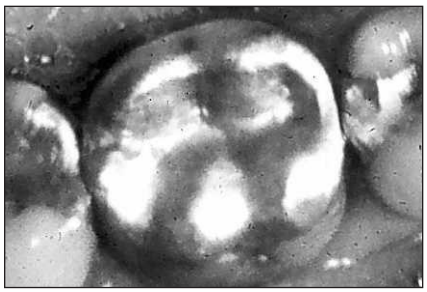

Figure 6. *Eleven-year post-op.*

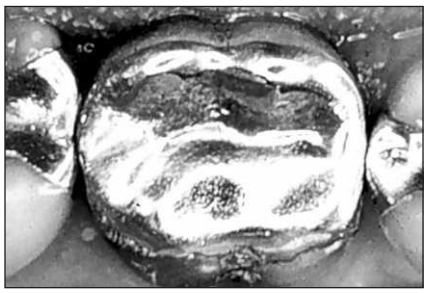

Figure 7. *Fourteen-year post-op. Lost of surface anatomy became evident and the surface showed slight pitting.*

Figure 8. *Sixteen-year post-op.*

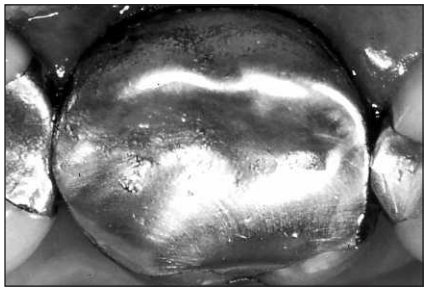

Figure 9. *Seventeen-year post-op.*

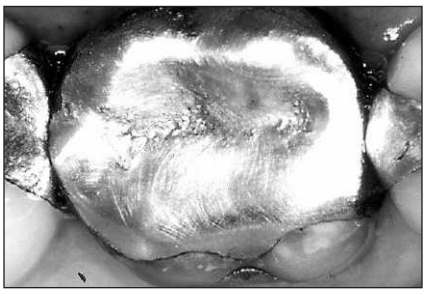

Figure 10. *Twenty-year post-op.*

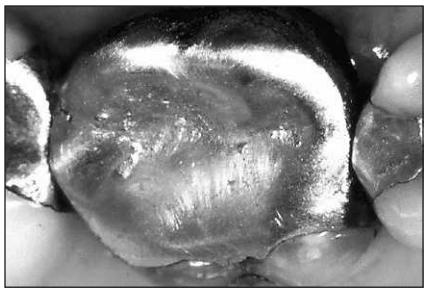

Figure 11. *Twenty two-year post-op.*

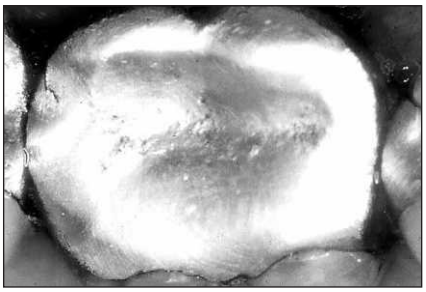

Figure 12. *Twenty four-year post-op.*

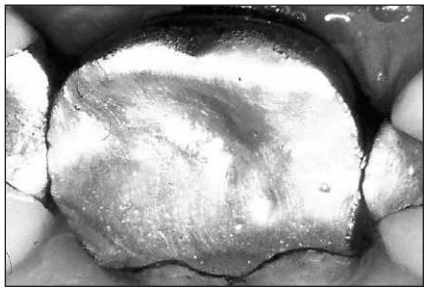

Figure 13. *Thirty two-year post-op.*

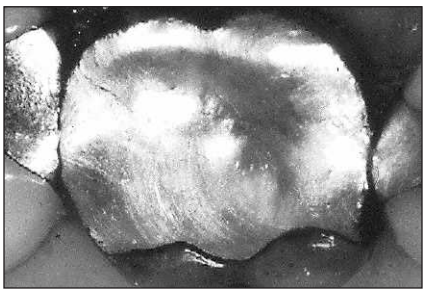

Figure 14. *Thirty five-year post-op. Notice that the margin discrepancies between the restoration and tooth is becoming visible and can be probed at a width close to 0.4 mm on an occlusal surface margin. Based on the proposed guideline, the decision was made not to re-treat at this time.*

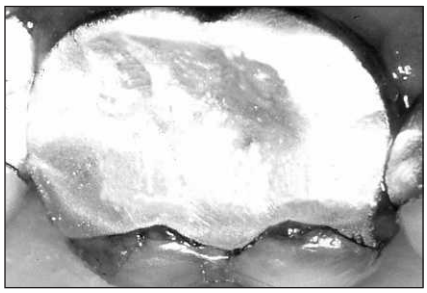

Figure 15. *Forty-year post-op just before the tooth was to receive full crown coverage.*

Despite minor problems, the restoration's survival for this number of years can best be explained by the periodic recalls, good patient home care and staying with the same dentist. Good routine maintenance by patient and dentist is a must for patients to keep their restorations and teeth. It has been reported that patients who changed dentists were likely to be over-treated compared to those who stayed with the same dentist (Hasegawa & Matthews, 1995). This can apply to replacement and new restorations.

The unique value of this case report was in documenting a five-surface complex restoration that survived 40 years. This is possible because the patient remained with the same private practice, where the patient received annual examinations. At the 40-year recall, the dentist and patient agreed to have full crown coverage for tooth #30. The authors in no way imply that all complex amalgam restorations will last that long, although conservative amalgam restoration that has lasted 58 years or more has recently been reported (Berry & others, 1998).

Guidelines for Amalgam Restoration Replacement

Based on an evidence-based literature review, the following criteria is proposed as guidelines for amalgam restoration replacement:

1. Missing restoration.
2. Gross fracture through the body of the restoration (Letzel & others, 1989).
3. Irrefutable clinical evidence of marginal caries, the removal of which compromises the integrity of the remaining restoration.
4. Combined clinical and radiographic evidence of marginal or internal caries. Consideration must be given to the possibility for presence of a radiolucent base (Kidd, Joyston-Bechal & Beighton, 1994; Hewlett & others 1993).
5. The restoration moves in the preparation when examined.
6. Poor proximal contour with evidence of new dental disease (caries, periodontal, occlusion) (Parsell & others, 1998).
7. Gross color mismatch and the patient desires cosmetic replacement.
8. Margin discrepancies between restoration and tooth, which can be probed at a width >0.4 mm on an occlusal surface margin should be given careful consideration but not necessary replaced (Kidd & O'Hara, 1990; Kidd, Joyston-Bechal & Beighton 1995).
9. Margin discrepancies between restoration and tooth (>0.2 mm) at the cervical or cervical third of the proximal (Klausner, Green & Charbeneau, 1987; Derand, Birkhed & Edwardsson, 1991).
10. Fracture of the tooth structure such that the integrity of the existing restoration is compromised (Akerboom & others, 1993).
11. A substantial margin overhang causes periodontal problems that cannot be removed through alternative means (Kells & Linden, 1992; Parsell & others, 1998).

CONCLUSION

Despite the increased demand for esthetic restorations, amalgam has many positive benefits and is a durable, cost-effective treatment option for the coming millennium. These proposed guidelines will help dentists decide whether or not to replace an amalgam restoration.

Disclaimer

The slide pictures were digitally cropped and orientated for comparison across a timeline.

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grams and interdisciplinary program development is preferred. Participation in appropriate national and international professional and scientific organizations is desired.

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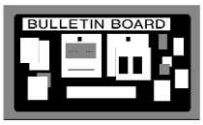
Qualifications:	Graduate qualifications and practical experience at the Masters level are preferred. Effective computer skills are a prerequisite.
Private Practice:	Is encouraged and available on site.
Equity:	The University is committed to Employment Equity. Members of designated groups (women, Aboriginal people, people with disabilities and visible minorities) are encouraged to self-identify on their applications. All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority.
Advertising:	This position has been cleared for advertising at the two-tier level. Applications are invited from qualified individuals regardless of their immigration status in Canada.
Website:	Further information about our College and its programs are available at www.usask.ca/dentistry.
Application:	Please submit application complete with curriculum vitae, credentials, a statement of teaching and research interests and the names of three references to: Dr D Tyler, Department of Community & Clinical Dentistry, College of Dentistry, University of Saskatchewan, 105 Wiggins Road, Saskatoon, Saskatchewan, Canada, S7N 5E4.

Announcements



32nd ANNUAL MEETING of the ACADEMY OF OPERATIVE DENTISTRY
26-28 February 2003
Fairmont Hotel, Chicago, IL

The Academy of Operative Dentistry's 32nd Annual Meeting once again offers an incredible group of essayists, an outstanding table clinic session and a wonderful social program.

SCIENTIFIC SESSION: Thursday begins with Dr Sasha Jovanovic speaking on "Optimal Esthetics with Implant Dentistry," followed by Dr Jimmy Eubanks discussing "Occlusion and Restoration Design." This year's Buonocore Memorial Lecturer is Dr Bart Van Meerbeek, who will present "Bonding to Tooth Tissue: Current Status and Challenges of the Future." Thursday afternoon features Dr William "Buddy" Mopper's presentation on "The Efficacy of Veneering with Direct Bonding" and Dr Shane White explains the new model of enamel microstructure in "Enamel and DEJ: Structure, Function and Why We Need to Preserve It."

Dr Richard D Tucker leads off on Friday morning with "Cast Gold Restorations with Integral Pins," and Dr. Edward McLaren follows with "Ceramic Systems: Material Considerations and Selection Criteria." Finally, Dr Bruce W Small wraps up the essay sessions with an evidence-based protocol for restorative dental practice titled "Putting it All Together." Friday afternoon's exceptional group of table clinics organized by Dr Richard Kloehn will complete the 2003 Scientific Session.

COMPANION PROGRAM: The Companion Activities Program offers participants an opportunity to enjoy some of Chicago's unique and delicious attractions. On Thursday, a tour bus will whisk registered guests to a "Chef Demo and Lunch" provided by chef Erwin

Dreshsler at his very popular Erwin Restaurant. Chef Dreshsler has reserved his entire restaurant for the Academy and will demonstrate the preparation of a three-course lunch that will then be served to attendees.

Friday morning features a "Continental Buffet Breakfast at the Fairmont with Barbara Rinella." Ms Rinella's presentation, "Dramatizing Current Literature—Academic Entertainment" is a fascinating and witty program of history in which she becomes many recent First Ladies to tell their stories of power and perspective.

RECEPTION: Finally, our Gala Reception on Thursday evening will once again provide a wonderful, once-a-year, platform for socializing with all our friends and colleagues from across the country and around the world.

Please do not miss this fantastic opportunity for education, information exchange and fun. See you in Chicago in February!

For more meeting information, please contact Dr Gregory Smith, PO Box 14996, Gainesville, FL 32604-2996; Fax (352) 371-4882.

Operative Dentistry Home Page

We hope all our readers will take advantage of the information available by accessing our Internet home page. Our address is: **http://www.jopdent.org/**

The home page contains a search engine and buttons that, hopefully, will lead you to answers to any questions you may have related to Operative Dentistry. These are:

Journal: leads to information on the Editorial Staff and Editorial Board; a complete index of journal volumes; a compilation of direct gold references; highlights of the current, next, and future issues, as well as a more detailed look at published Editorials and Clinical Pearls.

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Affiliates: provides links to the American Academy of Gold Foil Operators, the Academy of Operative Dentistry, the AADS-Operative Section, and our Corporate Sponsors. In addition, membership applications for the journal's parent academies are available for downloading.

News: announcements of interest to our readers, including meeting information, advertised faculty positions, and upcoming CE courses.

Authors: complete instructions for contributors to the journal.

Reviewers: password-protected link for our Editorial Board to submit manuscript reviews electronically.

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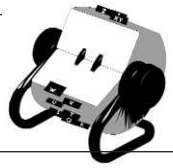

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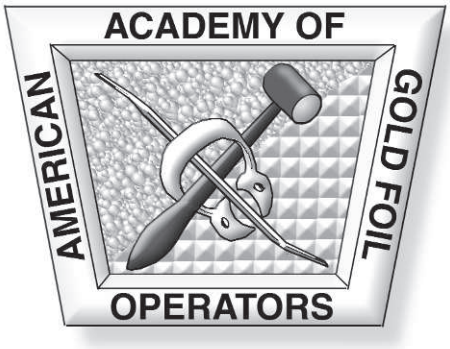

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