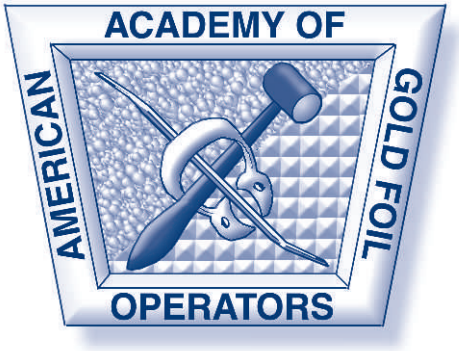
OPERATIVE DENTISTRY



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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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Editorial

What Does It All Really Mean?

I recently received an e-mail from my good friend John Osborne that prompted this editorial. John had put together a picture (Figure 1) that provides a very interesting perspective on the clinical release of mercury from dental amalgam. As I looked at this photograph and contemplated its significance, I decided to share some of my observations with you on improvements in measuring techniques, the impact on dental laboratory research and what we know about the actual clinical significance of things that we are now able to quantify to the n^{th} degree.

Advances in science and technology create wonderful opportunities to evaluate the materials and procedures used in dentistry. As instrumentation improves, we are able to visualize microscopic details and measure smaller and smaller increments. We can photograph the molecular structure of substances, analyze composition and evaluate the effects of time, temperature and stress. We utilize laboratory testing to provide us with data, and we are so impressed with the amazing technology that gives us glimpses into the infinitesimal that we attempt to extrapolate all this information to the clinical setting… and this is where the breakdown begins.

Make no mistake. Laboratory research is essential to the understanding and evolution of all aspects of our profession. It provides an environment in which we can standardize techniques, eliminate variables and pinpoint specific problems in ways that would be nearly impossible to achieve in a clinical setting. It allows us almost complete control over all aspects of investigation…and, thereby, distances our results and conclusions from the real world in which we work and live. What appears to be positively confirmed in the laboratory may or may not be a truism when the information is applied to patient treatment. Structures we can see at extremely high magnification are not visible to us clinically, and we must assume that what occurs in an extracted tooth on the laboratory bench also happens in a vital tooth during restorative treatment. We are not currently able to confirm that a hybrid layer of appropriate dimensions has formed in the cavity preparation we have just completed. Faith has become an integral part of our practice. Clinical studies are usually necessary to validate laboratory data. However, considering the expense, time and variables involved in human research, there is a tendency to base treatment decisions and materials selection on information gleaned from less expensive, more controllable laboratory experiments.

Examples abound. Literally thousands of laboratory papers have reported on microleakage of restorative materials and now nanoleakage research has captured our attention. However, what conclusive evidence exists showing a direct relationship between these phenomena and the clinical longevity of restorations? We know gross leakage is bad, but do these other situations automatically progress to a carious stage? What is the clinical impact of nanoleakage versus water sorption in resin restorations? Measurements of bond strengths and microtensile bond strengths of restorative resins to enamel and dentin fill millions of pages in dental jour-

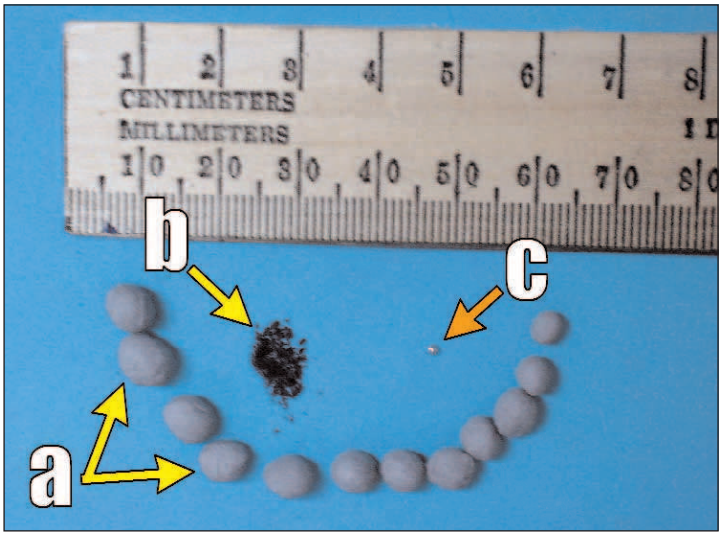

Figure 1. *Currently accepted science suggests that 12 dental amalgams will release 1.7 µg of mercury per day. Therefore, the total mercury loss of these amalgams to the oral environment over a 30-year period would be 18.7 mg. Figure 1 demonstrates visually this with a) showing 12 mixes of dental amalgam containing 11.5 g of mercury (42.5% ratio), b) an example of the granular form of a dental amalgam after all mercury has been removed and c) 19 mg of mercury, or the total amount that would be released from these 12 amalgams during 30 years of clinical service.* Photo courtesy of Dr John Osborne.

nals, but how much is necessary to keep a restoration from failing and is there any relationship between bond strength, leakage and longevity of a restoration? Studies fueling the controversy on the miniscule amount of mercury release from dental amalgam restorations and its effect on our patients' health and the environment are frequently in the news. However, if the amount of mercury release predicted in some studies was accurate in the clinical setting, dental amalgam restorations would crumble to dust after a few years in the oral environment (see b in Figure 1). Finally, although we can describe the microscopic structure of carious lesions and are finally moving away from the outdated surgical model of dental care, we still cannot agree on a foolproof technique to clinically diagnose the presence of beginning dental caries or what is the most appropriate treatment for the initial stages of the disease.

We want our patient care to be based on sound, scientific evidence. We also realize that this evidence can come from many sources including well-conducted laboratory and clinical research, retrospective studies of large patient populations and careful observation of the clinical successes and failures in our own practice (in my opinion, one of the most useful resources when evaluated properly). Reasonable caution must be exercised when listening to recommendations from colleagues, CE speakers and manufacturers. More important, however, is using good rationale, judgment and common sense based on experience when reading the dental literature. As we peruse this journal or any other, the questions we should be asking are "What does this data really mean and does it support the conclusions?" "Does this information have any immediate or long-term clinical implications or is it just a piece of a bigger puzzle?" and "Should I change something in my practice because of the conclusions reached by this researcher?" Be careful. The answers you give to these questions may have a much greater impact on your patients' well being than you realize.

Michael A Cochran
Editor

Acknowledgement

The editor thanks Dr Osborne for his dose of inspiration.

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Clinical Research

Pulp Reaction to Vital Bleaching

JO Fugaro • I Nordahl
OJ Fugaro • BA Matis • IA Mjör

Clinical Relevance

Only slight histological changes were noticed following nightguard vital bleaching with 10% carbamide peroxide for up to two weeks in approximately one-third of the intact teeth.

SUMMARY

This study evaluated the histological changes in dental pulp after nightguard vital bleaching with 10% carbamide peroxide gel. Fifteen patients between 12 and 26 years of age with caries-free first premolars scheduled for orthodontic extraction were treated with 10% Opalescence (Ultradent Products, Inc). Tooth #5 had four days of bleaching, tooth #12 was treated for two weeks, tooth #21 was bleached for two weeks followed by two weeks without treatment and tooth #28, serving as the control, was without treatment. All teeth were extracted at the same time. Immediately after extraction, 4 mm of the most apical portion of the root was sectioned off and each specimen was placed in a vial containing 10% neutral buffered formalin. The samples were prepared for histological evaluation at the Scandinavian Institute of Dental Materials (NIOM) and microscopically examined independently at both NIOM and Indiana University School of Dentistry (IUSD). Pulp reactions were semi-quantitatively graded as none, slight, moderate and severe. Slight pulpal changes were detected in 16 of the 45 bleached teeth. Neither moderate nor severe reactions were observed. The findings indicate that the slight histological changes sometimes observed after bleaching tend to resolve within two weeks post-treatment. Statistical differences existed only between the untreated control and the four-day (p=0.0109) and two-week (p=0.0045) treatment groups.

The findings from this study demonstrated that nightguard vital bleaching procedures using 10% carbamide peroxide might cause initial mild, localized pulp reactions. However, the minor histological changes observed did not affect the overall health of the pulp tissue and were reversible within two weeks post-treatment. Therefore, two weeks of treatment with 10% carbamide peroxide used for nightguard vital bleaching is considered safe for dental pulp.

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INTRODUCTION

Currently, the dental profession relies on a wide variety of esthetic treatments, some more conservative than others. Vital bleaching procedures are considered one of the most conservative treatments, since they do not require any reduction in tooth structure. This fact has led to its increased popularity in the field of cosmetic dentistry.

Little is known about the effects of hydrogen peroxide and/or carbamide peroxide on dental pulpal tissues. Therefore, controversy exists relative to the safety of this procedure despite certain products having been accepted by the American Dental Association (ADA) as being safe and effective. The majority of the evidence of pulp sensitivity is based on subjective reports by clinicians and patients. *In vivo* (Edwall & Olgart, 1972) and *in vitro* (Cooper, Bokmeyer & Bowles, 1992; Markovic & others, 2000) data have shown that hydrogen peroxide penetrates enamel and dentin within minutes. Pulp studies of histological changes following bleaching with carbamide peroxide have indicated a range of reactions varying from none to minor (Cohen, 1979; Anderson & others, 1999) to occasionally mild to moderate inflammatory responses (Kwong & others, 1993). Thus, uncertainty related to pulp reactions to vital bleaching procedures still exists.

This *in vivo* study evaluated an ADA-accepted home vital bleaching product on human dental pulp tissues in an attempt to answer some of the concerns associated with vital bleaching procedures. The study evaluated histological changes in pulp as a response to vital bleaching procedures.

METHODS AND MATERIALS

The study population consisted of 11 females and 4 males ranging in age from 12 to 26 years, with a mean age of 16.7 years. Each required the extraction of permanent premolars for orthodontic reasons. The patients were recruited from the Universidad Latinoamericana Graduate Orthodontic Program and Centro de Estudios Superiores de Ortodoncia, both in Mexico City, Mexico and were required to meet the following criteria:

Patient inclusion criteria:

- Permanent first premolars scheduled for orthodontic extraction.
- Scores of 2 or less using the periodontal screening record. (Evaluation consisted of examining the premolars with a periodontal probe).
- Completed root formation.
- 12 to 35 years of age.

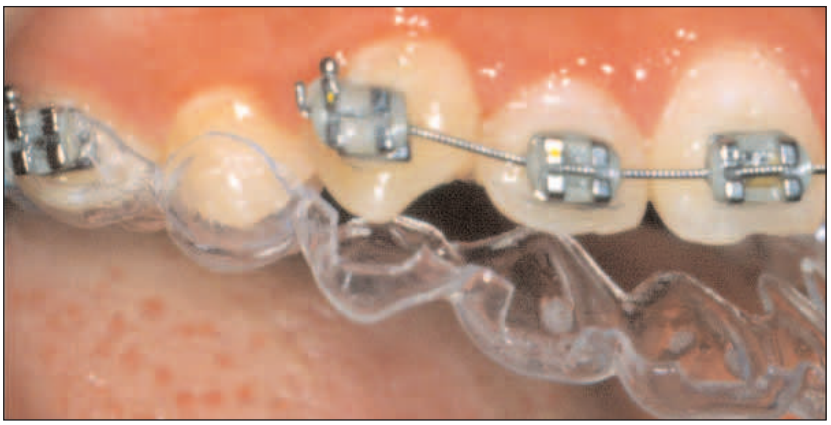

Figure 1. *The trays used for bleaching.*

Tooth exclusion criteria:

- Presence of caries.
- Presence of restorations.
- Presence of visible structural defects.
- Presence of pulpal symptoms or radiographic periapical lesions.

The Indiana University-Purdue University Indianapolis Institutional Review Board approved the study.

The patients who agreed to be a part of the study were asked to sign a consent form. Parents were asked to sign the consent form for those patients under 18 years of age. One patient required extraction of only three first premolars, making 59 premolars available for the study, 45 equally divided into three bleaching groups and 14 which served as controls.

At the screening appointment, maxillary and mandibular alginate impressions were taken of each patient. Study models were fabricated and trimmed appropriately using Modern Materials Labstone Buff (Heraeus Kulzer, Amherst, NY, USA). On teeth #5, 12 and 21, a 0.5-mm thick veneer of unfilled Block Out Resin (Ultradent Products Inc, South Jordan, UT, USA) was placed on the facial surface to within 1.0 mm of the mesial, distal and occlusal margins and to 1.5 mm of the gingival margin. Vacuum-formed bleaching trays were then fabricated from 0.035-inch plastic sheets (Sof-Tray, Ultradent Products Inc) for each of the maxillary and mandibular casts (Figure 1). Using microscissors, the trays were trimmed to within 0.5 mm of the gingival margin to minimize gingival trauma. The trays were modified with windows to provide accommodation for orthodontic brackets, and the molar areas of the trays were removed to allow for better seating because of orthodontic bands (Figure 1).

At the second appointment the patient was provided a mandibular bleaching tray with a single reservoir for tooth #21, one tube of 10% carbamide peroxide

(Opalescence, Ultradent Products, Inc) whitening gel and a container to hold the tray when not in use. The tray was placed in the mouth to ensure a good fit and no interference. The patient was instructed to wear the tray for at least six hours each night for 14 days.

The third appointment followed 15 days after the second appointment. Patients returned their mandibular bleaching trays and were then given the maxillary bleaching tray with reservoirs for teeth #12 and #5, along with one tube of Opalescence whitening gel. They were then instructed to bleach tooth #12 for 10 days as described above; on the 11th day, they were to continue bleaching tooth #12 and begin bleaching tooth #5 for four days. This schedule provided alternative treatment times for the premolars as follows: #5 bleached four days, #12 bleached two weeks, #21 bleached for two weeks followed by two weeks without treatment and #28, which comprised 14 teeth, served as controls with no bleaching treatment. The patients were questioned about any sensitivity during the bleaching treatment.

Oral surgeons extracted the premolars under local anesthesia (2% lidocaine with 1:100,000 epinephrine) using a simple elevator-forceps technique; immediately after extraction, the teeth were wiped clean of any debris with gauze. The most apical 4 mm of the root was than sectioned off using a Lil-trimmer saw (Lapcraft Inc, Powell, OH, USA). After sectioning, the tooth was placed in a screw top vial (Nalgene cryoware, Nalge Co, Rochester, NY, USA) containing 10% neutral buffered formalin and securely fastened. Each vial was labeled with a patient identification number and the corresponding tooth number. The time between tooth extraction and placement in 10% neutral buffered formalin was not more than five minutes. Once all teeth in the study were bleached, all samples were returned to IUSD at which point the samples were sent for histological processing at NIOM. The teeth were demineralized in 5% HNO_3 for 16 to 30 hours. The endpoint of demineralization was checked radiographically. The teeth were embedded in paraffin and serially sectioned axio-facio-lingually through the pulp. Four to six slides, each with four to six sections from different locations in the central part of the pulp, were then stained with hematoxylin and eosin. After histological preparation and examination, the sections were returned to IUSD for an independent examination.

Histological Evaluation

Light microscopic examination of the pulps in stained axio-bucco-lingually sectioned teeth was performed at 40x to 400x magnifications. Since no system for classifying *general* pulp reactions exists, the well-established semi-quantitative classification commonly used to evaluate *local* pulp reactions (Stanley, 1968a,b; Mjör & Tronstad, 1972; Browne, Plant & Tobias, 1980) was adapted for generalized pulp reactions in this study. The evaluation included a qualitative assessment of the number of cells in the cell-free zone, irregularities in the odontoblastic layer, the presence of inflammatory cells and extravasated erythrocytes, with attention to the facial aspect of the pulp. Examination for additional reactions included assessment of displaced odontoblasts nuclei into dentinal tubules and disturbance of predentin formation.

A total of 1,068 stained sections were examined microscopically, and the number of sections in each group that showed pulp reactions was evaluated for statistical differences using the generalized estimation equation and paired *t*-tests.

RESULTS

Most of the experimental and control teeth showed no pulp reactions (Figure 2). Sixteen of the 45 premolars subjected to bleaching demonstrated a slight pulp reaction in a limited part of the coronal pulp. The cell-free zone was less distinct in some areas on the facial surface of those teeth, that is, cells may have migrated into the area (Figure 3). Scattered leukocytes were occasionally observed and irregularities in the pseudostratified odontoblastic layer could be discerned. None of the teeth demonstrated a moderate or severe reaction to the bleaching agent. Scattered free erythrocytes were occasionally observed in both the bleached and untreated experimental teeth (Figure 4). Displaced odontoblast nuclei were sometimes discerned in the dentin that corresponded to the trauma caused by the forceps at the cemento-enamel junction in both the experimental and control teeth. Vacuolization of the odontoblastic layer was observed in some teeth, and it was the same in bleached and untreated teeth. If present, it was predominantly found in the area of the pulp horns, indicating that it could be an artifact due to inadequate fixation of the pulp. No signs

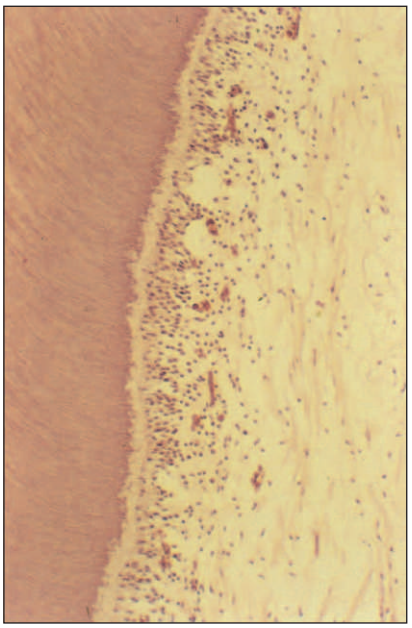

Figure 2. *Normal pulp structure showing cell-rich and cell-free zones, a normal pseudostratified odontoblastic layer, and predentin. Hematoxylin/eosin stain. Original magnification 100x.*

of disturbance in the predentin formation were found in any of the teeth. None of the patients had experienced any pulpal discomfort during treatment, but one patient reported gingival sensitivity from incorrect use of the bleaching tray.

Table 1 outlines the distribution of pulp reactions according to bleaching treatment. The intraindividual comparison of teeth as a function of bleaching time showed that in the six patients with slight pulp reactions after four days of bleaching, three teeth exhibited slight reactions after two weeks of bleaching, along with one of the teeth that was treated for two weeks followed by two weeks with no treatment. Three of the seven patients with slight reactions after two weeks of bleaching also showed slight reactions in the three teeth bleached for four days, but in none of the teeth bleached for two weeks followed by two weeks of no treatment. Of the three patients with teeth showing slight pulp reactions after two weeks of bleaching and two weeks recovery, only one of the other teeth showed a slight reaction after four days of treatment and another demonstrated a slight reaction after two weeks of bleaching. In one patient, the only tooth showing a slight reaction was the one bleached for two weeks followed by two weeks with no treatment. Thus, no pattern could be discerned when comparing slight reactions in teeth from the same patient.

Statistical assessments were based on the number of sections in each treatment group that showed slight or no reactions. Significant differences were found between the four-day bleaching group and the control teeth and between the two found between other groups that were compared (Table 2).

DISCUSSION

Young patients were selected for this study because they had teeth scheduled for extraction in conjunction with orthodontic treatment and they had intact teeth that were subject to minimal wear or age changes. The enamel and dentin in teeth from young patients is also more permeable than that of older individuals (Mjör, 1980; Mjör, Sveen & Heyeraas, 2001). Furthermore, teeth from young patients are generally recommended for testing for pulp reactions (Schroff, 1952; Langeland, 1957; Stanley, 1968a,b; Gvozdenovic-Sedlecki, Qvist & Hansen, 1973).

The time intervals selected for bleaching in this study were based on previous studies, where four days had been the shortest time to show histological changes and two weeks was generally considered the minimum time

Figure 3. *Slight pulp reaction on buccal side of pulp in a tooth bleached for four days. No distinct cell-free zone is present. Hematoxylin/eosin stain. Original magnification 100x.*

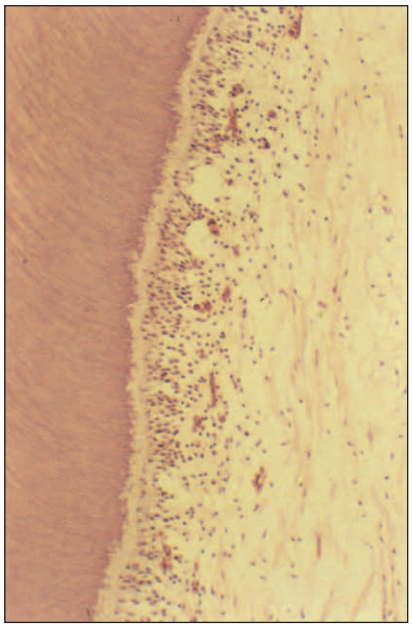

Figure 4. *Extravasated red blood cells in the pulp on the facial side of pulp in a tooth bleached for four days. These cells may have been dislodged from the blood vessel during the histological procedure. Hematoxylin/eosin stain. Original magnification 100x.*

Table 1: *Number of Teeth With and Without Pulp Reaction After Bleaching as a Function of Observation Time*

	Number of Teeth	
Time of Treatment	**No Pulp Reaction**	**Slight Pulp Reaction**
4 days	**9**	**6**
2 weeks	**8**	**7**
2 weeks + 2 weeks recovery	**12**	**3**
Control	**14**	**0**

Table 2: *Significance of Differences Between Sections With and Without Slight Pulp Reaction at the Different Observation Periods*

Treatment	P
4-day versus control	0.0109
2-week versus control	0.0045
2-week plus 2-week recovery versus control	0.0877
4-day versus 2-week	0.88
4-day versus 2-week plus 2-week recovery	0.27
2-week versus 2-week plus 2-week recovery	0.25

recommended by dentists and manufacturers for use of 10% carbamide peroxide bleaching agents. These time intervals could also accommodate the needs of orthodontists treating patients.

Methodology is particularly important in evaluating pulpal reactions (Langeland, 1957; Stanley 1968a,b; Mjör, 1980). The histological preparation of teeth for pulp studies has many possibilities for introducing artifacts. However, histological evaluation is considered the most reliable method to evaluate pulpal reactions to clinical procedures (Mjör & others, 2001; Heyeraas, Sveen & Mjör, 2001). Artifacts are generally easily distinguished from histological changes (Langeland, 1957). The few artifacts found in this study were credited to poor fixation or they could be introduced during sectioning of the teeth. Vacuolization of odontoblasts was observed predominantly in pulp horns, irrespective of treatment time. The presence of red blood cells outside blood vessels may be a sign of hemorrhage, but red blood cells may also escape from vessels during passage of sections through various solutions during staining of the sections.

A technique to evaluate histological changes to caries, operative procedures and restorative materials is well established (Langeland, 1957; Stanley, 1968a,b; Fiore-Donno, 1970; Kafrawy, 1978; Heyeraas & others, 2001), and the histological changes are part of a biological assessment of restorative materials for preclinical testing of medical devices used in dentistry (ANSI/ADA Specification 41, 1982; ISO Standard 7405, 1997). The technique is common use focus on pulp reactions subjacent to a discrete lesion, allowing for a comparison with adjacent pulp tissue. There is no classification system available for conditions affecting the main part of pulp or the entire pulp. Therefore, the system used to evaluate localized pulp reactions was adapted to this experimental design, where the entire facial surface of premolars was subjected to bleaching using 10% carbamide peroxide and untreated teeth served as the controls.

The current histological results conform to those reported in other studies (Kwong & others, 1993; Anderson & others, 1999). Since no pulpal sensitivity was reported, the findings also confirm those from other studies (Haywood & others, 1994; Leonard, Haywood & Philipps, 1997; Matis & others, 2000) and are in agreement with the histological findings.

Since pulp reactions were small, it was difficult to ascertain whether bleaching *per se* caused the minor reactions noted. Furthermore, the slight reactions that occurred in some teeth did not show a pattern in the intra-individual comparison of teeth from the same patient. However, statistical analyzes of the number of sections with slight reactions compared to those from the control material showed that significantly more slides were diagnosed with slight reactions in the four-day and two-week bleaching series than in the untreated control material. While these results are encouraging for nightguard vital bleaching with 10% carmabide peroxide gel, the current trend in bleaching is to use faster acting, more efficient products. These approaches generally mean using products of higher concentrations and those that use an activating light or heat source. Great care should be taken in using the current results to justify the use of these higher concentrations. Previous studies have shown that using high concentrations of hydrogen peroxide and heat is potentially harmful to pulp tissue (Seale, McIntosh & Taylor, 1981; Nathanson, 1997).

CONCLUSIONS

This study has shown that the nightguard bleaching of teeth with 10% carbamide peroxide gel may cause minor short-term reactions in pulp in about one-third of the intact teeth from young individuals subjected to bleaching. If such changes occur, they are reversible over time. No pulpal sensitivity was reported clinically during the up to two-week bleaching period.

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In Vivo Antibacterial Effects of Dentin Primer Incorporating MDPB

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Y Noiri • S Ebisu

Clinical Relevance

In a clinical situation, experimental primers containing the antibacterial monomer MDPB might inactivate residual bacteria in cavities.

SUMMARY

This study examined the hypothesis that experimental primer containing the antibacterial monomer 12-methacryloyloxydodecylpyridinium bromide (MDPB), which was previously reported to show bactericidal effects *in vitro*, inhibits bacteria in cavities under *in vivo* conditions. The number of bacteria resulting from applying primer solution to cavities in dog teeth infected with *Streptococcus mutans* was determined. The infected cavities were also restored using primer and the pulp response was histopathologically examined after 7, 30 and 75 days. No bacteria were recovered after applying the experimental primer, although the bactericidal effects of the proprietary primer were insignificant. Restoration with the experimental primer resulted in little or no pulpal inflammation for all periods; whereas, mild to moderate inflammatory response was observed when using proprietary primer. These results indicate that the experimental primer containing MDPB could exhibit *in vivo* antibacterial effects, suggesting its possible clinical benefit.

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INTRODUCTION

The development of adhesive systems that have enabled variable cavity design to preserve intact tooth structure and the treatment of caries has recently been shifted from the traditional method to that with downsized cavities (Tyas & others, 2000). However, when attention is focused on less removal of tooth structure, it is possible that some active bacteria reside in the cavity (Ratledge, Kidd & Beighton, 2001). On the other hand, the number of dentulous elderly is increasing, a trend that has multiplied the number of root caries (Beck, 1993). Many root surface carious lesions are extensive and adequate caries removal and restoration placement are difficult (Lynch, 1996). For caries treatments that may not completely remove the infected

dentin, adhesive systems with antibacterial effects are considered beneficial to achieving a better prognosis.

Previously, the authors have reported that incorporating an antibacterial monomer 12-methacryloyloxydodecylpyridinium bromide (MDPB) was an effective method for providing a self-etching primer with antibacterial effects without causing any adverse influence on bonding ability and cytotoxicity (Imazato & others, 1997, 1998, 2000). MDPB was originally developed for immobilization of the antibacterial component in resin-based materials (Imazato & others, 1994; Imazato, Russell & McCabe, 1995). However, unpolymerized MDPB possesses strong antibacterial activity (Imazato & others, 1999), and primer containing MDPB was found by *in vitro* tests to be bactericidal against streptococci or anaerobes isolated from carious lesions (Imazato & others, 1997; 2001). This study examined the hypothesis that MDPB-containing primer that has bactericidal activities *in vitro* exhibits antibacterial effects *in vivo* via animal tests. A model that simulates an infected dentinal cavity was used, and the effects were examined by bacterial recovery test and histopathological evaluation.

METHODS AND MATERIALS

Adhesive Systems

A two-liquid type proprietary self-etching primer, LB primer (Kuraray, Tokyo, Japan) served as the control material. The main components of LB primer are 2-hydroxyethyl methacrylate, water and adhesion-promoting monomer 2-methacryloyloxyethyl phenyl hydrogen phosphate. The experimental primer was prepared by adding MDPB to B-liquid of LB primer at 10%, giving a final concentration of 5% after mixing liquids A and B.

Bacteria

Streptococcus mutans MT8148 was cultured in Brain Heart Infusion broth (BHI, Becton Dickinson, Sparks, MD, USA) supplemented with 0.5% yeast extract (Becton Dickinson) and used for experiments after being checked by Gram-staining.

Animals

Five beagle dogs (female, 13 to 24 months old, weighing 10-15 kg) were housed in the Osaka University Animal Facility and used according to the protocol approved by the ethical guidelines for animal care of Osaka University Graduate School of Dentistry.

Bacterial Recovery Test

Each dog was subjected to general anesthesia by intramuscular injection of 20-mg/kg ketamine and intravenous injection of 10-mg/kg sodium pentobarbital. The teeth were cleaned with 3% hydrogen peroxide and 5% tincture of iodine. Class V cavities (2 mm x 4 mm, approximately 1.5-mm deep) were prepared on the buccal surfaces using a high-speed diamond bur (D1, Shofu, Kyoto, Japan) under water spray. The cavity was then etched with 37% phosphoric acid (K-etchant, Kuraray) for 60 seconds and washed with copious amounts of water to remove the smear layer and to open the dentinal tubules. *S mutans* cultured overnight was suspended in 20 mmol/L phosphate buffered saline (PBS, pH 6.8) and dispersed using an ultrasonic apparatus (Handy sonic, Tomy Seiko, Tokyo, Japan). Two µL of this suspension (ca 2 x 10^6 CFU) was inoculated into the cavity and left for 30 minutes.

When penetration of the suspension was confirmed visually, the teeth were divided into four groups. For the first (LB group) or second group (MDPB group), LB primer or the experimental primer was applied to the cavity and dried with a gentle stream of air after 30 seconds. For the third group (CHX group), the cavity was gently scrubbed with a commercially available cavity disinfectant containing 2.0% chlorhexidine gluconate (Consepsis, Ultradent, South Jordan, UT, USA) for 60 seconds and air dried. Then, the dentinal substrate below the cavity wall and floor was ground using a sterile steel round bur (#5, Dentsply, Baar, Switzerland) at low speed without a water flush and collected into 1 mL of PBS. To avoid heat generation, grinding was carefully performed intermittently. Whole dentin from the cavity surface to the pulpal wall was collected and immediately subjected to microbial procedures. The dentin sample was dispersed with a vortex mixer and the suspension was serially diluted 10-fold. One hundred µL aliquots were plated on Mitis salivarius agar plates (Becton Dickinson) and the number of viable bacteria (CFU) was determined after anaerobic incubation for 48 hours at 37˚C. For the fourth group, which served as the control, collection of the dentin sample was performed without any treatment. Four cavities were prepared in mature molars or second premolars of each of five dogs and randomly allocated to each of four groups.

Histopathologic Evaluation

Class V cavities were prepared and infected with *S mutans* using the same procedure mentioned above. The cavities were then treated in three different ways.

LB group: The cavity was treated with LB primer for 30 seconds and air dried. Adhesive resin (LB bond, Kuraray) was applied and cured with a light-activation unit (Quick Light, Morita, Kyoto, Japan) for 20 seconds. Then, resin composite (Clearfil AP-X, Kuraray) was placed in the cavity and light cured for 40 seconds. The excess material beyond the cavosurface margin was removed with a finishing point (#60, Shofu).

MDPB group: The cavity was restored in the same manner as the LB group, using the experimental primer instead of LB primer.

Control: The infected cavity was dressed with temporary stopping (GC, Tokyo, Japan) and filled with glass-

ionomer cement (Base Cement, Shofu).

A total of 40 intact, mature second or third incisors and five upper first premolars, not under occlusal pressure, were used. Twenty-seven teeth from three dogs were examined for the evaluation period of seven days, and nine teeth from one dog each for 30 and 75 days. Each dog received eight cavity preparations in second or third incisors and one preparation in the upper first premolar, with an allocation of three cavities to the LB group, the MDPB group or the control. The first premolar was included in the MDPB group in every case.

Table 1: *Pulpal Responses at the Experimental Periods of 7, 30 and 75 Days for Each Group*

		Pulpal Responses						
		Inflammatory Cell Response				Odontoblastic Layer		RDT (mm)
		0	1	2	3	Normal	Disruption	Mean (SD)
Day 7	Control	0	3	6	0	0	9	0.54 (0.20)
	LB group	0	5	3	0	2	6	0.47 (0.33)
	MDPB group	9	0	0	0	5	4	0.50 (0.30)
Day 30	Control	0	0	3	0	0	3	0.48 (0.08)
	LB group	0	3	0	0	0	3	0.49 (0.06)
	MDPB group	3	0	0	0	3	0	0.48 (0.06)
Day 75	Control	0	0	3	0	0	3	0.50 (0.07)
	LB group	0	3	0	0	0	3	0.54 (0.06)
	MDPB group	3	0	0	0	3	0	0.53 (0.06)

Inflammatory cell response

0: No inflammation beneath the cut tubules.

1: Few scattered inflammatory cells beneath the cut tubules (mild or slight response).

2: General or localized moderate inflammatory cells infiltration in the pulp beneath the cut tubules (moderate response).

3: Severe inflammation and/or abscess formation (severe response).

Odontoblastic layer organization

Normal: No disruption below the remaining dentin.

Disruption: Disruption or loss of odontoblasts below the remaining dentin.

The results display the number of specimens.

At each period, the dog was sacrificed and the teeth were extracted carefully. The teeth were immersed in 10% neutral buffered formalin for two weeks at 4˚C after cutting the root tip to facilitate fixation and subsequently demineralized in 10% formic acid-citric acid solution for two weeks. The samples were then dehydrated using an ascending graded ethanol at concentrations of 50% to 100% followed by embedding in dimethacrylate-based resin (LR White, London Resin Company, London, UK). Serial sections 2-µm thick were cut in a buccolingual plane. The sections were stained with hematoxylin and eosin and examined independently by two investigators according to the criteria previously published (Six, Lasfargues & Goldberg, 2000). The average remaining dentin thickness (RDT) for each tooth was determined from the sectioned specimens. Several sections among each group were stained with Brown and Brenn's bacterial stain, and the pulpward invasion of bacteria inside the dentinal tubules was examined.

RESULTS

Bacterial Recovery Test

The control and LB groups showed 4.74 (+/-3.98) x 10^5 and 1.94 (+/-3.35) x 10^5 CFU of bacterial recovery, respectively, and there was no significant difference between these two groups ($p>0.05$, Student's t-test). No formation of bacterial colonies was found in all five replicates for the MDPB and CHX groups, resulting in bacterial recovery at <10 CFU for these groups.

Histopathologic Evaluation

Histologic results are summarized in Table 1. One tooth from the LB group that was part of the seven day-observation was eliminated due to a fracture during the procedure to prepare the specimen. There were no significant differences in RDT among the three groups at each evaluation period ($p>0.05$, ANOVA).

At day seven, the control demonstrated a mild to moderate inflammatory response predominated by polymorphonuclear leukocyte (Figure 1a), and a disruption of the odontoblast layer below the remaining dentin was observed in all specimens. Five of eight pulps from the LB group exhibited a slight to mild inflammatory response (Figure 1b), and three teeth showed moderate inflammation. The odontoblastic layer organization was disrupted in six teeth. None of the nine teeth from the MDPB group displayed any pulp inflammation (Figure 1c), and only four teeth showed an altered odontoblastic layer.

At day 30, the control showed mild to moderate inflammatory responses with the infiltration of mononuclear cells, with enlarged blood vessels and capillaries clearly seen (Figure 2a). The LB group presented slight or mild inflammatory responses associated with disturbance to the odontoblastic layer. Some parts of the odontoblastic layer underneath the cavity were lost and enlarged blood vessels were seen (Figure 2b). The MDPB group showed normal soft tissue organization (Figure 2c).

At day 75, disruption of the odontoblastic layer as well as mild or moderate infiltration of inflammatory cells was seen in the control and LB group. All three

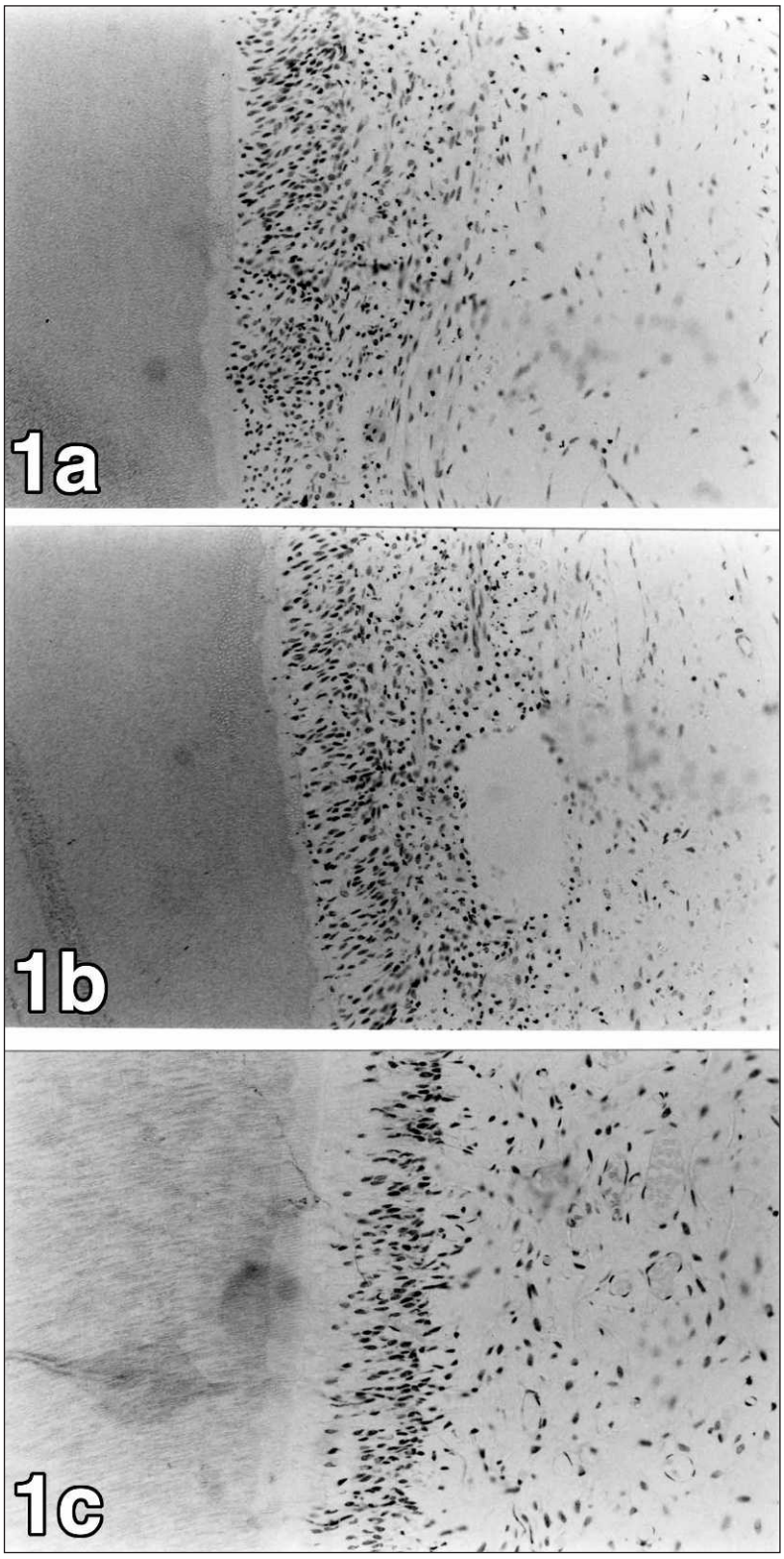

Figure 1. *The seven-day pulp beneath the cut dentinal tubules for each group. The stain is hematoxylin and eosin (original magnification 80x). The cavities are located on the left side of the figures: a) control, b) LB group, c) MDPB group. Note that there is no sign of inflammation for the MDPB group treated with the experimental primer (c).*

teeth from the MDPB group were judged to have intact soft tissue morphology, and no signs of inflammation were observed.

Using Brown and Brenn's staining, invasion of bacteria up to 30 µm deep from the cavity floor was observed for the control at day seven. After 30 days, bacteria invaded beyond 300-µm depth and reached the pulp chamber in a few teeth for this group (Figure 3). For the LB group, bacteria were confirmed to progress to 100 µm after 30 days and to more than 300 µm after 75 days. For the MDPB group, staining was limited on the cavity floor and bacterial invasion toward the pulp was not observed during the entire test period.

DISCUSSION

When simulating bacterial infection of dentin, few animal studies have employed the method of leaving the prepared cavity unfilled for three to eight days (Mjör & Tronstad, 1972; Tziafas & Kolokuris, 1987). However, this method has a disadvantage in that the amount and species of invading bacteria cannot be controlled and the pulp response of each tooth varies considerably (Mjör & Tronstad, 1972). Therefore, the authors established the *in vivo* method with standardized bacterial infection by modifying the *in vitro* test reported previously (Ohmori, Maeda & Kohno, 1999). By using scanning electron microscopy, it was found that the smear layer was removed and bacterial cells remained around the tubule orifice after inoculation (data not shown), and our model was considered appropriate for assessing the antibacterial effects of the experimental primer.

The results of the bacterial recovery test demonstrated that applying primer containing 5% MDPB was effective for killing bacteria in the cavity, similar to a disinfecting solution that contained chlorhexidine, whereas, the LB primer showed a slight, but not significant reduction. These findings were in accordance with the results previously reported by *in vitro* studies, where the antibacterial activity of the experimental primer was significantly greater than the LB primer (Imazato & others, 1997). The self-etching primers, including LB primer with a pH value of 1.3, demonstrated antibacterial effects due to acidity (Imazato, Imai & Ebisu, 1998); however, their effects were not intense enough to inactivate bacteria that existed in the dentinal cavity.

The present bacterial recovery test is more clinical-simulative than other methods that employed tooth extraction (Browne & others,

1983; Mejàre, Mejàre & Edwardsson, 1987) or placement of a bacteria-impregnated-filter disc (Bergenholtz & others, 1982; Heys & Fitzgerald, 1991). However, for controls where the dentinal sample was collected without primer treatment, recovery of all bacteria inoculated was not achieved. Since grinding with a round bur using no water spray was employed to collect the dentinal sample, some amounts of bacteria were considered damaged mechanically or by heat produced during sampling. Therefore, from the results of this experiment, it has not necessarily been concluded that bacteria in the cavity was completely eradicated, although it is clear that MDPB-containing primer demonstrated antibacterial effects.

MDPB is a monomer that polymerizes after curing of overlaid adhesive resin in restorative procedures. In bacterial recovery tests, the adhesive resin was not applied in order to collect bacteria, so it is possible that unpolymerized MDPB acted for longer periods. On the contrary, composite filling was conducted in histopathological tests and the results reflect clinical circumstances. The controls without primer application and the LB group demonstrated slight to moderate inflammatory responses throughout the seven to 75 days of the test period. In contrast, no pulpal inflammation was observed for the restoration using the experimental primer. Since there is a significant association between bacterial presence in the cavity and pulpal inflammation in animal tests (Mjör & Tronstad, 1972; Tobias & others, 1989), no inflammatory response by the MDPB group suggests that MDPB could kill or inactivate bacteria in the cavity and eliminate toxic effects that lead to inflammation of the pulp. The findings regarding bacterial staining coincided with the histopathological observation and support the effectiveness of MDPB-containing primer. No pulpward progression of bacteria for the MDPB group in contrast to the control and LB group, in which the bacteria were observed to invade significantly after 30 days, exemplifies the ability of the MDPB-containing primer to reduce the bacterial number to a non-toxic level.

The dentin bond strength of LB primer is not influenced by incorporating MDPB (Imazato & others, 1997). In addition, when composite fillings placed in the uninfected cavities of anterior teeth of beagle dogs were examined up to 75 days, no bacterial microleakage and no pulpal inflammation was observed for both LB primer and MDPB-containing primer (unpublished observation). Accordingly, these two primers

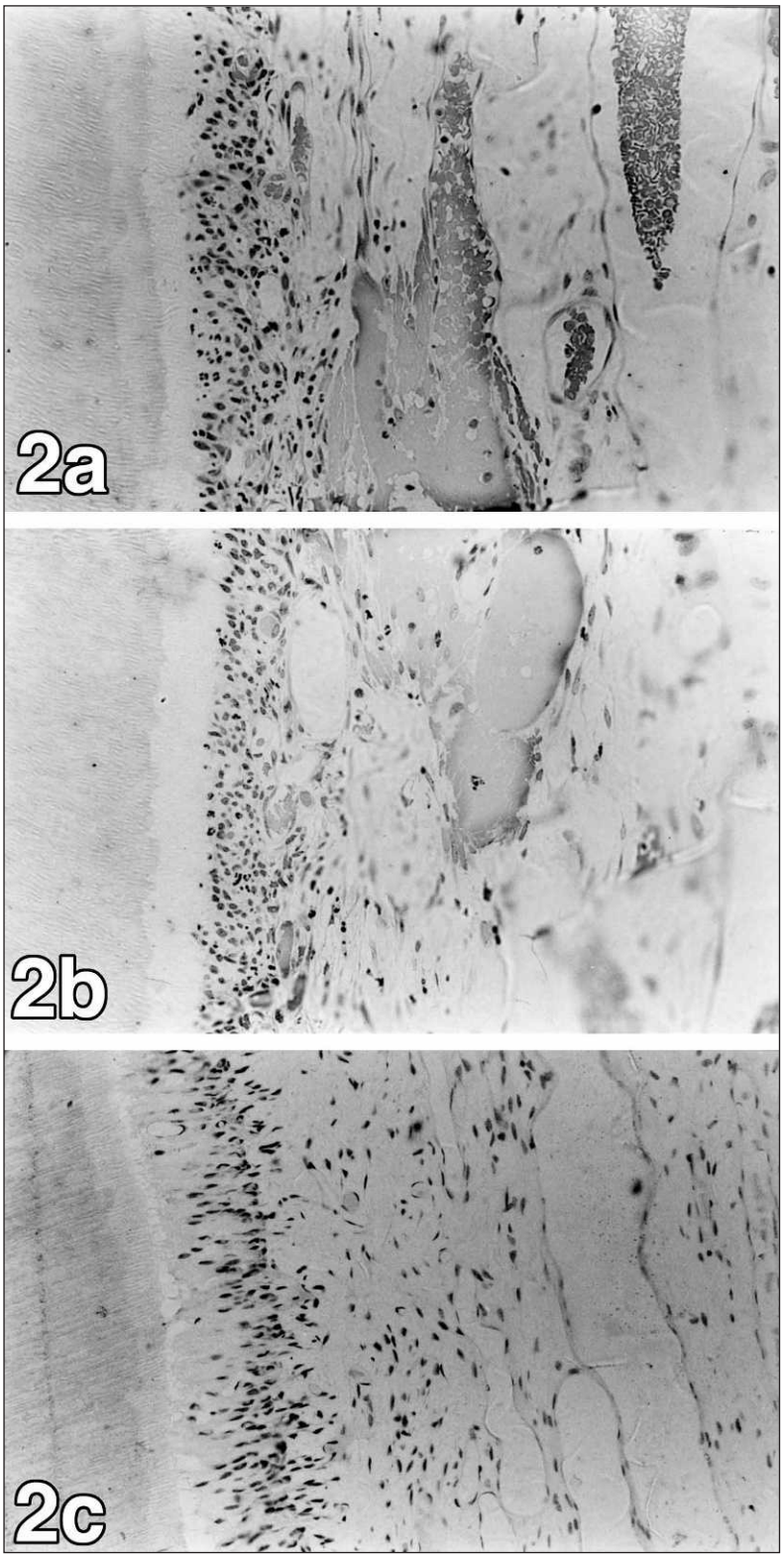

Figure 2. *The 30-day pulp beneath the cut dentinal tubules for each group. The stain is hematoxylin and eosin (original magnification 80x). The cavities are located on the left side of the figures: a) control, b) LB group, c) MDPB group. Note that there is no sign of inflammation for the MDPB group treated with the experimental primer (c).*

Figure 3. *A view of 30-day specimen for control stained with Brown and Brenn's bacterial staining (40x magnification). The cavity is located on the top, and bacteria reaching the pulp chamber can be seen at the bottom of the figure in this specimen.*

have the same sealing ability for sound dentin. Furthermore, it has been reported that bond strength of LB primer and MDPB-containing primer to dentin inoculated with bacteria was not different (Ohmori & others, 2000). Therefore, although the cavity inoculated with bacteria was restored in this study, the marginal seal of the LB group and MDPB group are considered similar, so that no pulpward bacterial invasion in the MDPB group is dependent upon the antibacterial effects exhibited by the MDPB-containing primer, rather than the inhibition of microleakage. Lower pulpal reaction for the LB group compared with the control may be, in part, due to inactivation of bacteria to some degree by its acidity. However, the damage was not effectively excluded by the LB primer-application, and providing intrinsic antibacterial activity by incorporating MDPB was confirmed to be beneficial to producing reliable *in vivo* inhibitory effects against bacteria.

The evaluation of pulpal responses using animals basically has the limitation that the variation in pulp reaction is attributed in part to the vitality of each pulp. Therefore, it is important to exclude variables that compromise comparison of the effects of materials as much as possible. The small variation in the histopathologic results for each group at each test period is possibly ascribed to the characteristics of our method to standardize bacterial infection, suggesting an advantage for producing reproducible pulpitis. Since the number of bacteria inoculated into the cavity in this study was in the range of variation reported by clinical sampling (Hoshino & others, 1988; 1989), the experimental primer is expected to exhibit antibacterial effects in clinical situations. However, dentinal lesions contain a variety of bacterial species including obligate anaerobes (Hoshino, 1985), and the *in vivo* effects of MDPB-containing primer on different species other than *S mutans* remains to be determined. In addition, severe inflammation was more frequently observed when the cavity was left unfilled (Mjör & Tronstad, 1972), and it is not clear how precisely our test method simulates clinical virulence of residual bacteria and its product. Clinical trials and modification of this model study are necessary to elucidate further the benefit of MDPB-containing primer.

CONCLUSIONS

The experimental primer containing MDPB exhibited antibacterial activity in an infected-cavity model prepared in dog teeth *in vivo*.

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A Randomized, Controlled Trial Evaluating the Three-year Clinical Effectiveness of Two Etch & Rinse Adhesives in Cervical Lesions

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Clinical Relevance

Both three-step etch & rinse adhesives OptiBond FL and PermaQuick performed well in non-carious cervical lesions over a three-year period. No significant difference was observed between the use of a more flexible micro-filled and a stiffer hybrid composite to restore cervical lesions.

SUMMARY

A three-year randomized, controlled prospective study evaluated the clinical performance of two three-step etch & rinse adhesives (OptiBond FL, Kerr: O-FL; PermaQuick, Ultradent: PMQ) in Class V cervical erosion–abrasion lesions. The latter adhesive was also tested with two restorative composites with contrasting stiffness in order to evaluate the effect composite stiffness might have on the clinical longevity of cervical restorations. A total of 150 lesions were randomly restored in pairs of the three adhesive/composite combinations (PMQ combined with Amelogen Hybrid: PMQ/A-Hy, Ultradent; PMQ combined with Amelogen Microfill: PMQ/A-Mi, Ultradent; O-FL combined with Prodigy: O-FL/Pro, Kerr) per patient and evaluated at baseline, after six months, one year, two years and three years of clinical service. After three years, the retention rate was 100% for O-FL/Pro and 98% for both PMQ/A-Hy and PMQ/A-Mi, thereby, satisfying the "full acceptance" guidelines specified by the American Dental Association. A pairwise comparison showed no significant difference in adhesive performance between restorations made using the microfilled and hybrid composite for any evaluation criteria ($p>0.05$).

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INTRODUCTION

Adhesive technology in dentistry evolves at a rapid rate, resulting in a high turnover of products. As a con-

sequence, today's adhesive materials are commercialized, often without sufficient proof of their clinical performance. The major reason is that manufacturers often introduce a new version of an adhesive before an ongoing study on a predecessor has been concluded, making materials quickly outdated. In addition, the current market drive towards adhesives with simplified application protocols forces manufacturers to release by preference "one-step," simplified adhesives that, so far, do not perform as well as conventional three-step systems in the laboratory (De Munck & others, 2003a; Van Meerbeek & others, 2003). Nevertheless, the ultimate test for adhesives is not their performance in the laboratory, but rather their performance in the clinical environment (Van Meerbeek & others, 1996b; Perdigão, 2002). Even good laboratory results are not per se a guarantee of clinical success (Browning, Brackett & Gilpatrick, 2000).

Today's most popular bonding method remains the "total-etch" or "etch & rinse" technique involving separate phosphoric acid etching of both enamel and dentin. The prime mechanism of etch & rinse adhesion is based on micro-mechanical interlocking (Buonocore, 1955; Nakabayashi, Kojima & Masuhara, 1982; Van Meerbeek & others, 1992, 1993b; Inokoshi & others, 1993). At enamel, selective dissolution of hydroxyapatite through etching is followed by *in situ* polymerization of resin; thereby, enveloping individually exposed hydroxyapatite crystals. This is still the most effective approach to predictably achieving stable bonding to enamel (Van Meerbeek & others, 2001; 2003). At dentin, bonding is obtained through hybridization, which results from infiltration and *in situ* polymerization of resin within a collagen fibril scaffold exposed by phosphoric-acid etching. At the same time, the opened dentinal tubules are sealed with resin tags, which, through hybridization in the tubule walls, also help to counteract debonding forces (Van Meerbeek & others, 2001; 2003).

While clinical retention is usually no longer a problem, none of the current adhesives appear capable of completely eliminating marginal leakage, at least in the long-term (Perdigão & Swift, 1994; Van Meerbeek & others, 2001; 2003). The dynamic nature of dentin as a substrate should first be regarded as responsible for inconsistent and unstable bonding. This, to a large extent, causes clinical problems commonly associated with adhesive restorations, as there are postoperative sensitivity, marginal staining and, eventually, possibly recurrent caries. Consequently, rapidly deteriorating margins remain the major reason to replace adhesive restorations, thus, substantially reducing their clinical longevity (Perdigão, 2002; Van Meerbeek & others, 2003). Furthermore, still regarded as one of the most significant factors affecting adhesion to tooth tissue at an early stage is the incapacity of adhesives to effectively deal with the detrimental effects of polymerization shrinkage of the restorative composite (Carvalho & others, 1996; Alani & Toh, 1997). A sufficiently thick, flexible adhesive layer has therefore been suggested to serve as a shrinkage-stress absorber, preventing debonding of the tooth-resin bond following an "elastic bonding concept" (Kemp-Scholte & Davidson, 1990; Van Meerbeek & others, 1993c; Frankenberger & others, 2002). Also, and in particular with regard to Class V restorations, studies point to cyclic compression and tensile stress produced at restoration-tooth interfaces by flexure of the tooth during natural function. This factor has been shown to promote marginal leakage or even dislodgement of the restoration (Grippo, 1991a,b; Heymann & others, 1991; Van Meerbeek & others, 1993a). Therefore, utilization of more flexible restorative materials (with low stiffness) has been suggested as helping to absorb such tooth-flexure stress.

This study evaluated the clinical effectiveness of two three-step etch & rinse adhesives. In order to exclude any macro-mechanical retention, the adhesives were used along with resin composite to restore non-carious cervical lesions with incisal enamel and cervical dentin borders. The testing of both adhesives provided a particle–filled adhesive resin that was expected to function as an intermediary stress breaker between the shrinking composite and the rigid cavity wall. In addition, one of the adhesives was employed with two different restorative composites that had contrasting stiffness. The authors hereby tested the hypothesis that a microfilled composite with higher intrinsic flexibility better withstands tooth flexure forces compared to a small-particle hybrid composite with less elastic capacity but better physico-mechanical properties. The other adhesive/composite combination served as the control ("golden standard"), since it presented in laboratory research consistently with high bonding effectiveness (Inoue & others, 2001, 2003; Van Meerbeek & others, 2001, 2003).

METHODS AND MATERIALS

Selection Criteria

Seventy-five subjects were enrolled in the study and were non-hospitalized patients recruited from the university hospital. All were in need of cervical restorations. Patients with compromised medical history, severe or chronic periodontitis, extreme caries sensitivity and heavy bruxism were excluded from the study. The Commission for Medical Ethics of the Catholic University of Leuven approved the clinical trial protocol. Prior to participating in the study, all patients signed a written consent. Essentially, the teeth were randomly assigned for restoration with 1) the three-step etch & rinse adhesive PermaQuick (Ultradent, South Jordan, UT, USA: PMQ) combined with the small-particle hybrid composite Amelogen Hybrid (Ultradent: PMQ/A-Hy), 2) PermaQuick (Ultradent)

Table 1: *Adhesives Investigated in the Study*

Code	Adhesive	Manufacturer	Components and Composition	Application Procedure
PMQ	PermaQuick	Ultradent, South Jordan, UT, USA	**Etchant:** 35% phosphoric acid, thickener	Apply etchant onto the surfaces and leave for 15 seconds; Thoroughly rinse and gently air dry; Scrub primer for 15 seconds; Gently air dry for 2 seconds; Light cure for 20 seconds;
			Primer: Canadian balsam, HEMA, ethanol	
			Adhesive: Bis-GMA, HEMA, filler[1]	Apply a coat of bonding resin onto primed surface; Gently air thin; Light cure for 20 seconds.
O-FL	OptiBond FL	Kerr, Orange, CA, USA	**Etchant:** 37.5% phosphoric acid, silica thickener **Primer**: HEMA, GPDM, PAMM, ethanol, water, photoinitiator **Adhesive:** TEGDMA, UDMA, GPDM, Bis-GMA, filler[2], photoinitiator	Apply etchant for 15 seconds; Rinse thoroughly and gently air dry; Scrub primer for 15 seconds; Gently air dry; Apply a thin coat of adhesive; Light cure for 30 seconds.

Bis-GMA = bisphenol-glycidyl methacrylate; GPDM = glycerophosphoric acid dimethacrylate; HEMA = hydroxyethyl methacrylate; PAMM = phthalic acid monoethyl methacrylate; TEGDMA= triethylene glycol-dimethacrylate; UDMA= urethane dimethacrylate; 145% by weight, average film thickness of 20 µm; 248% by weight, mean particle size of 0.6 µm, average film thickness of 20 µm.

along with the microfilled composite Amelogen Microfill (Ultradent: PMQ/A-Mi) or 3) the three-step etch & rinse adhesive OptiBond FL (Kerr, Orange, CA, USA: O-FL) in combination with the small-particle hybrid composite Prodigy (Kerr: O-FL/Pro) that served as control (Table 1). Fifty restorations per adhesive were placed in cervical non-carious erosion/abrasion/abfraction lesions of incisives, canines and premolars. The restored lesions were categorized in terms of shape (wedge-sharp versus saucer-rounded), depth (<1 mm or >1 mm), cervico-incisal size (<1.5 mm, 1.5 mm-2.5 mm, >2.5 mm), degree of dentin sclerosis (none, slight, moderate, severe) and presence of attrition facets on the incisal edge or occlusal cusp. Only two restorations were placed in one patient, so that the per patient restorations prepared following two different experimental groups were mutually compared.

Restorative Procedure

Two specially instructed and experienced dentists from the university dental school performed the operative procedures. If needed to prevent patient discomfort during restorative procedures, local anesthesia was applied with 1.8 ml of 2% lidocain with 1:80,000 epinephrine (Lignospan 2%, Septodent, St-Maur, France). All restorative procedures were done under rubber dam isolation using the gingival retraction clamp Ivory 212 (Columbus Dental, St Louis, MO, USA). The tooth surface was first cleansed with slurry of pumice and water to remove the salivary pellicle and any remaining dental plaque. Tooth preparation included a short enamel bevel to increase surface area for bonding and enhance aesthetics. No lining material was applied. Lesions were restored according to manufacturer's instruction (Table 1). The respective composite was inserted in two or three increments to reduce polymerization shrinkage effects and achieve effective setting upon curing using an Optilux light-curing unit (Demetron-Kerr). Finishing and polishing was accomplished using pine tree-shaped contouring diamonds (Komet, Lemgo, Germany), rubber points (Eve, Ernst Vetter, Pforzhein, Germany), flexible discs and finishing strips (Sof-Lex Pop-On set, 3M, St Paul, MN, USA).

Evaluation Criteria and Procedures

Restorations were examined at baseline, after six months and one, two and three years of clinical service for retention, marginal integrity, clinical microleakage, caries recurrence, preservation of status of tooth vitality and postoperative sensitivity. All parameters were recorded using a modified index system introduced by Vanherle and others (1986). Color slides were made pre-operatively at baseline and at each recall. Epoxy replicas were made from selected cases and examined using field-emission scanning electron microscopy (Philips XL30 Feg, Eindhoven, The Netherlands). Two examiners carried out all evaluations using the predetermined set of criteria (Vanherle & others, 1986). The evaluators were blinded to the material used in any given restoration. Any discrepancy between evaluators was resolved at chairside. Clinical effectiveness was determined in terms of the above mentioned parameters, of which retention, marginal integrity and clinical microleakage were considered key parameters determining the overall parameter "clinical success rate."

Statistical Analysis

Statistical analysis compared on a pair-wise basis the ratings of retention, perfect marginal integrity and absence of clinical microleakage among the experimental groups using the McNemar test at a significance level of 5% ($p<0.05$).

RESULTS

Table 2 summarizes the clinical data for the diverse parameters evaluated. Major parameters such as retention rate, perfect marginal integrity, absence of

Table 2: *Clinical Results for the Different Parameters Evaluated in Percentage*

Recall	Experimental Group	Recall Rate	Retention Rate	Perfect Marginal Integrity	Enamel Margin Defects	Small Enamel Margin Defects	Severe Enamel Margin Defects	Dentin Margin Defects	Small Dentin Margin Defects	Severe Dentin Margin Defects	Absence of Clinical Microleakage	Superficial Localized Margin Dislocation	Deep Generalized Restoration Dislocation	Absence of Sensitivity	Mild Sensitivity	Severe Sensitivity	Absence of Caries Recurrence	Preservation of Tooth Vitality	Clinical Success Rate
6 months	**PMQ/A-Hy**	100	**100**	51	28	26	2	32	32	0	**98**	2	0	87	13	0	100	100	**98**
	PMQ/A-Mi	100	**100**	50	27	27	0	38	38	0	**96**	4	0	92	8	0	100	100	**100**
	O-FL/Pro	100	**100**	49	21	21	0	40	40	0	**98**	2	0	91	9	0	100	100	**100**
1 year	**PMQ/A-Hy**	100	**100**	53	26	24	2	32	32	0	**96**	4	0	87	13	0	100	100	**98**
	PMQ/A-Mi	100	**100**	45	36	36	0	32	32	0	**94**	6	0	92	6	2	100	100	**98**
	O-FL/Pro	100	**100**	47	19	19	0	38	38	0	**94**	6	0	89	11	0	100	100	**100**
2 years	**PMQ/A-Hy**	100	**98**	53	28	26	2	28	28	0	**91**	9	0	87	13	0	100	100	**96**
	PMQ/A-Mi	100	**98**	53	28	28	0	28	28	0	**81**	17	2	96	2	2	100	100	**94**
	O-FL/Pro	100	**100**	55	23	23	0	28	28	0	**91**	9	0	89	11	0	100	100	**100**
3 years	**PMQ/A-Hy**	96	**98**	51	16	14	2	33	33	0	**84**	16	0	89	11	0	100	100	**96**
	PMQ/A-Mi	100	**98**	51	23	23	0	34	34	0	**74**	22	4	96	2	2	100	100	**92**
	O-FL/Pro	96	**100**	69	18	18	0	16	16	0	**89**	9	2	100	0	0	100	100	**98**

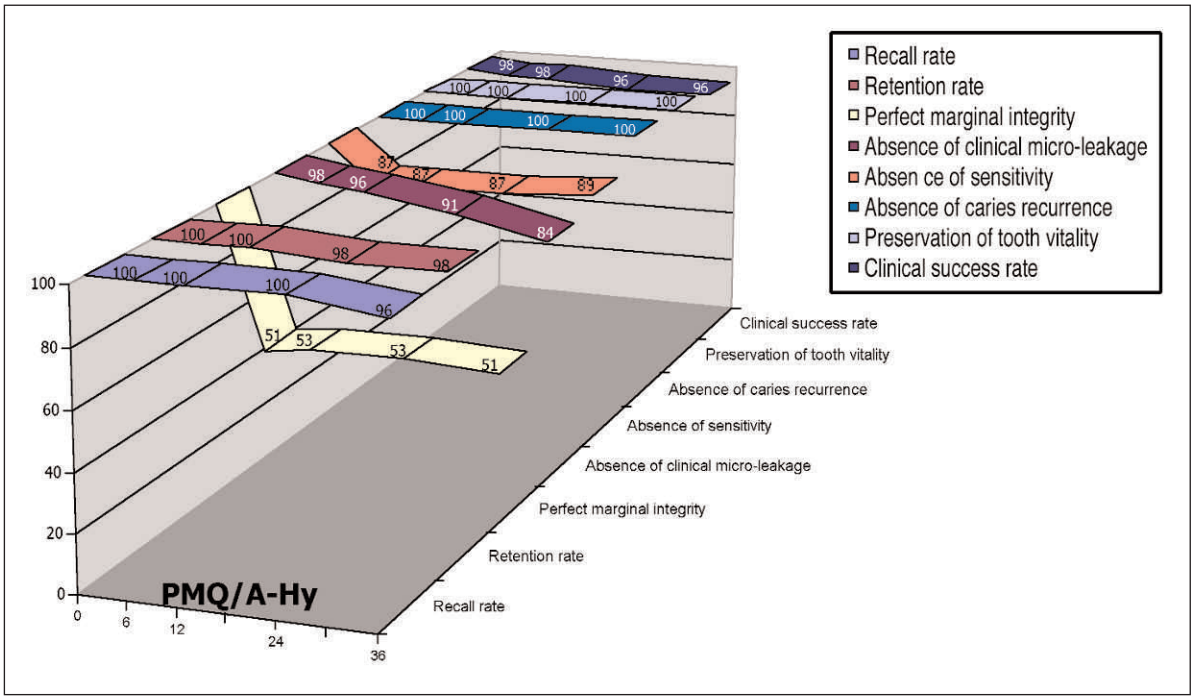

Figure 1. *Major parameters of PermaQuick adhesive with Amelogen Hybrid as a function of time.*

clinical microleakage, absence of sensitivity, absence of caries recurrence, preservation of status of tooth vitality and clinical success rate are depicted as a function of time for the three experimental groups in Figures 1 to 3, respectively. The recall rate was 96% or higher at the different recalls for each of the experimental groups. A 100% retention rate was recorded for O-FL/Pro during the three-year study period. One PMQ/A-Hy restoration and one PMQ/A-Mi restoration was lost at two years, resulting in a final retention rate of 98% for both PermaQuick experimental groups at three years. At this recall, there was, however, no significant difference in retention rate between both adhesives (p=0.5).

More pronounced differences among the three experimental groups were recorded with regard to marginal integrity (Table 2). At three years, the highest percentage of perfect marginal integrity was recorded for

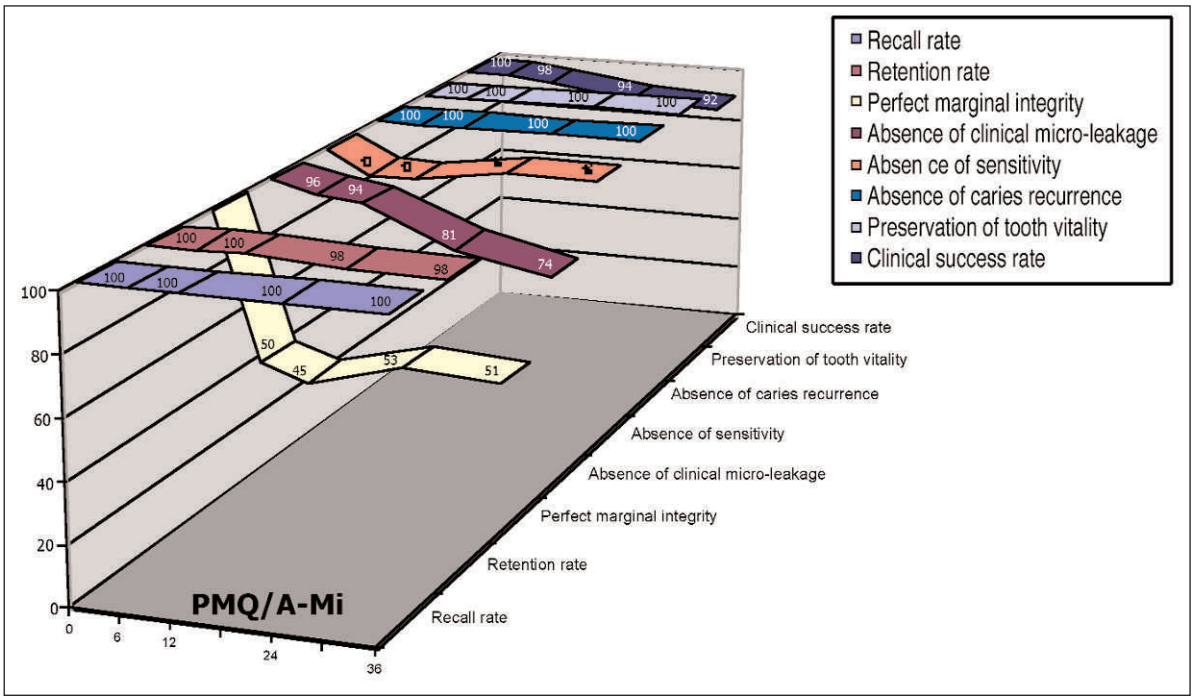

Figure 2. *Major parameters of PermaQuick adhesive with Amelogen Microfil as a function of time.*

O-FL/Pro (69%). Both PMQ/A-Mi (51%) and PMQ/A-Hy (51%) showed a higher incidence of marginal defects. However, no statistically significant difference could be observed when comparing the parameter "perfect marginal integrity" for both types of composite (PMQ/A-Hy versus PMQ/A-Mi; p=0.6875) or for both adhesives (PMQ versus O-FL; p=0.4545). For all three groups tested, most marginal defects were, however, small, either located at the incisal enamel margin or the cervical dentin margin. Only one severe enamel margin defect (2%) was already recorded for PMQ/A-Hy at the six-month recall. None of the restorations showed severe dentin margin defects during the study period. When the marginal integrity results were combined, both PMQ groups showed a higher percentage of detectable, but clinically acceptable margin defects compared to O-FL/Pro. In particular, both PMQ groups exhibited a higher percentage of small defects at the cervical dentin than at the enamel margin. OptiBond FL, however, showed nearly equal percentages of defects at both the enamel and dentin margin. Although PMQ/A-Mi restorations showed a greater incidence of margin defects than the PMQ/A-Hy restorations, the defects were small and clinically irrelevant.

With regard to clinical microleakage, the percentage of restorations showing no discoloration gradually decreased with time (Table 2). For all three experimental groups, clinical microleakage was mostly rated as superficial, localized discoloration. At three years, 9% of the O-FL/Pro restorations, 16% of the PMQ/A-Hy restorations and 22% of the PMQ/A-Mi restorations demonstrated superficial, localized margin discoloration. Only one O-FL/Pro restoration (2%) and two PMQ/A-Mi restorations (4%) exhibited deep, generalized restoration discoloration. These restorations were recorded to be clinically unacceptable and were replaced. The least clinical microleakage was noted for O-FL/Pro (89% absence of clinical microleakage). These observed differences in the parameter "absence of clinical microleakage" were also found not to be statistically significantly different when comparing both types of composite (PMQ/A-Hy versus PMQ/A-Mi; p=0.375) or both adhesives (PMQ versus O-FL; p=0.7266).

At the one-year recall, one PMQ/A-Mi restoration had to be replaced due to post-operative sensitivity. Caries recurrence was not observed in the three-year study period. No tooth became non-vital due to the cervical restoration. The overall three-year clinical success rate was excellent for O-FL/Pro (98%). Also, 96% and 92% of the PMQ/A-Hy and of the PMQ/A-Mi restorations, respectively, were rated as clinically successful at three years.

DISCUSSION

Non-carious mixed enamel/dentin Class V lesions were selected to test the clinical effectiveness of three adhesive/composite combinations in this study. Cervical lesions are regarded as the ideal cavities to test the clinical effectiveness of adhesives, because 1) they present no macro-mechanical undercuts, 2) they require at least 50% bonding to dentin, 3) when restored, they result in an enamel and dentin margin, 4) they are widely available, 5) they are usually found in anterior teeth or premolars with good access and 6) they have the worst long-term prognosis because of the high proportion of dentin margins and the high stress build-up in the cervical area (Van Meerbeek & others, 1998a,

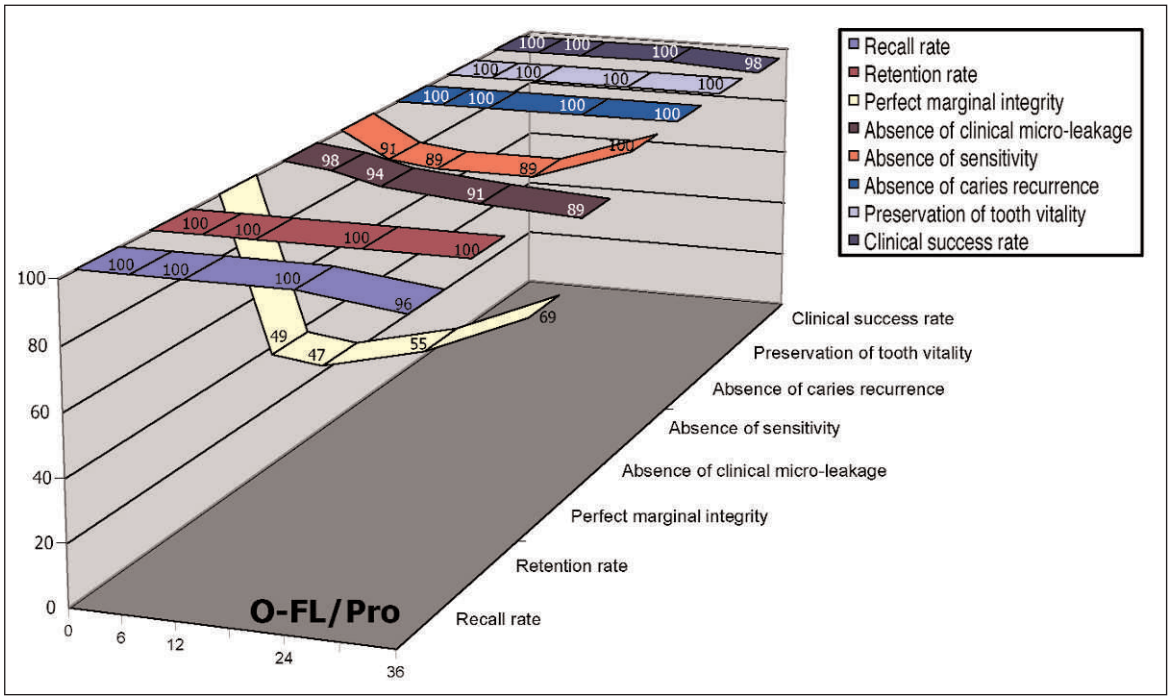

Figure 3. *Major parameters of OptiBond FL with Prodigy as a function of time.*

2003; Blunck, 2001). This clinical trial was randomized and the examiners were blinded to the adhesive/composite combination used per lesion and per patient. The split-mouth design involved placement of only two of the three adhesive/composite combinations per patient, and this was done in pairs of equal teeth (first and second premolar at the same side, left and corresponding right incisor, canine or premolar, respectively). Consequently, clinical effectiveness was pair-wise evaluated at the patient level, each time comparing two of the three experimental groups. OptiBond FL/Prodigy was chosen as the control adhesive/composite combination because of its repeatedly proven excellent performance in independent laboratory studies (Wakefield & others, 1998; Pilo & Ben-Amar, 1999; Jain & Stewart, 2000; Peschke, Blunck & Roulet, 2000; Inoue & others, 2001, 2003; Sahafi, Peutzfeldt & Asmussen, 2001; Van Meerbeek & others, 2001, 2003; De Munck & others, 2003a,b).

Although not statistically significantly different from the other experimental groups, O-FL/Pro revealed a 100% retention rate, the highest percentage of perfect marginal integrity and the least clinical microleakage after three years of clinical service (89% absence of clinical microleakage). In the laboratory, the conventional three-step etch & rinse adhesive O-FL often presented with the highest bond strength values among the diverse adhesives tested (Inoue & others, 2001, 2003; Van Meerbeek & others, 2001, 2003; Bouillaguet & others, 2002; De Munck & others, 2003a,b). This superior bonding effectiveness and resultant clinical performance in this study must probably, to a great extent, be attributed to optimal enamel interlocking and dentin hybridization as was demonstrated in several ultramorphologic interface analyses (Van Meerbeek & others, 1996a, 1998b, 2003). The conventional three-step protocol that guarantees a low technique-sensitive application procedure, the specific monomer/solvent cocktail of the primer solution (Table 1), the viscous solvent-free and glass-filled adhesive and other ingredients, such as an adequate polymerization initiator, may have contributed to this *in vitro* and *in vivo*, highly successfully and reliably performing adhesive. In the literature, there is only one publication that reported on the clinical effectiveness of O-FL. Boghosian (1996) reported 100% alpha for retention and 94% alpha for marginal integrity at two years of clinical service.

Also, PMQ is a three-step etch & rinse adhesive, on which, according to the literature, almost no clinical data has been published. Up to three years of clinical service, no difference in restoration retention of PMQ could be observed compared to O-FL. Only due to lower scores for marginal integrity and sealing (absence of clinical microleakage), has the clinical success rate of PMQ (96% for PMQ/A-Hy and 92% for PMQ/A-Mi) underscored O-FL/Pro (98%), though not statistically significantly different (p=0.2188). Burrow and Tyas (2001) reported a 93% retention rate for PMQ at two years, which, according to the authors, was in line with the clinical performance of other contemporary bonding systems.

The type of composite is thought to play an important role in the clinical longevity of cervical restorations. It has been hypothesized that microfilled composites, thanks to their lower stiffness (lower elastic modulus) and, thus, higher flexibility, can better relieve stress imposed by polymerization contraction or tooth flexure compared to hybrid composites that, due to a higher filler loading, are more stiff (higher elastic modulus)

and less flexible. The latter would less effectively dissipate stress by flow and therefore compensate less or not at all for the stress accumulated during polymerization (Heymann & others, 1991; Van Meerbeek & others, 1993a). Only in restorations where the flow of shrinking resin composite can relieve a significant part of the stress developed during polymerization will the restoration-tooth bond survive (Carvalho & others, 1996). Likewise, tooth-flexure effects would more easily be transmitted to the interface and cause detachment of the restoration (Heymann & others, 1991; Van Meerbeek & others, 1993c; Perdigão, 2002). It has been reported previously that microfilled composites with relatively low elastic moduli compress rather than dislodge during tooth flexure. Moreover, forces created by compressing the filling are localized within the mass of the composite as compressive stress and less as shear stress at the resin-tooth interface. However, when a stiffer composite such as a hybrid composite, is used, the shear stress at the adhesive interface could well exceed the compressive stress and, thus, act primarily on the integrity of the weakest bond, that to dentin. Based on those findings, microfilled resin composites with their inherently high elasticity and flow reservoir were recommended as the materials of choice for restoring cervical Class V restorations (Van Meerbeek & others, 1993a). McCoy and others (1998), for instance, speculated that failure of restorations placed using the three-step etch & rinse adhesive All-Bond 2 (BISCO, Schaumburg IL, USA), combined with the hybrid composite Z100 (3M ESPE) at two years, might be due to the cumulative effects of occlusal stress over time, as Z100 is a very stiff material. However, at that time adhesives were not that good as today, and their conclusions were drawn when comparing the clinical effectiveness of diverse adhesive/composite combinations in cervical lesions. Consequently, many clinical co-variables must have played at the same time, so that one could not be sure that the flexibility of the composite was the sole factor involved. In this study, the two experimental groups only differed in the kind of composite employed. The microfilled composite Amelogen Microfill was measured to have an elastic modulus of 6.9 GPa versus 14.7 GPa for Amelogen Hybrid (elastic modulus measurement following Braem & others, 1986). Despite this difference in stiffness, no higher retention rate was recorded with PMQ/A-Hy compared with PMQ/A-Mi. This indicates that when using three-step etch & rinse adhesives, there is no significant difference in clinical behavior between high- and low-stiffness composites in non-carious Class V lesions (at least up to three years of clinical service), by which the hypothesis advanced was rejected. Browning and others (2000) also reported almost identical two-year retention rates when Scotchbond Multi-Purpose was used in combination with the microfilled composite Silux Plus (3M ESPE), having an elastic modulus of 9.5 GPa, or with the hybrid composite Z100 (3M ESPE), having a high elastic modulus of 21.0 GPa (elastic modulus data gathered from Willems & others, 1992 and measured following the above mentioned non-destructive methodology by Braem & others, 1986). In a similar study conducted by Tyas and Burrow (2001), similar retention rates were recorded for the hybrid composite Estio LC (GC, Tokyo, Japan) and the microfilled composite Silux (3M ESPE) when used in combination with the resin-modified glass ionomer adhesive Fuji Bond LC (GC). They also concluded that there was no association between elastic modulus of the composite and restoration loss rate. Also, in this study, no restorations were lost when they were placed using O-FL combined with the hybrid composite Prodigy, which has an elastic modulus of 13.9 GPa (measured following the methodology by Braem & others, 1986).

Altogether, the retention rates of the two adhesives applied following the three experimental protocols exceeded the 90% retention rate at the 18-month recall required by the ADA guidelines to acquire "full acceptance" (Council on Dental Materials, Instruments and Equipment. Revised American Dental Association acceptance program guidelines for dentin and enamel adhesive materials, 1994). As mentioned before, retention is no longer a problem, at least when the restorations are bonded using conventional three-step etch & rinse adhesives. Also, with regard to clinical microleakage, both adhesives easily met the second ADA requirement (less than 10% generalized, deep discoloration at 18 months) to be "fully" accepted. However, without restoration loss, marginal sealing might get compromised and lead to undesirable clinical consequences. Indeed, in all experimental groups, several restorations exhibited discoloration as a sign of clinical microleakage, and the percentage of restorations exhibiting clinical microleakage clearly increased over the three-year observation period.

As some authors suggested in the past (Folwaczny & others, 2000), despite marginal gap formation, an excess or deficiency of the filling material may also contribute to the occurrence of marginal discoloration. In fact, the formation of margin deficiencies is commonly the result of a multi-factorial process. Dimensional changes of the overlying composite restoration caused by polymerization shrinkage, water-sorption and thermal effects will primarily affect restoration marginal integrity (Alani & Toh, 1997; Heymann & others, 1988, 1991). As mentioned above, stress produced by flexure of the tooth during natural function also facilitates microleakage (Heymann & others, 1991). Tooth flexure has been described as either a lateral bending or an axial bending of a tooth during occlusal loading, producing maximal strain in the cervical tooth area (Lee & Eakle, 1984). This may eventually also lead to rupture of the bond between the tooth and restorative material,

especially if the restoration does not flex in the same way as the tooth (Browning & others, 2000). In this regard, microleakage of Class V resin composite restorations was reported to significantly increase when the restorations were subjected to occlusal stress (Pilo & Ben-Amar, 1999). When occlusion is not ideal, significant lateral forces that can cause bending of the tooth and create two types of stress at the cervical tooth structure, are generated. The first is compressive stress, located primarily on the side in which the tooth is being bent; the second type is a tensile force that acts on the side away from the bending (Unterbrink & Liebenberg, 1999). This twofold stress production has been hypothesized to underlie the occurrence of so-called "abfraction" lesions (Lee & Eakle, 1984; Grippo, 1991a,b; Braem, Lambrechts & Vanherle, 1992; Rees, 1998; Geramy & Sharafoddin, 2003). Class V restorations placed in such stress-induced lesions are subject to identical tensile stresses, thus, compromising their marginal integrity and bond durability. A high correlation was shown to exist between the stiffness of the restorative composite and marginal leakage (Kemp-Scholte & Davidson, 1988). This study found that cervical gaps increased in number and size when a composite with high stiffness was used. In this study, no difference in perfect margin integrity was observed when PMQ was combined with either the low or high stiffness composite. Although not statistically significantly (p=0.375) different, PMQ combined with the microfilled composite revealed a higher incidence of clinical microleakage than when combined with the hybrid composite. In a Class III study, van Dijken and Horstedt (1987) reported more and severe marginal defects at microfilled composite fillings than at hybrid composite fillings. Thus, they suggested that greater polymerization shrinkage of microfilled composites in combination with a higher coefficient of thermal expansion might have resulted in more defects.

Also noteworthy is that both PMQ/A-Hy and PMQ/A-Mi exhibited a higher percentage of cervical dentin than incisal enamel defects. O-FL/Pro, however, showed equal percentages of defects at both incisal and cervical margins. This finding, together with the higher percentage of perfect margin integrity at three years (as compared to both PMQ experimental groups), demonstrates that overall O-FL is clinically more effective at restoring mixed enamel/dentin cervical lesions, as was also found by Pilo and Ben-Amar (1999).

A special note should be included to explain the unexpected increase in the percentage of "perfect marginal integrity," with time, especially for O-FL/Pro, while this parameter remained more or less stable for both PMQ groups. This effect can be due to improved marginal adaptation with time due to a polishing effect (by toothbrush) and/or the chipping of filling overhangs that resulted in better marginal adaptation. However, this effect was also more likely caused by a less severe evaluation at later recalls of what is recorded as a restoration with a "perfect marginal integrity," rather than with a "small marginal defect." The recorded, improved marginal integrity should be ascribed to a lower prevalence of small defects, particularly at the dentin margin. It should also be emphasized that these defects are small in the sense that they can hardly be spotted by the naked eye, but can only be sensed by moving a relatively sharp probe under light pressure across the restoration-tooth margin. These defects did not require any repair and, therefore, should actually be regarded as being of clinically negligible relevance. Furthermore, as each recall was done blind and per patient and a pair of restorations belonging to two different experimental groups was always evaluated, all the experimental groups have been evaluated using the same set of criteria applied with the same degree of severity (however, that apparently was not the same at the different recalls). Taking the latter explanation into account, the apparently improved marginal integrity of O-FL/Pro versus the more stable marginal integrity of PMQ/A-Hy and PMQ/A-Mi confirms the markedly better marginal adaptation of O-FL/Pro compared to both PMQ groups.

Another factor that may have contributed to the excellent clinical performance of both adhesives is the particle-filled adhesive resin provided with both O-FL and PMQ. Due to the inherent high viscosity, such adhesives are typically applied in a relatively thick layer. As mentioned above, besides improved mechanical properties and reduced polymerization shrinkage, a relatively thick adhesive layer may act as a stress breaker between the shrinking resin composite and the rigid tooth substrate following the "elastic bonding concept" (Kemp-Scholte & Davidson, 1988; Van Meerbeek & others, 1993c; Perdigão & others, 1996; Alomari, Reinhardt & Boyer, 2001; Armstrong, Keller & Boyer, 2001). The hybrid layer generated as the major bonding mechanism pursued by most adhesives may also function as a stress-relaxation layer, since it has a lower stiffness than the underlying mineralized dentin (Van Meerbeek & others, 1993c). However, this zone is not as wide as the adhesive resin layer; as a result, it must play a significantly smaller role in relieving interfacial stress and maintaining marginal integrity when compared to the low-viscosity resins (Van Meerbeek & others, 1993c). Many studies have also reported that adding filler to the resin adhesive had provided significant clinical benefits, especially with regard to preserving marginal integrity (Van Meerbeek & others, 1993a; Boghosian, 1996; Swift & others, 2001). Consequently, the excellent results found in this study may also be partially due to using particle-filled adhesives.

Other evaluation criteria, such as caries recurrence, aesthetics, gingival response, tooth vitality and postoperative sensitivity, were all rated satisfactory. Other

clinical co-variables described as affecting adhesion to tooth tissue include patient age, dentin sclerosis, lesion size and shape, tooth type, enamel and dentin structure, tooth location and stressful occlusion, among others (Bayne & others, 1991; Van Meerbeek & others, 1998a). The clinical failure rates in this study were so low that no correlation could be made between these co-variables and retention failures.

CONCLUSIONS

During this three-year clinical trial, the performance of the three adhesive/composite combinations was excellent. A pair-wise comparison showed no significant difference in clinical effectiveness between the two three-step etch & rinse adhesives, or when a rather stiff or more flexible composite was used to restore non-carious cervical lesions. Long-term recalls are planned to determine if a difference in clinical performance among the three experimental groups will occur at later restoration ages.

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Analysis of Longitudinal Marginal Deterioration of Ceramic Inlays

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Clinical Relevance

Longitudinal marginal deterioration of fired ceramic inlays progressed in a sequential three-stage pattern.

SUMMARY

This study quantitatively and morphologically analyzed and clarified the longitudinal marginal changes of ceramic inlays and determined the mechanism for those changes. Epoxy replicas of 15 Class II ceramic inlays in permanent premolars prepared at baseline, 6, 12, 24, 48, 72 and 96 months after placement were selected. A CCD optical laser scanner was employed to measure quantitative changes in the occlusal surfaces of restored teeth. Longitudinal cross-sections of marginal areas of a ceramic inlay were computed, and two profiles of the same location obtained at different periods were superimposed using software. The area enclosed by the two profiles obtained at different periods was defined as the quantitative marginal change, and both the area and maximum depth in the area enclosed were calculated with picture analysis software. The marginal deterioration pattern was analyzed by drawing a longitudinal curve of quantitative change for each restoration. Morphological observation was carried out by scanning electron microscopy at magnifications from 20x to 75x. Quantitative measurement and morphological observation identified a sequential three-stage pattern of marginal deterioration; initial rapid progress of wear of resin composite cement in the first stage, followed by a second stage without any remarkable visible change, then rapid progression of microfractures of ceramics and/or enamel in the third stage. Boundaries between the first and second stage were found in the six and 21-month period, and those between the second and third stage at 72 months. It was concluded that longitudinal marginal deterioration of fired ceramic inlays progressed in a sequential three-stage pattern.

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INTRODUCTION

Marginal deterioration of ceramic inlays has been observed over time in clinical situations (Pallesen & van Dijken, 2000; Frankenberger, Petschelt & Kramer, 2000; Kramer & Frankenberger, 2000). The likelihood

of marginal deterioration from eight to 10 years after placement has been reported to range from 80% to 96% (Pallesen & van Dijken, 2000; Hayashi & others, 2000; Reiss & Walther, 2000). Such marginal deterioration should be urgently addressed, since deterioration can cause a catastrophic bulk fracture of the restoration (Hayashi & others, 2000).

Understanding the mechanism of marginal deterioration is important to improving the durability of ceramic inlays, and accurate measurement of the longitudinal quantitative change is necessary to clarify the mechanism of *in vivo* marginal deterioration. However, a few studies have investigated quantitative marginal change of ceramic inlays *in vivo* (Peters & others, 1999; Roulet & others, 1997).

The purpose of this ongoing series of studies has been to clarify the mechanism of marginal deterioration of ceramic inlays. The initial investigation, as reported in the previous paper (Hayashi & others, 2004), established quantitative, non-destructive methods of measuring marginal deterioration of ceramic inlays using an accurate CCD optical laser scanner system. The accuracy of the system developed was confirmed to be 4.3 μm in distances measured and 2.0% in areas and was comparable to other measuring methods (Lugassy & Moffa, 1985; Taylor & others, 1990; Bayne & others, 1994; Delong, Pintado & Douglas, 1985; Mehl & others, 1997). In this study, the longitudinal pattern of marginal deterioration of ceramic inlays was analyzed quantitatively using the CCD scanning system, and morphologically using scanning electron microscopy (SEM). These analyses revealed details of the process of long-term marginal deterioration.

METHODS AND MATERIALS

Teeth Evaluated

Epoxy replicas of 15 Class II ceramic inlays in permanent premolars were employed for quantitative measurement and morphological observation of marginal deterioration. Table 1 summarizes distribution of the teeth evaluated. Ceramic inlays fabricated with a feldspathic porcelain system (G-Cera Cosmotech II, GC Co, Tokyo, Japan) were placed in 12 patients using a dual-cured resin composite cement (G-Cera Cosmotech II Composite, GC Co) as reported previously (Hayashi & others, 1998). Replicas obtained at baseline, 6, 12, 24, 48, 72 and 96 months after placement were subjected to the analyses.

Table 1: *Distribution of Teeth Evaluated*

	First premolar	Second premolar	Total
Upper premolar	5	2	7
Lower premolar	2	6	8
Total	7	8	15

Quantitative Measurement

Details of the quantitative measurements of the marginal disintegration have been described previously (Hayashi & others, 2004). However, brief comments are needed.

Preparation of a Specimen

Since the accurate positioning of the replicas obtained at different reviews of the restorations was essential for a precise analysis, a special apparatus was developed. A replica made at baseline was secured in a metal frame and a guide pattern was made with pattern resin (Pattern Resin, GC Co) for exact positioning of the specimens. Longitudinal replicas obtained at different times were placed in the metal frame guided by the pattern resin, and impressions of the occlusal surfaces of the restorations at the different time periods were taken with a polyvinylsiloxane impression material (Exafine, GC Co). The occlusal surfaces of impressions from different replicas secured in exactly the same position were used for quantitative measurement. With this accurate positioning technique, superimposition of occlusal cross sections of the replicas obtained in different time periods was possible.

3-D Quantitative Measurement

The measuring devices that consisted of a CCD laser displacement meter (LE-4000, Keyence Co, Osaka, Japan), an x-y stage (Mark-201/MSG-552, Sigma Koki Co, Tokyo, Japan) with an electric stage controller (Mark-201/MSG-552, Sigma Koki Co) and a personal computer (Mebius PC-PJ2, Sharp Co, Tokyo, Japan) were used for the 3-D morphological measurements. The morphological measurement of a marginal area was conducted at a 200 μm interval across a margin of the restoration over a width of 2500 μm at a measuring speed of 2000 μm/second. A 3-D occlusal surface was then constructed from a series of line profiles.

Superimposition of Profiles

From the 3-D occlusal surface that was constructed, two profiles of the same location obtained at different periods were superimposed using graphics software (Excel 97, Microsoft, Redmond, WA, USA). The area enclosed by the two profiles was defined as the quantitative marginal change, and both the area and maximum depth in the area enclosed were calculated with picture analysis software (NIH image1.61, NIMH, Bethesda, MD, USA).

Morphological Observation

Longitudinal morphological observation was carried out by means of a SEM (S-2100B, Hitachi Ltd, Tokyo, Japan) under magnifications from 20 to 75. Three characteristics were evaluated: wear of resin cement, wear and/or microfracture of enamel or ceramics and any visible fractures.

Analysis of Marginal Deterioration Mechanism

The marginal deterioration pattern was analyzed by drawing a longitudinal curve of quantitative marginal change for each restoration. Then, the longitudinal marginal deterioration pattern was confirmed by synthesizing the findings of the quantitative and morphological analyses.

Statistical Analysis

The marginal changes were compared in terms of location of the margin using the Wilcoxon signed-ranks test at a 95% level of confidence.

RESULTS

Quantitative Measurement

Eight-year longitudinal marginal deterioration, as presented by areas and maximum depths, is summarized in Table 2. A total of 285 measurements (157 in functional cusp areas and 128 in non-functional cusp areas) were made at eight years. The average number of measuring areas per tooth was 21. Differences in the marginal deterioration presented by areas and the maximum depth between functional and non-functional cusp areas became statistically significant at eight years after placement (Wilcoxon signed-ranks test, $p<0.05$).

The marginal deterioration pattern was confirmed by drawing a longitudinal curve of quantitative marginal change for each restoration. The longitudinal results in 13 of the 15 restorations presented by the areas identified a deterioration pattern consisting of three sequential stages; the initial rapid progress of deterioration in the first stage, followed by a second stage, then a recommencement of rapid deterioration in the third stage. The remaining two restorations showed a two-stage pattern consisting of the first and second stages. Figure 1 shows two types of sequential patterns of longitudinal marginal deterioration presented by the areas. Curves were generated by calculating the means of all the values measured at every observation period for each type of deterioration pattern. Boundaries between the first and the second stages were found in

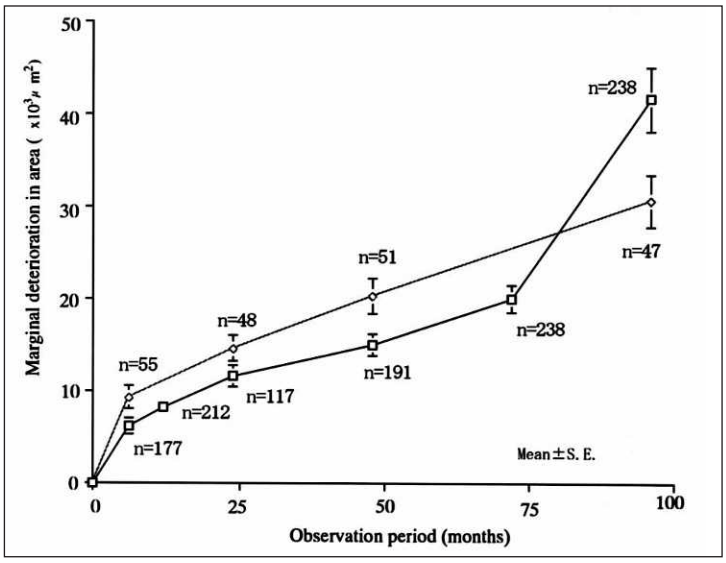

Figure 1. *Longitudinal marginal deterioration presented by area. Two types of deterioration patterns were observed (—□— : three-stage pattern in 13 restorations, —◇— : two stage pattern in two restorations).*

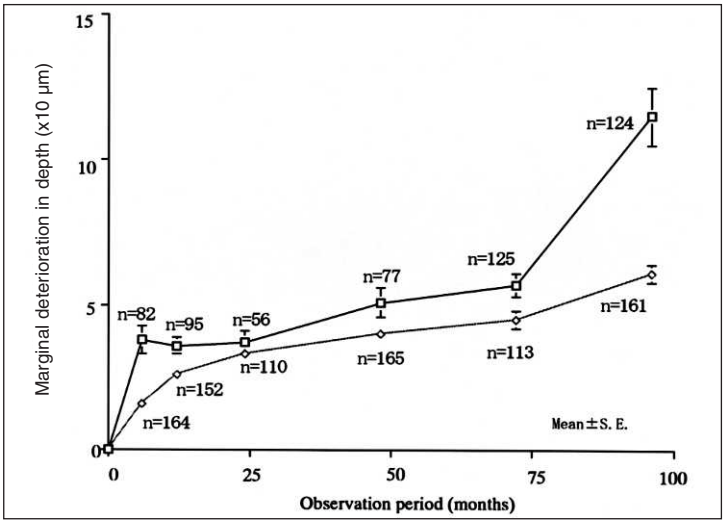

Figure 2. *Longitudinal marginal deterioration presented by depth. Two types of deterioration patterns were observed (—□—: three-stage pattern in seven restorations, —◇— : two stage pattern in eight restorations).*

Table 2: *Eight-year Marginal Deterioration of Class II Ceramic Inlays*

Observation Period	6 Months		12 Months		24 Months		48 Months		72 Months		96 Months	
Tooth type and areas measured		(n)		(n)		(n)		(n)		(n)		(n)
Presented by area (Unit: 10^3 μm²)												
Premolars	7 ± 1	(231)	9 ± 1	(247)	13 ± 1	(166)	16 ± 1	(242)	20 ± 1	(238)	40 ± 3	(285)
Functional cusp area	5 ± 1	(130)	8 ± 1	(127)	11 ± 1	(85)	16 ± 2	(121)	21 ± 3	(143)	50 ± 5	(157)
Non-functional cusp area	9 ± 1	(101)	11 ± 1	(120)	14 ± 1	(80)	16 ± 1	(121)	19 ± 2	(95)	28 ± 2	(128)
Presented by depth (Unit: 10x μm)												
Premolars	2 ± 0.2	(231)	3 ± 0.2	(247)	3 ± 0.2	(166)	4 ± 0.2	(242)	5 ± 0.3	(238)	8 ± 0.5	2(285)
Functional cusp area	2 ± 0.2	(130)	3 ± 0.3	(127)	3 ± 0.3	(85)	4 ± 0.3	(121)	5 ± 0.3	(143)	10 ± 0.8	2(157)
Non-functional cusp area	3 ± 0.4	(101)	3 ± 0.3	(120)	4 ± 0.3	(80)	5 ± 0.3	(121)	6 ± 0.4	(95)	7 ± 0.4	3(128)

Mean±S.E.
The groups connected with lines showed significant differences at a 95% level of confidence by means of the Wilcoxson signed-ranks test.

Table 3: *Longitudinal Morphological Changes of Marginal Areas*

Observation Periods	First Stage (0-21 months)				Second Stage (22-72 months)				Third Stage (73-96 months)			
Ratings of Evaluation Characteristics of Marginal Deterioration	_	±	+	++	_	±	+	++	_	±	+	++
Wear of resin cement	5	6	4	0	1	1	13	0	0	0	8	7
Wear and/or microfracture of enamel	15	0	0	0	6	8	1	0	0	9	4	2
Wear and/or microfracture of ceramics	15	0	0	0	6	7	2	0	0	8	5	2

The results of morphological observation were evaluated with four ratings : -; no change, ±; superficial change observed by SEM under magnification of 20x, +; substantial defect observed by SEM under magnification of 20x, ++; visible change.

the six to 12 month periods in 10 of the 15 restorations, while they were in the 17 to 21 month periods in the remaining five restorations. Boundaries between the second and third stages were found at 72 months in all 13 of the restorations that presented the three-stage pattern.

The results, as presented by maximum depths, indicated that seven of the 15 restorations showed the sequential three-stage pattern, as in the results presented by the areas, while the remaining eight showed the two-stage pattern (Figure 2). Boundaries between the first and second stages were found in the six-to-12 month period in nine restorations and in the 17-to-21 month period in the remaining six restorations. Boundaries between the second and third stages were found at 72 months in all seven restorations that showed a three-stage pattern.

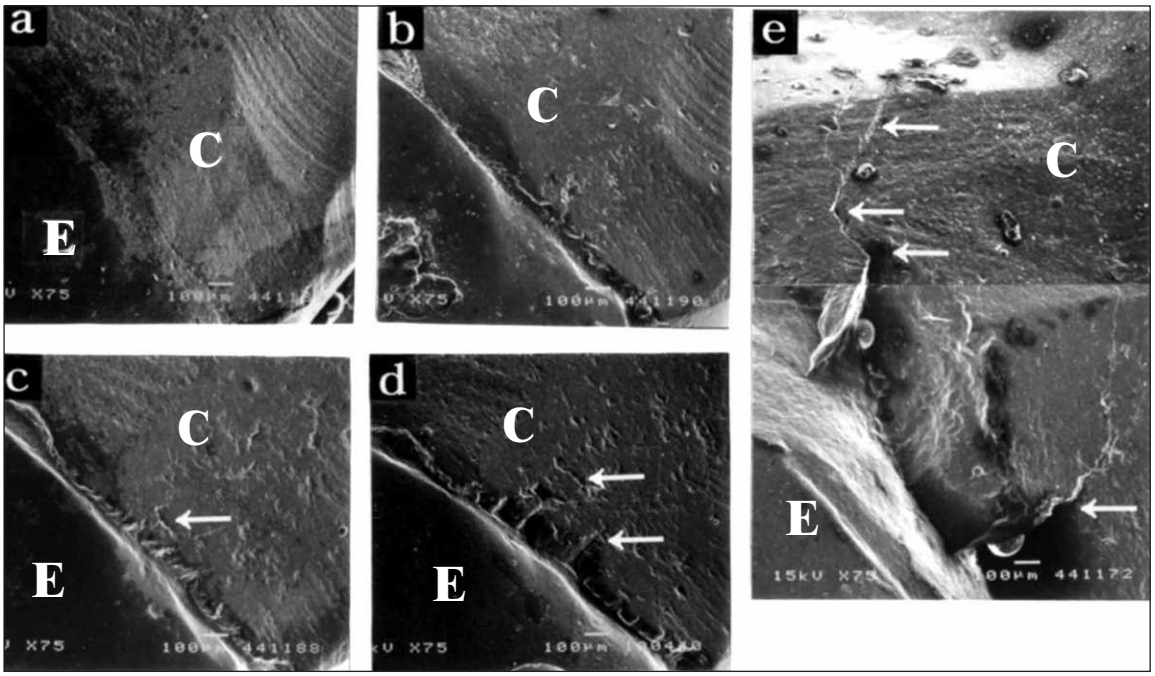

Figure 3. *Longitudinal deterioration of palato-occlusal margin of a Class II ceramic inlay in a left upper first premolar: a) Smooth margin was observed one month after placement. b) Wear of resin composite cement was detected six months after placement in the first stage. c) Microfracture was first observed 24 months after placement in the second stage. d) Crack propagation was detected in microfractured area 48 months after placement in the later second stage. e) The microfracture proceeded to a macroscopic fracture and visible crack propagation was found 96 months after placement in the third stage. C: ceramics, E: enamel.*

Morphological Observation

Table 3 summarizes the morphological changes. In two-thirds of the restorations, wear of the resin cement was initiated in the first stage, while no morphological changes in enamel or ceramics were found. In the second stage, wear of the resin cement progressed in most restorations, and superficial changes in enamel and ceramics were detected in approximately half of the restorations. In the third stage, deterioration was found in all restorations in the three characteristics observed. Wear of the resin cement was apparent in all restorations, and wear in half of the restorations became visible. Substantial visible defects in enamel or ceramics were found in approximately half of the restorations. Among those, marginal fractures in enamel and ceramics in the same two restorations needed repair.

Figure 3 presents typical longitudinal morphological changes.

DISCUSSION

In the previous study, a non-destructive measuring method of the quantitative marginal deterioration of ceramic inlays by means of a CCD laser system was developed (Hayashi & others, 2004). In this study, the mechanism of longitudinal marginal deterioration of ceramic inlays was analyzed quantitatively by means of the CCD laser system and morphologically used a SEM.

The marginal deterioration, as presented by the areas, showed the sequential three-stage pattern in most of the 15 restorations. Only two restorations showed the two-stage pattern. While eight of the 15 restorations showed the two-stage pattern, it was presented by maximum depths. There were restorations that were categorized differently based on areas and maximum depths. These diversities may be explained by the differences in detectability between the two presentation methods and by the longitudinal pattern of morphological change. In the early part of the first stage, the wear of the resin composite cement proceeded in both the horizontal and vertical directions. After initial wear of the resin composite cement, marginal ridges of enamel or ceramics were revealed. Then, microcracks that began to propagate surrounding the marginal ridges were observed. Such fragile ridges, which tended to chip off by direct occlusal force, fractured in an invisible range. When these substantial changes proceed in a horizontal direction within the depth of the initial wear of the resin composite cement, marginal deterioration could not be detected by changes in maximum depths but could be detected by those in the cross sectional areas. It could, therefore, be concluded that the marginal changes presented by the cross-sectional areas were of a more sensitive, accurate method than that presented by maximum depths. Hence, marginal deterioration presented by cross sectional areas was employed for analysis of the deterioration mechanism in this study.

The quantitative and morphological analyses clarify the mechanism of longitudinal marginal deterioration. Marginal deterioration in an area over a period of eight years was confirmed as following a sequential three-stage pattern in 13 of the 15 restorations. In the first stage, where quantitative marginal deterioration progressed rapidly, the resin composite cement deteriorated initially. Then, the deterioration slowed in the second stage, in which the initial wear of the composite cement had been almost completed and the initial propagation of microcracks or microfractures of ceramics or enamel gradually progressed due to occlusal force. No remarkable change was detected in this stage, as these changes progressed internally in the enamel and ceramics. At 72 months after placement, the deterioration moved to the third stage, where rapid deterioration was observed. Substantial marginal fracture in both enamel and ceramics accelerated.

The other two restorations presented a two-stage deterioration pattern, and no remarkable changes such as microfractures of enamel or ceramics were found over the eight years. One of the two restorations had no direct occlusal contact to the opposite teeth due to crossbite. The other achieved an excellent marginal adaptation of less than 100 μm. These two could be considered exceptional restorations. Thus, the marginal deterioration of fired ceramic inlays presented by an area can be summarized as being a sequential three-stage pattern (Figure 4).

While the boundaries between the second and third stages were found at 72 months in all restorations with three-stage pattern, the boundaries between the first and second stages varied in the 6–to-21 month period. This diversity reflected the variety of conditions in individual restorations. The amount of excess resin composite cement, marginal widths of resin cement and occlusal forces might differ in each restoration.

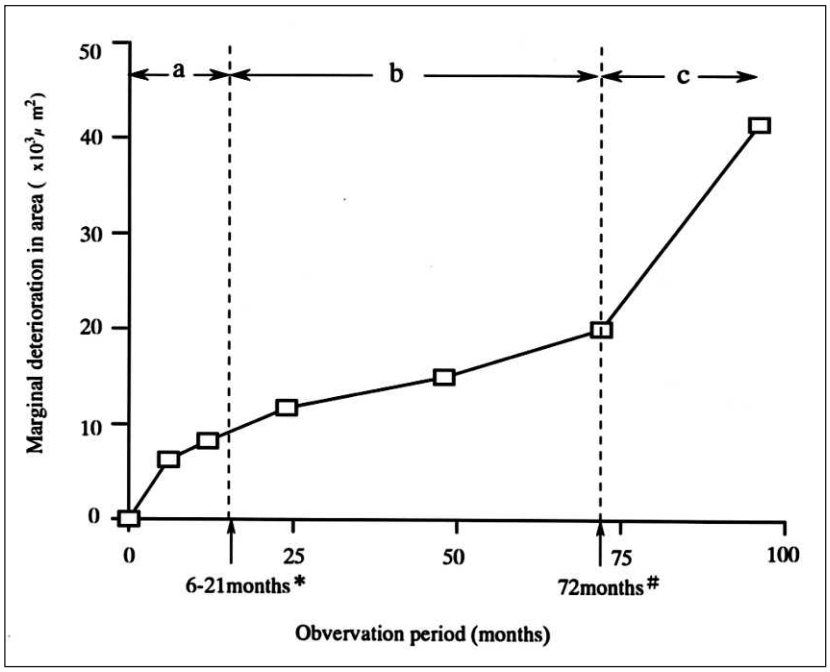

Figure 4. *The longitudinal marginal deterioration pattern consisting of the three sequential stages: a) First stage: quantitative marginal deterioration rapidly progressed due to wear of resin composite cement; b) Second stage: deterioration speed was reduced, since initial microcrack propagation and microfracture of enamel or ceramics gradually progressed invisibly; c) Third stage: Rapid deterioration recommenced, since marginal microfractures in both enamel and ceramics accelerated.*
**: Boundaries between the first and second stages were found in the 6 to 21 month periods. #: Boundaries between the second and third stages were found at 72 months.*

The sequential three-stage pattern was confirmed in the long-term marginal deterioration of the fired ceramic inlays investigated. Improvements in the mechanical properties of ceramics and adhesive systems can be expected to reduce the incidence of marginal deterioration. Further investigations of other types of ceramics and cement would be required to lend support to these findings of the sequential three-stage pattern of marginal deterioration of ceramic inlays.

CONCLUSIONS

It was concluded that quantitative measurement by means of our CCD laser system and morphological observation by means of a SEM confirmed that the longitudinal *in vivo* marginal deterioration of the fired ceramic inlays investigated progressed in a sequential three-stage pattern. In the first stage, wear of the resin composite cement initially progressed during a six-to-21 month period, followed by a stable second stage without any remarkable change being visible. After 72 months, the deterioration of enamel and/or ceramics rapidly progressed and was accompanied by visible microfractures.

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Laboratory Research

Repair or Replacement of Amalgam Restorations: Decisions at a USA and a UK Dental School

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Clinical Relevance

For a set of defective amalgam restorations examined by clinical dental students, *replacement* was the major treatment choice, particularly for failure due to secondary caries, unsightly appearance, partial loss of restoration and tooth fracture. The more conservative treatment decision of *repair* was made for reasons of partial loss of restoration and marginal ditching; and for *refurbishment*, the major reasons were poor anatomic form and marginal ditching.

SUMMARY

Whereas replacement of failed restorations is the major treatment for adults in dental practice, repair is an important alternative with the potential to save tooth structure and increase the longevity of restorations at a lower cost. This *in vitro* study recorded the choices of treatment for the same set of teeth with defective Class II amalgam restorations by students and faculty at two dental schools (University of Manchester, UK and University of Florida, USA). Treatment options (*monitor, refurbish, repair and replace*) and reason(s) for the choice of treatment for 24 marked amalgam restorations were selected.

Overall, participants more frequently chose *replacement* of restorations; whereas, *repair* was the least favored option. The reasons cited the most to *replace* restorations were secondary caries including unsightly appearance, partially lost restoration and tooth fracture; for *repair*, the major reasons included loss of part of the restoration and marginal ditching; and for *refurbishment*, the major reasons included poor anatomic form and marginal ditching. There was a significant difference between the students and faculties at the two sites in their choice of treatment ($p<0.0001$; Chi-square test). The treatment decision to "*monitor*" the restorations was more frequent for the Manchester site than the Florida

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site. Conversely, the combined treatment decisions to "*refurbish, repair and replace*" were more frequently chosen in Florida than in Manchester.

INTRODUCTION

Replacement of failed restorations forms a major part of the oral health care of adults with restored dentitions (Mjör, 1981). The successive replacement of a restoration may result in escalating consequences (Elderton, 1975, 1977; Mjör & others, 1998), even to extraction of the tooth (Lutz, Krejci & Mormann, 1987; Simonsen, 1991). Each time a restoration is replaced, more sound tooth tissue is lost, the preparation is enlarged and both the tooth and the restorations tend to become more susceptible to catastrophic failure. Successive restoration replacement may lead to crowning, with or without the need for endodontic therapy (Osborne, Binon & Gale, 1980). Therefore, it is highly desirable to increase the life expectancy of a restoration and, thereby, delay the possible demise of the tooth that it restores.

An important treatment decision that greatly affects the longevity of a failing restoration is whether to remove the restoration completely or to repair only the defective portion (Anusavice, 1992). Repair is an important alternative to replacement of a failing restoration. It preserves tooth tissues and is more cost effective and acceptable to the patient than restoration replacement, and above all else, may contribute to more patients retaining more of their teeth over their lifetime (Mjör, 1993). An alternative operative approach is to refurbish rather than repair a less than ideal restoration. Whereas a repair involves partial replacement of a restoration with the same or a different restorative material, refurbishment typically involves the refinishing of a restoration with or without recontouring. Refurbishment may eliminate superficial marginal discrepancies and limited surface irregularities. Such improvements in the qualities of a restoration may render the restoration clinically satisfactory for a further period of clinical service.

This study investigated how dental students and faculty at two dental schools (Florida, USA and Manchester, UK) made treatment decisions and diagnosed the reason(s) for the choice of treatment for the same set of teeth with defective Class II amalgam restorations.

METHODS AND MATERIALS

Questionnaire

A questionnaire was developed to record four treatment options for each restoration: *monitor, refurbish, repair or replace*; and eight reasons for each treatment option selected: secondary caries, bulk discoloration (unsightly appearing restoration), tooth fracture, margin discoloration (tooth), lost part of restoration, marginal ditching with no caries, poor anatomic form and other reasons. It is realized that bulk and marginal discoloration are criteria that apply primarily to tooth-colored restorations, but they are included in this study as part of the criteria for replacement of restorations in general.

Selection of Teeth

From a large number of extracted teeth, 238 teeth with amalgam restorations were pre-screened. After further visual examination of these teeth, 55 were selected to provide a sample of posterior teeth restored with Class II amalgam restorations with a wide range of defects. These defects included: marginal breakdown, deep marginal ditching, tooth discoloration, chipped or fractured restoration, tooth fracture and secondary caries. The teeth were radiographed in a standardized manner using a cephalograph (operating at 40kV and 2mA) to identify any caries not clinically visible. This eliminated an additional 10 teeth. The remaining 45 selected teeth were mounted in labstone, producing three dental casts with the teeth in normal relationships with appropriate proximal contacts. Any missing teeth in the arch were replaced with acrylic resin typodont teeth to produce complete dental arches. The teeth were kept moist throughout the study to avoid tooth crazing or cracking and were only dried for a short time with compressed air during examinations.

A pilot study was initially undertaken to exclude unsuitable restorations from the study. Nine fourth-year (penultimate) dental students at Manchester participated in the pilot study based on the 45 selected teeth using the questionnaire described earlier. A restoration was considered unsuitable if most candidates chose the same treatment option. From the pilot study, 24 of the 45 selected teeth with Class II amalgam restorations were identified for the current study. Thus, the restorations examined were selected to serve the purpose of this study and do not represent the incidence of common reasons for replacement.

Data Collection and Analyses

Thirty-eight fourth year dental students at the University of Manchester (UM), 49 juniors (penultimate year, equivalent to 4th year students in Manchester) and 28 senior (final year) dental students at the University of Florida (UF) participated in the study. The Florida dental students were asked to examine the same set of teeth and complete the questionnaires again approximately two weeks after the first examination. Forty-one juniors and all 28 seniors completed the questionnaires twice. Seven faculty members at UF and 12 faculty members at UM also took part in this study.

A number of assumptions were specified to all assessors for completing the questionnaires by the same

researcher at each location. These included whether the patient was a cooperative, regular attendee, had no patient symptoms and exhibited no radiographic evidence of caries; only teeth and their restorations were under examination, the contact points were to be considered satisfactory so that no extraneous confounding patient factors were included. Furthermore, there was no occlusion to check. The same set of restored teeth was examined by all assessors in a simulated clinical manner using appropriate light and a dental explorer. Each participant was asked to exercise care during probing of the margins so as not to damage the restorations for the subsequent assessor.

Data obtained from the Florida dental students who completed the questionnaires on two separate occasions were used to test *intra-examiner reliability* by kappa coefficient. The responses of the students and faculty were compared with those of their counterparts at the other institute using the Chi-square test. Similar analyses were carried out between the responses of the faculty and students at the same institute.

RESULTS

(a) Intra-examiner Consistency (reliability). Figure 1 shows distribution of the treatment option selected at two separate examinations by the junior and senior dental students at UF. The statistical analysis of these data gave a value of kappa = 0.46 for the juniors and kappa=0.55 for the seniors, indicating a moderate level of agreement. Chi-square test showed that the first and second examination data are not statistically significantly different for both juniors (p=0.3093) and seniors (p=0.7286). Figure 2 shows the treatment option deviation of the second examination from each option category of the first recording set at 100%. The changes in treatment options between the two examinations were 38% for the juniors and 31% for the seniors. The frequency of changes by individual tooth was not statistically different between juniors and seniors by the Chi-square test (p=0.9857).

(b) Comparison of Florida Junior, Senior Student and Faculty Groups. The data obtained from the junior (first examination), senior students and faculty members were compared with respect to the selected treatment options (Figure 3). The Chi-square test for the three groups resulted in a p=0.0622, indicating no significant difference in their responses.

(c) Comparison of the Manchester and Florida Groups. Data from 38 Manchester 4th year students were com-

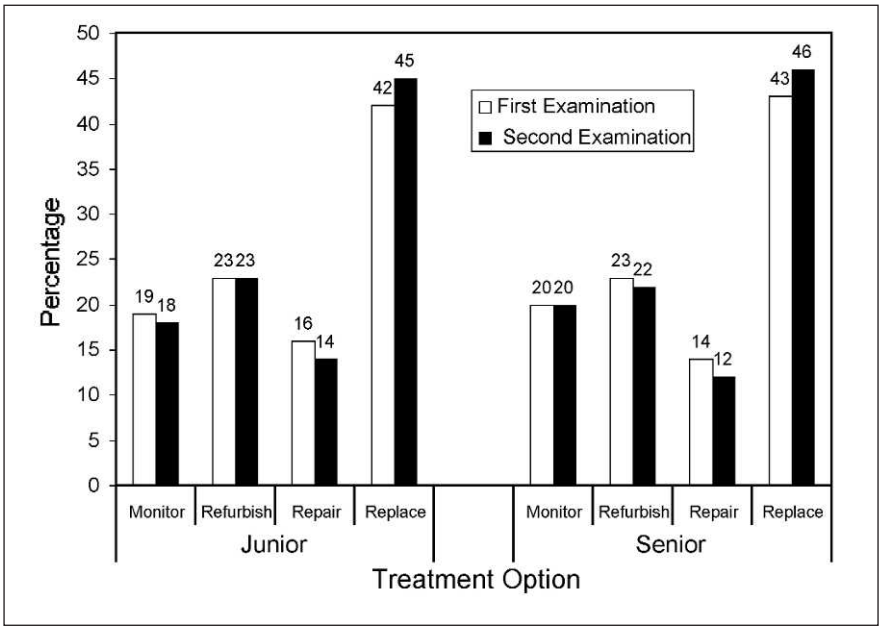

Figure 1. *Comparison of first and second examinations by Florida junior students (n=41) and senior students (n=28) as a measure of intra-examiner consistency. The number at the top of each bar is the percentage found.*

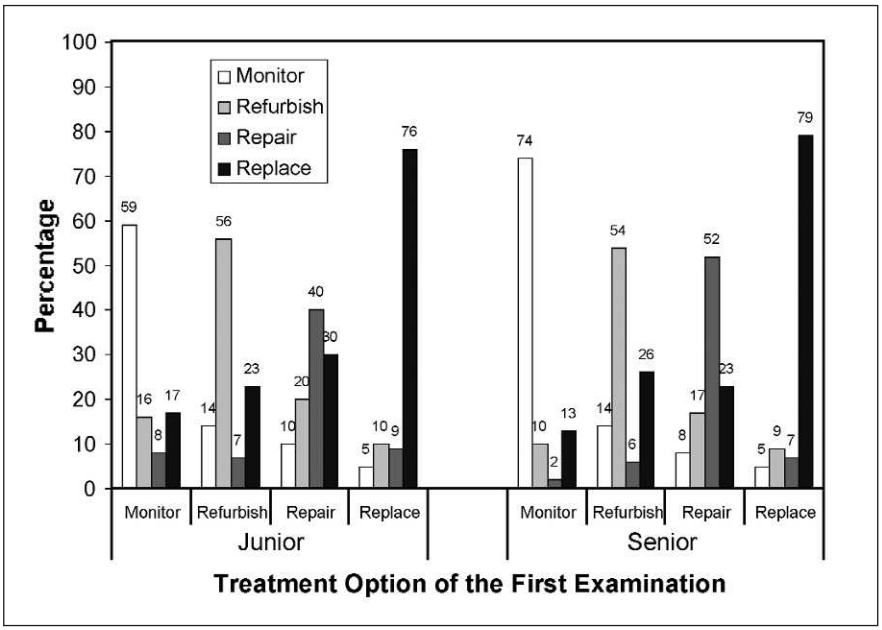

Figure 2. *The difference between first and second examination for each of the four treatment options recorded by the Florida dental students. The number at the top of the bars of each category reflects the distribution of treatment option recorded at the second examination, and the category axis represents the option recorded at the first examination set at 100%.*

pared separately with the Florida junior and senior students (Figure 3). The Chi-square test resulted in $p<0.0001$ for both tests, indicating a significant difference in their responses. The most significant difference occurred in relation to the treatment option *to monitor* and *to replace* the restorations.

The Chi-square test shows a statistically significant difference between the two faculty groups ($p=0.0024$). The greatest difference occurred in the selection *to monitor*, which was 36% for the Manchester faculty and 20% for the Florida faculty, and *to replace*, which was 24% for the Manchester faculty and 34% for the Florida faculty.

(d) Comparison of Manchester Student and Faculty Groups. The Chi-square test shows that there is a statistically significant difference between the student and faculty groups ($p=0.0002$). While there is no significant difference in selection of the *to repair* option, the faculty selected far less replacement and more monitor and refurbishment than the students.

(e) Comparison of Combined Data from All Groups. The combined percentages for the treatment decision are 47% *to replace*, 19% *to monitor*, 20% *to refurbish* and 14% *to repair*. Table 1 shows the frequency and percentage of diagnosis defects selected by each evaluation group and all groups combined. There was no obvious scattering of cited reasons for treatment for individual tooth examined. Regarding reasons for treatment, marginal ditching, poor anatomy or other reasons are the leading choice in 23 of the 24 teeth examined. The remaining one tooth had secondary caries as the leading reason for treatment. Table 2 shows the combined percentages of each treatment option with respect to diagnosis of defect. It can be readily seen that the predominant treatment decision for each of eight diagnoses is replacement of the restoration, except for "other reasons."

DISCUSSION

The selection of teeth and restorations at the initial stages of a study such as reported here could play a significant role in the distribution of treatment options selected by the participants. If the majority of teeth and restorations had been sound, it could have been expected that the treatment option *to monitor* would have dominated. Conversely, if all the restorations had suffered frank failure or were associated with cavitated lesions of secondary caries, then the decision *to replace* would have dominated. In an attempt to obtain a wide range of restoration defects and qualities within the selected restorations, the resultant sample is unlikely to fully reflect distribution of the nature and extent of defects and limitations observed in clinical practice. This study, in common with studies of a similar nature (Elderton &

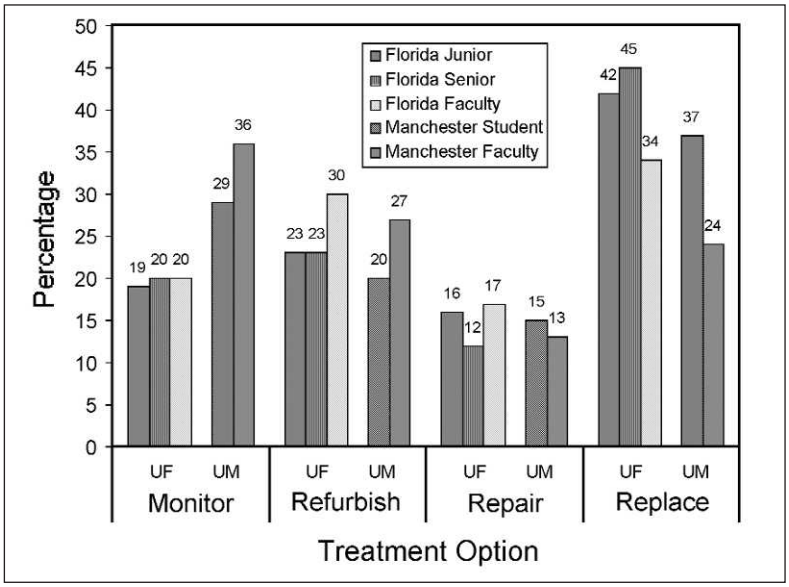

Figure 3. *The percent responses of treatment option for the junior students (n=49), the senior students (n=28) and the faculty (n=8) of the University of Florida (UF), and the 4th year students (n=38) and the faculty (n=11) of the University of Manchester (UM). The number at the top of each bar is the percentage found for the respective group.*

Table 1: *Summary of Diagnoses of Defects Reported by Each Evaluation Group*

Diagnoses of Defects	Evaluation Groups					
	Florida Junior	Florida Senior	Florida Faculty	Manchester Student	Manchester Faculty	All Groups
Secondary caries	116 (9%)	91 (10%)	21 (9%)	110 (10%)	21 (7%)	359 (9%)
Marginal discoloration	44 (3%)	30 (3%)	5 (2%)	58 (5%)	3 (1%)	140 (4%)
Bulk discoloration	32 (2%)	15 (2%)	0 (0%)	38 (3%)	3 (1%)	87 (2%)
Marginal ditching	381 (29%)	247 (27%)	43 (19%)	212 (19%)	54 (17%)	938 (24%)
Lost part of restoration	80 (6%)	48 (5%)	17 (8%)	67 (6%)	8 (3%)	220 (6%)
Tooth fracture	77 (6%)	57 (6%)	6 (3%)	70 (6%)	3 (1%)	213 (6%)
Poor anatomy	309 (24%)	233 (26%)	53 (23%)	224 (20%)	55 (17%)	874 (22%)
Other reasons	276 (21%)	195 (21%)	81 (36%)	341 (31%)	167 (53%)	1060 (27%)

Note: Percentage in the parentheses represents the percent of diagnoses of defects within the evaluation group (column).

Nuttall, 1983; Merrett & Elderton, 1984), is concerned with variations in the decision making of treatment options rather than the frequency of reasons for restorations to be considered to fail or to have failed in clinical service. However, when certain defects are present, there are more likely choices for the treatment to be offered, as seen by the trends seen in Table 2. Thus, for a defect such as secondary caries, the predominant choice of treatment is *to replace* the restoration, whereas, for poor anatomic form, the major treatment choice is either *to replace* or *refurbish* the restoration, and so on.

The Manchester students were significantly more likely to decide *to monitor* restorations than the Florida students. This was also seen as a trend for the faculty at the two schools, with the Manchester faculty surveyed as being more likely to select *to monitor* restorations than the Florida faculty. At both schools some of these dentists were teachers of the dental students surveyed, and it is to be expected that their views would filter down to their students. The results also show that faculty are more likely to select refurbishment and less likely to replace restorations than the students at both sites.

Decisions *to monitor* restorations may be related to arrangements for the continuing care of the patients. If a patient is not a regular attendee and is being provided with what may well be an isolated course of treatment, the dentist is forced to make, in effect, a dichotomous decision with respect to each restoration. In such circumstances, the decision is whether the restoration is clinically satisfactory and likely to remain so for an indeterminate interval until the next sporadic attendance, or whether to proceed with some form of operative intervention now. Conversely, if a patient is a regular attendee, there might be a higher likelihood that a decision *to monitor* will be invoked for a questionable restoration, especially if the patient is in a low-risk category for new and recurrent disease and the examining dentist placed is familiar with the restorations. In this study, the students and faculty recruited to assess the restorations were provided with information about there being no radiographically visible caries below the restorations and no occlusal problems but they received no information about the patient's oral home care.

The statistical analysis for *intra-examiner consistency* was applied to determine how reliable the treatment decisions were; in other words, would the examiners select the same option at a later time. There was a moderate degree of intra-examiner agreement for the Florida students who repeated the examination at a later date. The senior students exhibited a higher degree of *intra-examiner consistency* than the junior students. Despite the fact that these students have minimal clinical experiences, the level of consistency agrees favorably with the values found for similar studies among practicing dentists (Elderton & Nuttall, 1983; Merrett & Elderton, 1984). It is possible that the level of intra-examiner agreement reported in this study was the result of the assessor's memory from first examination. Increasing the number of restorations and the time span between two examinations should reduce the influence of the assessor's memory. It is important to note that the percentage of changes from the initial treatment option varies. The least changes (21%) occurred with the category *to replace* by the seniors and the most changes (60%) occurred with the category *to repair* by the juniors (Figure 2). It implies that the students with little clinical experience were more confident with the choice *to replace* than *to repair*. This observation is consistent with a recent study showing that younger dentists tend to replace more often than their older counterparts (Mjör & others, 2002).

The total number of restorations with bulk and margin discoloration was at the 0% to 5% level of the reasons cited by each group and 3% to 4% for all groups combined (Table 1). This low incidence indicates that these criteria, as expected, are not suitable for evaluating amalgam restorations even though bulk and margin discoloration often lead to replacement of the restorations. For extreme situations, they reflect unsightly amalgam restorations or discoloration of enamel and dentin adjacent to the restoration. Tooth fracture and a lost part of the restoration also generally triggered a choice for replacement.

While *repair* was the least favored option overall (Figure 3), the reasons cited to repair a restoration were not quite as clearly drawn. This could be due to the condition of specific restorations. Taking an extreme example, while in general a repair might not be chosen if there was secondary caries, it might have been selected if caries was an apparently early, superficial lesion localized to one part of a defective margin.

Table 2: *The Decision of Restorative Options as a Percentage of the Selected Treatments for Each of Eight Diagnoses of Defects*

	Replace	Refurbish	Repair	Monitor
Secondary caries	86	1	13	0
Marginal discoloration	69	18	13	0
Bulk discoloration	80	14	6	0
Marginal ditching	51	26	22	1
Lost part of restoration	62	4	34	0
Tooth fracture	79	4	15	2
Poor anatomy	47	42	10	1
Other reasons	16	10	7	67

Furthermore, it seems to be a difficult decision to intervene to only partially replace part of another dentist's work. With the knowledge of one's own techniques and experiences, repair would likely be more frequently selected for a dentist's own personally placed restorations.

A major factor in the decisions reached is considered to be instruction the students receive on the use of refurbishment and repair techniques and in relation to the nature and extent of the defects. Findings of studies in Europe and North America indicate that students receive little instruction in conducting refurbishment and repair procedures (Gordan & others, 2003; Blum & others, 2003). As a consequence, such students would have been unlikely, if included in this study, to reach many decisions *to refurbish* or *to repair*. In the two schools in which students were recruited to participate in this study, techniques for the refurbishment and repair of restorations have been and are increasingly taught to the students.

Given that more than 60% of everyday restorative dentistry is replacement dentistry (Mjör, 1981), it is not surprising to find that replacement is the most favored option for any diagnosed defects, except when "other reasons" is cited. To promote an alternative approach to repairing or refurbishing, a less than ideal restoration requires setting issues that pertain to the replacement, repair and refurbishment of existing restorations including cost-benefit analysis, a major priority in the field of operative dentistry. In addition, developing criteria for replacement, repair and refurbishment is an urgent need along with meaningful clinical studies to compare and contrast repair with replacement.

In the meantime, teachers should consider placing emphasis on the use of existing criteria for the replacement of restorations (Deligeorgi, Mjör & Wilson, 2001) in their teaching and give consideration to introducing and/or expanding teaching of the repair and refurbishment of restorations.

CONCLUSIONS

The treatment decision to "*monitor*" restorations was more frequently used by assessors in the Manchester groups than in the Florida groups. Conversely, in Florida, the combined treatment decisions to "*refurbish, repair and replace*," with the emphasis on *replace*, were more frequently chosen than in Manchester. The dental students surveyed in Manchester were more conservative in their selected treatments than their counterparts in Florida.

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The Effect of Home Bleaching Agents on the Surface Roughness of Tooth-colored Restoratives with Time

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Clinical Relevance

Resin-based restoratives may be significantly roughened by the extended use of home bleaching agents. The re-polishing or replacement of polyacid-modified composite restorations is recommended after home bleaching treatment.

SUMMARY

This study evaluated the effects of home bleaching agents on the surface roughness of composite restoratives. Two home bleaching gels (10% and 15% carbamide peroxide, Opalescence) and five different tooth-colored restorative materials from the same manufacturer (3M-ESPE) were selected. They included microfill (Filtek A110 [FO]), flowable (Filtek Flow [FF]), polyacid-acid modified (F2000 [FT]) and minifill (Z100 [ZO]; Filtek Z250 [ZT]) composites. Thirty-six specimens of each material were fabricated, randomly divided into three groups (n=12) and treated as follows: Group 1—Stored in distilled water, Group 2—Bleached with 10% carbamide peroxide (CP) eight hours/day; Group 3—Bleached with 15% CP eight hours/day. All treatment was conducted at 37°C and fresh gel applied and rinsed off daily for eight weeks. For the bleached groups, the specimens were stored in distilled water at 37°C during the hiatus periods. All the specimens were subjected to roughness testing (Ra) at weeks 0, 1, 2, 4, 6 and 8 using a profilometer. The results were analyzed using general linear model with Scheffe's post-hoc tests at significance level 0.05. The results showed that the effect of bleaching on surface roughness was material and time dependent. ZT was not affected by bleaching treatment, while FT was significantly roughened after one week of bleaching with 15% CP compared to the control group. FO, FF and ZO were not significantly roughened until eight weeks of bleaching. Repolishing or replacement of tooth-colored restorations may be required after bleaching procedures.

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INTRODUCTION

The prognosis and longevity of a restoration depends not only on mechanical properties, but also on the physical and biological properties of the material used. Surface roughness has been a major concern for researchers and clinicians, as it is associated with plaque retention, which may lead to gingival inflammation and caries formation. Studies have shown that initial colonization of bacteria starts from surface irregularities where the bacteria are protected against shear forces (Lie, 1977; Nyvad & Fejerskov, 1987). They have also shown that restorations with rough surfaces increased glucan adhesion and bacteria colonization (Quirynen & others; 1990, Quirynen & others, 1996; Kawai & Urano, 2001).

Vital bleaching has gained popularity over the past decade due to its efficiency, ease of use and minimal side effects. Thus, the effect of bleaching agents on the properties of restorative materials is important. Several studies have evaluated its effect both on the mechanical and physical properties of restoratives. However, investigations on the surface roughness of restoratives after bleaching treatment have shown contradictory results. Some studies showed that the surface finish of composite restorations was not affected by home bleaching agents (Türker & Biskin, 2000; Langsten & others, 2002; García-Godoy, García-Godoy & García-Godoy, 2002), while others reported surface changes after bleaching treatment (Bailey & Swift, 1992; Kao, Peng & Johnston, 1991). The opposing results may be attributed to the diverse bleaching protocols and materials tested. While some study specimens were bleached once (García-Godoy & others, 2002), others have bleached specimens for two to four weeks (Langsten & others, 2002; Kao & others, 1991; Türker & Biskin, 2000; Bailey & Swift, 1992). In this study, bleaching treatment was carried out for two months based on a clinically relevant protocol. This study observed the effect of bleaching agents on the surface finish of tooth-colored restoratives over time.

METHODS AND MATERIALS

Five tooth-colored restorative materials from the same manufacturer (3M-ESPE Dental Products, St Paul, MN, USA) and two commercial bleaching agents (Opalescence, Ultradent Products, Inc, South Jordan, UT, USA) were selected for this study. The bleaching agents were 10% and 15% carbamide peroxide (Opalescence) and the restorative materials included a microfill resin composite (Filtek A110 [FO]), a flowable composite (Filtek Flow [FF]), a polyacid-acid modified composite (F2000 [FT]) and two hybrid or minifill composites (Z100 [ZO]; Filtek Z250 [ZT]). All materials were of the A2 shade. Table 1 shows the technical profiles of the materials.

The restorative materials were placed in the rectangular recesses (4 mm x 3 mm x 2 mm deep) of customized acrylic molds. The materials were then covered with Mylar strips to ensure a uniform finish. A glass slide was placed over and light pressure applied to exude the excess material. The materials were then light cured through the glass slide to ensure a uniform distance between the light source and the material. The materials were light cured according to the manufacturer's cure times (FO-40 seconds, FF-20 seconds, FT-40 seconds, ZO-40 seconds and ZT-20 seconds) with a

Table 1: *Materials Evaluated*

Material	Manufacturer	Cure Time	Resin	Filler	Filler Size (μm)	Filler Content % by volume
Filtek A110 (lot 1720A2D) **[FO]**	3M Dental Products St Paul, MN, USA	40 seconds	BisGMA TEGDMA	Colloidal Silica	0.01 - 0.09	40
Filtek Flow (lot1400A2) **[FF]**	3M Dental Products St Paul, MN, USA	20 seconds	BisGMA TEGDMA	Zirconia/Silica	0.01- 6	47
F2000 (lot 2020A2) **[FT]**	3M Dental Products St Paul, MN, USA	40 seconds	CMDA GDMA	Fluoro-Alumino-silicate glass, silica	3 - 10	67
Z100 (lot 8004A2) **[ZO]**	3M Dental Products St Paul, MN, USA	40 seconds	BisGMA TEGDMA	Zirconia/Silica	0.01 - 3.5	66
Filtek Z250 (lot 1370A2) **[ZT]**	3M Dental Products St Paul, MN, USA	20 seconds	BisGMA UDMA BisEMA	Zirconia/Silica	0.01 - 3.5	60

BisEMA = Ethoxylated bisphenol-A-glycidyl methacrylate
BisGMA = Bisphenol-A-glycidyl methacrylate
CDMA = Dimethacrylate functional oligomer derived from citric acid
GDMA = Glyceryl methacrylate
TEDGMA = triethylene glycol dimethacrylate
UDMA = Urethane dimethacrylate

Table 2: *Means Ra Values (μm) of Materials Evaluated at Various Time (standard deviations in parenthesis)*

Week	0			1			2			4			6			8		
Medium / Material	H_2O	10% CP	15% CP	H_2O	10% CP	15% CP	H_2O	10% CP	15% CP	H_2O	10% CP	15% CP	H_2O	10% CP	15% CP	H_2O	10% CP	15% CP
FO	0.08 (0.02)	0.08 (0.02)	0.09 (0.02)	0.07 (0.01)	0.10 (0.03)	0.10 (0.03)	0.08 (0.01)	0.09 (0.02)	0.09 (0.02)	0.07 (0.01)	0.09 (0.03)	0.08 (0.03)	0.07 (0.02)	0.09 (0.03)	0.10 (0.03)	0.08 (0.01)	0.10 (0.02)	0.10 (0.02)
FF	0.05 (0.01)	0.05 (0.01)	0.06 (0.02)	0.06 (0.01)	0.05 (0.01)	0.06 (0.01)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)	0.06 (0.01)	0.05 (0.01)	0.05 (0.01)	0.06 (0.01)	0.05 (0.01)	0.05 (0.01)	0.10 (0.04)
FT	0.09 (0.01)	0.09 (0.02)	0.11 (0.02)	0.09 (0.02)	0.10 (0.02)	0.21 (0.05)	0.09 (0.01)	0.12 (0.02)	0.34 (0.03)	0.09 (0.01)	0.17 (0.03)	0.62 (0.09)	0.09 (0.01)	0.21 (0.02)	0.69 (0.13)	0.11 (0.02)	0.26 (0.04)	0.82 (0.03)
ZO	0.05 (0.02)	0.04 (0.01)	0.04 (0.02)	0.05 (0.02)	0.05 (0.02)	0.04 (0.02)	0.04 (0.01)	0.04 (0.01)	0.04 (0.02)	0.04 (0.01)	0.04 (0.01)	0.04 (0.02)	0.06 (0.03)	0.04 (0.01)	0.06 (0.03)	0.04 (0.02)	0.05 (0.01)	0.06 (0.03)
ZT	0.03 (0.01)	0.04 (0.02)	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.06 (0.02)	0.04 (0.02)	0.05 (0.02)	0.04 (0.01)	0.05 (0.02)	0.05 (0.01)	0.06 (0.03)	0.05 (0.02)	0.06 (0.01)	0.08 (0.04)	0.05 (0.02)	0.07 (0.02)

H_2O = Distilled Water, CP = Carbamide Peroxide

Table 3: *Results of Statistical Analysis at Week Eight*

Variables		Significance
Materials	**FO**	10%CP, 15%CP > Distilled water
	FF	15%CP > 10%CP, Distilled water
	FT	15%CP > 10%CP > Distilled water
	ZO	15%CP > Distilled water
	ZT	NS

Results of one-way ANOVA/Scheffe's test (p<0.05) > indicates statistical significance and NS indicates no statistical significance.

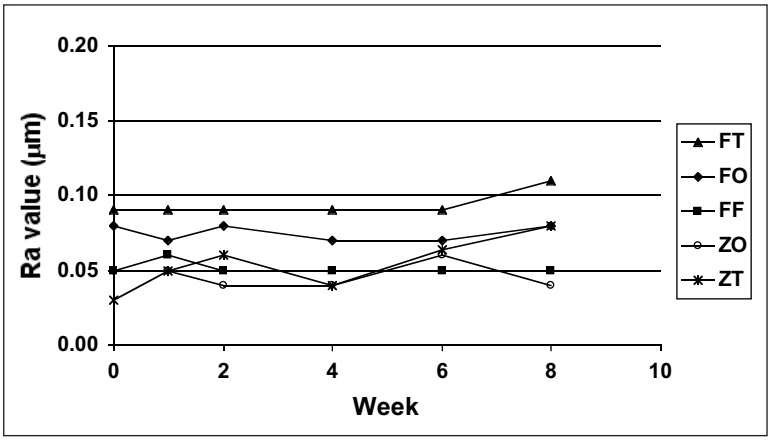

Figure 1. *Surface roughness (Ra) of control group.*

Poly LUX II light cure unit (KavoDental, Warthausen, Germany). The mean intensity of the light source (690±10 W/cm^2) was determined with a commercial radiometer (CureRite, EFOS INC, Ontario, Canada) prior to the start of the experiment.

Thirty-six specimens of each material were made and randomly divided into three groups of 12. All specimens were stored in distilled water at 37°C for two weeks prior to the start of the experiment. Upon commencement of the experiment, the specimens in Group 1 (control group) were stored in distilled water at 37°C. Groups 2 and 3 were treated with 10% and 15% CP for eight hours/day, respectively. Fresh gel was applied and rinsed off daily for eight weeks. The bleaching treatment was conducted at 37°C. For the bleached groups, the specimens were stored in distilled water at 37°C during the hiatus periods. All the specimens were subjected to roughness testing (Ra) at weeks 0, 1, 2, 4, 6 and 8 of treatment using a profilometer (Surftest SV-400, Mitutoyo, Kanagawa, Japan). Four sampling lengths of 0.25 mm were used, providing a total evaluation length of 1.0 mm. Selected specimens were examined by Scanning Electron Microscopy at 1000x magnification (JSM 5600LV, JOEL Asia Ltd, Japan) to evaluate material surfaces after bleaching.

A general linear model was conducted to determine the effects and interaction between materials, mediums and time. One-way ANOVA and Scheffe's post-hoc tests were performed with materials, time and bleaching agents as independent variables to determine the effects of the home-bleaching gels and compare the surface roughness of the materials at the various time intervals. All statistical analysis was conducted at a significance level of $p<0.05$.

RESULTS

The mean Ra values of the five materials at weeks 0, 1, 2, 4, 6 and 8 are shown in Table 2 and Figures 1 through 3. Statistical analysis revealed that generally, specimens in the control group were significantly smoother than those in bleached groups and the use of 15% CP resulted in significantly rougher surfaces than 10%CP.

Table 3 shows the results of statistical analysis after eight weeks of treatment.

Throughout the test, ZT specimens showed no significant difference in roughness between the bleached and control groups. For FO, FF and ZO, no significant dif-

ferences in Ra values were observed between the bleached and control groups from week one to week six.

At week eight, the FO specimens bleached with 10% and 15% CP were significantly rougher than the control. For FF, the groups bleached with 15% CP were significantly rougher than those with 10% and the control group. ZO specimens bleached with 15% CP also showed a significant increase in roughness compared to the control after week eight.

At the close of week one, FT specimens treated with 15% CP showed significantly greater surface roughness compared to the control (15%CP>control). Starting at week two, specimens treated with 10% CP were significantly rougher compared to the control, and specimens treated with 15% CP were significantly rougher than those treated with 10%CP (15% > 10% > control). The SEM images of F2000 are shown in Figures 4, 5 and 6. Specimens bleached with 15% CP revealed a very irregular surface with numerous cracks and cratering caused by filler dislodgement. Specimens bleached with 10% CP also showed scattered cracks along the surfaces. The surfaces still appeared relatively intact when compared to specimens treated with 15% CP. A few minor cracks were observed for the control group.

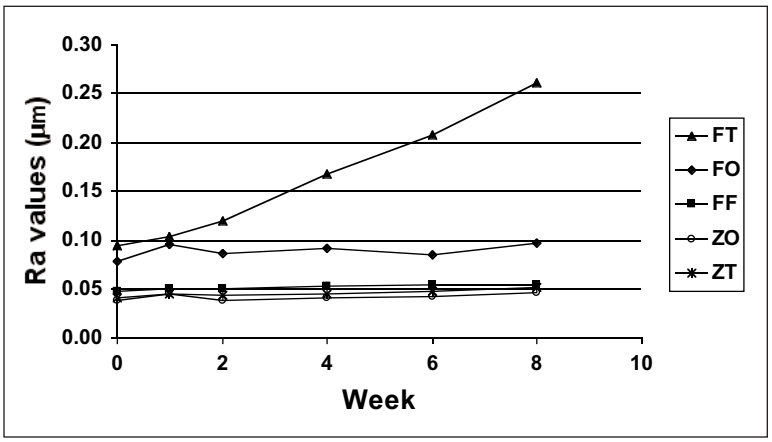

Figure 2. *Surface roughness (Ra) of materials bleached with 10% CP.*

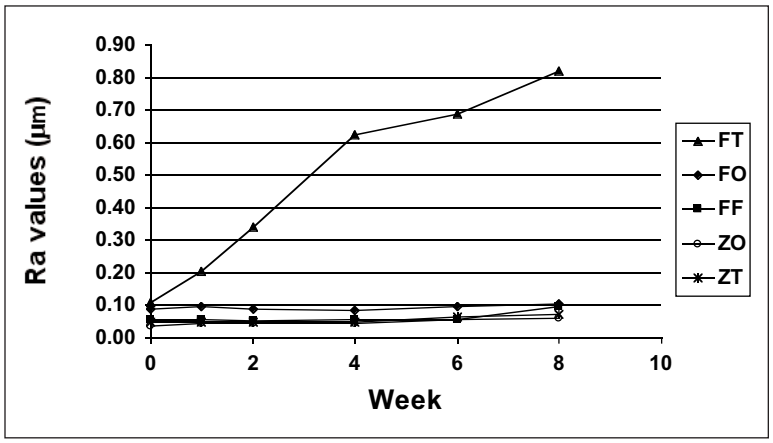

Figure 3. *Surface roughness (Ra) of materials bleached with 15% CP.*

DISCUSSION

A clinically relevant home bleaching regimen involving eight hours of bleaching treatment per day was adopted in this study. The experiment was carried out for two months to investigate the effects of bleaching agents on the surface roughness of restorations over time. Even though the usual duration of home bleaching is between two and four weeks, darker, discolored teeth, especially tetracycline stained teeth, may require longer bleaching time (Small 1994; Haywood, Leonard & Dickinson, 1997). An argument can be made that anterior restorations are usually replaced after bleaching to improve the shade match. However, deep cervical lesions and defective restorations should be filled/refilled before bleaching treatment. In such cases, clinicians might choose lighter shades, so that the restorations do not need replacement after bleaching. Moreover, Class I and II restorations of premolars and molars are usually not replaced after bleaching, as color match is not as critical.

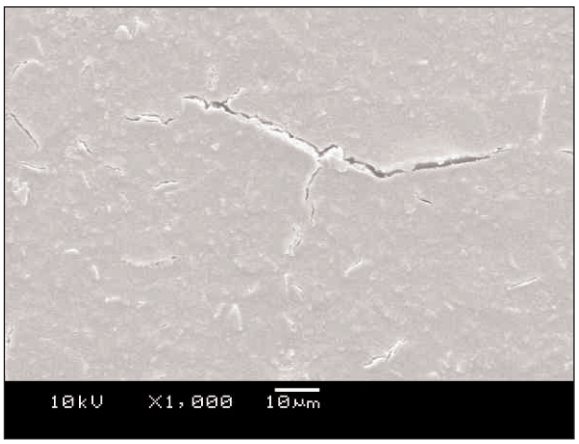

Figure 4. *SEM micrograph of F2000 control group.*

Surface roughness of a restoration is important, as it plays a major role in the formation of biofilms and bacterial adhesion (Quirynen & Bollen, 1995) that may lead to gingival inflammation and caries. Several studies have investigated the effects of bleaching agents on the surface characteristics of restorative materials. Most studies found no significant increase in composite surface roughness after exposure to home bleaching agents (Türker & Biskin, 2000; Langsten & others, 2002; García-Godoy & others, 2002). Others (Bailey & Swift, 1992; Kao & others, 1991) reported roughening and cracking of resin composite when evaluated under SEM.

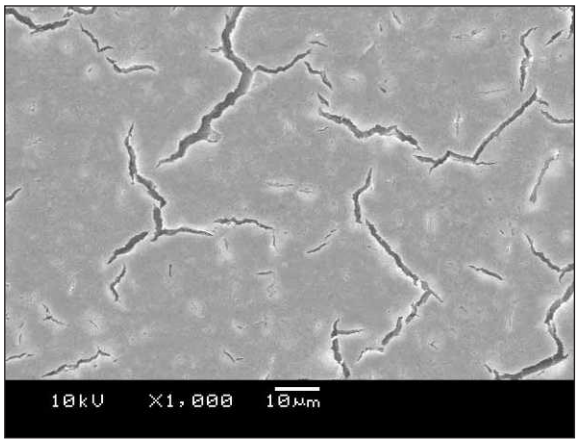

Figure 5. *SEM micrograph of F2000 specimen bleached with 10% CP.*

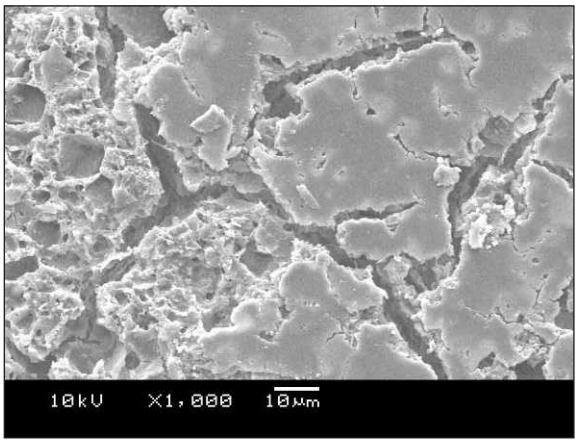

Figure 6. *SEM micrograph of F2000 specimen bleached with 15% CP.*

The results of this study showed that the effect of bleaching agent on the surface roughness of restorative materials is material and time dependent. Z250 showed no significant difference between the bleached and control group. F2000 showed a dramatic increase in roughness over time, while the others were not affected by bleaching until week eight. Statistical analysis also showed that the use of a higher concentration of hydrogen peroxide resulted in greater roughness. Except for F2000, similar behaviors were observed for all materials throughout the study (Figures 1, 2 and 3). This may result from the resin matrix components and filler size of these resin composites being similar (Table 1).

Bleached F2000 specimens were significantly rougher than unbleached specimens after one week of treatment with 15% CP and two weeks of treatment with 10% CP. SEM images revealed numerous cracks and cratering. Munack and others (2001) also demonstrated that F2000 specimens exhibited numerous cracks (under SEM) and significantly increased surface roughness after storage in various buffer solutions. This might be attributed to the resin matrix and fillers of F2000 being different from the other materials tested in this study. Water uptake and expansion has been reported in compomers (Jedynakiewicz & Martin, 2001; Yap & others, 2000). Water uptake may result in stress corrosion and complete or partial debonding of fillers, leading to cracking (Söderholm & others, 1984; Roulet & Walti, 1984) and increased surface roughness. The resin matrix of F2000, CDMA (Dimethacrylate functional oligomer) GDMA (Glyceryl methacrylate), may be more susceptible to hydrolysis and oxidation. Furthermore, hydrogen peroxide is known to have high capacities of oxidation and reduction and may generate free radical species. Hydrogen peroxide and these high energy free radicals may have an effect on the resin-filler interface and cause a filler-matrix debonding, thereby, resulting in further crack propagation leading to a drastic increase in surface roughness.

Studies by Quirynen and others (1996) and Bollen and others (1996) demonstrated that rougher surfaces accumulated more plaque. For surface roughness below 0.2 µm, no significant effect on plaque accumulation and composition was found. This led to the suggestion of a 0.2 µm "threshold Ra" (Bollen, Lambrechts & Quirynen, 1997), where any decrease in surface roughness below this level causes no further reduction in plaque accumulation. In this study, even though the increase in surface roughness was statistically significant, all bleached specimens exhibited Ra values less than 0.2 µm except for F2000. Therefore, the significant increase in surface roughness of these materials may not be clinically relevant. On the other hand, specimens of F2000 treated with 15% CP showed Ra values higher than 0.2 µm from the first week, while those treated with 10% CP showed higher RA values on the sixth week. The results suggest that the polyacid-modified resin composite F2000 should be replaced or re-polished after bleaching. Microfilled and hybrid resin composites are recommended if patients are to have restorations placed prior to bleaching.

It is also important to exercise caution when interpreting the results of *in-vitro* studies (St Germain & Meiers, 1996). Correlation to clinical practice may be limited to situations where accessible, relatively flat surfaces were involved. In addition, some degree of finishing/polishing of composite restorations is usually required clinically despite careful clinical placement of matrix strips. This inevitably violates the smoothness obtained with mylar strips used in this study.

CONCLUSIONS

1. The effect of bleaching on surface roughness of tooth-colored materials was material and time dependent.
2. Surface roughness of F2000 reached a critical threshold value of 0.2 µm after one week of bleaching with 15% CP and after six weeks using 10% CP.

3. With the exception of F2000, the effect of bleaching on the surface roughness of resin-based materials was not clinically significant, as the Ra values obtained were below the critical threshold of 0.2 μm.
4. Repolishing or replacement of tooth-colored restorations may be required after long periods of bleaching treatment.

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Bending Resistance of Prefabricated Titanium Posts Following Molten Cast Core Attachment

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P Schmage • U Platzer

Clinical Relevance

Precision-fit titanium posts with separately cast cores may provide superior bending resistance compared to prefabricated titanium posts with molten cast core attachment.

SUMMARY

Posts and cores are used to restore endodontically treated teeth that have substantial loss of the coronal tooth structure. This *in vitro* study was designed to determine the mechanical properties of prefabricated titanium posts following attachment of their metal cores by molten casting (cast-on). Prefabricated tapered titanium posts (ER post-restoring system, Komet, Lemgo, Germany) in three diameter sizes (ISO 50, 90, 110) (n=9) were cast over with the metal cores of three different alloys (Au-Ag-Pt, Au-Pt-Pd, Co-Cr-Mo). Also, posts of each size were precision fit into the central core channels of the different cast metal cores to serve as control specimens. The 0.2% yield strengths ($R_{0.2}$) of all specimens were tested on a universal testing machine. Statistical analyses of the results were carried out with an analysis of variance (ANOVA, one-way, two-way) and Bonferroni-Dunn's multiple comparisons post-hoc analysis for test groups (α=0.05). There was a significant decrease in yield strength (p<0.05) as a result of casting the various metals over the different post sizes, considered to be due to the detrimental thickening and porosity formation of the titanium surface oxide layer. Twenty-one percent, 51% and 33% reduction in yield strength, respectively, was obtained for the ISO 50, ISO 90 and ISO 110 cast-on groups relative to controls (p<0.05). Statistically significant differences in various core alloys were found only for the Au-Ag-Pt alloy compared to the Co-Cr-Mo alloy (post size ISO 50) and the Au-Pt-Pd

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alloy compared to the Co-Cr-Mo alloy (post size ISO 110) ($p>0.05$). Prefabricated titanium posts with metal cores cast over them showed inferior mechanical properties compared to precision-fit posts. These results indicate greater strength of the titanium posts when their cast cores were attached mechanically rather than by the molten casting method.

INTRODUCTION

Post and core restorations are often required to compensate for the coronal loss of endodontically treated teeth, especially when they are exposed to increased functional loading as anchors for further prosthetic replacements (Gutmann, 1992; Isidor & Brøndum, 1992; Christensen, 1993; Morgano, 1996).

Most popular is the use of prefabricated metal posts in combination with polymer core buildups, for example, composite (Assif & others, 1989; Cohen & others, 1997; Nergiz & others, 1997). Also, individual metal posts-and-cores either cast in one piece or involving dowel locks (two pieces) are sometimes indicated (Nathanson & Ashayeri, 1990; Libman & Nicholls, 1995; Morgano & Brackett, 1999). The one-piece post-and-core can be produced either by a single wax pattern of root and core portions or by casting the metal core directly over a prefabricated metal post (cast-on) (Isidor & Brøndum, 1992; Butz & others, 2001). The dowel lock method includes a core burnout pattern constructed around the *in situ*-placed post. This core is cast separately. A dowel is later fit in place through the channel in the cast core and luted by a zinc phosphate cement while inserting the post and core in the root canal (Boberick & Rickert, 1999).

Some relevant parameters for the long-term success of post-retained restorations are a tight fit into the prepared root canal and reliable mechanical properties of the post-core complex, itself (Lambjerg-Hansen & Asmussen, 1997; Stockton, 1999; Cohen & others, 2001), including high resistance to bending or fracture during fatigue testing (Gutmann, 1992; Peutzfeldt & Asmussen, 1990). The material, diameter and shape of the post and core affect its fracture strength (Peutzfeldt & Asmussen, 1990; Cohen, Musikan & Deutsch, 1992; Effah, Bianco & Ducheyne, 1995). Only two investigators have evaluated the mechanical properties of cast-on posts (Butz & others, 2001; Pfeiffer, Nergiz & Platzer, 2001). Pfeiffer and others (2001) found that the bending resistance of prefabricated titanium posts was significantly superior to Pt-Ir cast-on posts.

This *in vitro* study compared the bending resistance of posts precisely fit to separately cast metal cores with prefabricated titanium posts after casting their metal cores.

METHODS AND MATERIALS

Nine groups (n=9) of prefabricated tapered titanium posts (ER post-restoring system, Komet, Lemgo, Germany) of three diameter sizes (ISO 50, 90, 110) were cast-on with metal cores of three different alloys (Au-Ag-Pt, Au-Pt-Pd, Co-Cr-Mo) (Table 1). As a control, three groups of similar posts (one group of each diameter size) were precision fit into the central core channels of the separately cast cores (Co-Cr-Mo, Table 1).

The specimens were produced according to manufacturers' instructions. Cylindrical molds (brass metal) were used to produce the acrylic burnout core patterns (height: 9 mm, diameter: 5 mm) onto the post (Pattern Resin LC, GC Germany, München, Germany). For the control groups, the titanium posts were used to form

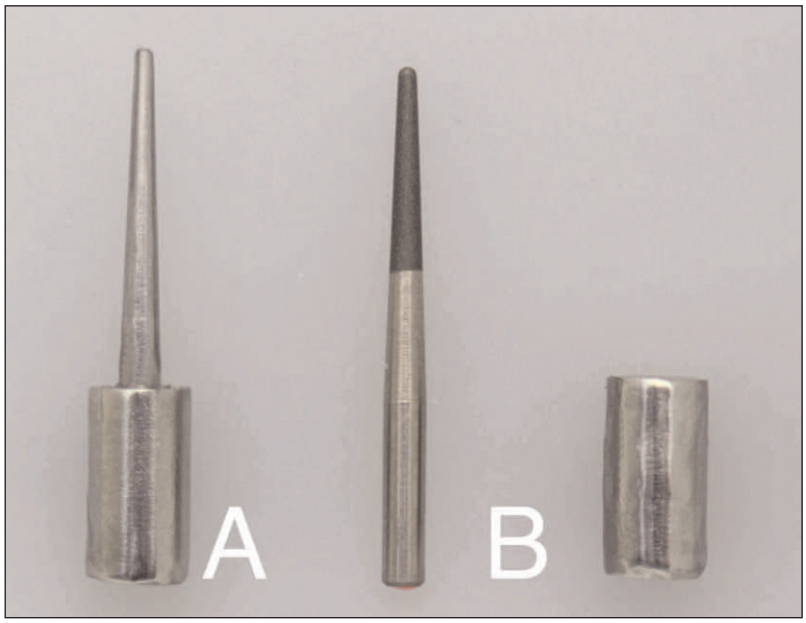

Figure 1. *Titanium post with cast-on core (A) and precision fit titanium post with separately cast core (B, control group).*

Table 1: *Core Alloys*

Core Alloy	Manufacturer	Mass Percentage	Melting Interval (°C)
Degunorm	Degussa Dental, Hanau-Wolfgang, Germany	Au 74, Ag 9, Pt 9	900-990
Degudent U	Degussa Dental, Hanau-Wolfgang, Germany	Au 77, Pt 10, Pd 9	1150-1260
Wirobond C	Bego, Bremen, Germany	Co 61, Cr 26, Mo 6	1270-1380

acrylic patterns. The resin patterns were cast into the Co-Cr-Mo alloy (Table 1). The central channels of the cores were then finished for precision re-fitting of the posts (Figure 1). The 0.2% yield strengths ($R_{0.2}$) of all specimens were tested on a universal testing machine (Zwicki 1120, Zwick, Ulm, Germany). The core was fixed between two plates, positioning the post horizontally and free for testing (two-point bending test, Figure 2). The load was transmitted using a steel cutting edge 0.8-mm in width with a crosshead speed of 2.5-mm/minute. The load hit the post with a 10-mm distance from the post tip at a 90° angle (Figure 2). The 0.2% bending force was recorded for each specimen. Statistical analyses of the results were carried out with a 3 (post sizes) x 3 (core alloy attachments) two-way analysis of variance (ANOVA, α=0.05) to evaluate the interaction effects between these two independent variables. One-way ANOVA and Bonferroni-Dunn's multiple comparisons post-hoc analyses of the load values were conducted for the test groups (α=0.05).

RESULTS

Two-way ANOVA revealed significant effects of post size and core attachment on the bending resistance (p<0.05). An interaction effect was found between these variables (p>0.05). Bonferroni-Dunn's post-hoc analysis showed statistical differences in bending resistance (p<0.05) between the groups (Figures 3 through 5). Titanium posts with cast-on cores significantly decreased in yield strength (p<0.05) regardless of post diameter or alloy type compared with the precision-fitting control (Figures 3, 4 and 5). The mean bending resistance $R_{0.2}$ of cast-on posts was 43 N ± 5 N for ISO 50 (control group: 54 N ± 3 N, Figure 3), 58 N ± 14 N for ISO 90 (control group: 117 N ± 11 N, Figure 4) and 95 N ± 15 N for ISO 110 (control group: 141 N ± 12 N, Figure 5) (p<0.05). The reduction in yield strength was 21%, 51% and 33%, respectively, for ISO 50, ISO 90 and ISO 110 cast-on groups relative to the controls (p<0.05). The cast-on posts of ISO size 90 showed the same 0.2% yield strengths $R_{0.2}$ (Figure 4) as the precision-fit titanium posts of ISO size 50 (Figure 3) (p>0.05). The $R_{0.2}$ of posts of ISO size 110 with cast-on cores (Figure 5) were significantly lower than the $R_{0.2}$ of precision-fit posts of ISO size 90 (Figure 4) (p<0.05). Maximum values were found for the $R_{0.2}$ of precision-fit titanium posts of ISO size 110 (Figure 5), whereas, the lowest $R_{0.2}$-values exhibited cast-on cores of ISO size 50 (Figure 3). Statistically significant differences of various core alloys were found only for the Au-Ag-Pt alloy compared to the Co-Cr-Mo alloy (post size ISO 50) and the Au-Pt-Pd alloy compared to the Co-Cr-Mo alloy (post size ISO 110) (p>0.05).

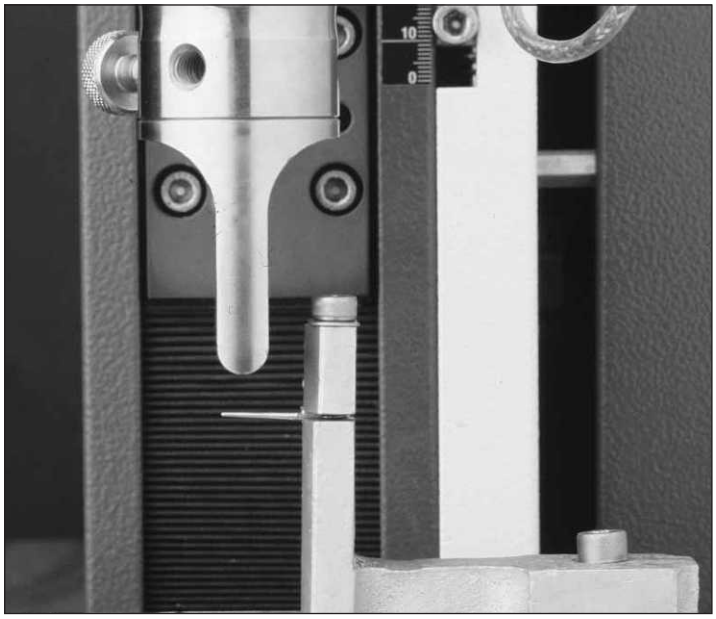

Figure 2. *Apparatus for testing bending resistance of titanium posts (two-point bending test).*

DISCUSSION

The tapered, passive post system of the ER-post system was selected, as its shape follows that of the prepared conical root canals (Assif & others, 1989; Nathanson & Ashayeri, 1990; Lambjerg-Hansen & Asmussen, 1997; Nergiz & others, 1997). Many studies have evaluated the fracture or bending strengths of posts and cores (Peutzfeldt & Asmussen, 1990; Isidor & Brøndum, 1992; Cohen & others, 1994; Libman & Nicholls, 1995; Cohen & others, 1997; Lambjerg-Hansen & Asmussen, 1997; Purton, Chandler & Love, 2001). Individually cast post-core buildups are indicated in cases with massive coronal destruction to prevent rotation or loosening of the restoration; this is achieved by an auxiliary cavity (slightly conical-sided with surrounding dentinal walls of at least 1-mm thickness) prepared in the coronal root portion that also provides thickening of the critical area of the post-core complex. This is confirmed in photoelastic-stress- and finite-element studies (Assif & others, 1989; Gutmann, 1992; Cohen & others, 2001) which showed that under functional loading, the highest bending forces occurred at the post-core junction of the coronal portion of the root.

In this study, the yield strengths of the posts were tested without cementing them into teeth to evaluate the material properties without any additional influence on the cement type or load transmission to the root (Cohen & others, 1992; Libman & Nicholls, 1995; Purton & others, 2001; Pfeiffer & others, 2001).

Precision-fit titanium posts of the control group were attached in the central core channels of separately cast Co-Cr-Mo cores. The core was tightly fixed between two covering plates for the two-point bending test. As the core was a stable part of the post fixation and the post could only bend outside the core, the alloy type of the core (control group) had no effect on bending resistance.

Post-and-core buildups can be fabricated in one or two pieces (Boberick & Rickert, 1999). An individually cast post-and-core proved to have inferior adaptation and resistance to intermittent loading compared to a prefabricated post (Isidor & Brøndum, 1992). Therefore, prefabricated posts are used in this *in vitro* study in combination with cast-on cores. The post alloy has to resist the melting temperatures of the core alloy, and the core alloy has to form a direct compound with the post metal. Prefabricated posts consist of different materials—gold alloy and titanium. The reasons for considering prefabricated titanium posts for cast-on cores include: Titanium posts are rigid, biocompatible and generally less expensive than gold alloys (Cohen & others, 1992). Their yield strength is superior to high noble alloy posts of the same diameter (Pfeiffer & others, 2001).

This *in vitro* study showed a significant reduction in the bending resistance of prefabricated titanium posts following the direct cast-on of a metal core. Titanium as a transition metal transforms from an ambient hexagonal close-packed alpha phase to a body-centered cubic beta phase at 882°C (Eichner & Kappert, 1996). Thus, the grains within the titanium become larger and change their previous direction. Moreover, the oxide layer, which is always present on the surface of titanium, becomes thicker and more porous; this is considered to be due to the detrimental oxide formation from the casting temperature. The porous oxide layer mixes with the cast-on alloy causing changes in alloy composition, rendering the titanium surface more soluble. This subsequently leads to disintegration of the titanium (Effah & others, 1995), which may explain why the cast-on process reduced the yield strength of the titanium. Another reason for the results may be that titanium is rather susceptible to oxygen, nitrogen and hydrogen impurities that cause it to become more brittle (Eichner & Kappert, 1996). Elevated temperature processing must be used under special conditions in order to avoid diffusion of these gases into the titanium. Titanium needs to be cast in a vacuum furnace because of its reactive nature. Otherwise, it can become brittle because of the incorporation of impurities.

Bending resistance of the post depends on its physical properties and diameter (Nathanson & Ashayeri, 1990; Peutzfeldt & Asmussen, 1990; Lambjerg-Hansen & Asmussen, 1997). Increasing the thickness of a post would be correlated to a stronger bending resistance. Yet, the post diameter has to be chosen according to the root diameter, otherwise root fracture occurs (Assif & others, 1989; Stockton, 1999).

Though casting onto prefabricated posts of high noble alloy revealed acceptable results (Pfeiffer & others,

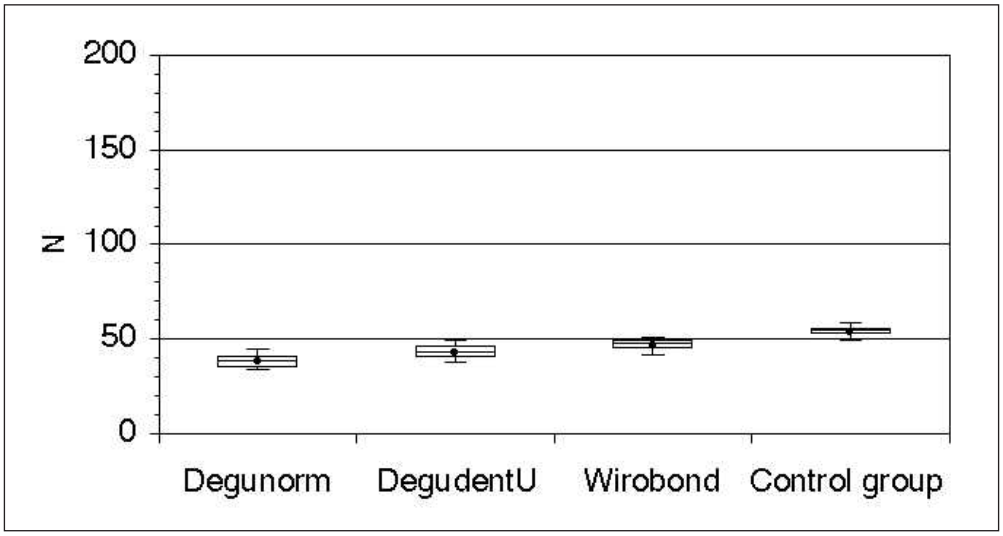

Figure 3. *0.2% yield strength ($R_{0.2}$) of titanium posts ISO size 50 with various cast-on core alloys compared to the precision-fit titanium posts (control group).*

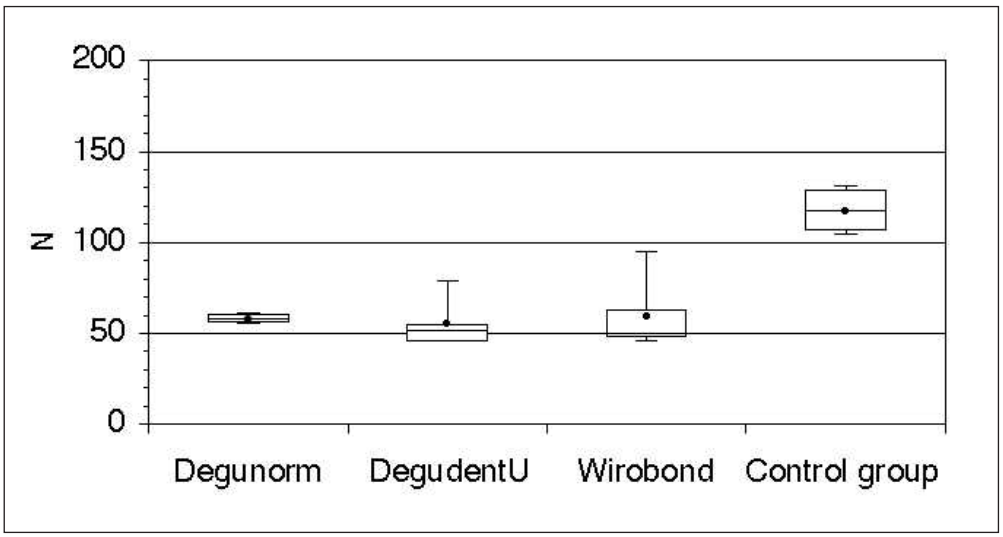

Figure 4. *0.2% yield strength ($R_{0.2}$) of titanium posts ISO size 90 with various cast-on core alloys compared to the precision-fit titanium posts (control group).*

2001), it could be concluded that prefabricated titanium posts with metal cores cast over them offer inferior mechanical properties compared to precision-fit titanium posts.

Some flexibility of the titanium posts is usually desirable to prevent root stress fracture potential. It is not evident how many Newtons of bending type forces are likely to be encountered to be clinically significant enough to functionally deform or dislodge a luted casting. Clinical trials are required to verify the clinical significance of these *in vitro* results.

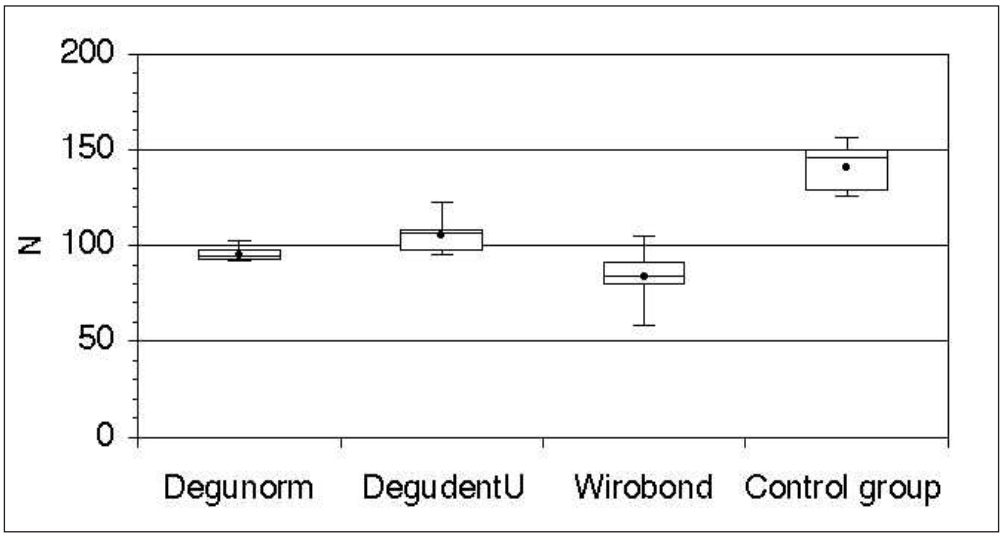

Figure 5. *0.2% yield strength ($R_{0.2}$) of titanium posts ISO size 110 with various cast-on core alloys compared to the precision-fit titanium posts (control group).*

CONCLUSIONS

1. It may be especially important not to weaken smaller titanium posts. This can be avoided by not directly casting metal cores to them.
2. The maximum strength of titanium posts is maintained by casting their cores separately and attaching them mechanically, such as by precision fitting and the use of a luting agent.

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Influence of Curing Lights and Modes on Cross-link Density of Dental Composites

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Clinical Relevance

The cross-link density of dental composites is dependent on curing light source and mode. Composites cured with LED lights may be less cross-linked than those cured with conventional halogen lights.

SUMMARY

This study investigated the influence of curing lights and modes on the cross-link density of dental composites. Four LED/halogen curing lights (LED–Elipar Freelight [FL], 3M-ESPE and GC e-light [EL], GC; high intensity halogen–Elipar Trilight [TL], 3M-ESPE; very high intensity halogen–Astralis 10 [AS], Ivoclar Vivadent) were selected for this study. Pulse (EL1), continuous (FL1, EL2, TL1), turbo (EL3, AS) and soft-start (FL2, EL4, TL2) curing modes of the various lights were examined. A conventional, continuous cure halogen light (Max [MX], Dentsply-Caulk) was used for comparison. Six composite (Z100, 3M-ESPE) specimens were made for each light-curing mode combination. After polymerization, the specimens were stored in air at 37°C for 24 hours and subjected to hardness testing using a digital microhardness tester (load=500g; dwell time=15 seconds). The specimens were then placed in 75% ethanol-water solution at 37°C for 24 hours and post-conditioning hardness was determined. Mean hardness (HK)/change in hardness (ΔHK) was computed and the data subjected to analysis using one-way ANOVA/Scheffe's test and Independent Samples *t*-test ($p<0.05$). Softening upon storage in ethanol (ΔHK) was used as a relative indication of cross-link density. Specimens polymerized with AS, TL2 and all modes of both LED lights were significantly more susceptible to softening in ethanol than specimens cured with MX. No significant difference in cross-link density was observed among the various modes of EL and FL. For TL, curing with continuous mode resulted in specimens with significantly higher cross-link density than curing with the soft-start mode.

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INTRODUCTION

Polymerization of methacrylate monomers in dental resin composites results in a highly cross-linked structure. Monomer conversion is, however, never complete and the polymer usually contains considerable quantities of remaining, unreacted double bonds (Ferracane & others, 1997). Light-initiated polymerization has not improved the situation. On the contrary, it has increased the risk of less than optimal conversion during clinical work, since new sources of failure, including light intensity, spectral distribution, curing time and access have been introduced (Silikas, Eliades & Watts, 2000; Davidson-Kaban & others, 1997; Øilo, 1992). For dental composites, the degree of conversion is an important factor, as it influences mechanical properties (Asmussen, 1982; Ferracane & Greener, 1986) and the amount of free monomer that can be eluted from the materials (Ferracane, 1994; Munksgaard, Peutzfeldt & Asmussen, 2000). Despite its importance, the degree of conversion does not give a complete characterization of polymer structures. Conversion is an average measure and does not take into account that areas of high and low conversion may demonstrate the same quantity of remaining double bonds as a more homogeneously polymerized material. In addition, polymers differing in linearity and, therefore, having different cross-link densities, may have similar conversion values (Asmussen & Peutzfeldt, 2001a,b).

Soft-start (ramped) and pulse curing of composites may give rise to reduced polymerization shrinkage due to stress relief (Davidson & Feilzer, 1997; Sakaguchi & Berge, 1998; Suh & others, 1999). These slow start methods may lead to different polymer structures even though the degree of monomer conversion is the same (Asmussen & Peutzfeldt, 2001a). It was speculated that slow start polymerization is associated with relatively few centers of polymer growth, which will result in a more linear structure with relatively few cross-links. On the other hand, a rapid or turbo cure was thought to result in a multitude of growth centers and, consequently, a polymer with higher cross-link density (Asmussen & Peutzfeldt, 2001a).

Aside from the possible influence of rate of cure, the cross-link density of a polymer structure may also depend on the type of light source. Light Emitting Diode (LED) curing lights were introduced to overcome some of the drawbacks of halogen lights (production of a significant amount of heat during curing cycles and bulb/reflector/filter degradation over time due to high operating temperatures). The effect of LED lights on the cross-link density of composites has not been reported in the dental literature. This study investigated the influence of curing lights and modes on the cross-link density of dental composites. The hypothesis tested was that using different light sources and curing modes would result in polymers of different cross-link densities.

METHODS AND MATERIALS

The degree of cross-linking may be assessed by measuring the glass transition temperature (Tamareselvy & Rueggeberg, 1994) and by swelling tests. In this study, the cross-link density was estimated by softening in alcohol as proposed by Asmussen and Peutzfeldt (2001a,b). Since poly(methymetacrylate) dissolves completely in ethanol, it can be assumed that a more linear polymer would be softened to a higher degree than a more cross-linked polymer. A minifill composite (Z100; 3M-ESPE, St Paul, MN, USA) and

Table 1: *Details of the Curing Lights and the Various Curing Modes Evaluated*

LCU	Curing Modes	Curing Profiles
GC e-light (LED) GC Europe, Leuven, Belgium	Pulse Curing (EL1)	750 mW/cm² (10 pulses x 2 seconds)
	Standard (EL2)	350 mW/cm² (40 seconds)
	Turbo (EL3)	600 mW/cm² (20 seconds)
	Soft-start curing (EL4)	0-600 mW/cm² (20 seconds) → 600 mW/cm² (20 seconds)
Elipar Freelight (LED) 3M-ESPE, Seefeld, Germany	Standard (FL1)	400 mW/cm² (40 seconds)
	Exponential (FL2)	0-400 mW/cm² (12 seconds) → 400 mW/cm² (28 seconds)
Max (Halogen) Dentsply-Caulk, Milford, DE, USA	Standard (MX)	400 mW/cm² (40 seconds)
Astralis 10 (Halogen) Ivoclar-Vivadent, Schaan, Liechtenstein	High Power (AS)	1200 mW/cm² (10 seconds)
Elipar Trilight (Halogen) 3M-ESPE, Seefeld, Germany	Standard (TL1)	800 mW/cm² (40 seconds)
	Exponential (TL2)	100-800 mW/cm² (15 seconds) → 800 mW/cm² (25 seconds)

Curing profiles are based on manufacturers' information.

four LED/halogen curing lights (LED–Elipar Freelight [FL] and GC e-light [EL]; high intensity halogen–Elipar Trilight [TL]; very high intensity halogen–Astralis 10 [AS]) were selected for this study. Pulse (EL1), continuous (FL1, EL2, TL1), turbo (EL3, AS) and soft-start (FL2, EL4, TL2) curing modes of the various lights were examined. A conventional, continuous cure halogen light (Max [MX], Dentsply-Caulk) was used for comparison. Table 1 lists the details of the curing lights and curing modes evaluated. The light intensities of the light sources were checked with a commercial radiometer (Hilux; Benlioglu Dental Inc, Ankara, Turkey) before beginning the experiment to ensure the consistency of light output.

The composite material was placed in the square recesses (3-mm long x 3-mm wide x 2-mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was placed over the acetate strip and pressure applied to extrude excess material. The composite specimens were then polymerized using the various curing lights and modes at a curing distance of 1 mm. Immediately after light polymerization, the acetate strips were discarded and the specimens stored in air at 37°C for 24 hours. The specimens were then subjected to hardness testing with a digital microhardness tester (FM7; Future-Tech Corp, Tokyo, Japan). A 500g load was applied through the indentor with a dwell time of 15 seconds to obtain pre-conditioning Knoop Hardness Number (HK1). Specimens were then placed in 75% ethanol-water solution at 37°C for 24 hours and post-conditioning hardness (HK2) was determined. Hardness deterioration was computed as follows: ΔHK=HK1–HK2. One-way ANOVA and Scheffe's post-hoc test were used to determine differences in mean HK/ΔHK among the various curing methods and the control light source MX. For lights with multiple curing modes (EL, FL and TL), differences in mean ΔHK among the modes were assessed with one-way ANOVA/Scheffe's test and Independent samples *t*-test depending on the number of curing

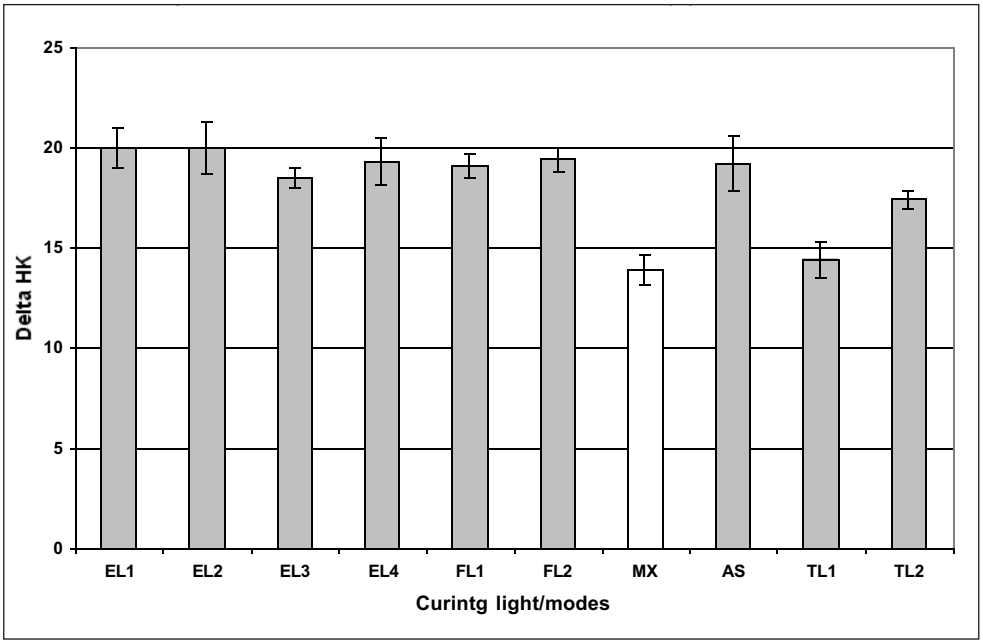

Figure 1: *Mean hardness deteriotation associated with the different curing lights and modes.*

Table 2: *Mean HK and ΔHK for the Various Curing Light and Modes*

Curing Lights	Curing Modes	HK 1 (Pre-Conditioning)	HK 2 (Post-Conditioning)	ΔHK
e-light	**EL1**	90.9 (0.77)	71.0 (1.02)	20.0 (1.02)
	EL2	87.5 (1.73)	67.4 (1.93)	20.0 (1.29)
	EL3	87.8 (0.32)	69.4 (0.23)	18.5 (0.50)
	EL4	89.2 (0.65)	69.9 (0.99)	19.3 (1.18)
Freelight	**FL1**	89.3 (0.93)	70.2 (1.07)	19.1 (0.59)
	FL2	90.0 (1.04)	70.6 (0.86)	19.4 (0.63)
Max	**MX**	89.0 (0.29)	75.1 (0.83)	13.9 (0.73)
Astralis 10	**AS**	92.7 (1.44)	73.6 (1.75)	19.2 (1.35)
Trilight	**TL1**	89.8 (0.77)	75.5 (0.65)	14.4 (0.88)
	TL2	94.4 (0.39)	77.0 (0.27)	17.4 (0.49)

Standard deviations in parentheses.

modes. All statistical analysis was carried out at significance level 0.05.

RESULTS

Table 2 and Figure 1 show the mean HK and ΔHK values for the various curing lights/modes. Results of the statistical analysis of HK and ΔHK values are shown in Tables 3 and 4. Mean pre-conditioning HK values ranged from 87.5 to 94.4 for EL2 and TL2, respectively, while mean post-conditioning values ranged from 67.4 to 77.0 for the same lights. The greatest softening in ethanol was observed for EL1 and EL2, while the lowest was with MX.

Prior to conditioning in ethanol, specimens cured with AS and TL2 were significantly harder than those cured with MX. No significant difference in mean pre-conditioning HK values was observed between MX and the LED curing lights. After conditioning in ethanol solution, specimens cured with all LED lights/modes were significantly softer than those cured with MX. The ΔHK values for all curing lights and modes were significantly greater than MX with the exception of TL1. For lights with multiple curing modes, no significant difference in ΔHK values was observed between modes with the exception of TL. For the latter, specimens cured with TL1 were less susceptible to softening in ethanol than specimens cured with TL2

Table 3: *Statistical Comparison of Mean HK/ΔHK Values Among the Various Curing Methods and the Control Light Source MX*

Variables	Differences
HK1 (Pre-conditioning)	AS, TL2 > MX
HK2 (Post-conditioning)	MX > EL1, EL2, EL3, EL4, FL1, FL2
ΔHK	EL1, EL2, EL3, EL4, FL1, FL2, AS, TL2 > MX

Results of One-way ANOVA/Scheffe's test (p<0.05). > denotes statistically significant differences.

Table 4: *Statistical Comparison of Mean ΔHK Values Among Modes for Lights with Multiple Curing Modes*

Curing Lights	Differences
e-light	NS
Freelight	NS
Trilight	TL2 > TL1

Results of One-way ANOVA/Scheffe's test and Independent Samples t-test (p<0.05). NS denotes no significant difference, while > denotes statistically significant differences.

DISCUSSION

The composite material and curing distance were standardized in this experiment. As such, any difference and change in hardness can be attributed solely to variations in light sources and curing modes. Hardness is defined as the resistance to permanent indentation or penetration (Anusavice, 1996). Knoop hardness is widely employed as an indirect method of determining the degree of conversion, as it has been shown to have a good correlation to infrared spectroscopy (DeWald & Ferracane, 1987). The degree of conversion associated with AS and TL2 can be assumed to be greater than MX in view of the significantly higher HK values observed. Despite this, composite specimens polymerized with AS and TL2 were more susceptible to softening in ethanol than MX. Findings corroborated the hypothesis put forth by Asmussen and Peutzfeldt (2001a) which states that polymers differing in linearity and, therefore, having different cross-link densities, may have similar conversion values. As no significant difference in pre-conditioning HK values was observed between MX and the other curing lights/modes, the degree of conversion associated with these lights can be presumed to be similar at the surface of restorations.

Asmussen and Peutzfeldt (2001a,b) used 100% ethanol as the conditioning medium in their studies. Instead of 100% ethanol, 75% ethanol-water solution was used in this study, as this concentration of ethanol has been shown to result in maximum softening of BisGMA-based composites like Z100 (Wu & McKinney, 1982; Kao, 1989). This mixture has a solubility parameter value (3.10×10^{-4} $J^{1/2}$ $m^{-3/2}$) approximating that of BisGMA (Kao, 1989). Although no general correlation between hardness deterioration and the degree of cross-linking may be present, the degree of softening is useful as a relative indication of low cross-linking density (Asmussen & Peutzfeldt, 2001b). Slightly more material is expected to dissolve from a relatively linear polymer than one that is more cross-linked. Polymers with lower cross-link densities are therefore expected to experience more softening in ethanol solution, resulting in greater ΔHK values. Composites with lower cross-link densities may be more prone to hydrolysis and water sorption, leading to less than optimal material properties and reduced clinical longevity (Yap, Teoh & Tan, 2000; Indrani & others, 1995).

Two types of curing lights (LED and halogen) and several curing modes were evaluated with a conventional, continuous cure halogen light as a control. These modes involved variations in intensity of curing time between and before final cure. With the exception of TL1, specimens cured with all curing lights and modes were more susceptible to softening in ethanol solution than MX. This may be interpreted as the manifestation of composite structures having fewer cross-links. As the degree of conversion is similar (no significant difference in pre-conditioning HK values), differences in ΔHK values between MX and the LED lights could be attributed to spectral distribution and/or thermal emission. Halogen bulbs generate light by the electric heating of

a tungsten filament to extremely high temperatures. Mostly heat radiation, which is in the infrared of the electromagnetic spectrum, is generated (Althoff & Hartung, 2000) and only a small percent of the light output is in the visible part (including the blue range) desired for polymerization. Despite the use of dielectric filters, halogen curing lights emit a considerable number of other wavelengths beyond the absorption spectrum of the camphorquinone photoinitiator (400 to 500 nm) employed in most composites. LEDs are solid-state semiconductor devices that convert electrical energy directly into light. The generation of light produced by LEDs results in high efficacy, as most of the energy radiated falls within the absorption spectrum of camphorquinone photoinitiators (Mills, Jandt & Ashworth, 1999). Thermal emission of halogen lights has been shown to be significantly higher than LED lights (Yap & Soh, 2003). In addition, spectral impurities generated by halogen lights are highly absorbed by dental materials, inducing further heating of the composites during the curing process (Masutani & others, 1988; Hannig & Bott, 1999). The aforementioned may be responsible for the greater cross-link density observed with MX.

Although AS and TL2 employ the use of halogen bulbs, specimens polymerized with these curing modes were also more susceptible to softening in ethanol when compared to MX. The voltage of the halogen bulbs used by MX, AS and TL was similar and ranged from 12 to 14V. Large differences in bulb wattage were, however, observed among the three halogen lights. Wattage of the bulbs was 35W, 75W and 100W for MX, TL and AS, respectively. The higher light intensities of AS and TL could be mitigated by the use of turbo and soft-start curing modes. This was substantiated by the lack of statistical differences in ΔHK values between MX and the continuous cure mode of TL (TL1). While slow start methods were introduced to reduce polymerization shrinkage, turbo cure was developed to reduce clinical time. Although high intensity lights may provide higher values for degree of conversion and physical properties, they also produce higher contraction strain rates during polymerization (Sakaguchi & Berge, 1997).

EL is programmed with multiple curing modes (continuous, turbo, soft-start and pulse cure), while FL and TL are equipped with two curing modes (continuous, soft-start). No significant difference in ΔHK values was observed between standard continuous cure and the other irradiation modes for the LED lights EL and FL. Consequently, slow start curing methods appear to have minimal influence on polymer cross-link density for LED lights. For TL, composites cured with soft-start mode (TL2) were more susceptible to softening in ethanol than those which were continuously cured (TL1). Silikas and others (2000) reported that soft-start irradiation did not reduce the degree of conversion for halogen lights. The findings of this study suggest that soft-start curing with halogen lights does not affect the degree of conversion but reduces the degree of cross-linking in composite materials. Results parallel those of Asmussen and Peutzfeldt (2001a), involving pulse-delay irradiation with halogen lights.

Results of this study suggest that the use of certain manufacturer-recommended curing modes have an influence on the degree of composite cross-linking. In the clinical situation, variations in cross-link density may be considerable given the difficulties in access for curing, shadowing of curing lights by matrixes/other items and problems in obtaining the close proximity of curing tips to restorative materials. These factors, in addition to the use of LED lights, may contribute to less than ideal cross-link density, resulting in early restoration failure. The effects of curing lights and modes on cross-link density warrant further investigation. This should involve a spectrum of visible light cured materials (composites, resin-modified glass ionomers and other hybrid materials), standardization of light energy densities and the determination of glass transition temperatures.

CONCLUSIONS

Within the limitations of this *in-vitro* study, the following conclusions can be made:

1. The cross-link density of composites was light and curing mode dependent.
2. Composites cured with LED lights were less cross-linked than those cured with conventional halogen lights.
3. For halogen curing lights, soft-start irradiation significantly reduced the cross-link density of composites.

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Effects of Multiple Adhesive Coatings on Dentin Bonding

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Clinical Relevance

The simple method of multiple consecutive coating during dentin bonding improved bond strength and reduced nanoleakage.

SUMMARY

Simple changes to bonding techniques can improve resin-dentin bond strengths. This study evaluated the effect of multiple consecutive coatings of adhesive resin on dentin by measuring both microtensile bond strength and nanoleakage following exposure to ammoniacal silver nitrate. Resin-dentin bonded specimens were prepared using two total-etch adhesives (OptiBond Solo Plus/Kerr or Single Bond/3M ESPE). During bonding, resin application and air evaporation were done 1, 2, 3, 4, 6 or 8 times on acid-etched, moist dentin surfaces. Mean microtensile bond strengths were evaluated by two-way ANOVA and Fisher's PLSD test ($p<0.05$; n=16 for each group). Additionally, nanoleakage of silver nitrate was evaluated by transmission electron microscopy (TEM). The results indicated that bond strengths increased with each coating up to four coats. Nanoleakage decreased with each coat, becoming very small after four or more coats. This adhesive application method can be easily applied to clinical practice, thereby improving the quality of resin-dentin bonds.

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INTRODUCTION

It is well accepted that bond strength is affected by the extent of resin infiltration into the exposed collagen network (Gwinnett, 1992). Different techniques of acid conditioning, rinsing and application of adhesive resin and evaporation of solvents can change the amount of resin uptake and the resulting bond strength (Pashley & others, 1995). Air-drying has been shown to induce a col-

lapse or recession of primer-treated collagen networks due to loss of interfibrillar spaces that are necessary for resin infiltration (Nakaoki & others, 2000). A significant improvement in resin bond strength was achieved by the wet bonding technique (Kanca, 1992; Gwinnett, 1992; Perdigão, Swift & Cloe, 1993). When acid-etched dentin surfaces are left wet, resin uptake into interfibrillar spaces of the matrix can occur using hydrophilic monomers. Any procedure that increases resin infiltration into the collagen fibrils should improve the quality and strength of resin-dentin bonds.

It has been suggested that imperfect hybridization or polymerization of the resin adhesive creates voids in the hybrid layer that permit nanoleakage of silver as a tracer (Sano & others, 1994; Li, Burrow & Tyas, 2001; Pioch & others, 2001; Okuda & others, 2002; Tay & others, 2002b). Several recent TEM studies have revealed various types of nanoleakage (spotted, reticular patterns and water treeing) (Lai & others, 2001, 2002; Tay, Pashley & Yoshiyama, 2002a). Evaluation of silver uptake by TEM examination provides good spatial resolution of submicron defects in resin infiltration or polymerization. The effectiveness of consecutive coats has shown using a self-etching adhesive (Frankenberger & others, 2001; Pashley & others, 2002). However, no report is available on the effect of the multiple consecutive coatings of total-etch adhesives. Moreover, the effect of resin-dentin bond strength on nanoleakage has remained unclear. The authors hypothesized that multiple consecutive applications of adhesives may increase resin infiltration into acid-etched moist dentin, thereby increasing bond strength.

This study evaluated the effect of multiple consecutive adhesive applications to dentin on bond strength using the microtensile bond test. The quality of the resin-dentin bonds was tested by measuring the nanoleakage of silver by transmission electron microscopy. The null hypothesis tested was that multiple applications of resin have no effect on either bond strength or nanoleakage.

METHODS AND MATERIALS

Teeth

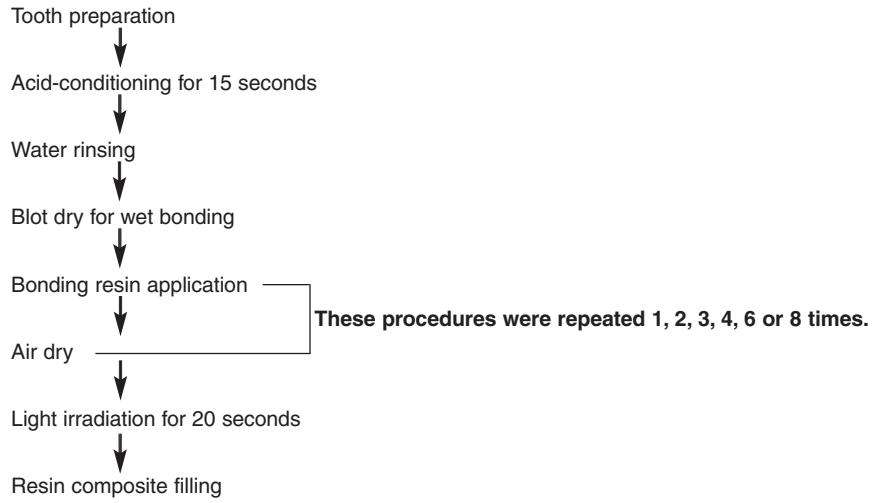
Seventy-two non-carious human premolars were extracted for orthodontic reasons with the patients' informed consent under a protocol approved by the appropriate institutional review board. Forty-eight premolars were used for the microtensile bond test and 24

Table 1: *Chemical Formulations of the Two Adhesive Systems and Bonding Procedures*

Material (Manufacturer)	Acid-conditioner	Bondlng Resin
OptiBond Solo Plus (Kerr Corp, Orange, CA, USA)	37.5% phosphoric acid	Bis-GMA, GPDM, GDM, HEMA, ethanol, water, fumed silica, barium glass, sodium hexafluorosilicate
Single Bond (3M ESPE, St Paul, MN, USA)	35.0% phosphoric acid	Bis-GMA, HEMA, dimethacrylates, ethanol, water, polyalkenoic acid

Abbreviations: Bis-GMA: bisphenol-glycodyl methacrylate
GDM: glycerol dimethacrylate
GPDM: glycerophosphate dimethacrylate
HEMA: 2-hydroxylethyl methacrylate

-Bonding Procedure-



were used for TEM nanoleakage examination. The teeth were stored in a 0.1% chloramine T solution at 4°C and were used within one month following extraction. Each tooth was sectioned perpendicular to its longitudinal axis using a slow-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under water coolant to expose midcoronal dentin. Each surface was ground with 600-grit silicon carbide paper under running water for 30 seconds just prior to bonding.

Test Materials and Consecutive Coating

Two commercially available total-etch adhesives (OptiBond Solo Plus, Kerr Co, Orange, CA, USA; Single Bond, 3M ESPE, St Paul, MN, USA) were used in this study (Table 1). The prepared dentin surfaces were acid conditioned for 15 seconds and subsequently thoroughly washed using a water spray for 10 seconds. Excess water was blot dried from the dentin surface with a cotton pellet, leaving the surface visibly moist. For single applications of Single Bond adhesive system, the bonding adhesive was applied to the entire dentin surface without agitation and allowed to dwell undisturbed for three seconds, the solvent was then gentled evaporated for three seconds at a distance of 10 cm to form a slightly shiny adhesive film. For multiple consecutive applications (2, 3, 4, 6 or 8 applications), adhesive application and solvent evaporation steps were done repeatedly (Table 1) but, without any light-curing until all layers had been applied. For OptiBond Solo Plus, the adhesive was applied on prepared dentin surfaces for three seconds with a light brushing motion according to the manufacturer's instructions. Subsequently, the adhesive was gently air-dried for three seconds as described above to form a shiny adhesive film. The method of multiple consecutive coatings was conducted in a same manner as Single Bond. After the final application and solvent evaporation, the adhesive layer was light-illuminated for 20 seconds with a light-curing unit (Curing Light XL 3000, 3M ESPE) with a light output of not less than 550 mW/cm^2. Following surface treatment, five 1-mm increments of a resin composite (Z250; 3M ESPE) were built up and individually light activated for 60 seconds.

Microtensile Bond Test

After the resin-bonded specimens had been stored in distilled water at 37°C for 24 hours, the samples were sectioned perpendicular to the adhesive interface with a diamond saw to produce beams (adhesive area: approximately: 0.9 mm^2) under water cooling/lubrication. Four beams were obtained per tooth and there were four teeth per group. A total of 16 beams were used for each group. The beams were then attached with cyanoacrylate adhesive (Model Repair II Blue, Sankin Industry Co Ltd, Tokyo, Japan) to a testing apparatus, and a tensile load was applied with a material tester (EZ Test, Shimadzu Co, Kyoto, Japan) at a crosshead speed of 1.0 mm/minute. The mean bond strengths were evaluated by a two-way ANOVA and Fisher's PLSD test ($p<0.05$: n=16 for each group).

Nanoleakage Evaluation of TEM

Twenty-four non-carious human premolars were used for TEM analysis of nanoleakage. The tooth preparation and bonding procedures were conducted in the same manner as previously described. After applying the bonding resin, a thin layer (1-mm) of silica-filled resin composite (Protect Liner F, Kuraray Co Ltd, Osaka, Japan) was applied and light activated for 60 seconds. The resin-bonded specimens were stored in distilled water at 37°C for 24 hours. After storage in water, the resin-dentin bonded specimens were vertically sectioned to produce about 1 x 2 x 5 mm bar-shaped specimens using a low-speed diamond saw under water lubrication. Two sections were obtained from each resin-dentin bonded specimen. A total of 48 beams were used and four beams were tested for each group. There were two materials, six different coating groups (1, 2, 3, 4, 6 and 8 coats) for a total of 12 subgroups. Two teeth were used in each subgroup and each tooth yielded two specimens.

Ammoniacal silver nitrate solution (pH=9.5) was prepared according to the protocol of Tay and others (2002a). The resin-bonded beams were immersed in 50 w/v% ammonical silver nitrate for 24 hours immediately after they were formed. The silver-impregnated specimens were then rinsed thoroughly in distilled water and placed in photodeveloping solution for eight hours under a fluorescent light.

Demineralized and undemineralized specimens were prepared for TEM. In the demineralized group, the silver stained samples were demineralized in an aqueous solution of 10% w/v EDTA that was buffered with sodium formate to a pH of 2.5 for 72 hours at room temperature. Both demineralized and undemineralized specimens were fixed in 2.5% glutaraldehyde in 0.1 M cacodylate buffer titrated to pH 7.2 for two hours, then rinsed several times with 0.1 M sodium cacodylate buffer. They were dehydrated in increasing concentrations of ethanol (30, 40, 50, 60, 70, 80, 90, 95 and 100%) for 20 minutes each, immersed in propylene oxide as a transition fluid and embedded in epoxy resin (TAAB 812 resin, TAAB Laboratories, Aldermaston, UK) at 60°C for 120 hours. The undemineralized specimens were fixed, dehydrated and embedded in the same manner. After resin embedding, ultrathin transverse sections (70 nm) were cut with an ultramicrotome using a diamond knife and collected onto 150 mesh copper grids. After drying without staining, the sections were observed with a transmission electron microscope (H-800, Hitachi Ltd, Tokyo, Japan) operated at 75 kV. Ten sections were examined for each group. A schematic of the experimental design is illustrated in Table 1.

RESULTS

The mean bond strengths for each adhesive system, as a function of the number of applications of the adhesive, are shown in Table 2. The bond strength of OptiBond Solo Plus gradually increased from 1 to 4 consecutive coatings (13.4 to 69.5 MPa, respectively) and reached a plateau that did not change with subsequent coatings (six or eight times). With a single application, the bond strength of Single Bond (38.5 ± 22.1 MPa) was significantly greater ($p<0.05$) than OptiBond Solo Plus (13.6 ± 6.6 MPa). The maximum bond strength (87.3 ± 15.1 MPa) was recorded, with four applications of Single Bond significantly higher ($p<0.05$) than the other groups, except for six applications of Single Bond.

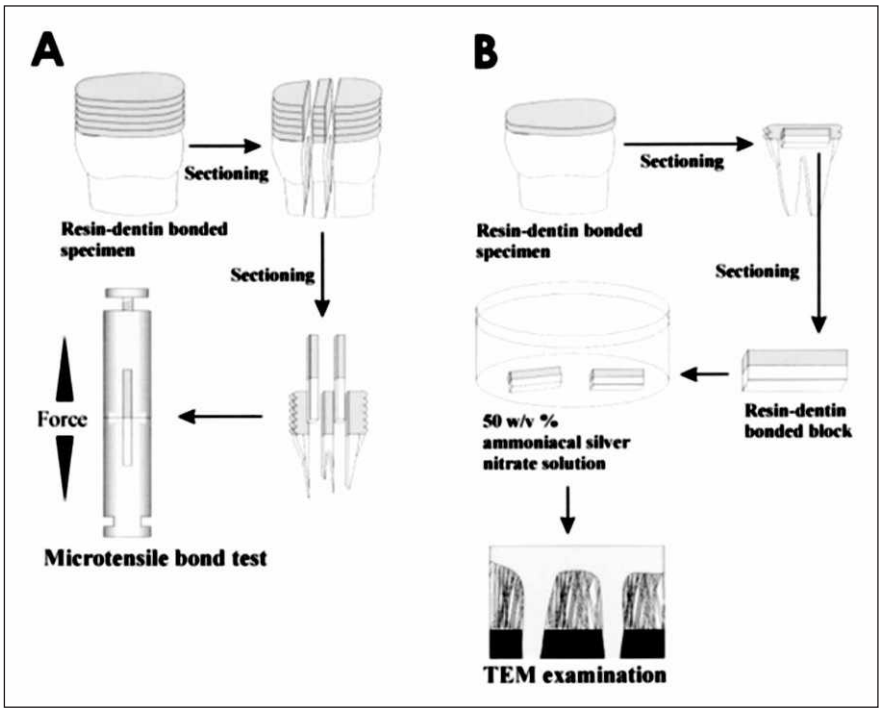


Figure 1: *Test design of microtensile bond test (A) and nanoleakage evaluation by TEM (B).*

Table 2: *Microtensile Bond Strength in Each Treatment Group*

Number of Coats	OptiBond Solo Plus	Single Bond
1	13.6 ± 6.6 (16)[d]	38.5 ± 22.1 (16)[4]
2	49.1 ± 15.3 (16)[c]	55.5 ± 12.1 (16)[3]
3	58.1 ± 16.7 (16)[b,c]	54.1 ± 23.3 (16)[3]
4	69.5 ± 20.5(16)[a,b]	87.3 ± 15.1 (16)[1]
6	60.0 ± 12.2 (16)[a,c]	75.1 ± 19.0 (16)[1]
8	69.4 ± 12.2 (16)[a]	64.8 ± 10.5 (16)[2]

Results are presented as mean ± standard deviation (number of specimens) bond strength in MPa. Groups identified with the same lower case letters or numbers are not significantly different for each group (p>0.05).

Transmission electron microscopy revealed extensive silver staining within the hybrid layer in the specimens that only received a single application of either adhesive systems (Figures 2A and 3A). Two typical nanoleakage patterns (reticular and isolated spot types) were seen in the hybrid layer of specimens that received one and two coats of OptiBond Solo Plus (Figures 2A and 2B). In Figure 2A, the spotted type of silver nanoleakage was observed scattered within the overlying adhesive layer. The size and density of silver grains seen in the hybrid layer gradually diminished in specimens that received three or four layers of adhesive. Although silver uptake was greatly reduced, there was no further reduction in silver uptake after four coats (six or eight coats, not shown). Isolated, discontinuous silver deposits were observed in some areas of the hybrid layer in the specimens that received four, six and eight applications of adhesive in both material groups. No major differences in hybrid layer thickness (approximately 3 μm) or the thickness of the adhesive layer were found between the groups regardless of the number of adhesive applications. Single Bond treated specimens were easily identified by the presence of polyalkenoic acid copolymer on the surface of the hybrid layer (Figure 3). The nanoleakage results obtained with demineralized and undemineralized TEM sections were similar for both materials.

DISCUSSION

The highest values for bond strengths were achieved following four consecutive applications of Single Bond (87.3 MPa) and OptiBond Solo Plus (69.5 MPa). Numerous studies have reported bond strengths of Single Bond (Sanares & others, 2001; Inoue & others, 2001; Van Meerbeek & others, 2001; Yoshiyama & others, 2002) and OptiBond Solo Plus (Inoue & others, 2001; Van Meerbeek & others, 2001) using the microtensile bond test. However, the bond strength reported in this study exceeded those reported in previous studies, presumably because of the additional number of adhesive coatings.

Good resin infiltration in total-etched, wet bonding specimens can be achieved if the adhesive resin replaces all the water within the demineralized matrix that was previously occupied by mineral, without collapse of the collagen matrix. However, small amounts of silver remained within the hybrid layer even in the specimens with relatively high bond strength. A large amount of silver was taken up in the hybrid layers created using a single coating of adhesive. Silver uptake is thought to occur in water-filled voids (Tay & others,

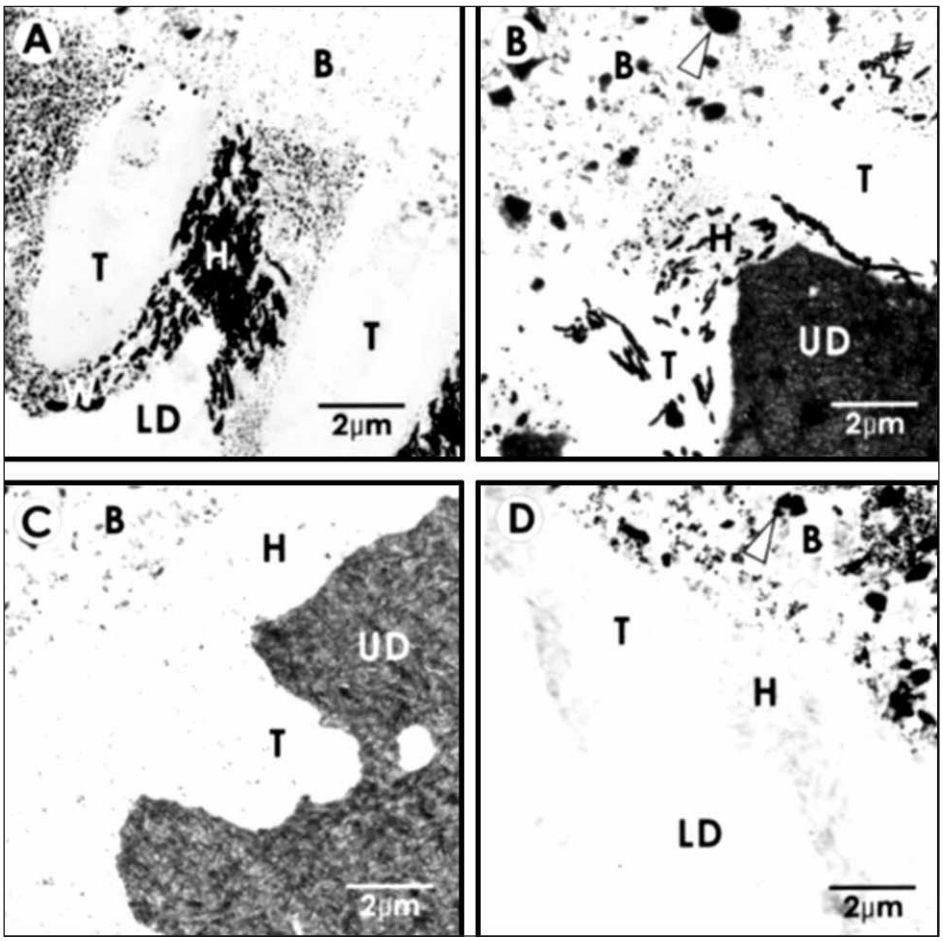


Figure 2: *TEM micrographs illustrating the adhesive interfaces produced by OptiBond Solo Plus for 1, 2, 3 and 4 consecutive coatings. (A) Demineralized section with single coat. (B) Undemineralized section with two coats. (C) Undemineralized section with three coats. (D) Demineralized section with four coats. (A, B) The spotted and reticular modes of nanoleakage were seen along the resin-dentin interfaces in specimens that had received one and two applications of bonding resin. The spotted-mode of leakage is present in the bonding resin. These leakage patterns were also seen in the hybridized complex along the resin tags (W). (C, D) For three and four coats, the spotted type of nanoleakage was observed in the hybrid layer. The filler particles do not infiltrate into the resin tags. All TEM micrographs are shown at the same magnification.*
B=bonding resin, T=resin tag, H=hybrid layer, UD=undemineralized dentin, LD=laboratory demineralized dentin. W=hybridized tubule wall. (White arrowheads represented the filler particles of OptiBond Solo Plus.)

2002b). Residual water in the hybrid layer is thought to occur in regions where resin did not infiltrate the collagen network. The amount of silver uptake was reduced following four consecutive coatings for both adhesive materials (Figures 2 and 3). However, small amounts of silver remained within the hybrid layer even in the specimens with relatively high bond strengths. The repeated procedure of adhesive application and subsequent solvent evaporation may promote improved resin infiltration within the exposed collagen fibrils. This speculation was supported by the reduced amount of silver deposition into the hybrid layer as the number of applications increased. These results confirm previously reported technique sensitivity of the bonding procedures (Pashley & others, 2002; Peutzfeldt & Asmussen, 2002).

The term "nanoleakage" is used to describe silver uptake into nanometer-sized spaces that are present within resin-dentin bonds without an interfacial gap (Sano & others, 1994; Li & others, 2001; Piock & others, 2001; Okuda & others, 2002). Moreover, many studies have suggested that these nanometer-sized spaces are created by a discrepancy of depth between the demineralization and resin infiltration (Spencer & Swafford, 1999; Spencer & Wang, 2002; Hashimoto & others, 2000; 2001; 2002a,b; 2003a,b). Recently, several TEM studies have classified the types of nanoleakage as spotted, reticular and water treeing within the bonded interface using ammoniacal silver nitrate as a tracer (Tay & others, 2002a; Lai & others, 2001, 2002; Yiu & others, 2002). Moreover, a recent TEM study revealed the susceptibility of poorly polymerized resin to silver nitrate staining (Pashley & others, 2002; Yiu & others, 2002; Tay & others, 2002b). These results indicate that defects of resin impregnation and imperfect polymerization of the adhesive resin can create water-rich zones that permit silver uptake. During wet bonding, residual water in interfibrillar spaces might decrease polymerization of the bonding resin (Jacobsen & Söderhold, 1995) and/or lead to hydrogel formation of HEMA in the bottom half of the hybrid layer (Wang & Spencer, 2003). However, the increased extent of resin impregnation into collagen caused by the consecutive coating method might remove residual water, thereby, improving resin-infiltration and cross-linking of the adhesive comonomers within the hybrid layer. Recently, a study showed increased bond strength by the techniques of applying multiple layers and curing successive layers using a self-etching primer system (Pashley & others, 2002). This technique eliminated the oxygen-inhibited zone at the top of the first coating of the bonding resin layer. However, our method of multiple coatings without light curing between each layer increased the resin saturation into

the collagen web. That is, by not polymerizing the comonomers, monomers can continue to diffuse inward, while solvents are diffusing outward. The improvement in bond strength produced by these two methods has different underlying mechanisms. When multiple coats are applied but not cured, the resin infiltration of the hybrid layer and the removal of residual water may be more complete without increasing the thickness of the overlying adhesive layer. When each successive layer is light cured, the adhesive layer becomes thicker without changing the quality of the hybrid layer. This may increase bond strength by improving stress distribution via increased elasticity of the thicker adhesive layer (Choi, Condon & Ferracane, 2000). The results of this study require rejection of the null hypothesis that there is no difference in bond strength or nanoleakage following multiple application of adhesive.

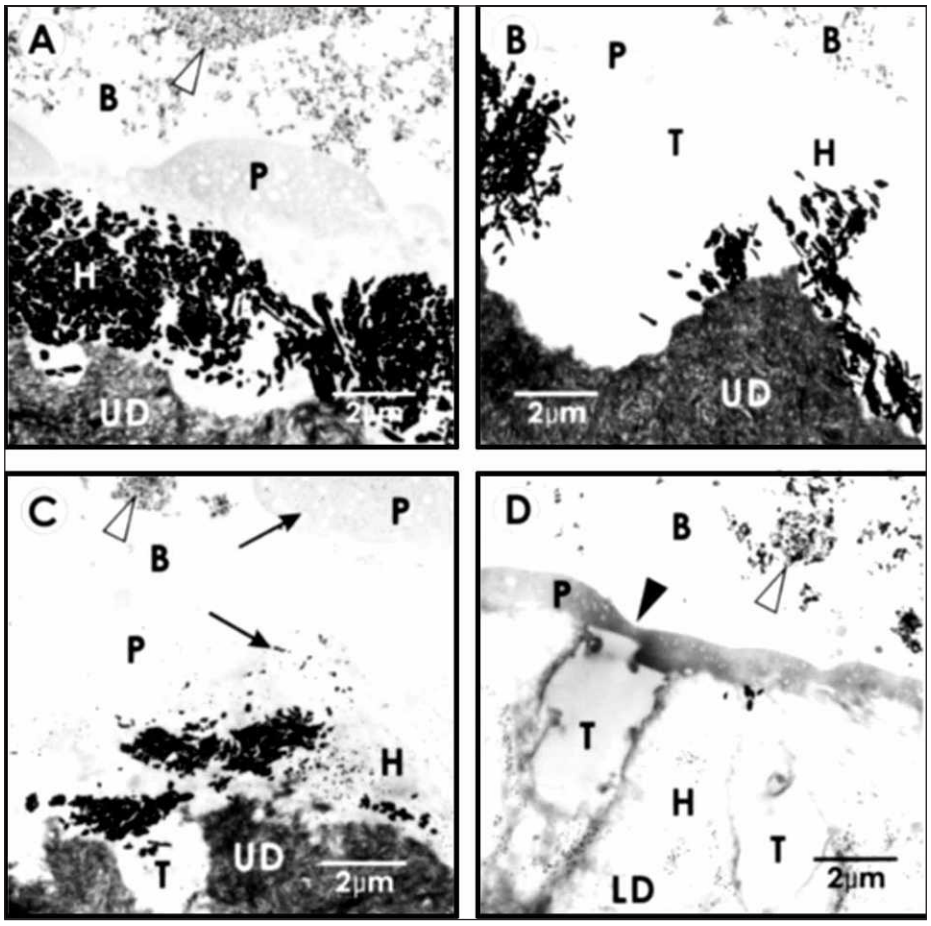


Figure 3: *TEM micrographs illustrating the adhesive interfaces in the specimens of Single Bond for 1, 2, 3 or 4 consecutive coatings. (A) Undemineralized section with single coat. (B) Undemineralized section with two coats. (C) Undemineralized section with three coats. (D) Demineralized section with four coats. (A, B) The reticular mode of nanoleakage occupies a large area of the resin-dentin interfaces for one and two coats. The layer of polyacarboxylate salts (P) is localized upon the hybrid layer, that was created by the chemical reaction of the polyalkenoic acid co-polymer with calcium remaining at the dentin surface (Van Meerbeek & others, 1996). (C) Spotted- and reticular-mode silver grains are found within the hybrid layer. The silver depositions are frequently entrapped within the gel phase of the polycarboxylate salts (black arrows). (D) For four coats, the isolated spotted-type of nanoleakage partially spreads in the hybrid layer. The gel phase is frequently occluding at the orifices of dentinal tubules (black arrowhead). All TEM micrographs are shown at the same magnification. B=bonding resin, T=resin tag, H=hybrid layer, P=polycarboxylate salts, UD=undemineralized dentin, LD=laboratory demineralized dentin.(White arrowheads indicate the filler particles of unfilled bonding resin [Protect Liner F]).*

Most single bottle adhesive systems are used in two layers or coats. The first coating serves to wet the moist surface and begins substituting solvated adhesive comonomers for water in the interfibrillar spaces. Water may diffuse from the demineralized dentin and tubules so rapidly that comonomers undergo phase changes (Eliades, Vougiouklakis & Palaghias, 2001; Spencer & Wang, 2002). The second application of adhesive removes or resolubilizes resin globules and is thought to remove more water. A recent report showed that longer resin application times increased resin-dentin bond strength, presumably due to increased resin infiltration into the hybrid layer (El-Din & Abd el-Mohsen, 2002). The use of multiple applications of adhesives without curing allows more time for removal of water from the interfibrillar spaces and more time for inward diffusion of adhesive monomers. This hypothesis could be tested using micro-Raman spectroscopy measurements of the concentration gradients of adhesive monomers (Wang & Spencer, 2002; 2003). The authors used two ethanol-based adhesives in this test. However, similar results were obtained using an acetone-based adhesive (One-Step Plus, BISCO: Hashimoto & others, unpublished results).

The reduction of nanoleakage and the increases in bond strength in the short-term (after 24 hours bonding) obtained by simply increasing the number of consecutive coating of adhesives suggests that this technique might be useful in all total-etch systems.

In summary, the consecutive coating method with four applications of resin used for the total-etch adhesives tested in this study provides a simple technique that improved the quality of resin-dentin bonds.

CONCLUSIONS

The method of multiple consecutive coating during dentin bonding improved the bond strength of two total-etch adhesive systems and reduced nanoleakage. This is thought to be due to an increase in resin-infiltration of the hybrid layer.

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Composite Bond Strength to Enamel with Self-etching Primers

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Clinical Relevance

Clearfil SE Bond was the only self-etching system that achieved high composite-to-enamel bond strength, similar to the total-etch bonding system tested in this study.

SUMMARY

This study compared the shear bond strength (SBS) to enamel of five self-etching primer/adhesive systems and one total-etch, one-bottle adhesive system. Sixty freshly extracted bovine incisors were mounted, polished to 600-grit and randomly assigned to six groups (n=10): Adper Prompt Self-Etch (AD), OptiBond Solo Plus Self-Etch (OP), AdheSE (AS), Tyrian (TY) and Clearfil SE Bond (SE) as self-etching systems; and Single Bond (SB) as a total-etch system (control). The respective hybrid composite was applied in a #5 gelatin capsule and light-cured. After 500 thermal cycles (5°C-55°C), the specimens were loaded in shear using an Instron at 5 mm/minute. Mean bond strengths were analyzed with one-way ANOVA, followed by a Duncan's *post-hoc* test (p 0.05). SBS (mean ± SD) were: AD=13.0(±2.5); OP=5.6(±2.3); AS=12.6(±3.7); TY=7.6(±2.6); SE=17.6(±4.5) and SB=17.9(±4.4). ANOVA showed a significant difference at $p<0.0001$. Duncan's *post-hoc* test ranked this difference in three homogeneous subsets. Only SE showed similar enamel SBS compared to the total-etch system tested (SB). AD and AS were ranked in the intermediary Duncan's subset, while TY and OP resulted in the lowest SBS. SBS to enamel with self-etching primers may depend on its specific composition.

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INTRODUCTION

Bonding to enamel has become routine and a reality in restorative dentistry. Acid etching with phosphoric acid can change the surface of enamel, making it more receptive to adhesion (Buonocore, 1955). In this way, a low viscosity fluid resin wets this high-energy surface and is then pulled into the microporosities created by etching through capillary attraction (Van Meerbeek & others, 1996). After polymerization, the resin tags formed by this extension of fluid resin into the microporosities form a strong micromechanical interlocking with enamel (Buonocore, Matsui & Gwinnett, 1968; Gwinnett & Matsui, 1967). The skill of clinicians to create adequate bonding to etched enamel has changed the concepts of cavity preparation, caries prevention and esthetics (Jordan, Suzuki & Davidson, 1993; Irinoda & others, 2000).

Total-etch one-bottle adhesive systems combine the functions of primer and adhesive into a single bottle. Thus, less viscous monomers are present and diluted in solvents with a high volatile power, such as ethanol and acetone. Considering enamel bonding, this property seems to contribute to a complete interdiffusion of the adhesive system all over the acid etching area (Fritz & Finger, 1999), resulting in high bond strength to enamel (Swift, Perdigão & Heymann, 1998; Swift & others, 1999).

Many different self-etching primer/adhesive systems are on the market today. The low pH of these systems allows mineralized tissue to be etched in a single treatment step (Miyazaki, Sato & Onose, 2000). Despite the consistent bonding results in dentin (Tay & others, 2000; Inoue & others, 2001; Lopes & others, 2002a), bonding to enamel is still unpredictable with this strategy (Rosa & Perdigão, 2000). The ability of self-etching systems to demineralize dental tissue is inversely proportional to the buffering capacity exhibited by the dental substrate (Lopes & others, 2002b). Thus, these self-etching agents may achieve different when applied to different dental hard tissues due to the characteristics of the composition of the enamel and dentin. Some of these systems have been recently introduced and their behavior in bonding to enamel is unknown.

This study compared the enamel shear bond strength (SBS) of five self-etching primer/adhesive systems with a total-etch one-bottle adhesive system. The null hypothesis tested in this project was that using self-etching primers/adhesive systems would not result in lower bond strength to enamel compared to what would be obtained with a total-etch one-bottle system.

METHODS AND MATERIALS

Sixty freshly extracted bovine incisors were obtained at a local abattoir and refrigerated in a solution of 0.5% chloramine until use. The roots were removed and the crowns cleaned of debris and embedded in phenolic rings with chemically activated acrylic resin

Table 1: *Materials Used, Composition and Respective Manufacturers*

Group	Adhesive System	Manufacturer	Composition	Etchant/Primer pH
AD	Adper Prompt Self-Etch (+ Filtek P60)	3M ESPE St Paul, MN, USA	Adhesive (Liquid 1)[A]: Methacrylated phosphoric esters, Bis-GMA, Initiators based on camphorquinone, stabilizers; (Liquid 2): water, HEMA, polyalkenoic acid co-polymer, stabilizers	1.5[A]
OP	OptiBond Solo Plus Self-Etch (+ Prodigy)	Kerr Co Orange, CA, USA	Primer[B]: Ethyl alcohol, water, Alkyl dimethacrylate resins, Stabilizers and Activators. Adhesive[B]: Ethyl alcohol, Alkyl dimethacrylate resins, 10-20% fillers: fumed silica (silicon dioxide), barium aluminoborosilicate glass, sodium hexafluorosilicate	1.2-1.5[B]
AS	AdheSE (+ TetricCeram)	Ivoclar Vivadent Amherst, NY, USA	Primer[C]: Phosphonic acid acrylate, Bis-acrylamide, water, initiators and stabilizers Adhesive[C]: Dimethacrylate, HEMA, highly dispersed silicon dioxide, initiators, stabilizers	1.7[C]
TY	Tyrian (+ Renew)	BISCO, Inc Schaumburg, IL, USA	Primer[D]: 2-Acrylamino-2-methyl propanesulfonic acid, Bis (2-(methacryloyloxy) ethyl phosphate, ethanol Adhesive[D]: BPDM, HEMA, acetone, 8.5% fillers (Glass frit ±0.93µm)	1.0[D]
SE	Clearfil SE Bond (+ APX)	Kuraray Co Osaka, Japan	Primer[E]: HEMA, hydrophilic dimethacrylate, MDP (10-methacryloyloxydecyl dihydrogen phosphate), N,N-diethatol-p-toluidine, D,L-camphorquinone, water Adhesive[E]: Silanated colloidal silica, Bisphenol A diglycidyl-methacrylate, HEMA, MDP, hydrophobic dimethacrylate, N,N-diethatol-p-toluidine, D,L-camphorquinone	1.9[E]
SB	Single Bond (+ Filtek P60)	3M ESPE St Paul, MN, USA	Etchant[F]: 35.0% H_3PO_4 Adhesive[F]: Bis-GMA, HEMA, dimethacrylates, polyalkenoic acid co-polymer, water, ethanol	0.6[F]

Source: A) 3M ESPE (2002) Adper Prompt Self-Etch Adhesive Technical Product Profile, St Paul, MN, USA. B) Kerr Co (2002) OptiBond Solo Plus Self-Etch Adhesive System Technical Manual, Orange, CA, USA. C) Ivoclar/Vivadent (2002) Scientific Documentation AdheSE, Liechtenstein. D) BISCO Inc (2002) Tyrian MSDS, Schaumburg, IL, USA. E) Yamada T & Sugizaki J (2000) Basic properties and clinical applications of the Clearfil SE Bond Osaka, Japan. F) 3M (1996) Single Bond Dental Adhesive System Technical Product Profile, St Paul, MN, USA.

(AcryliMet, South Bay Technology Inc, San Clemente, CA, USA). The specimens were randomly assigned to six groups (Table 1). The labial surface of 60 teeth was ground with a mechanical grinder to obtain a flat enamel surface and were subsequently polished for 30 seconds with wet 240-, 400- and 600-grit silicon carbide abrasive paper. Ten enamel specimens were randomly assigned to each adhesive system (applied according to manufacturer's instructions):

Group AD—The Adper Prompt Self-Etch (3M ESPE, St Paul, MN, USA) Liquid A and Liquid B were mixed with a micro brush. The mixed adhesive was applied to enamel using continuous rubbing for 15 seconds; the adhesive was air dried with oil-free compressed air from an air syringe until it became a thin film and was light-cured for 10 seconds.

Group OS—OptiBond Solo Plus Self-Etch Primer (Kerr Co, Orange, CA, USA) was applied to enamel with continuous rubbing for 15 seconds and gently air dried with oil-free compressed air from an air syringe for three seconds. The bonding resin OptiBond Solo Plus (Kerr Co) was applied with continuous rubbing for 15 seconds, gently air thinned for three seconds and light-cured for 20 seconds.

Group AS—AdheSE Primer (Ivoclar Vivadent, Amherst, NY, USA) was applied to enamel with continuous rubbing for 30 seconds and the excess primer was dispersed and air dried with oil-free compressed air from an air syringe until the mobile liquid film disappeared. The bonding resin AdheSE Bond (Ivoclar Vivadent) was applied, gently air blown and light cured for 10 seconds.

Group TY—Tyrian SPE (BISCO Dental Products, Schaumburg, IL, USA) was applied to enamel with continuous rubbing for 10 seconds. Two coats of the bonding resin One-Step Plus (BISCO Dental Products) were applied, gently air dried for 10 seconds and light cured for 10 seconds.

Group SE—Clearfil SE Primer (Kuraray Co, Osaka, Japan) was applied to enamel with continuous rubbing for 20 seconds and gently air dried with oil-free compressed air from an air syringe for three seconds. The bonding resin Clearfil SE Bond (Kuraray Co) was applied, gently air dried and light cured for 20 seconds.

Group SB—Enamel was acid-etched for 15 seconds with 35% phosphoric acid (Scotchbond Etching Gel, 3M ESPE) and washed with water for 10 seconds. The surface was air dried. Single Bond (3M ESPE) was applied in two consecutive coats, gently air dried with oil-free compressed air from an air syringe for two-to-five seconds and light cured for 10 seconds.

A hybrid composite (Filtek P-60, 3M ESPE) was condensed into a #5 gelatin capsule (Torpac Inc, Fairfield, NJ, USA), filling two-thirds of the capsule, and was light-cured for 180 seconds in a UnisX (Heraeus Kulzer, Dormagen, Germany) visible light-curing unit. Following application of the adhesive system, a final increment of proprietary hybrid resin composite (Table 1) was inserted into the gelatin capsule, which was seated securely against the flattened enamel surface. Excess material was carefully removed from the periphery of the capsule and the composite was light-cured for a total of 40 seconds (20 seconds from two opposite directions) using an XL 1500 curing light (3M ESPE). The intensity of the light was monitored with a Curing Radiometer (Demetron/Kerr, Danbury CT, USA) and was in excess of 450 mWcm^2 throughout the study.

After 24 hours in distilled water, the specimens were thermocycled for 500 cycles between water baths held at 5°C and 55°C with a 30 second dwell time in each bath and a transfer time of two seconds. Shear bond strengths were measured with an Instron Universal Testing Machine (Model 4444, Instron Corporation, Canton, MA, USA) using the Series IX Software System (Instron Corp) to record the data. A knife-edge shearing rod with a crosshead speed of 5-mm/minute was used to load the specimens until fracture.

The data were subjected to one-way ANOVA (Independent variable: adhesive system; outcome variable: SBS). A Duncan's *post-hoc* test was used to identify statistical differences between pairs of means at a confidence level of 95% for each set of data. The statistical analyses were carried out with the SPSS 10.0 for Windows software system (SPSS Inc, Chicago, IL, USA).

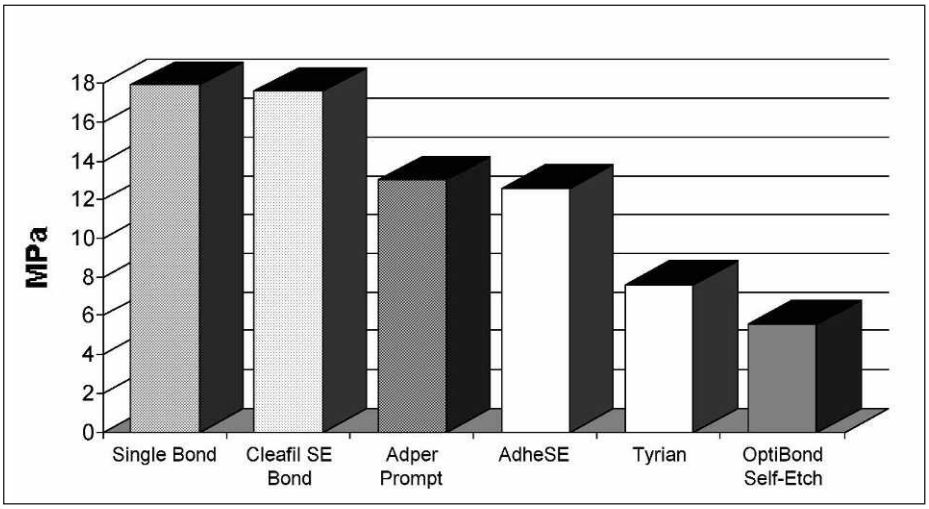

Figure 1. *Mean shear bond strength to enamel (MPa).*

Table 2: *Mean Shear Bond Strength to Enamel (MPa)*

Adhesive System	OP	TY	AS	AD	SE	SB
SBS	5.6±2.3[c]	7.6±2.6[c]	12.6±3.7[b]	13.0±2.5[b]	17.6±4.5[a]	17.9±4.4[a]
***p*-value**	0.205		0.799		0.864	

Means with same superscript are not statistically different at p<0.05.

Table 3: P-*values for Comparison Among Adhesive Systems (Duncan* post hoc*)*

Adhesive System	OP	TY	AS	AD	SE	SB
OP	-	0.205	0.0001	0.0001	0.0001	0.0001
TY	0.205	-	0.002	0.001	0.0001	0.0001
AS	0.0001	0.002	-	0.799	0.002	0.001
AD	0.0001	0.001	0.799	-	0.004	0.002
SE	0.0001	0.0001	0.002	0.004	-	0.864
SB	0.0001	0.0001	0.001	0.002	0.864	-

RESULTS

Mean SBS are summarized in Table 2 and Figure 1. The mean SBS varied from 5.4±2.3 MPa for OP to 17.9±4.4 MPa for SB. One-way ANOVA revealed a significant difference at $p<0.0001$.

Duncan's *post hoc* test ranked these differences in three subsets at a confidence level of 95% (Table 2). SB and SE resulted in higher SBS. AD and AS were ranked in the intermediary Duncan's subset, while TY and OP resulted in the lowest SBS. Table 3 shows the *p*-values for comparison between adhesive systems (Duncan's *post hoc* test).

DISCUSSION

The null hypothesis was countered. Only one (Clearfil SE Bond, Kuraray Co) of the five self-etching primer/adhesives tested had SBS to enamel similar to the control group (total-etch one-bottle system). Clearfil Liner Bond II (Kuraray Co) resulted in high bond strength when applied to enamel, despite not providing an enamel etching pattern as deep as phosphoric acid-etching (Barkmeier, Los & Triolo, 1995; Perdigão & others, 1997); the formulation of this adhesive may account for this feature. The simplified primer version tested in this study (Clearfil SE Bond) presents the primer in a single bottle. The results of enamel SBS with SE in this study are in agreement with the literature (Toledano & others, 2001; Lopes, Kronners & Vieira, 2001). This system also has a resistance to microleakage similar to that of total-etch systems on enamel (Gordan & others, 1998). Recently, a study by Yazici, Baseren and Dayangaç (2002) has shown that SE results in no die penetration on enamel margins after a previous enamel acid-etching step or according to the manufacturer's instructions (no acid-etching). It was reported that after extended thermocycling, the SBS to enamel with Clearfil Liner Bond II (Kuraray Co) and other self-etching primers is diminished, while this did not occur with total-etch adhesives systems (Miyazaki & others, 1999). SE contains MDP (10-methacryloyloxydecyl dihydrogen phosphate) (Yamada & Sugizaki, 2000); the enamel etching patterns from MDP self-etching primer treatment are different from Phenyl-P self-etching primer (present in previous version Clearfil Liner Bond II and 2V, Kuraray Co) (Hayakawa, Kikutake & Nemoto, 1998; Kubo & others, 2001). MDP is considered a more favorable adhesive monomer since it has two hydroxyl groups that chelate to calcium ions of enamel (Yamada & Sugizaki, 2000). Further research should be conducted using SE after an extended thermal cycling to verify the durability of this high bond strength to enamel.

Micromechanical interlocking, an essential factor for enamel bonding, is attributed to the formation of resin tags into etched enamel (Buonocore & others, 1968). The adhesive functional monomer contained in self-etching primer simultaneously infiltrates to prime the enamel during decalcification (Itou & others, 2001). As a result, the acidic monomer can completely infiltrates into the etched and primed enamel to produce adequate bond strength. Considering these results, it seems that the decalcification ability of the self-etching primer could not be related to the different mean enamel SBS between the self-etching primer systems. Although the pH of SE is less acidic than the other tested self-etching systems (Yamada & Sugizaki, 2000) (Table 1), it was the only self-etching primer system that result in enamel SBS similar to the total-etch system tested (SB). Differences in the specific compositions of the self-etching primers may be the major reason for the different mean SBS to enamel achieved by each self-etching bonding agent tested in this project.

Adper Prompt (AD) was the only one-step self-etching adhesive system tested. Its solution includes methacrylate phosphoric esters and water (3M ESPE, 2002). Its pH and composition are similar to the previous version (Prompt L-Pop, ESPE), which may be the reason for the

similar bond strength to enamel achieved with these two versions (Perdigão & others, 2003). The authors' results of SBS to enamel with AD are in accordance with Chang and others (2003). Despite the lack of literature about AD, some articles showed that its predecessor (Prompt L-pop, 3M ESPE) is acidic enough to create an etching pattern similar to 32% to 40% phosphoric acid (Perdigão & Lopes, 1999; Lopes & others, 2002b). The addition of polyalkenoic acid on the AD formulation may contribute to bonding stability over time. Ca-Polyalkenoic acid complex in the presence of water forms a polyalkenoate salt at the bonded interface with a stress-relaxation capacity (Eliades, 1993). It is stated that the electron-dense layer left on the dental surface after treatment with polyalkenoic-acid based adhesives reacting with residual calcium provides a bonding-water stability with a dynamic potential for breaking and renewing the bonds between the carboxial groups and calcium (Eliades, 1993; Perdigão, Swift & Lopes, 1999).

AdheSE (AS) is a solution consisting of phosphonic acid acrylate, Bis-acrylamide and water (Ivoclar Vivadent, 2002). A recent study showed that total-etch systems result in higher bond strength to enamel than AS (De Munck & others, 2003). Additionally, when AS was applied to Class V restorations *in vitro*, marginal adaptation to enamel was still considered superior, using a total-etch adhesive system (Albrecht & others, 2003).

Currently, no bond strength studies on Tyrian (TY) and OptiBond Solo Plus Self-Etch (OP) have been published. One abstract has reported that One-Step Plus (BISCO) results in higher bond strength to enamel with previous phosphoric acid etching compared to using Tyrian SPE primer (Lilley & others, 2003). The low bond strength to enamel of TY and OP can be attributed to three main factors: (1) difficulty of acidic primer to promote a consistent enamel etching pattern; (2) formation of calcium precipitate on the enamel surface that prevents the monomer from interlocking (Fritz & Finger, 1999); (3) difficulty of filled adhesives to interdiffuse on thin, interprismatic areas. The bonding resin of these two adhesive systems is relatively highly filled (8.5% for One-Step Plus, BISCO, and 10% to 20% for OptiBond Solo Plus, Kerr). Some laboratory studies have shown that filled adhesive systems present low bond strength to acid etched enamel (Swift & others, 1998, 1999; Devaney, Swift & Perdigão, 1999), a fact apparently related to the high viscosity of these bonding resins (Swift & others 1998, 1999; Devaney & others, 1999). As a consequence, they would not be able to penetrate the interprismatic areas as profoundly as unfilled bonding agents (Perdigão & others, 1999).

The main objective of bond strength tests is to establish a demonstrative value for how strong the bonding of an adhesive system is to dental hard tissues (Oilo, 1993). When composites are bonded, the volumetric shrinkage that occurs under polymerization generates stresses on the bonded opposing walls in box-like cavities (Feilzer, de Gee & Davidson, 1987; Pashley & others, 2002). It has been stated that composite bond strength should be as high as 17 to 20 MPa to resist this shrinkage stress (Davidson, de Gee & Feilzer, 1984). In this case, the authors expect that Clearfil SE Bond (Kuraray Co) and Single Bond (3M ESPE) would be able to avoid gap formation and microleakage on the resin-enamel interface.

CONCLUSIONS

Based on the result obtained, the following conclusions can be inferred:

1. SBS to enamel with self-etching primer/adhesive systems may depend on specific composition.
2. Clearfil SE Bond was the only self-etching system that achieved a composite-to-enamel bond strength similar to a total-etch bonding system.

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Influence of the Use of Er:YAG Laser for Cavity Preparation and Surface Treatment in Microleakage of Resin-modified Glass Ionomer Restorations

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Clinical Relevance

The use of an Er:YAG laser device for cavity preparation and surface treatment adversely affected the marginal sealing ability of resin-modified glass ionomer Class V restorations.

SUMMARY

This study quantitatively assessed the amount of microleakage on Class V cavities prepared by Er:YAG laser and high-speed handpiece, varying the surface treatment and restoring with a resin-modified glass ionomer cement. Fifty cavities were prepared using either an Er:YAG laser device or a carbide bur at high speed. The surface treatment was performed as follows: Er:YAG laser irradiation (G1); 40% polyacrylic acid (G2); laser + acid (G3); finishing with low speed + laser + acid (G4); conventional bur preparation + acid (G5–control). The samples were restored with Fuji II LC, thermocycled, isolated and immersed in a 50% $AgNO_3$ solution. The restorations were serially sectioned and the extent of dye penetration was measured in milimeters using specific computer software. Data were analyzed by two-way ANOVA and Tukey test. The lowest degree of microleakage was observed for G5, which was statistically similar ($p>0.05$) to G4 but different ($p<0.05$) from all the other experiental groups. Lesser microleakage was observed at the occlusal margins than at the cervical margins ($p<0.05$). It may be concluded that the use of Er:YAG laser for cavity preparation and surface treatment negatively affected the marginal sealing of resin-modified glass ionomer restorations.

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INTRODUCTION

The marginal sealing ability of a restorative material is an issue of paramount importance in the longevity of a restoration (Going, 1972). In recent decades, dental research has prompted the development and/or improved both restorative and materials techniques, aiming to minimize the potential for leakage (Sidhu, 1994; Rodrigues & others, 1999). The formation of marginal gaps allows for the penetration of bacteria, fluids, molecules or ions between the cavity wall and restorative material, which inherently leads to marginal discoloration, recurrent caries, post-operative sensitivity and even the development of pulpal pathologies (Kidd, 1976).

Several adhesive systems and glass ionomer cements have been introduced in an attempt to optimize the bonding of resin restorative materials to cervical lesions and promising results have been achieved (Gordon, Plasschaert & Stark, 1986; Mount, 1990). Nevertheless, microleakage at dentin-cementum margins of restorations remains a problem of clinical significance (Kidd, 1976; Gordon & others, 1986; Kaplan & others, 1992; Quo & others, 2002).

Glass ionomer cements (GIC) are alternative materials to composites for the conservative restoration of cervical lesions due to their properties, including adhesion to tooth structure, fluoride release, biocompatibility, lower polymerization shrinkage, reduced microleakage and acceptable esthetics (Gladys & others, 1997; Toledano & others, 1999). Resin-modified glass ionomer cements (RMGIC) were further developed to improve the handling and working characteristics of the conventional glass ionomer formulation (Antonucci, McKinney & Stansbury, 1988; Gladys & others, 1997). The improved adhesion to dentin of RMGIC versus GIC is at least partially due to the greater tensile bond strength of RMGIC and probably results from both a chemical bond from the polyacrylic acid component and the formation of a hybrid layer from the hydrophilic HEMA (Charlton & Haveman, 1994; Ferrari & Davidson, 1997; Toledano & others 1999).

To date, newer technologies for preparing dental hard tissue, such as laser irradiation, have become widespread. Laser application for dental practice has been a research interest for the past 25 years. By varying a number of parameters (pulse mode, irradiation time, frequency and energy outputs), several types of lasers, such as the CO_2 laser (Palamara & others, 1992; McCormack & others, 1995), excimer laser (Frentzen, Koort & Thiensiri, 1992) and Nd:YAG laser (White, Goodis & Rose, 1991; Bassi, Chawla & Patel, 1994), have been indicated for oral soft tissue procedures, curing of light-activated materials and treatment or removal of dental substrate.

The most promising wavelength has been the Er:YAG laser at 2.94 micrometers. Many investigators (Hibst & Keller, 1989; Wigdor & others, 1995; Cozean & others, 1997; Niu & others, 1998; Hatibovic-Kofman, Wright & Braverman, 1998; Zyskind & others, 1998; Wright & others, 1999; Armengol & others, 1999) have reported the ability of the Er:YAG laser to ablate tooth structure, which is indicated for selective removal of carious lesions, cavity preparation and modification of dentin and enamel surfaces, prior to restoring with adhesive materials. Er:YAG laser wavelength is coincident with the main absorption band of water (~3.0 mm) and is also well absorbed by the OH^- groups in hydroxyapatite. The incident radiation is highly absorbed by the water molecules present in the hydrated organic compounds of the tissues, mainly, the intratubular fluid and collagen network, causing sudden boiling and water evaporation. The resulting high-stream pressure leads to the occurrence of successive microexplosions with ejection of tissue particles that characterize the ablation process and determine the microcrater-like appearance of lased tooth structure. Dentin surfaces irradiated with Er:YAG laser lack the formation of smear layer and exhibit open dentinal tubules without entrance enlargement (Yazici, Frentzen & Dayangac, 2001). In addition, a clinical report of cavity preparation with this laser showed that when compared to bur treatment, patients feel less pain during cavity preparation with the laser system and, in some cases, anesthesia was not needed (Harashima & others, 1999).

However, it is important to emphasize that all adhesive materials and procedures were developed to be accomplished on tooth substrate prepared and treated with rotatory cutting instruments and conventional techniques. So, in view of the increasing interest in laser equipment in the dental practice and a lack of reported research on the influence of the use of Er:YAG laser for cavity preparation and surface treatment in the microleakage of glass ionomer restorations, the goal of this *in vitro* study was to assess quantitatively the amount of microleakage in Class V cavities prepared by either Er:YAG laser or high-speed handpiece submitted to various surface treatments and restored with a resin-modified glass ionomer cement.

METHODS AND MATERIALS

Twenty-five sound human molars extracted within a six-month period, examined macroscopically for defects in enamel and dentin and stored in a saline solution at 4°C were selected for the study. The teeth were carefully cleaned with a hand scaler and a water-pumice slurry in dental prophylactic cups and randomly assigned to five groups of equal size according to cavity preparation method and cavity surface treatment. Table 1 displays the experimental groups.

Fifty Class V cavities were prepared on both buccal and lingual surfaces with the occlusal margin located in enamel and the cervical margin in dentin/cementum.

For each tooth, the buccal and lingual cavities were always prepared by different methods, which means that they never belonged to the same group. The cavity outline was previously traced on surfaces with a marker to define a uniform size (4-mm mesio-distal width and 3-mm occluso-gingival measurement). The depth of the cavity was approximately 2 mm, calibrated by a pre-marked periodontal probe.

The laser device used in this study was a Kavo Key Laser 2 model (KaVo Co, Biberach–Germany), an Er:YAG laser emitted at a 2.94-micrometer wavelength with a 250-500 µs pulse duration and a 0.63-mm spot size when the laser beam is focused. All teeth were prepared with a non-contact and focused beam (at a distance of 12 mm from tooth surface) with a 400 mJ output, 4 Hz frequency and a 128.33 J/cm^2 energy density under water spray coolant (5 mL/minute).

For Groups 1, 3 and 4, the cavity surface treatment was performed with the same Er:YAG laser equipment, with the laser beam in a non-contact, defocused mode (at a 17-mm distance from tooth surface), an 80 mJ output and a 2-Hz frequency under water spray coolant (5 mL/ minute).

The cavity finishing of specimens in Group 4 was accomplished with a #245 carbide bur at low speed.

For Group 5 (control), the cavities were prepared using a #245 carbide bur and high-speed handpiece under water spray coolant, and cavity finishing was done with the same bur using a low-speed handpiece. The occlusal cavosurface bevel was accomplished with a #1195 diamond point.

For Groups 2, 3, 4 and 5, the cavities were etched with a 40% polyacrylic acid (Durelon Liquid–ESPE Dental AG, Seefeld, Germany) with a light scrubbing motion for 10 seconds, thoroughly rinsed with a water spray for 30 seconds and gently air dried.

Resin-modified glass ionomer cement Fuji II LC (GC Co, 76-1 Hasunuma-Cho, Tokyo, Japan) powder and liquid components were dispensed at 2.3g:1g ratio by weight, mixed, loaded into an injector syringe (Centrix, DFL Industria e Comércio Ltda, Rio de Janeiro, 22713-001, Brazil) and injected into the preparation in a single increment. The excess material was removed and the restoration light-cured for 40 seconds with a visible light curing unit with a 450 mW/cm^2 output (XL 3000, 3M Dental Products, St Paul, MN, USA). The unfinished restorations were then coated with a layer of a single component adhesive system (Single Bond, 3M Dental Products) and light cured for 20 seconds. The specimens were stored for 24 hours in distilled water at 37°C and the restorations polished with Super-Snap disks (Shofu Inc, Kyoto, Japan) in a decreasing abrasive order, ensuring that all restorations were finished back to the cavosurface margins. All cavity preparations, restorations and finishing procedures were performed by the same operator.

The specimens were submitted to a thermocycling regimen of 500 cycles between 5°C and 55°C water-baths. Dwell time was one minute, with a three-second transfer time between baths. In preparation for the dye penetration test, the teeth were superficially dried, the apices of all teeth were sealed off with epoxy resin and the entire tooth received two coats of nail varnish, except for a 2-mm window around restoration margins. After the nail varnish dried, the teeth were immersed in distilled water for two hours, then immersed in a 50% aqueous silver nitrate solution for eight hours and kept in a light-proof container. The teeth were then rinsed thoroughly in tap water and the nail varnish removed with a sharp instrument.

The specimens were embedded in chemically activated acrylic resin (JET, Clássico, São Paulo, Brazil) and sectioned longitudinally in a mesiodistal direction with a water cooled diamond saw in a sectioning machine (Minitom, Struers A/S, Copenhagen, Denmark). The separated buccal and lingual cavities were embedded again in acrylic resin blocks and sectioned in a buccolingual direction, providing three 1.0-mm thick sections of each cavity. Afterwards, the sections were exposed to the light of a photoflood lamp for

Table 1: *Experimental Groups*

Groups (n=10)	Preparation Technique	Surface Treatment
G1	Laser Er:YAG	Laser Er:YAG
G2	Laser Er:YAG	40% polyacrylic acid
G 3	Laser Er:YAG	Laser Er:YAG + 40% polyacrylic acid
G 4	Laser Er:YAG + bur finishing	Laser Er:YAG + 40% polyacrylic acid
G 5 (control)	High-speed bur preparation + bur finishing (conventional preparation)	40% polyacrylic acid

Table 2: *Mean (± standard deviation) Dye Penetration at Occlusal and Cervical Margins (as a % of total cavity depth) (n=10)*

Margin	Group 1	Group 2	Group 3	Group 4	Group 5
Occlusal	52.5 (30.8)^{a,f}	51.8 (23.4)^{a}	52.5 (26.8)^{a}	25.8 (12.8)^{b,g}	22.4 (13.4)^{b}
Cervical	66.6 (31.7)^{d,f}	82.2 (20.0)^{d,e}	85.1 (24.1)^{e}	30.9 (28.2)^{c,g}	42.8 (29.3)^{c}

Different letters indicate significant difference (p<0.05)

20 minutes to reveal the silver nitrate, which, exposed to light, acquires a dark color, allowing for visualization of the dye-penetrated areas. The sections were initially thinned in a polishing machine (Politriz, Struers A/S, DK-2610, Copenhagen, Denmark) with 180- to 600-grit silicon carbide paper, then manually smoothed with 1000- to 1200-grit SiC paper to obtain a flat surface and a final thickness of approximately 0.25 mm.

The three cuts of each cavity were carefully fixed on microscopic slides and identified according to their group number, with the margins analyzed separately; each margin was viewed under a 5x magnification optical microscope (Axiostar Plus, Carl Zeiss Vision) connected to a digital camera (Cyber-shot 3.3 MPEG Movie EX, model #DSC-S75, Sony Corporation, Japan). The images obtained were transmitted to a personal computer and, after digitization, were analyzed by Axion Vision 3.1 software (Carl Zeiss Vision) that performs a standardized assessment of the tracer agent's extent along the margins and allows for a quantitative measurement in millimeters. The depth of the cavity wall and dye penetration along occlusal and cervical margins toward the axial wall were determined, and the percentage of dye penetration was calculated. When leakage occurred around the line angle and onto the axial wall, it was given a 100% score. The averages of dye penetration for enamel and dentin interfaces of each cavity were calculated and the mean of each group appraised.

Data were analyzed for distribution, being normal and homogeneous, and subjected to statistical analysis using a two-way ANOVA and Tukey test at a 0.05 significance level.

RESULTS

Table 2 shows the mean (± standard deviation) dye penetration at the enamel and dentin-cementum margins for each experimental group.

Analysis of the results showed statistically significant differences ($p<0.01$) between the occlusal (enamel) and cervical (dentin-cementum) margins for all groups. As a rule, there was less microleakage in the enamel margins. However, the Analysis of Variance did not reveal significant interaction ($p>0.05$) between the two main factors (margin and treatment).

Comparing the different associations proposed for cavity preparation and surface treatment, it was observed that Group 5 (control) showed the lowest degree of microleakage and was statistically similar ($p>0.05$) to Group 4 (laser preparation + laser treatment + bur finishing + polyacrylic acid etching). However, both groups were significantly different ($p<0.05$) from the other groups.

At the occlusal margins, Groups 4 and 5 showed the best overall performance and their results were statistically different from the other groups ($p<0.05$). There was no significant difference among Groups 1 (laser preparation + laser treatment), 2 (laser preparation + polyacrylic acid etching) and 3 (laser preparation + laser treatment + polyacrylic acid etching) ($p>0.05$).

At the cervical margins, the lowest means of dye penetration were found in Groups 4 and 5, which were statistically similar ($p>0.05$), yet different from the other groups ($p<0.05$). There was significant difference ($p<0.05$) between Groups 1 and 3, but none between Groups 2 and 3 ($p>0.05$).

DISCUSSION

Despite the unquestionable evolution of dental materials and techniques, mainly in the last decades, many studies (Saunders & Saunders, 1996; Choi, Condon & Ferracane, 2000; Mathew, Parameswaran Nair & Krishnan, 2001; Al-Ehaideb & Mohammed, 2001) have stated that none of the currently available restorative techniques and materials promote complete marginal sealing, which is an issue of major concern for microleakage.

Microleakage can be favored by both marginal gaps and changes in interfacial pressure. Gap formation at tooth/restoration interface may result from the difference between dental structures' thermal expansion coefficient and the restorative material. The greater the difference between the thermal expansion coefficients, the higher the pressure variation at the interface. Furthermore, resin restorations show volumetric shrinkage during polymerization, resulting in stress at the interface that can breach the union of the restorative material to the cavity wall, thus promoting imperfections at this interface (Trowbridge, 1987; Retief, 1994; Versluis & others, 1996).

On the other hand, resin-modified glass ionomer cements present chemical adhesion to dental structure by bonding between the cement's carboxylic groups and calcium and phosphate ions from the tooth, as well as micro-mechanical interlocking of the resinous components, leading to the formation of a hybrid layer (Pereira & others, 1998; 2000) that minimizes the occurrence of the microleakage phenomenon (Mount, 1994). RMGICs show not only superior bond strength to tooth substrates compared to conventional glass ionomers, they also show a high setting shrinkage due to the polymerization of HEMA (2-hydroxyethyl methacrylate), which is incorporated as a resin component (Attin & others, 1995). Such dimensional changes may possibly have occurred during and after polymerization of the RMGIC evaluated in the current work. In addition, polymerization shrinkage of the material could not have been sufficiently compensated for by hygroscopic expansion from the water absorption (Doerr, Hilton & Hermesch, 1996).

It has been demonstrated that applying weak acid solutions, such as polyacrylic acid, for the superficial treatment of the dentin surface prior to glass ionomer restorations is strongly advised due to their ability to promote surface cleaning, increase surface energy and optimize contact between the material and substrate by eliminating only the smear without demineralizing dentin or removing smear plugs (Fritz, Finger & Uno, 1996; Miyazaki & others, 1997,1998; Abdalla, 2000). Such treatment maintains calcium ions available for chemical reaction with cement, also avoiding contamination of the restoration by moisture from dentinal fluid (Glasspoole, Erickson & Davidson, 2002).

The findings of this research disclosed that the use of Er:YAG laser for cavity preparation and surface treatment adversely affected the marginal sealing of Class V resin-modified glass ionomer restorations. This could be ascribed to the fact that cavities prepared by Er:YAG laser do not present precise, clearly identifiable outlines and, therefore, the unevenness of margins and walls might have interfered with the adaptation of the restorative material to laser-prepared tooth structure. Moreover, the cavosurface margin produced by Er:YAG laser irradiation appears quite rough as compared to that produced by conventional preparations. This fact has been reported as increasing micro-spacing and marginal microleakage (Ceballos & others, 2001). Nevertheless, the heat generated during laser irradiation has been reported to cause melting and fusion of superficial crystalline microstructures (Yazici & others, 2001) that could limit the availability of calcium ions, thereby compromising the bonding of glass ionomer cements to dentin substrate. However, Hossain and others (2003) stated that laser cavities revealed a rough or irregular surface with the absence of any charring, carbonization or cracking of the enamel and dentin and, on the other hand, cavity surfaces using the bur showed well-delimited cavity angles, floors and walls, clear margins and relatively smooth cavity floors.

Conventionally, bur-prepared enamel exhibits subsurface damage in the form of medium-sized cracks and microcracks (Xu & others, 1997). Laser-beveled enamel margin tends to be irregular, with grooves, flakes, shelves and pits (Hoke & others, 1990; Keller & Hibst, 1989; Aoki & others, 1998) that can affect the sealing ability of resinous material restorations. Moreover, the crater-like defects that can be observed in the laser-beveled enamel margin are easily seen under the restoration at this level, which could result in an unaesthetic effect (Ceballos & others, 2001). Conventionally, bur-prepared dentin viewed at 50x magnification also features groove marks produced by the rotating action of the bur, and at higher magnification, a smear layer can be observed (Aoki & others, 1998). The surface configuration of the lased dentin is smoother and more rounded than enamel, with smaller pits and grooves. In addition, it lacks a smear layer, with the orifices of many of the tubules exposed (Aoki & others, 1998).

Some studies have suggested that the roughness of the lased dental surface would be favorable to the mechanical interlocking of adhesive materials (Wright, McConnell & Keller, 1993) and that the use of Er:YAG laser alone or combined with acid treatment results in bonding strength similar or better than that produced by acid-etching alone (Visuri & others, 1996; Hibst & Keller, 1989). In contrast with the outcomes of this work, the results of *in vitro* investigations (Khan & others, 1998; Niu & others, 1998; Roebuck, Saunders & Whitters, 2000; Roebuck, Whitters & Saunders, 2001; Quo & others, 2002) have suggested that Er:YAG laser can be used for cavity preparation without adversely influencing the marginal integrity of composite and resin-modified glass ionomer restorations. It has also been advocated that the cracks at cavity margins after laser preparation may have arisen from the storage conditions of teeth after extraction rather than from the laser preparation itself (Khan & others, 1998; Niu & others, 1998). Nevertheless, this would imply that all the experimental conditions evaluated in this study had been equally affected and that no differences would be expected among the studied groups.

The findings of the reported study highlighted that the group prepared by Er:YAG laser and further submitted to bur finishing had statistically similar results to those of the conventionally bur-prepared control group. A feasible explanation for such behavior is that low-speed bur finishing could have removed at least a portion of the laser-modified layer of tooth structure, which could eliminate the areas that were structurally altered by laser irradiation, thereby, allowing the restorative material to have contact with the dental substrate that was morphologically similar to the conventionally bur-prepared group. Moreover, cavity finishing promotes regularization of cavity margins and walls, which may contribute to enhancing adaptation of the restorative material (Hossain & others, 2003).

No matter the length, it is important to emphasize that, clinically, the presence of significant leakage is a problem. Thus, further investigation focusing on the long-term effect of ultrastructural changes observed in Er:YAG laser irradiated dental substrates may provide restorations with increased marginal sealing and therefore lead to improved microleakage prevention and a more widespread applicability of these new technologies in clinical practice.

CONCLUSIONS

Based on the findings of this study and within the limitations of an *in vitro* investigation, it seems feasible to conclude that the use of Er:YAG laser for cavity preparation and surface treatment may adversely affect the

marginal sealing of resin-modified glass ionomer cements, except when a conventional bur finishing is performed after laser preparation and that none of the different surface treatments promoted a complete marginal sealing in Class V restorations using the tested resin-modified glass ionomer cement.

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The Influence of Salivary Contamination on Shear Bond Strength of Dentin Adhesive Systems

J Park • KC Lee

Clinical Relevance

The results of this experiment showed that One-step total-etch adhesive was not affected by salivary contamination on the etched surface when the bonding surface was kept wet. Clearfil SE Bond also tolerated salivary contamination, except when the contamination occurred after application of the primer.

SUMMARY

This study evaluated the influence of salivary contamination during dentin bonding procedures on shear bond strength and investigated the effect of contaminant-removing treatments on the recovery of bond strength for two dentin bonding agents.

One hundred and ten human molars were embedded in cylindrical molds with self-curing acrylic resin. The occlusal dentin surface was exposed by wet grinding with #800 silicon carbide abrasive paper. The teeth were divided into five groups for One-step (OS) (BISCO, Inc) and six groups for Clearfil SE Bond (SE) (Kuraray Co, Ltd, Osaka, Japan). For One-step, the grinding surface was treated with 32% phosphoric acid; BAC (BISCO Inc) and divided into five groups: OS control group (uncontaminated), OS I (salivary contamination, blot dried), OS II (salivary contamination, completely dried), OS III (salivary contamination, wash and blot dried) and OS IV (salivary contamination, re-etching for 10 seconds, wash and blot dried). For SE bond, the following surface treatments were done: SE control group (primer applied to the fresh dentin surface), SE I (after salivary contamination, primer applied), SE II (primer, salivary contamination, dried), SE III (primer, salivary contamination, wash and dried), SE IV (after procedure of SE II, re-application of primer) and SE V (after procedure of SE III, re-application of primer).

Each bonding agent was applied and light cured for 10 seconds. Clearfil AP-X (Kuraray Co, Ltd) composite was packed into the Ultradent mount jig mold and light cured for 40 seconds. The bonded specimens were stored for 24 hours in a 37°C waterbath. The shear bond strengths were measured using an Instron testing machine (Model 4202, Instron Corp).

The data for each group were subjected to one-way ANOVA followed by the Newman-Keuls test to make comparisons among the groups.

The results were as follows:

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• In the One-step groups, the OS II group showed statistically significant lower shear bond strength than the OS control, I, III and IV ($p<0.05$).

• In the Clearfil SE Bond groups, the SE II and SE III groups had decreased shear bond strength compared with the control and SE I, SE IV and SE V groups ($p<0.05$).

In conclusion, when using One-step total etch adhesive and when the etched surface is contaminated by saliva, blotting the surface and applying the primer can recover the bond strength. Complete drying of the salivary contaminated surface should be avoided. In the Clearfil SE Bond groups, the re-priming treatment (SE IV and SE V) resulted in the recovery of shear bond strength in the specimens contaminated after priming.

INTRODUCTION

Adhesion to dentin has been the subject of considerable interest, because dentin is a more heterogeneous substrate, with much higher organic and water content than enamel (Johnson & others, 1994). Therefore, improving adhesive restorative materials has been the object of considerable research in recent years. Generally, chemical composition of the adhesive agent and the condition of the tooth structure affect bond strength (Van Meerbeek & others, 2000).

Clinically, there are many factors that affect adhesion and retention of resin-containing restorative materials. Moisture, such as gingival fluid, blood, handpiece oil (Xie, Powers & McGuckin, 1993) and, in particular, saliva, can affect the quality of the bond, leading to microleakage at the interface. As a result, loss of the restoration, recurrent caries, post-operative sensitivity and discoloration may occur (Hitmi, Attal & Degrange, 1999). Therefore, it has been well known that bonding procedures require proper isolation and prevention of preparation contamination.

However, many carious lesions which require the use of dentin bonding agents are found in areas that are difficult to isolate, especially when the site is near or at the gingival margin where saliva contamination may be more likely to occur (Mojon & others, 1996).

Some studies have reported that saliva contamination of etched enamel caused a significant decrease in bond strength between the resin and enamel surface (Hormati, Fuller & Denehy, 1980). It was suggested that contamination of the etched enamel by salivary proteins prevented monomers from penetrating the pores in enamel to reduce bond strength (Xie & others, 1993). Microscopic examination of saliva-contaminated acid-etched enamel, regardless of exposure time, showed the formation of an organic pellicle that could not be removed by rinsing with water (Silverstone, Hicks & Featherstone, 1985). The organic pellicle coating masked the underlying enamel pores, decreased resin accessibility and impaired mechanical adhesion. However, the contaminated enamel could be reconditioned by an additional 10 seconds of acid etching (Hormati & others, 1980).

Dentin adhesion is extremely complex when compared with enamel bonding, and micromechanical resin adhesion to dentin differs fundamentally from the relatively simple interlocking of bonding agents with enamel. Therefore, the results of many studies related to the bonding efficacy of saliva-contaminated dentin bonding agents are not in agreement (Johnson & others, 1994). Fritz, Finger and Stean (1998) found that salivary contamination of cured one-bottle type adhesive resulted in low shear bond strengths and wide marginal gaps. Others reported that the saliva contamination of dentin had no adverse effect on the bonding efficiency of one-bottle adhesive systems (Taskonak & Sertgoz, 2002).

Recently developed adhesives systems, such as the "one-bottle" system or the "self-etching primer" system, have been shown to be resistant to salivary contamination (El-Kalla & García-Godoy, 1997; Hitmi & others, 1999). Furthermore, in addition to simplifying the bonding technique, self-etching primer eliminates the rinsing and drying steps that reduce the possibility of overwetting or overdrying, both of which can negatively influence adhesion (Milia, Lallai & García-Godoy, 1999; Jin, Kim & Park, 2002). These dentin bonding agents have a reduced number of components and application steps, and this reduces the risk of saliva contamination in the field of operation.

Even though contemporary dentin adhesive systems are easier to use and less technique sensitive, salivary contamination may still occur during bonding procedures, resulting in a reduced bond strength and marginal seal. But, there is little research on the effect of treatment methods of saliva contaminated dentin surfaces for the recovery of bond strength for contemporary adhesive systems.

This study evaluated the influence of salivary contamination of dentin during the bonding procedure on shear bond strength and investigated the effect of contaminant-removing treatments on the recovery of bond strength of two dentin bonding agents.

METHODS AND MATERIALS

Two dentin adhesives were tested in this study (Table 1): One-step (BISCO Inc, Schaumburg, IL, USA), and Clearfil SE Bond (Kuraray Co, Ltd, Osaka, Japan). Clearfil AP-X resin composite (Kuraray Co, Ltd) was used for both groups.

For the shear bond test, 110 extracted, sound human molars stored in isotonic saline at 4°C were used. The teeth were cleaned of soft tissue debris, then embedded in cylindrical molds with self-curing acrylic resin (Orthodontic Resin, Dentsply/Detrey, Konstanz, Germany) up to their cervical region.

The occlusal surfaces of the teeth were reduced on the long axis of the tooth on a water-cooled, model-trimming wheel to create flat dentin surfaces. The surfaces were then wet ground with 600 and 800 grit silicon carbide abrasive papers, and the teeth were randomly divided into five groups for One-step and six groups for Clearfil SE Bond. Ten specimens were made for each procedure.

For each adhesive, the specimens were divided into non-contaminated (control) and contaminated (experimental) groups. In specimens of the contaminated groups, fresh, whole saliva was applied to the surface with a disposable brush for 20 seconds, followed by contaminant-removing treatments, if applicable.

A mounting jig (Ultradent Products Inc, South Jordan, UT, USA) with an internal ring 2.4-mm in diameter and 2.0-mm in height was placed against the tooth surface and stabilized with an alignment tube. Clearfil AP-X resin composite was packed into the mold and light cured for 40 seconds. Details of the bonding procedure for each adhesive are presented in Figures 1 and 2.

After polymerization, the alignment tube and mold were removed and the specimens placed in 37°C distilled water. Twenty-four hours after storage, the specimens in each group were tested in shear mode using a chisel-shaped rod in an Instron testing machine (Model 4202, Instron Corp, Canton, MA, USA) at a crosshead speed of 1-mm/minute.

The data for each group were subjected to one-way ANOVA followed by the Newman-Keuls test to make comparisons among the groups ($p<0.05$).

Table 1: *Composition of the Adhesive Systems Used in the Study*

Adhesive	Manufacturer	Composition
One-step	BISCO	Bis-phenol A diglycidylmethacrylate (Bis-GMA) 2-Hydroxyethyl methacrylate (HEMA) Bisphenol dimethacrylate (BPDM) Acetone
Clearfil SE Bond	Kuraray	Primer: 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) 2-Hydroxyethyl methacrylate (HEMA) Hydrophilic dimethacrylate dl-Camphorquinone N,N-diethanol-p-toluidine Water Bond: 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) Bis-phenol A diglycidylmethacrylate(Bis-GMA) 2-Hydroxyethyl methacrylate (HEMA) dl-Camphorquinone Hydrophobic dimethacrylate N,N-diethanol-p-toluidine Silanated colloidal silica

BISCO, Schaumberg, IL, USA
Kuraray Co, Ltd, Osaka, Japan

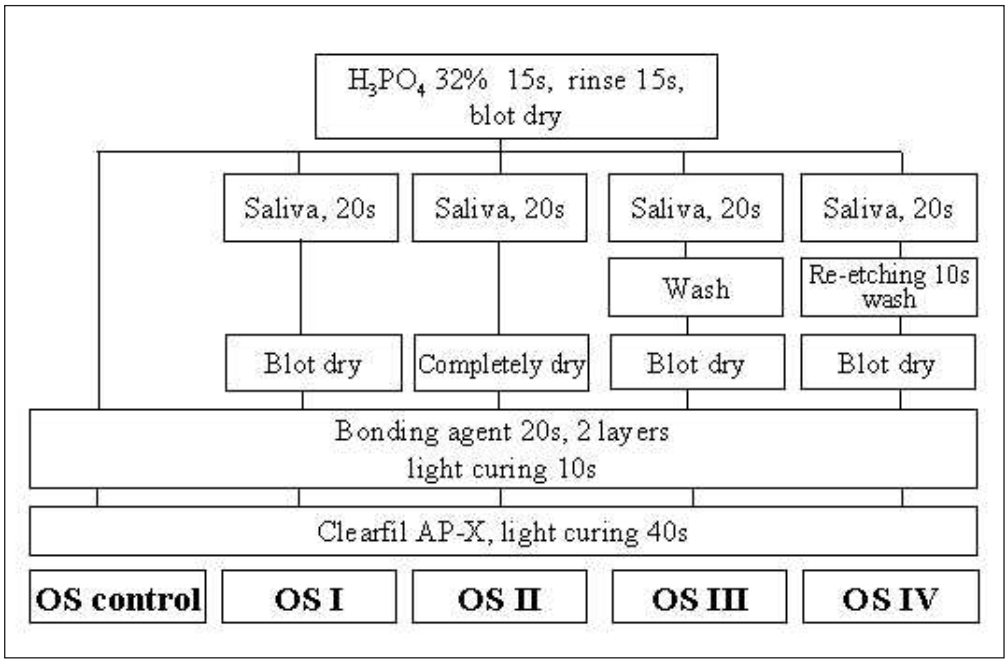

Figure 1. *Bonding procedures for One-step (OS groups).*

RESULTS

The results of the shear bond strength tests to One-step are shown in Table 2 and those of Clearfil SE Bond in Table 3.

In the One-step groups, there was a significant difference between the group that was dried with strong, oil-free air after contamination (OS II) and the other groups. When the etched surface was contaminated by saliva, there was no statistical difference between just blot dry, wash or the re-etching groups (OS I, OS III and OS IV) if the dentin surface was kept wet before priming. However, when the etched dentin surface was dried (OS II), the shear bond strength was decreased to 9.8±4.0 MPa compared to 22.4±4.9 MPa (control group).

In Clearfil SE Bond, the groups with salivary contamination after primer application (SE II or SE III) were significantly lower than the group that was not contaminated (Control) or the one that was contaminated before primer application (SE I). The bond strengths of the groups where the primer was reapplied after contamination (SE III and SE IV) were 20.7±6.8 and 19.7±5.6. These are similar to the control and SE I (22.4±6.1 and 21.5±8.0) groups.

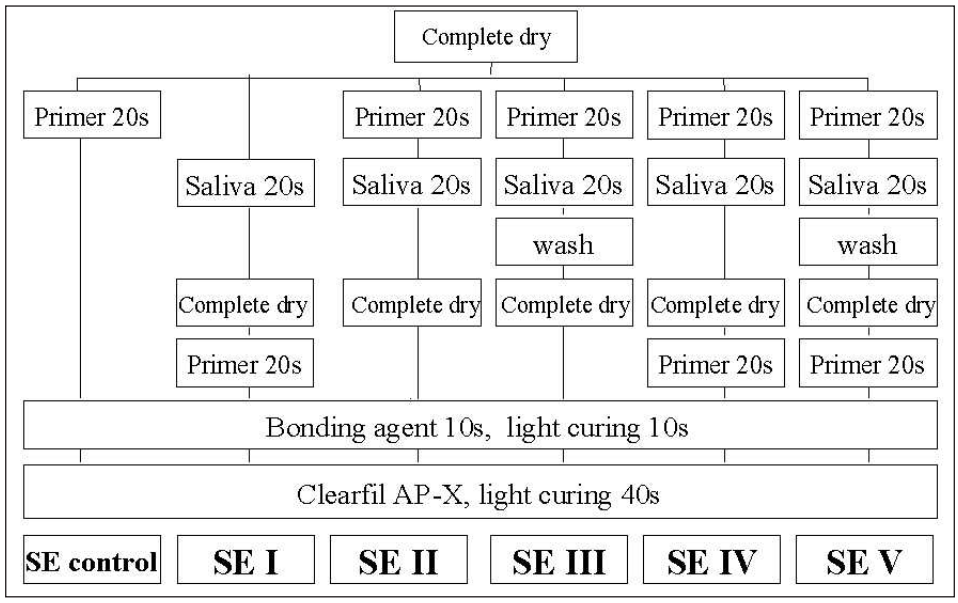

Figure 2. *Bonding procedures for Clearfil SE Bond (SE groups).*

Table 2: *Shear Bond Strengths for One-step Groups (Mean±SD, MPa)*

Group	n	Shear Bond Strength	Newman-Keuls Test
OS control	10	22.4 ± 4.9	A
OS I	10	17.9 ± 7.0	A
OS II	10	9.8 ± 4.0	B
OS III	10	20.5 ± 5.2	A
OS IV	10	21.1 ± 4.8	A

A, B: The same letters are not significant by Newman-Keuls test at the 0.05 level

Table 3: *Shear Bond Strengths of Clearfil SE Bond Groups (Mean±SD, MPa)*

Group	n	Shear Bond Strength	Newman-Keuls Test
SE control	10	22.4 ± 6.1	A
SE I	10	21.5 ± 8.0	A
SE II	10	13.7 ± 4.2	B
SE III	10	13.2 ± 4.0	B
SE IV	10	20.7 ± 6.8	A
SE V	10	19.7 ± 5.6	A

A, B: The same letters are not significant by Newman-Keuls test at the 0.05 level

DISCUSSION

Contamination of the field of operation by saliva or blood protein is a frequent problem in adhesive dentistry when rubber dam isolation is not used, cavity margins extend below the gingival tissues or indirect restorations are seated (Fritz & others, 1998; Safar, Davis & Overton, 1999). As pointed out by Pashley and others (1988), dentin bonding systems are sensitive to contamination by excess water, artificial saliva and plasma. This has been attributed to the absorption of macromolecules from contaminating materials into the dentin tubules (Pashley, Horner & Brewer, 1992). Therefore, adhesive systems capable of tolerating contamination are highly desirable. In this study, the authors evaluated the influence of salivary contamination on shear bond strength using One-step, a total etch one-bottle system and Clearfil SE Bond, a self-etching primer system.

In the One-step groups (OS), when the contaminated surface was dried completely (OS II), bond strength decreased significantly. This result agreed with that of Fritz and others (1998). During air dry, the water-filled collagen layer collapses and dried protein film is absorbed onto the dentin surface (Kanca, 1992). The protein-absorbing properties of hydroxyapatite are well known (Pashley, Nelson & Kepler, 1982). Both phenomena prevent penetration of the adhesive into the exposed collagen mesh.

However, if the salivary contaminated surface was blot dried (OS I), the decrease in bond strength of One-step was not significant. The hydrophilic nature of One-step dentin bonding agents allows them to function to some degree in the presence of saliva contamination. Studies have shown that one-bottle adhesives used with the total-etch, moist bonding technique are less sensitive to salivary contamination of etched enamel and dentin than are fourth-generation, three compo-

nent bonding agents (Fritz & others, 1998; Hebling & Feigal, 2000). Thus, for One-step, blot drying the surface was sufficient to achieve optimal bond strength after salivary contamination.

Previous studies have shown that an additional 10 seconds of acid etching beyond the manufacturers' recommendation is not detrimental to bond strength (Kanca, 1992). Therefore, in this study, the salivary contaminant was removed by washing followed by a 10 second re-etching using the original acid-etching agent. The results revealed that there were no significant differences among the OS III, OS IV and control groups.

In contrast to the results of this study, Xie and others (1993) found that salivary contamination of the dentin surface produced a significant decrease in shear bond strength. This may be explained by the application of excessive amounts of water and artificial saliva (4 µL) in the previous study. It is possible that the excess moisture diluted the primer, thus producing a weak hybrid layer.

The reactive components in self-etching primers are esters from bivalent alcohols with methacrylic acid and phosphoric acid or its derivatives. As the phosphate residue demineralizes the dentinal surface, the concentration of calcium and phosphate increases, thus, neutralizing the acidic primer and limiting further dissolution of apatite. Simultaneously, the methacrylate component of the molecule is available for co-polymerization with the bonding agent and the resin composite. With this process, there is no need to rinse off the reaction products or residual phosphoric acid ester (Gordan & others, 1998; Nakabayashi & Saimi, 1996; Watanabe, Nakabayashi & Pashley, 1994; Gordan & others, 1997; Hannig, Reinhardt & Bott, 1999; Chigira & others, 1994). Thus, in the Clearfil SE Bond groups, difficulty in finding an ideal humidification of the dentin is eliminated (Tay, Gwinnett & Wei, 1996) and possible negative influences on adhesion are dramatically reduced.

In the Clearfil SE Bond groups, a significant decrease in bonding strength was seen for the SE II and SE III groups, regardless of washing or drying, when there was salivary contamination after application of the primer. Therefore, it was not sufficient to dry or wash off the salivary contaminated surface after application of the primer to recover the bond strength. However, bond strength could be recovered after reapplication of the primer. It is likely that the bond strength was recovered, owing to the hybrid layer reformation after removing the unstable primer layer.

It is known that self-etching primers are able to bond to dentin through a very heterogeneous smear layer. The early version of self-etching primers was not very successful in establishing a bond to smear layer-covered dentin, because the resin monomer did not penetrate through the weak smear layer (Tao, Pashley & Boyd, 1988). Therefore, additional acids, such as maleic or nitric acid, were added to increase the acidity of the hydrophilic resin monomer solution (Causton & Sefton, 1989). These additional acids have largely been replaced in contemporary self-etching primers by increasing concentration of the acidic resin monomer, such as 20 wt% phenyl-P or 30 wt% MDP (Hayakawa, Kikutake & Nemoto, 1998). The acidity of the self-etching primers is less than that of 32% to 37% phosphoric acid gel but is sufficient to etch through smear layers into the underlying enamel or dentin (Yoshiyama & others, 2000). Self-etching primers hybridize dentin for up to 2 µm and have been reported to withstand stresses from polymerization shrinkage clinically (Gordan & others, 1998). In addition, thickness of the smear layer has no effect on the bonding of self-etching primers to dentin, at least in immediate or short-term intervals (Tay & others, 2000). Therefore, in the SE I, SE IV and SE V groups, no decrease in shear bond strength was expected, because some additional glycoproteins of saliva present on the smear layer would not inhibit infiltration of the resin monomers during the combined etch/primer step.

CONCLUSIONS

This study showed that salivary contamination had no adverse effect on the shear bond strength of One-step total-etch adhesive when it was blot dried, washed or re-etched with phosphoric acid. In contrast, when saliva was removed strongly by air, there was a significant decrease in shear bond strength. Clearfil SE Bond was tolerant of salivary contamination, except when contamination occurred after application of the primer. However, the bond strength could be almost completely recovered by re-applying the primer. Further study is necessary to evaluate the clinical effect of saliva contamination of dentin on the overall performance of other one-bottle and self-etching primer systems.

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In Vitro Microleakage of Four Tracers with Multiple Applications to the Same Tooth

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Clinical Relevance

Different tracers used in microleakage testing do not exhibit equivalent amounts of microleakage; therefore, a comparison of the microleakage of materials from studies employing different tracers is problematic. The results from microleakage tests should only be one factor in clinical decision making.

SUMMARY

Microleakage testing continues to be undertaken using a variety of techniques and methodologies. This study compared four microleakage tracers to determine if a difference exists in their ability to demonstrate microleakage on a single dental amalgam restorative material by testing in two phases.

Class V amalgam restorations were placed on the facial surfaces of 105 extracted human premolars with all margins in enamel. The teeth were stored at 37°C in water for two weeks except during thermocycling for 2500 cycles between 8°C and 48°C. The teeth were prepared for microleakage testing by sealing the external surfaces with nail polish and tinfoil, leaving the restoration and surrounding 1 mm exposed. In the first phase, four groups of 15 teeth were randomly assigned to 0.5% basic fuchsin dye, 2.0% fluorescent dye, 1.5% reactive orange 14 and ^{45}Ca. In the second phase, another three groups of 15 teeth were immersed in ^{45}Ca, then immersed in one of the remaining three tracers. Ridit analysis and Newman-Keuls multiple comparisons were used to compare the groups at a significance level of 0.05.

The results indicate that there are differences in observed microleakage between tracers and there is no statistical influence on dye tracers by initial immersion in ^{45}Ca.

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INTRODUCTION

It has long been thought that the longevity of dental restorations would be enhanced with a restoration-tooth interface that inhibits the movement of bacteria and/or its toxins (Kidd, 1976). Microleakage evaluation remains a popular mechanism for evaluating that interface (Hilton, 2002). This is accomplished with a wide variety of methodologies and tracers (Williams, Schramke & Stockton, 2002). It has been reported that different tracers may elicit different results under similar conditions (Tangsgoolwatana & others, 1997; Barber, Lyell & Massler, 1964; Charlton & Moore, 1992; Going, Massler & Dute, 1960; Moll, Worle & Haller, 2000). In addition, the results may vary when eval-

uating the different types of materials (Christen & Mitchell, 1966). These studies would lead one to believe that any decisions that clinicians make concerning a product or class of material should be based upon multiple studies using multiple tracers. This task is nearly impossible, considering the variation in methodologies published (Taylor & Lynch, 1992; Hilton, 2002).

Varying results may occur when using different tracers, which complicates the interpretation of microleakage results. The number of dependent variables associated with extracted teeth only magnifies the problem. If multiple tracers could be used on the same teeth and restorations, the impact of variables associated with extracted teeth could be minimized. The number of teeth needed to obtain the results would also be reduced.

The purpose of this study was twofold: 1) to determine the ability of four different tracers to detect microleakage in a single restorative material; 2) to evaluate the impact of sequential exposure of the same tooth to multiple tracers.

METHODS AND MATERIALS

One hundred and five intact, extracted human premolars were used. The teeth were stored in 10% formalin solution for a minimum of two weeks immediately after extraction. They were then débrided and cleaned with pumice and placed in distilled water at 8°C until prepared. Class V cavity preparations were made on the facial surface with the gingival margins 2-mm occlusal to the cemento-enamel junction. The box-shaped preparations were 3-mm mesiodistal x 2-mm occlusogingival x 2-mm deep. The cavosurface margin was a butt joint at 90° to the tooth surface. The teeth were stored at 37°C in distilled water when not being processed.

After the cavity preparation was cleaned and air dried, two layers of Copalite Varnish (Cooley and Cooley, Houston TX, USA) were applied to the walls of the preparation. Tytin dental amalgam (Kerr-Sybron, Romulus MI, USA) was condensed into the cavity preparation, carved to the cavosurface margin at initial set and burnished. No final polishing was done.

The restored teeth were stored at 37°C in water for two weeks following preparation. During this time they were thermocycled 2500 cycles between 8°C and 48°C, with a dwell time of 30 seconds at each temperature.

The teeth were prepared for microleakage testing by sealing their external surfaces with nail polish to within 1 mm of the restoration margins. Tinfoil was adapted to the wet polish, leaving the restoration and 1 mm of surrounding tooth structure unsealed. Additional polish was used to seal the edges of the tinfoil.

Table 1 shows the tracers used, their concentration and exposure times. Microleakage testing was done in two phases. In the first phase, four groups of 15 teeth were immersed in one of the leakage tracers: Group A, 0.5% basic fuchsin; Group B, 2.0% fluorescent dye; Group C, 1.5% reactive orange 14 and Group D, ^{45}Ca radioisotope. Dye concentrations and exposure times were based on pilot studies and previous work with each of the respective tracers. In the second phase, three groups of 15 teeth were first immersed in ^{45}Ca, then immersed in the tracers used in phase one for Groups A, B and C, respectively, forming Groups A', B' and C'.

After immersion, the tinfoil was removed and the teeth scrubbed. Then, longitudinal sections were made buccolingually through the center of the restoration using a Gillings-Hamco (Rochester, NY, USA) thin sectioning machine with a 0.015-inch thick diamond blade and water-cooling.

For Groups A and B, specimen halves were evaluated using a stereomicroscope, AO Stereozoom (Fisher Scientific, Hanover Park, IL, USA) at 40x magnification and a visible light illuminator. Group C was evaluated using the same microscope with a UV light, Blak-Ray B100 (Ultra-Violet Products Inc, Upland CA, USA).

Autoradiographs were made for Group D using D-speed intraoral radiographic film, (Eastman Kodak, Rochester NY, USA). The films were evaluated with a white paper backing using the microscope and illuminator that were used for Groups A and B.

Each tooth half was evaluated by three independent evaluators and scored from 1 to 4, depending on the extent of tracer penetration.

1 = no leakage

2 = penetration up to 1/2 of the distance from the cavosurface to the axial wall

3 = penetration more than 1/2 of the distance from the surface to the axial wall

4 = penetration along the axial wall

Table 1: *Tracers*

Tracer	Concentration	Exposure Time	Source
Basic fuchsin	0.5 % solution pH 4.0	24 hours	Manufacturing Chemists, Norwood, OH, USA
Fluorescent dye	2.0% Zyglo ZL-54 pH 7.0	24 hours	MagnaFlux Corp Glenview, IL, USA
Reactive Orange #14	1.5% solution pH 3.7	2 hours	Sigma Chemical Co St Louis, MO, USA
^{45}Ca	Radioactive $CaCl_2$, pH 5.5, activity 0.1mCi/ml	2 hours	ICN Biomedicals, Inc, Irvine, CA, USA

Separate evaluations were made for each tooth half for the occlusal and gingival walls.

Each evaluator scored the specimens three times. A majority score was determined for the evaluator for each specimen at each margin, then a majority score among evaluators was determined.

The majority of leakage scores for the occlusal and gingival margins were examined and it was determined that the gingival scores showed greater leakage than the occlusal scores. The gingival score data was subjected to a Ridit analysis (Bross, 1958; Mahler, Terka & Eysden, 1973), then statistical comparisons were made on the Ridit means and standard deviations were made for the gingival data.

For Phase I data, Barlett's test was used to test for homogeneity of variances of the groups. If the variances were homogeneous, a one-way analysis of variance was performed. Otherwise, the Welch test was used. Newman-Keuls multiple comparisons were used to compare groups at a significance level of 0.05.

For Phase II data, the same tests were conducted to compare ^{45}Ca and the dye tracer data.

In addition, data for the same tracer from Phase I and Phase II were compared to determine if there was a statistically significant difference between leakage scores. In the case of ^{45}Ca, four sets of data were compared; one from Phase I and three from Phase II.

RESULTS

Table 2 presents the Ridit values and statistical comparisons of the four tracers employed in Phase I and Groups A, B, C and D. Basic fuchsin exhibited the most leakage, with fluorescent dye exhibiting the least. There was no statistically significant difference between ^{45}Ca and the fluorescent dye groups (D and B). Differences between all other pairs were statistically significant.

Table 3 presents the Ridit values and analysis from Phase II, which compared leakage measured with ^{45}Ca simultaneously with each of the dye tracers, Groups A', B' and C'. Basic fuchsin exhibited the most leakage and ^{45}Ca the least. There was no significant difference between ^{45}Ca and the fluorescent dye (B') or between ^{45}Ca and reactive orange (C'). The microleakage observed with basic fuchsin and ^{45}Ca was significantly different ($p<0.05$).

Table 4 presents the Ridit values and analysis for all ^{45}Ca measurements, Groups D, A', B' and C'. No significant difference was shown between ^{45}Ca measured independently and in combination with fluorescent dye (D and

Table 2: *Comparison of the Microleakage of Four Tracers Applied Individually*

Group	Tracer	Ridit Mean	Standard Deviation
B	Fluorescent dye	.3272	.2838
D	^{45}Ca	.3320	.1131
C	Reactive orange	.5565	.3406
A	Basic fuchsin	.7561	.1077

Vertical lines connect groups that are not statistically different p<0.05.

Table 3: *Comparison of ^{45}Ca and Dye Tracer Leakage with Tracers Applied Sequentially to Each Tooth*

Group	Tracers	Ridit Mean	Standard Deviation
A'	^{45}Ca	.4902	.2234
	Basic fuchsin	.7441	.1241
B'	^{45}Ca	.3482	.1615
	Fluorescent dye	.3885	.2873
C'	^{45}Ca	.5252	.2055
	Reactive orange	.6347	.2720

Vertical lines connect groups that are not statistically different p<0.05.

Table 4: *Comparison of Microleakage of ^{45}Ca Applied Individually and in Combination with Other Tracers*

Group	Tracers	Ridit Mean	Standard Deviation
		Phase I	
D	^{45}Ca	.3320	.1131
		Phase II	
B'	^{45}Ca and fluorescent	.3482	.1615
A'	^{45}Ca and fuchsin	.4902	.2234
C'	^{45}Ca and orange	.5252	.2055

Values connected by vertical lines are not statistically significantly different p<0.05.

Table 5: *Comparison of Dye Tracer Leakage from Phase I, Applied Individually, and Phase II, Applied Sequentially with ^{45}Ca*

Group	Dye	Ridit Mean	Standard Deviation
A	Basic fuchsin	.7561	.1077
A'		.7441	.1241
B	Fluorescent	.3273	.2838
B'		.3885	.2873
C	Reactive orange	.5565	.3406
C'		.6347	.2720

Values connected by vertical lines are not statistically significantly different p<0.05.

B'). There was also no difference shown for ^{45}Ca measured in combination with basic fuchsin or reactive orange (A' and C').

Table 5 presents the Ridit values and analysis for groups using dye tracers measured independently and in combination with ^{45}Ca. No significant differences were found between these groups from Phase I and Phase II (A and A', B and B', and C and C').

DISCUSSION

Radioactive tracers and dyes have been separately employed in numerous microleakage studies. It is difficult to compare results for the different tracers used in the different studies because of numerous other variations in testing methods. Few studies have employed more than one tracer using identical methodology to allow for comparison of data obtained with different tracers. The objective of this study was to allow comparison of data from ^{45}Ca and three different dyes used in identical microleakage measurements. In addition, the sequential use of ^{45}Ca and each of the dyes allowed for comparison of the different tracers on the same specimens. The study also provided information about whether using multiple tracers on the same tooth influenced the data obtained for a specific tracer.

In Phase I of this study, significant differences were found in the mean values of microleakage for the different tracers. Only ^{45}Ca and fluorescent dye had leakage means that were not significantly different. Basic fuchsin had the highest mean value and was scored in the 4-leakage category for 29 of 30 specimens. The restoration used in this study would have been expected to show leakage, therefore, the results obtained with basic fuchsin were not surprising. A study by Crim, Swartz and Phillips (1985) on leakage of resin composites found no significant difference between the results for ^{45}Ca and basic fuchsin but demonstrated much lower leakage than this study.

Reactive orange was intermediate in leakage means between basic fuchsin and ^{45}Ca and fluorescent dye. The color of this dye makes for difficult visual evaluation since lightly stained tooth structure is similar to dentin in color. No dye was seen along most of the enamel margins, even on specimens that were rated category 4. This dye is supposed to bond to proteins but may find few, if any, bonding sites in enamel. Drying the specimen provided greater visual contrast and leakage ratings often increased with drying time.

In Phase II, no significant difference was seen in microleakage between ^{45}Ca and reactive orange when they were used on the same physical specimens. This is in contrast to the results found in Phase I, where these two groups were different. Table 4 provides an indication that the leakage measured with ^{45}Ca was significantly increased when reactive orange and basic fuchsin were applied to the same teeth. A possible explanation might be related to the pH of reactive orange and basic fuchsin. ^{45}Ca ions deposited on the apatite component of tooth structure could be released by the more acidic environment and carried by diffusion deeper below the cavosurface of the restoration. Comparing the leakage in Phase II with that found in Phase I for the three dyes indicated no significant difference in performance when ^{45}Ca was used before immersion in the dyes.

CONCLUSIONS

This study indicated that the leakage measured with the four tracers that were used showed significant differences. Only ^{45}Ca and the fluorescent dye consistently yielded results that were not significantly different. The order of the mean leakage values consistently ran from highest to lowest: basic fuchsin, reactive orange, fluorescent dye and ^{45}Ca. Results for the four groups tested with ^{45}Ca suggested that leakage measured with this tracer showed the most variation between groups. Leakage measured with the three dyes was not significantly different whether the dyes were applied singly or in combination with ^{45}Ca. The data also suggests that leakage measured with ^{45}Ca may be influenced by subsequent application of two of the three dyes used.

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Elution of Leachable Components from Composites After LED and Halogen Light Irradiation

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Clinical Relevance

The elution of leachable components from composites is curing light dependent rather than light source and mode dependent.

SUMMARY

This study investigated the influence of curing lights and modes on the elution of leachable components from dental composites. Four LED/halogen curing lights (LED–Elipar Freelight [FL], 3M-ESPE and GC e-light [EL], GC; high intensity halogen–Elipar Trilight [TL], 3M-ESPE; very high intensity halogen–Astralis 10 [AS], Ivoclar Vivadent) were selected for this study. Pulse (EL1), continuous (FL1, EL2, TL1), turbo (EL3, AS) and soft-start (FL2, EL4, TL2) curing modes of the various lights were examined. A conventional continuous cure halogen light (Max [MX], Dentsply-Caulk) was used for comparison. Three composite (Z100, 3M-ESPE) specimens (6.5 mm in diameter and 1-mm thick) were made for each curing light-mode combination. After polymerization, the specimens were stored in air at 37°C for 24 hours and incubated in acetonitrile at 37°C for 24 hours. BisGMA and TEGDMA extracts were isolated by high performance liquid chromatography (HPLC). Data were subjected to analysis using one-way ANOVA/Scheffe's post-hoc test and Independent Samples *t*-test at significance level 0.05. The total monomer (BisGMA and TEGDMA) eluted ranged from 8.75 to 27.97 ppm for FL1 and AS, respectively. Significantly more unreacted monomers were leached from composites cured with all modes of EL and AS when compared to MX. No significant difference in the total monomer eluted was observed between the two modes of FL/TL and MX. Although composites cured with EL2 released significantly less monomer than EL1, 3 and 4, no significant difference in the total monomer eluted was observed between the continuous and soft-start modes of FL and TL. The elution of leachable components from composites appears to be curing light specific rather than light source (LED or halogen) and curing mode specific.

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INTRODUCTION

Light cured resin composites have several advantages, including control of contour during restoration placement, improved color stability and increased polymerization compared to chemically activated materials (Burgess & others, 1999). An inherent disadvantage of these materials is that they shrink during light polymerization (Yap, 2000; Lim & others, 2002). The setting stresses associated with light-cured composites have been found to be greater than chemically activated ones (Feilzer, de Gee & Davidson, 1993). Stresses arising from polymerization shrinkage may produce defects in composite tooth bond, leading to bond failure with associated postoperative sensitivity, microleakage and recurrent caries (Eick & Welch, 1986). If the composite-tooth bond is good, it may also cause deformation of the surrounding tooth structure (Sheth, Fuller & Jensen, 1988), predisposing the tooth to fracture. Polymerization shrinkage can be reduced in several ways, including the application of liners/bases, incremental placement of composites and allowing the composites to contract freely to the adhesive surface (Davidson & Feilzer, 1997). A more recent approach is to allow flow during setting by means of controlled polymerization. This is achieved by pre-polymerization at low light intensity followed by a final cure at high intensity (soft-start cure), applying short pulses of light energy (pulse cure) or a combination of the two. Contrasting light polymerization regimens involving the use of very high light intensities for short durations (turbo cure), however, have been developed. These curing regimens were established primarily to reduce clinical time and have been shown not to increase polymerization stresses if the total light energy density (intensity x time) is maintained (Yap, Wong & Siow, 2003).

LED (light emitting diodes) curing lights were recently introduced to the dental profession. They were designed to overcome some of the drawbacks of halogen lights, including production of a large quantity of heat during curing cycles and bulb/reflector/filter degradation over time due to high operating temperatures. LED curing lights are particularly effective for polymerizing dental composites, as most of the energy radiated falls within the absorption spectrum of camphoroquinone photoinitiators (Mills, Jandt & Ashworth, 1999). The majority of commercial LED lights are pre-programmed with multiple curing regimens including soft-start, pulse and/or turbo cure modes. Although thermal emission, depth of cure, degree of conversion and polymerization efficiency associated with LED/halogen lights and their various curing modes have been widely investigated (Mills, Uhi & Jandt, 2002; Yoon & others, 2002; Yap, Soh & Siow, 2002; Hofmann, Hugo & Klaiber, 2002a; Yap & Soh, 2003; Yap & others, 2003), studies reporting the elution of leachable components from composites cured with these lights/curing modes are generally limited (Hofmann & others, 2002b). The elution of unreacted components is clinically important, as it has a potential impact on both the biocompatibility and structural stability of dental composites (Caughman & others, 1991; Rathbun & others, 1991; Ferracane, 1994).

This study investigated the effect of curing lights and modes on the elution of leachable components from dental composites using reversed-phase high-performance liquid chromatography (HPLC). For lights equipped with different curing regimens, differences in the quantity of unreacted components eluted were compared among the various curing modes.

METHODS AND MATERIALS

A minifill composite (Z100; 3M-ESPE, St Paul, MN, USA) and four LED/halogen curing lights (LED–Elipar Freelight [FL], 3M-ESPE, Seefeld, Germany and GC e-light [EL], GC Europe, Leuven, Belgium; high intensity

Table 1: *Details of the Curing Lights and the Various Curing Modes Evaluated*

LCU	Curing Modes	Curing Profiles		
GC e-light (LED)	Pulse (EL1)	750 mW/cm² (10 pulses x 2 seconds)		
	Continuous (EL2)	350 mW/cm² (40 seconds)		
	Turbo (EL30)	600 mW/cm² (20 seconds)		
	Soft-start (EL4)	0 to 600 mW/cm² (20 seconds)	→	600 mW/cm² (20 seconds)
Elipar Freelight (LED)	Continuous (FL1)	400 mW/cm² (40 seconds)		400 mW/cm²
	Soft-start (FL2)	0 to 400 mW/cm² (12 seconds)	→	400 mW/cm² (28 seconds)
Max (Halogen)	Continuous (MX)	400 mW/cm² (40 seconds)		
Astralis 10 (Halogen)	Turbo (AS)	1200 mW/cm² (10 seconds)		
Elipar Trilight (Halogen)	Continuous (TL1)	800 mW/cm² (40 seconds)		
	Soft-start (TL2)	100 to 800 mW/cm² (15 seconds)	→	800 mW/cm² (25 seconds)

Curing profiles are based on manufacturers' information.

halogen light–Elipar Trilight [TL], 3M-ESPE; very high intensity halogen light–Astralis 10 [AS], Ivoclar-Vivadent, Schaan, Liechtenstein) were selected for the study. Pulse (EL1), continuous (FL1, EL2, TL1), turbo (EL3, AS) and soft-start (FL2, EL4, TL2) curing modes of the various lights were examined. A conventional, continuous cure halogen light (Max [MX], Dentsply-Caulk, Milford, DE, USA) was used for comparison. Table 1 lists details of the curing lights and modes evaluated. The intensity of the light sources was checked with a commercial radiometer (Hilux; Benlioglu Dental Inc, Ankara, Turkey) before beginning the experiment to ensure consistency of light output.

The composite material was placed in customized stainless steel molds with cylindrical recesses 6.5 mm in diameter and 1 mm in height sandwiched between two glass slides. Excess material was extruded by applying pressure and the composite material was polymerized with the different curing lights and modes as specified in Table 1. Three disk specimens were made for each curing light-mode combination. Immediately after light polymerization, the specimens were removed from their molds, sized with sandpaper and placed in centrifuge tubes. The centrifuge tubes were covered with aluminum foil and stored at 37°C for 24 hours. Five milliliters of acetonitrile were then added to each centrifuge tube and the specimens incubated at 37°C for 24 hours.

The incubation solutions were centrifuged in a vortex mixer (Hettich centrifuge universal 8S, Hettich, Germany) at 15,000 x g for 10 minutes. The solutions were filtered through 0.45 µm nylon filter paper into a sample vial. Twenty microlitres of each solution were injected into a Waters 600E system controller HPLC instrument (Millipore Corp, Billerica, MA, USA). Samples were eluted at a flow rate of 1.0 mL/minute for the first five minutes using a solvent linear gradient of 50% acetonitrile in water to 100% acetonitrile, then eluted at the same flow rate for 10 minutes with 100% acetonitrile. The concentration of acetonitrile was then gradually decreased for more than five minutes to 50% acetonitrile in water at a flow rate of 1.0 mL/minute. The same conditions were held for the next 10 minutes to wash the column. The eluted monomers were detected by a Waters 486 Tuneable Absorbance UV detector (Millipore Corp) at 205 nm.

Standard concentrations of 8, 10, 12 and 20 ppm of TEGDMA (triethyleneglycol dimethacrylate) and standard concentrations of 5.6, 8.4, 11.2 and 14 ppm of BisGMA (Bisphenol A glycidyl dimethacrylate) were prepared. The standards were injected into the reversed-phased HPLC instrument using the aforementioned conditions. Calibration plots were obtained from the peak areas and concentrations. The amount of monomer eluted was subsequently quantified based upon peak areas against standard curves obtained for BisGMA and TEGDMA. Data for BisGMA, TEGDMA and the total (BisGMA and TEGDMA) monomer eluted were computed and analyzed using One-way ANOVA/Scheffe's post-hoc test and Independent Samples *t*-test at significance level 0.05.

RESULTS

Table 2 shows the mean quantity of BisGMA and TEGDMA eluted. Computation of the total monomer released is also reflected in Table 2 and Figure 1.

Regardless of the curing light/mode, more TEGDMA was eluted compared to BisGMA. The amount of TEGDMA released ranged from 8.75 to 16.37 ppm, while BisGMA ranged from 0 to 12.74 ppm. Composites cured with EL1 through EL4 and AS leached significantly more BisGMA than MX. The amount of TEGDMA eluted from composites cured with EL2, EL3 and AS was significantly more than MX. The total monomer (BisGMA and TEGDMA) released ranged

Table 2: *Mean BisGMA, TEGDMA and Total Monomer Eluted*

Curing Lights	Curing Modes	BisGMA [ppm]	TEGDMA [ppm]	Total [ppm]
e-light	**EL1** (Pulse)	9.59 (0.71)	13.13 (0.72)	22.72 (1.43)
	EL2 (Continuous)	0	16.37 (0.91)	16.37 (0.91)
	EL3 (Turbo)	10.02 (0.43)	15.52 (0.99)	25.53 (1.42)
	EL4 (Soft-start)	9.16 (0.24)	14.04 (0.72)	23.19 (0.50)
Freelight	**FL1** (Continuous)	0	8.75 (0.74)	8.75 (0.74)
	FL2 (Soft-start)	0	9.22 (0.45)	9.22 (0.45)
Max	**MX** (Continuous)	0	11.28 (0.79)	11.28 (0.79)
Astralis 10	**AS** (Turbo)	12.74 (0.95)	15.23 (1.29)	27.97 (2.22)
Trilight	**TL1** (Continuous)	0	9.18 (0.71)	9.18 (0.71)
	TL2 (Soft-start)	0	10.92 (0.77)	10.92 (0.77)

Standard deviations in parentheses.

from 8.75 to 27.97 ppm for FL1 and AS, respectively. Significantly more unreacted monomers were eluted from composites cured with all modes of EL and AS when compared to MX. No significant difference in the total monomer eluted was observed between the two modes of FL/TL and MX.

For lights that offer multiple curing modes, significant differences in monomer elution were observed only for e-light (EL). Composites polymerized with pulse (EL1), turbo (EL3) and soft-start modes (EL4) leached significantly more BisGMA than composites that were continuously cured (EL2). Polymerization with EL1 resulted in significantly less TEGDMA release than EL2. When the total monomer eluted was compared, curing with the continuous mode (EL2) resulted in significantly less monomer release than polymerization with pulse (EL1), turbo (EL3) and soft-start (EL4) modes.

DISCUSSION

The mechanical and biological properties of dental composites are highly influenced by their monomer to polymer conversion. However, monomer conversion is, however, never complete, and the degree of conversion varies between approximately 35% and 77% (Ferracane, 1994, 1995; Spahl, Budzikiewicz & Geurtsen, 1998). Therefore, a significant amount of residual monomer or short chain polymer remains unbound in set dental composites and can be leached into aqueous media. The quantity of leachable molecules might not correspond to the degree of conversion, as polymers that differ in linearity, and therefore, have different crosslink densities, can have similar conversion values (Asmussen & Peutzfeldt, 2001a,b). BisGMA and TEGDMA were selected as target compounds, as they were the main constituents of the resin component of Z100. In addition, 80% to 90% of commercial composites utilize BisGMA and TEGDMA, which has excellent viscosity and copolymerization characteristics and is often used as a diluent monomer for BisGMA and UDMA (urethane dimethacrylates) (Ferracane, 1995). The composite materials were incubated only after 24 hours following polymerization to allow for composite post-cure (Tarumi & others, 1999; Yap & others, 2001). Ferracane and Condon (1990) investigated the elution of molecules from composites and showed that 50% of the leachable species were eluted within three hours of soaking in water, while 75% of leachable molecules were eluted into ethanol-water mixture. As elution of nearly all the leachable components in either solvent was complete within a 24-hour period, this incubation period was selected for this study. The use of both solvents (ethanol-water and water) was explored during our pilot study. A good separation between monomer and ethanol-water solvent peaks could not be achieved, and no monomer peaks were observed after incubation in water for 24 hours. Acetonitrile, which has been used in other HPLC analysis of dental composites (Noda, Komatsu & Sano, 1999), was selected as the solvent and mobile phase, as BisGMA and TEGDMA are hydrophobic and the results of our pilot study showed that monomer and acetonitrile solvent peaks were well separated.

For all curing lights and modes, more TEGDMA was eluted compared to BisGMA. The elution process occurs via diffusion through the resin matrix and is therefore dependent on the size and chemical composition of the leachable molecules (Ferracane, 1994). Smaller molecules have enhanced mobility when compared to larger, bulkier molecules. TEGDMA molecules being smaller (lower molecular weight) are, therefore, eluted at a faster rate than larger (higher molecular weight) BisGMA molecules (Thompson, Miller & Bowles, 1982). The findings of this study corroborated those of Tanaka and others (1991), who found that the majority of unreacted monomers present in BisGMA-TEGDMA composites were diluent TEGDMA molecules. The total monomer eluted from all modes of EL and AS was significantly greater than MX. The results obtained for EL were consistent with the findings of Soh, Yap and Siow (2003), who investigated the effectiveness of cure of

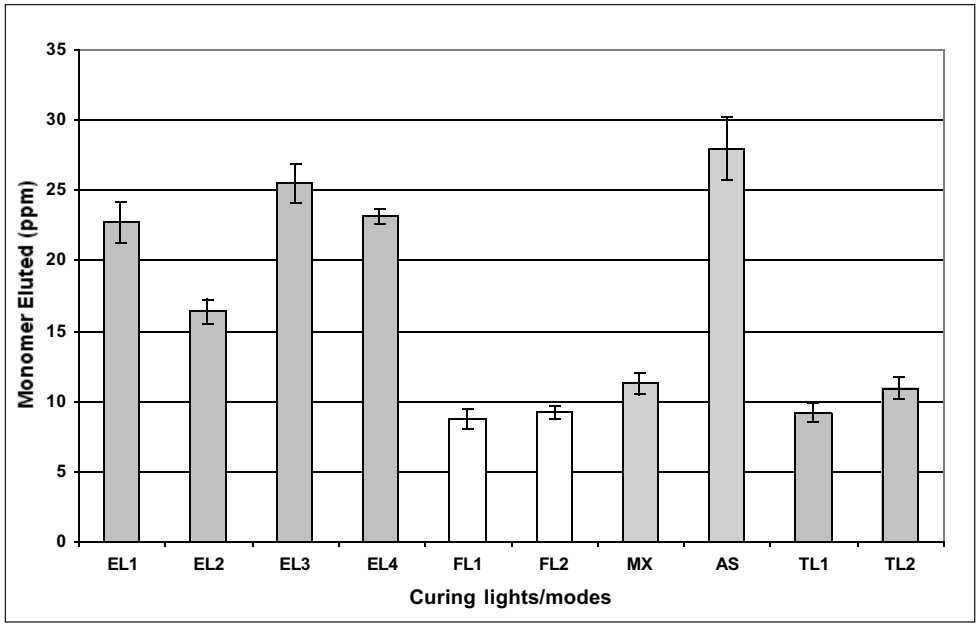

Figure 1. *Total monomer eluted by composites polymerized with the different curing lights and modes.*

LED curing lights at various cavity depths. The effectiveness of cure of EL was significantly poorer than MX at cavity depths of 2, 3 and 4 mm and was attributed to differences in light intensities and spectral distributions. The significantly greater quantity of monomer leached from composites cured with AS, when compared to MX, could be explained by the lower light energy density of AS (12 J/cm^2 [1200 W/cm^2 for 10 seconds]) when compared to MX (16 J/cm^2 [400 W/cm^2 for 40 seconds]). Higher light energy densities would lead to greater cure, resulting in less unreacted monomers and short chain polymers (Yap & Seneviratne, 2001).

Significant differences in the total monomer eluted were observed among the various modes of EL. For EL, composites cured with continuous mode released significantly less monomer than those cured with pulse, turbo and soft-start modes. The total monomer released was not significantly different among the latter three modes. Based on manufacturer's data, the light energy densities of EL1, EL3 and EL4 were comparable or greater than EL2. The amount of monomer leached from these modes should therefore be comparable or less. Yap and others (2002), however, reported that certain pulse activation and soft-start polymerization regimens may reduce the effectiveness of cure at the bottom surface of composite restorations. In addition, the pulse-delay technique has been shown to result in composite structures with fewer crosslinks despite having a similar degree of conversion to composite polymerized continuously (Asmussen & Peutzfeldt, 2001a). Composites that are less crosslinked may be more susceptible to the uptake of solvent and elution of molecules. The aforementioned could explain the greater amount of monomer released from EL1, 3 and 4. As no significant difference in total monomer eluted was observed between the continuous and soft-start modes of FL and TL, the influence of soft-start curing regimens on monomer release is curing light dependent.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The elution of leachable components from composites was curing light dependent and not light source and mode dependent.
2. Composites cured with all modes of GC e-light and Astralis 10 leached significantly more monomer than those polymerized with a conventional, continuous cure halogen light.
3. No significant difference in the monomer eluted was observed among composites cured with the continuous/soft-start modes of Elipar Freelight and Trilight and those polymerized with a conventional continuous cure halogen light.
4. For GC e-light, composites cured with the pulse, turbo and soft-start modes released significantly more monomer than composites that were continuously cured.

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The Influence of Dentin Adhesives on the Demineralization of Irradiated and Non-irradiated Human Root Dentin

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Clinical Relevance

The application of dentin adhesives on irradiated and non-irradiated root surfaces might have a positive effect on dentin demineralization. Between sound and irradiated root dentin, no differences are observable.

SUMMARY

This study determined the caries-protective effects of two different dentin bonding systems (Syntac, Scotchbond) on sound and irradiated root surfaces *in vitro*. The root surfaces of 30 freshly extracted caries-free human molars were used. The teeth were bisected in the mesio-distal direction and all lingual halves of the teeth were irradiated. The irradiation dose of 60 Gy was fractionally applied over six weeks (2 Gy/day, 5d/wk). All halves were then coated with acid-resistant nail varnish, exposing two rectangular windows 6 mm² each on the dentinal root surface. One window served as an untreated control, while the other was treated with one of the above mentioned dentin adhesive systems. The specimens were randomly distributed among the four experimental groups as follow: Group A: Syntac, non-irradiated; Group AR: Syntac, irradiated; Group B: Scotchbond, non-irradiated; Group BR: Scotchbond, irradiated. Subsequently, all specimens were demineralized for 14 days with acidified gel (HEC, pH 4.8, 37°C). From each window, two dentinal slabs were cut. The slabs were ground to a thickness of 80 µm and submerged in water. The depth of the lesions was determined using a polarized light microscope. The non-irradiated control specimens showed lesions with an average depth of 63 µm (+/-10,2 µm). In the case of the irradiated control specimen, the lesion depth was not significantly different. In all experimental groups, the lesion depth was significantly reduced compared to the control groups. Statistical analysis revealed no significant differences between the irradiated and non-irradiated specimens. It can be concluded that demineral-

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ization of the root surface can be hampered by application of the dentin adhesive systems tested. In this study, no differences between irradiated and sound root surfaces could be detected.

INTRODUCTION

According to dental literature, "radiation caries" is a rapidly developing and highly destructive form of tooth decay after radiotherapy of malignant tumors in the head and neck region. Hyposalivation, which is induced by irradiation (Frank, Herdly & Philippe, 1965) and dietary changes with concomitant alteration of the oral flora (Brown & others, 1975), are considered the most important aetiological factors. Previous investigations dealing with the irradiation effects on dental hard tissue have focused mainly on enamel as substrate. Moreover, with regard to caries susceptibility of irradiated dentin, little reliable data is available in the dental literature. Radiation-induced collagen damage within the main peptide chains (Fisher & others, 1971) and physical and chemical changes of the apatite and octacalcium-phosphate after radiation has been documented (Fisher & others, 1971; Geoffroy & Tocoan-Danguy, 1985; Kielbassa & others, 1999). Recent studies have described a reduced solubility and microhardness of irradiated dentin (Markitziu & others, 1986; Kielbassa & others, 1997). Focusing on the demineralization of sound and irradiated dentin, newer studies have observed no significant differences (Kielbassa, 2000). Unfortunately, all of those *in vitro* studies have limitations with regard to clinical observations that deal with the highly destructive progress of "radiation caries."

In addition to the buccal and oral smooth surfaces and the occlusal or incisal edges of the teeth (Jansma & others, 1993; Jongebloed, Gravenmade & Retief, 1988), "radiation caries" frequently occurs in the cervical regions (Pyykönen & others, 1986). Here, the lesion often strongly undermines the usually non-progressively demineralized enamel. Therefore, preventive concepts were developed to protect these vulnerable root surfaces against the cariogenic challenge. In the past, studies dealing with the preventive concepts for irradiated patients have focused mainly on the application of fluorides or fluoride-containing solutions (Jansma & others, 1989; Meyerowitz & others, 1991). Indeed, topically applied fluorides can prevent demineralization and reduce the incidence of root caries, but patient compliance with home care instructions, especially daily topical fluoride use, is a critical factor in the control of caries in irradiated patients with hyposalivation (Haveman & others, 2003). Furthermore, regarding the clinical situation of irradiated patients, it should be emphasized that this assumption strongly depends on the residual salivary flow rate. Due to irreversible, radiation-induced hyposalivation (xerostomia) (Frank & others, 1965), remineralization effects may be less likely in irradiated patients. It seems evident that saliva-deficient conditions are extremely caries promoting, and remineralization in the absence of saliva is assumed to be impossible. Indeed, a recent study indicated that a flow rate of the remaining saliva below 0.1 ml/minute leads to a significantly increased incidence of caries (Spak, Johnson & Ekstrand, 1994).

Thus, new preventive concepts for irradiated patients have to be found to protect the highly vulnerable root surfaces against carious attacks. Recent experiments have shown a caries-protective effect of dentin bonding agents on human root dentin (Hahn & others, 1999). Dentin adhesives are known to create a high acid resistance of the dentin surface due to a thin layer of resin-reinforced dentin, the so-called hybrid layer (Nakabayashi, Nakamura & Yasuda, 1991) that might influence demineralization of the underlying dentin. Since the influence of dentin bonding agents on irradiated root dentin has not yet been reported in the dental literature, the first objective was to evaluate the caries-protective effect of two different dentin adhesive systems on root caries development applied on non-irradiated and irradiated dentin. If the above mentioned radiation-induced changes have any clinical consequences, such as pronounced caries-susceptibility, irradiated dentin should reveal higher or at least different demineralization *in vitro*. Therefore, the second aim of this study was to compare the effects of irradiation on the onset of dentin demineralization.

METHODS AND MATERIALS

In this study, 30 freshly extracted, caries-free human lower molars were used. The teeth were stored at 8°C in a 0.9% sodium chloride solution for a maximum of eight days before the beginning the experiment. The root surfaces of the selected teeth were thoroughly cleaned. The cementum of the experimental areas was removed by polishing with Sof-Lex disks (3M Dental Products, St Paul, MN, USA). The prepared teeth were then bisected in the mesio-distal direction (Figure 1). The lingual half of the tooth served as a non-irradiated sample, while the other half was irradiated. The buccal part of each tooth was irradiated fractionally up to 60 Gy using a linear accelerator (Mevatron-MXE-2, Siemens, Munich, Germany) with a total of 30 doses (2 Gy/d, 5 d/wk, X-Ray, 6MV). For homogeneity of the irradiation, the specimens were stored in daily renewed saline (2 cm in depth). The radiation was performed at room temperature. After irradiation, all samples were coated with an acid-resistant nail varnish, exposing two rectangular 2 x 3 mm windows on the root surface. The windows were located 1 mm apical to the cementoenamel junction (Figure 1).

The 30 teeth, consisting of a lingual irradiated half and a buccal non-irradiated half, were randomly assigned to one of the used dentin adhesive systems (Table 1), resulting in four experimental groups and the

Table 1: *Composition of Dentin Adhesive Systems Used in This Investigation*

Group	Material	Manufacturer	Composition (Batch #)
A	Syntac	Vivandent, Ellwangen, Germany	Primer: Tetraethyleneglycolmethacrylate, maleic acid, dimethylketone, water Adhesive: Polyethyleneglycoldimetharcrylate, maleic acid, glutardialdehyde, water
B	Scotchbond 1	3M Dental Products, Loughborough, UK	2-hydroxyehyl-methacrylate, bisphenol-A-diglycidyl-ether-dimethacrylate, urethandimethacrylate, ethanol, water

Table 2: *Specifications Among the Different Experimental Groups*

Group	Dentin Adhesive System	Treatment
A	Syntac	Non-irradiated dentin specimens
AC	Control group	Non-irradiated dentin specimens
AR	Syntac	Irradiated dentin specimens
ARC	Control group	Irradiated dentin specimens
B	Scotchbond 1	Non-irradiated dentin specimens
BC	Control group	Non-irradiated dentin specimens
BR	Scotchbond 1	Irradiated dentin specimens
BRC	Control group	Irradiated dentin specimens

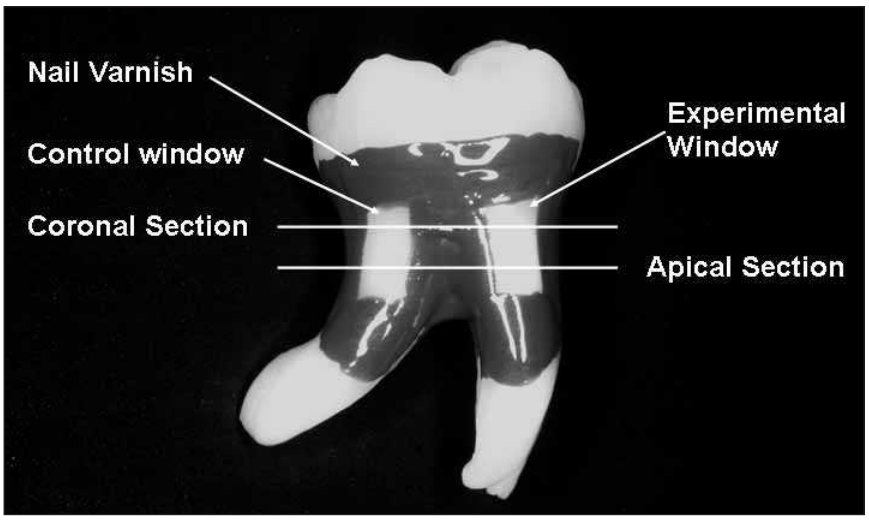

Figure 1. *Graphical expression of specimen preparation.*

corresponding control groups (Table 2). Each group contained 15 specimens.

One window of each half was treated with one of the dentin adhesive systems as recommended by the manufacturers. The root surface of the other quarter was left untreated as a control surface.

In Groups A and AR, the two-bottle dentin bonding system Syntac (Vivadent, Ellwangen, Germany) was used. First, Syntac Primer was applied and blown away for 15 seconds. Then, Syntac Adhesive was applied for 10 seconds and blown to a thin layer for 10 seconds. Finally, the applied layers were light-cured for 10 seconds using a photo-curing unit (EliparVisio, ESPE, Seefeld, Germany) running at 400 mW/cm^2.

The specimens in Groups B and BR were treated with the bonding system Scotchbond 1 (3M Dental Products). In this case, etching gel (35% phosphoric acid) was applied to the dentin surface and rinsed off after 15 seconds. The water was carefully removed with an air streamer but not dried extensively. Two layers of Scotchbond 1 were applied, blown to a thin layer and finally light-cured for 10 seconds using the above mentioned photo-curing unit.

The surfaces of all control specimens were left untreated. For demineralization, sodium hydroxide was acidified by titration with lactid acid to pH 4.5. Hydroxyethylcellulose (6% by weight) was added, resulting in a final pH of 4.8.

All 15 samples of each group were immersed in 100 ml demineralizing solution for two weeks at 37°C. After demineralization, all samples were washed under running tap water and gently dried. The specimens were then embedded in acrylic resin and two sections (cervical and apical of the window) of each sample were cut perpendicular to the root surface using a diamond-coated band saw (Exakt Apparatebau, Norderstedt, Germany) under continuous water cooling. Subsequently, the specimens were mounted on a plexiglass microscope slide and ground (1200-, 2400- and 4000-grit, Exakt Apparatebau) from the counterside to a uniform thickness of 80 µm (+/-20 µm) according to the method described by Donath and Breuner (1982).

A qualitative examination of the sections was performed and the experimentally demineralized areas were compared to the sound varnish-coated areas. The lesion depths of all samples were measured under an inverse polarizing microscope at an original magnification of 100x (Carl Zeiss, Oberkochen, Germany). In

Table 3: *Mean Lesion Depth (µm) and Standard Deviations (SD) of the Different Experimental Groups. The Irradiated (AC and ARC) and Non-irradiated (BC and BRC) Control Groups Were Pooled*

	Group A Syntac Non-irradiated	Group AR Syntac Irradiated	Group B Scotchbond Non-irradiated	Group BR Scothbond Irradiated	Control Groups Non-Irradiated	Control Groups Irradiated
Mean	62.7	63.6	61.6	64.5	91.8	92.4
SD	03.3	04.8	08.4	04.7	04.3	03.4
% reduction compared to the respective controls	31.7	31.2	32.9	30.2	X	X

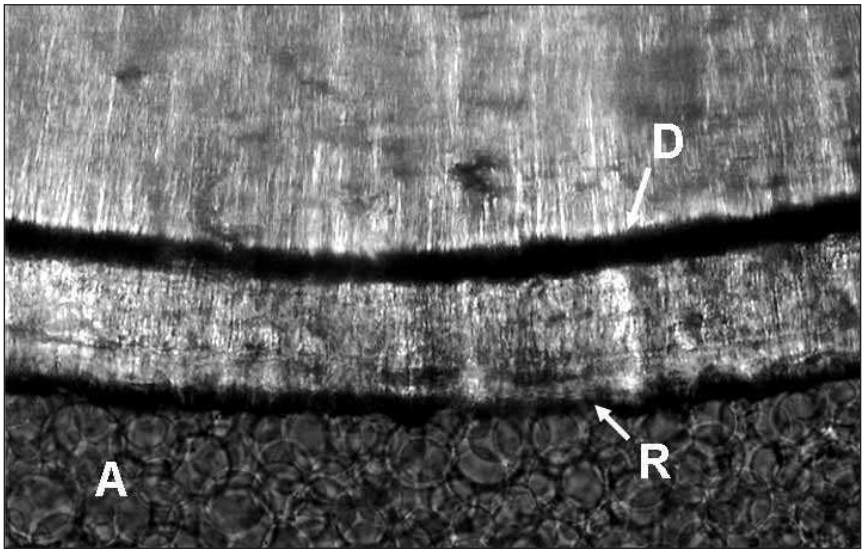

Figure 2. *Polarized light photomicrograph of a non-irradiated control specimen submerged in water (magnification 300x). A=acrylic resin; R=root surface; D=demineralization front.*

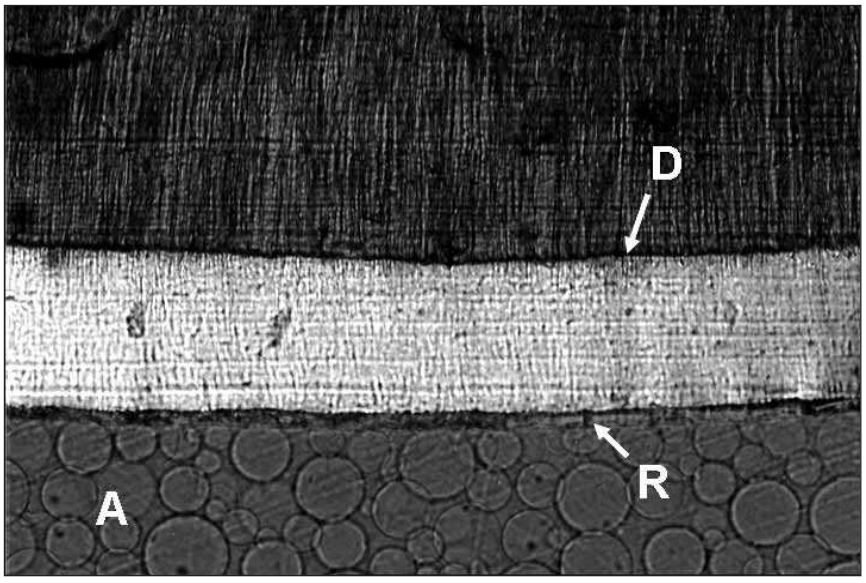

Figure 3. *Polarized light photomicrograph of an irradiated control specimen submerged in water (magnification 300x). A=acrylic resin; R=root surface; D=demineralization front.*

each section, 10 measurements were carried out and the corresponding photographs taken.

Data of the measured lesion depths were statistically analyzed with regard to the mean values of both the different locations of the control and the experimental sections and with regard to the mean lesion depths of the different experimental groups (Statistical software: SPSS for Windows Release 10.0, SPSS Inc, Chicago, IL, USA). Repeated measures ANOVA were used to evaluate the results at a 5% level of significance. Differences between the individual groups were calculated using the Wilcoxon test. Closed test procedure (comparison by pairs based on the Kruskal-Wallis test) was used to calculate differences between the materials; level of significance was set at 5%.

RESULTS

All specimens in every group developed demineralizations in the cervical and apical section. ANOVA revealed that the lesion depths among the eight groups proved to be significantly different ($p<0.001$). Regarding the different localizations of the sections, the control and the experimental samples showed no significant differences between the cervical and apical sections. Thus, the results of both sections were pooled for all groups. Table 3 shows the results for all groups. In the case of the untreated, non-irradiated control specimens (Groups AC and BC), the mean lesion depth caused by demineralization of the root dentin was 92.7 µm (+/-3.2 µm) and 91.0 µm (+/-5.3 µm). The irradiated control specimen (Groups ARC and BRC) exhibited lesions with an average depth of 93.4 µm (+/-3.1 µm) and 91.4 µm (+/-3.7 µm). Between the irradiated and non-irradiated control groups, no signifi-

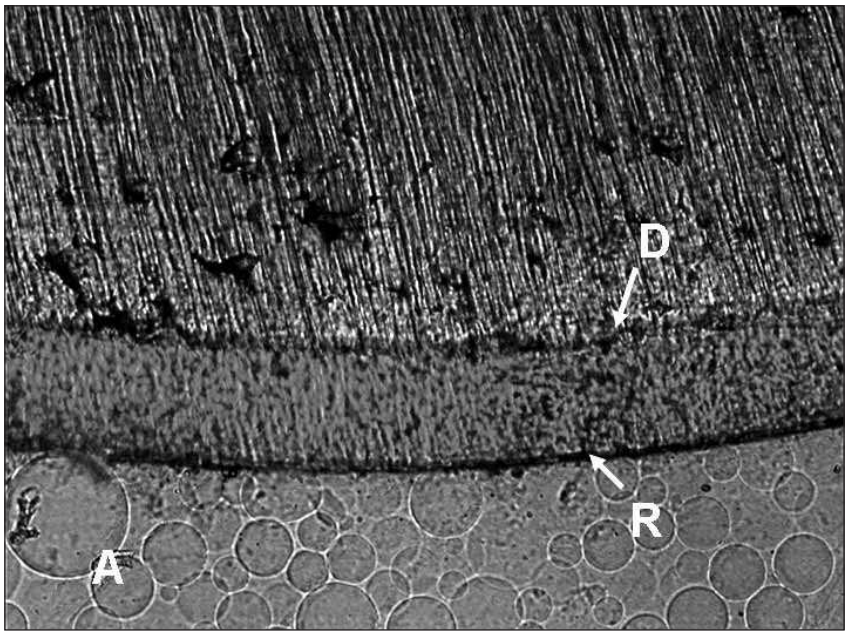

Figure 4. *Photomicrograph of a non-irradiated specimen treated with Syntac submerged in water (magnification 300x). Reduced demineralization compared to the control group (Figure 2). A=acrylic resin; R=root surface; D=demineralization front.*

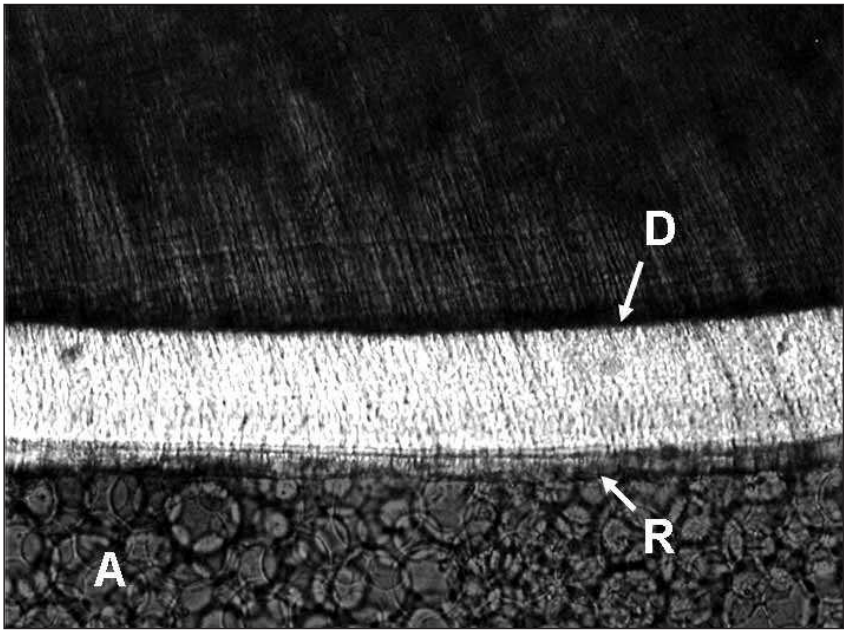

Figure 5. *Photomicrograph of an irradiated control specimen submerged in water (magnification 300x). Reduced demineralization compared to the control group (Figure 3). A=acrylic resin; R=root surface; D=demineralization front.*

cant differences could be detected. Thus, they were pooled in Table 3. Irradiation itself did not show any significant influence on demineralization of the control groups ($p>0.05$, ANOVA). After examining the experimental groups (A, AR, B and BR), statistical analysis revealed significantly reduced lesion depths compared to the corresponding controls ($p<0.05$, Wilcoxon).

In the case of the subgroups treated with Syntac (A, AR), the non-irradiated specimens (A) showed a mean lesion depth of 62.7 µm (+/-3.3 µm), while the irradiated specimens (AR) showed an average lesion depth of 63.6 µm (+/-4.8 µm), which means a reduction in demineralization depth of 31.7% and 31.2%, respectively, compared to the control specimens. Between the irradiated and non-irradiated groups treated with Syntac, no significant differences could be detected (p.0.05, Wilcoxon).

The Scotchbond 1 groups (B, BR) revealed a mean lesion depth of 61.6 µm (+/-4.8 µm) in the non-irradiated subgroup and 64.5 µm (+/-4.7 µm) in the irradiated subgroup. Compared to the corresponding control groups, this means a reduction in lesion depth of 32.9% and 30.2%. Again, no significant influence of irradiation could be found ($p>0.05$, Wilcoxon). In regard to the dentin adhesive systems, the more sensitive, closed test procedure (based on Kruskal-Wallis test) showed no significant differences among the four experimental groups.

The qualitative analysis of the various sections showed no differences between the irradiated and non-irradiated control specimens in view of the histological structure of the demineralization zones. Representative lesions developed in irradiated and non-irradiated dentin are shown in Figures 2 and 3. When the sections were examined in polarized light after being submerged in water, all increasingly demineralized areas appeared positively birefringent. The tubular structure was still evident and clearly visible. The histological structure of the demineralization zones of the four experimental groups (A, AR, B and BR) were similar, but the lesion depths were reduced. Representative sections are shown in Figures 4 and 5.

DISCUSSION

During this experiment, the extracted teeth were stored in saline solution after extraction. This is a common, well-described procedure (Hoppenbrouwers, Driessens & Borggreven, 1986; Zuidgeest, Herkströter & Arends, 1990; Hahn & others 1999), as it does not change the physical properties of human dentin used in *in vitro* experiments (Retief & others, 1989; Haller & others, 1993). In the case of denuded root surfaces after gingival recession, normally, the cementum is lost very soon due to its low abrasion resistance (Mellberg &

Sanchez, 1986). In most cases, no cementum is left on the exposed root surface where caries occurs (Wefel, Clarkson & Heilmann, 1985). Therefore, the cementum was removed with polishing discs before starting the experiment. The resulting dentinal tooth surface, covered by a smear layer that is also present in the oral cavity, has facilitated a more standardized artificial demineralization with reproducible lesions (Hahn & others, 1999).

The progression of root caries is known to be smaller when simulating dentin perfusion compared to samples where this simulation is not used (Shellis, 1994). In this experiment, the authors did not use this model, because the differences between the experimental and control groups within the same tooth delivered sufficient information about the influence of irradiation and effectiveness of the two dentin adhesives. However, an interaction between the dentinal fluid and acid on the root surface during demineralization cannot be excluded.

In this study, 30 specimens were irradiated with 60 Gy fractionally applied over six weeks. This corresponds to a common clinical procedure (Kielbassa & others, 1997; Kim & others, 2001). During irradiation, the specimens were kept wet. This should be emphasized, since the apatitic crystals of dental hard tissue are known to have incorporated sodium, carbonate and magnesium by entrapment during their formation. In the case of irradiation, these point defects could be mobilized from the surface layer of the crystals, thereby removing the entrapped ions. Wet conditions, on the other hand, have supposedly stabilized the surface layers of the apatite phase of dental hard tissue, thereby reducing the dissolution rate into one comparable to a slightly acidic environment (Jansma & others, 1990).

This study (using dentin irradiated *in vitro*) revealed no irradiation effects on caries susceptibility, suggesting that radiation-induced changes at the ultrastructural level have no clinical impact on initial demineralization. This confirms the assumptions published in previous journals that demineralization in irradiated enamel and dentin effectively resembled natural caries (Jongebloed & others, 1988; Kielbassa, 2000) or where the absence of structural changes after irradiation have been reported (Jansma & others, 1988). However, this contradicts earlier reports that demonstrated a decreased solution rate of irradiated dentin (Markitziu & others, 1986) or reduced mineral loss and lesion depths after the irradiation of enamel (Jansma & others, 1988; Markitziu & others, 1989). It should be mentioned that all these studies were based on *in vitro* conditions and might not reflect the clinical situation adequately. However, even the available *in situ* and *in vivo* studies related to the onset or prevention of caries in irradiated, saliva-deficient patients (Jansma & others, 1989; Meyerowitz & others, 1991; Kielbassa & others, 1999; Kielbassa, 2000) have certain limitations. Due to the extreme variations in the individual effects of radiotherapy (differences in salivary flow, microbial composition, dietary changes, radiation dose) and the often limited compliance of patients, a pronounced control of variations seems hardly achievable in this case. Thus, it seems clear that it is extremely difficult to evaluate the multifarious reasons for radiation caries in an *in vitro* experimental setup.

In this study, the mean lesion depths of the control specimens were comparable to the results of other investigations that also used acidified hydroxyethylcellulose (Mellberg & Sanchez, 1986; Hahn & others, 1999). In regard to the histological structure of the developed lesions, no differences in natural caries could be detected in all sections. The classic zones of the incipient dentin lesion were observed (Figures 2 through 5), including the closely defined surface layers and frontal zones with well-preserved tubular structures. Thus, polarized light photomicrographs of the lesions clearly resembled the known microscopic appearance of initial caries in non-irradiated dentin (Wefel & others, 1985). With regard to the reduced microhardness and the concomitant decrease of wear resistance in irradiated dentin (Davis, 1975; Kielbassa & others, 1997), this study only observed a negligible erosive loss of dental hard tissue at the surface (Figures 2 through 5). Even after the cutting and grinding procedures, all specimens were completely intact.

Observing the different locations within the root surface, no significant influence on lesion depth could be detected in this study. This confirms the assumptions made in previous publications, where no differences in demineralization between cervical and apical sections were reported (Zuidgeest & others, 1990; Hahn & others, 1999).

Both dentin adhesive systems used in this study reduced the demineralization depth regardless of the different application modes. These findings are in accordance with the results of other recently published studies (Grogono & Mayo, 1993; Swift & others, 1994) that also reported a significant reduction in lesion depth after dentin adhesive application. In contrast to this study, these other studies used different caries models. Another study, also using acidified hydroxyethylcellulose, observed similar results after applying bonding agents on sound dentin; a reduction of nearly 32% compared to the control specimens was achieved (Hahn & others, 1999). The adhesive systems tested were able to seal the root surface. From the dental literature, it is well known that the application of bonding systems containing acids or chelating agents result in an opening and widening of the dentinal tubules, as well as a demineralization of the intertubular dentin (Van Meerbeek & others, 1992). The maleic acid, which

is included in Syntac, and the initial use of etching gel (35% phosphoric acid) in the case of Scotchbond 1, perform this function. After applying the dentin adhesive system, the dentinal tubules are filled with resin tags and the included monomers infiltrate the collagen, forming the hybrid layer (Nakabayashi & others, 1991). This layer forms an acid-resistant envelope that seals the underlying dentin, preventing secondary caries. Furthermore, by filling the dentinal tubules, the surface area that is susceptible to carious attack is decreased. These factors may cause the reduction in lesion depth observed in this study. Additionally, glutardialdehyde, which is included in Syntac Adhesive, could be responsible for the reduced demineralization. Glutardialdehyde is known to have the ability to decrease demineralization of human dentin up to 30% *in situ* (Dijkman, de Vries & Arends, 1992). This might serve as an additional explanation for the observations made in this study.

CONCLUSIONS

All the dentin bonding systems tested in this study reduced the demineralization of sealed root surfaces. No differences could be detected between sound and irradiated dentin. Therefore, keeping the limitations of an *in vitro* investigation in mind, the future goal of described protocol might be use for prophylactic reasons during or after therapeutic irradiation. However, further studies must prove the clinical performance of dentin bonding agents for caries prevention on exposed root surfaces. Furthermore, whether the additional use of fluorides has any extra benefits must be clarified. Before human trials are conducted, additional *in vitro* studies must show whether the applied adhesive systems can resist the chemical, mechanical and physical challenges of the oral cavity. Moreover, the results of this study indicate that irradiated dentin (in the case of the therapeutic doses used) is not more susceptible to caries than non-irradiated dentin. This data shows that it is evident that the possible irradiation effects on dentin are not responsible for a higher initial demineralization.

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Effects of Cavity Configuration on Composite Restoration

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Clinical Relevance

The amount of constraint imposed upon the composite during polymerization, often referred to as the configuration factor, affects the mechanical properties of the composite and the strength of the interface between the composite and the tooth substrate.

SUMMARY

This study evaluated the effects of various cavity configurations on the bond strength, microleakage, flexural strength and elastic modulus of a hybrid (Clearfil AP-X) and a microhybrid (Esthet-X) composite restorative. After the specimens were made with C-factors of less than 1, 2.4 and 3.4, flexural strength and elastic modulus were evaluated in three-point bending using a mechanical testing machine. Fragments of the fractured specimens were selected randomly and the fracture surfaces were examined in SEM. To evaluate the microtensile bond strength and microleakage of composite restorations in bovine cavities, C-factors (ratio of bonded to non-bonded cavity surface) were controlled as 1.0, 2.3, 3.0 and 3.7. All specimens were stored in distilled water at 37°C for 24 hours and tested in a universal testing machine (EZ Test, Shimadzu, Japan). For the microleakage test, teeth with restorations were stained with silver nitrate and examined by two examiners under a stereomicroscope at 40x magnification.

The hybrid composite showed higher mechanical properties than the microhybrid composite. The flexural strength and elastic modulus of both composites decreased when polymerized under greater constraint, that is, with increasing C-factor. Mean microtensile bond strength to dentin was also decreased with increasing C-factor for both types of composites. Microleakage scores for the hybrid composite restorations were generally higher than the microhybrid composite.

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INTRODUCTION

One of the inevitable characteristics of dental composites is shrinkage during free radical polymerization as monomer molecules are converted into a polymer network, reducing intermolecular spaces. When this shrinkage occurs in a confined structure such as a tooth

cavity, contraction stresses are produced. Because the optimal performance of a composite restoration depends upon the formation of a complete bond with the surrounding tooth structure, these stresses, which can lead to failure of this bond, may compromise the longevity of the restoration.

The majority of the contraction stress produced in composite happens during the initial polymerization period after gelation occurs, and the rate of stress development decreases gradually with time. The stresses that would be produced during contraction before gelation are relieved by flow of the resin composite (Feilzer, de Gee & Davidson, 1990; Kemp-Scholte & Davidson, 1990; Alster & others, 1997). The internal stress generated in the restricted environment of a tooth cavity can exceed the adhesive bond strength and produce a delamination of the restoration interface (Davidson, van Zeghbroeck & Feilzer, 1991). In cases where higher bond strength is present, this stress may cause fractures of the marginal tooth substrate and/or the composite restoration, itself (Jorgensen, Asmussen & Shimokobe, 1975; Davidson, de Gee & Feilzer, 1984). Both cases result in the formation of a marginal gap that may allow possible ingress of oral fluids and bacteria through leakage. The leakage may eventually produce discoloration of the margins and/or recurrent caries and, consequently, may reduce the life of a restoration. Furthermore, marginal leakage is associated with postoperative sensitivity. A significant concern is that it is not easy to clinically detect this leakage around the cavity wall immediately after placement.

When resin bonds to the walls and floor of the cavity preparation, a competition occurs between the opposing walls, as the restorative resin shrinks during polymerization and pulls them closer together (Davidson & others, 1984). The magnitude of this phenomenon depends upon the configuration of the cavity and, hence, is called the cavity configuration factor or C-factor (Feilzer, de Gee & Davidson, 1987, 1993; de Gee, Feilzer & Davidson, 1993). The C-factor is defined as the ratio of the bonded surface area to the unbonded, or free surface area. This ratio becomes greatest in Class I and deep Class V (box-like) cavities. Higher C-factors have been shown to produce higher contraction stress by limiting the flow capacity of the resin composite when tested in rigid systems with minimal compliance (Feilzer & others, 1987; Choi, Condon & Ferracane, 2000). In contrast, the maximum contraction forces on the force/time curve were inversely related to the C-factor and directly related to composite volume when tested in a non-rigid system that allowed compliance (Bouschilcher, Vargas & Boyer, 1997). The case for the dental restoration probably lies somewhere in-between due to the limited compliance of the natural tooth.

Due to difficulties in testing, there have been few direct investigations into the relationship between the cavity configuration and the bond strength of composite restorations. However, it is currently possible to measure the bond strength of adhesive materials to the cavity wall under clinically relevant conditions by virtue of the microtensile bond strength test method first introduced by Sano and others (1994). Recently, Yoshikawa and others (1999) reported that the microtensile bond strength of several dentin adhesives fell as the C-factor was increased in a three-dimensional cavity preparation, but the difference was significant with only one adhesive system.

In light of the limited available information about the effect of cavity configuration on the properties and bonding ability of dental composites, further work is warranted. Therefore, this study evaluated the effects of various cavity configurations on the bond strength and microleakage of hybrid and microhybrid composite restorations and measured the mechanical properties of flexural strength and elastic modulus under similar conditions. The hypothesis tested was that the bond strength and properties of composites polymerized under conditions of greater constraint, that is, high C-factor, would be reduced due to the presence of significant internal stresses.

METHODS AND MATERIALS

Flexural Strength and Elastic Modulus Determination

Two resin composites and their corresponding dentin bonding agents were used in this study (Table 1).

The specimens for the control group for each composite were made in a split steel mold (25 x 2 x 2 mm)

Table 1: *Materials Used in this Study*

Materials (Batch #)	Main Components	Manufacturer
Clearfil SE Bond Primer(00184A) Adhesive(00175A)	 MDP, HEMA, water MDP, dimethacrylate, HEMA, microfiller	 Kuraray Co (Osaka, Japan)
Clearfil AP-X(0526A) - *Hybrid composite*	Barium glass, silicone dioxide 3.0 μm (0.1-15 μm), 84.5wt%	Kuraray Co (Osaka, Japan)
Prime & Bond NT	PENTA, UDMA, Resin R5-62-1, T-resin, D-resin, nanofiller, cetylaminehydrofluoride and acetone	Dentsply (Milford, DE, USA)
Esthet-X(530059) - *Microhybrid composite*	BAFG*; 0.6-0.8 μm (0.02-2.5 μm), silicon- dioxide nanofiller; 0.01-0.02 mm, 77wt%	Dentsply (Milford, DE, USA)

**BAFG : Bariumalumino fluorosilicate glass*

with the top and bottom surfaces covered by a clear matrix. The specimens (n=8) for each composite with C-factors of 2.4 and 3.4 were made in simulated cavities (25 x 5 x 3 mm and 25 x 5 x 5 mm, respectively) made of glass plates. Before placing the composite into the cavity, the inner surfaces of the glass were sandblasted and treated with silane and the corresponding dentin bonding systems. The specimens were all light activated in a curing unit (LABOLIGHT LV_, GC, Japan) for 60 seconds on both the top and bottom surfaces. The control bars were easily removed from the steel mold. Specimens (25 x 2 x 2 mm) were obtained from the composites cured in the glass plates by cutting along the longitudinal axis of the composite with a slow speed diamond saw (ISOMET, Buehler, Lake Bluff, IL, USA). All specimens were stored in distilled water at 37°C for 24 hours prior to testing.

Flexural strength and elastic modulus were evaluated in three-point bending following International Standards Organization (ISO) 4049 (1988) for testing of resin-based filling materials. The specimens were tested on a span of 20 mm at a crosshead speed of 1 mm/minute in the universal testing machine (EZ Test, Shimadzu, Japan). The crosshead speed of the universal testing machine was synchronized with the motion of the strip chart. The slope of the linear portion of the load-versus-time curve was used in the calculation of the elastic modulus. The data was evaluated using one-way analysis of variance (ANOVA)/Tukey's test at the ≤ 0.05 level.

Examination of the Fractured Surface

After flexural strength testing, specimen fragments were selected randomly, sputter coated with gold and the fracture surface examined with a scanning electron microscope (S-2300, Hitachi, Japan) at a magnification of 500x.

Microtensile Bond Test

For the control group (C=1), bovine teeth were ground with wet 600 grit SiC paper to expose the dentin surface. In the experimental groups with higher C-factor, cavities were prepared with a carbide steel bur (#245; Shofu Co, Japan) in bovine teeth. The depth of the cavities was 2.0 mm to ensure that uniform curing would occur throughout the material. The C-factor (C=1+4h/d, in which d and h are the diameter and height of the cylindrical cavities, respectively) was controlled by the diameter of the cavity (Table 2). The dimensions of the preparation were verified with an electronic caliper (Mitutoyo Corp, Japan).

Clearfil SE Bond (Kuraray Co, Osaka, Japan), a self-etching primer system, was applied on the dentin surfaces according to the manufacturer's instructions. The two composites, Clearfil AP-X and Esthet-X, were placed on the flat surface of the control group and in the cavities of the experimental groups in one 2-mm thick increment (Figures 1Bc and Be). The composite was light-cured (Spectrum 800, Dentsply, DE, USA) at 600mW/cm^2 for 40 seconds in all cases. Additional composite was built-up for mounting on the microtensile testing jig (Figure 1C). All restored teeth were stored in

Table 2: *Experimental Groups for Microtensile Bond Test*

Groups (code)	Configuration of Bonding Substrate
C=1 (C)	ground dentin surface
C=2.3 (C2)	cavity (depth – 2 mm, diameter – 6 mm)
C=3.0 (C3)	cavity (depth – 2 mm, diameter – 4 mm)
C=3.7 (C4)	cavity (depth – 2 mm, diameter – 3 mm)

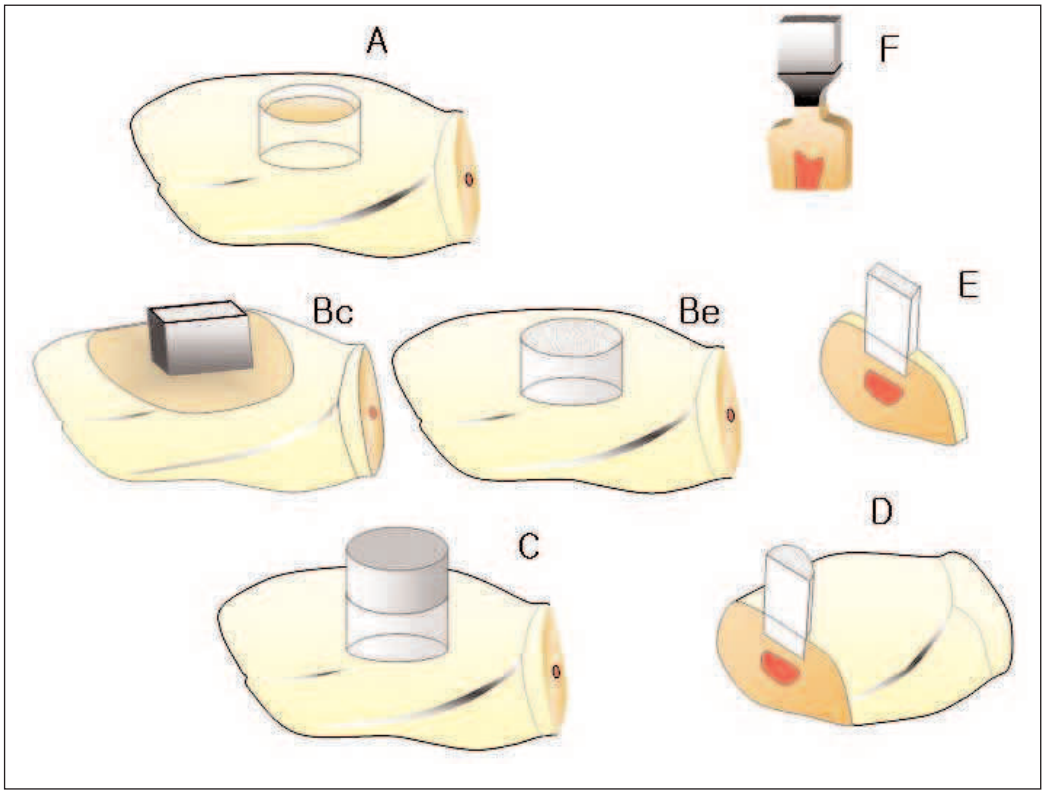

Figure 1. *Specimen preparation for tensile bonding test: A) cavity preparation for each C-factor; Bc) composite bonding on dentin surface for control group; Be) composite filling for experimental groups; C) additional composite build-up; D-E) vertical slices (1.0-mm thick) cut perpendicular to the long axis of the tooth and F) specimens trimmed to a hour-glass shape with the narrowest portion at the bonded interface.*

water at 37°C for 24 hours, then sliced serially perpendicular to the bonded surfaces to produce 1.0-mm thick sections using a low-speed diamond saw under copious water supply. Slices were trimmed into an hour-glass shape with the narrowest portion at the adhesive interface, using a diamond point (#104, Shofu, Japan) in a high speed handpiece, producing a bonded area approximately 1 mm^2 (Figure 1F). The trimmed specimens were mounted on the testing jig with cyanoacrylate adhesive (Zapit, MDS Products Co, Corona, USA), then stressed to failure in tension at a crosshead speed of 1 mm/minute in a universal testing machine. The number of specimens for each group was 10.

The maximum tensile force was divided by the area of the specimen, and the measured microtensile bond strength values were analyzed using ANOVA/Tukey's test at a significance level of α=0.05.

Microleakage Test

Cavities in 58 bovine incisors were prepared and restored with composites in the same manner as those for the microtensile test. No control group was used. All filled restorations were finished immediately using abrasive disks (Sof-Lex, 3M ESPE, St Paul, MN, USA). After finishing, the restored teeth were placed in 37°C water for one day. The teeth were then coated with nail varnish to within 2 mm of the restoration margins after the apices were blocked with utility wax. These measures were taken to prevent staining from routes other than marginal defects.

As described in a previous study (Choi & others, 2000), the teeth were immersed in 3 mol/L silver nitrate solution for 24 hours in amber vials kept in darkness. Thereafter, they were rinsed under tap water and immersed in a film developer (Eastman Kodak Co, Rochester, NY, USA) under fluorescent light for 24 hours. After the roots were cut off, the teeth were embedded in epoxy resin (Buehler Ltd, Lake Bluff, IL, USA). The epoxy was allowed to set overnight before the specimens were sectioned inciso-gingivally through the center of the restorations with a low-speed diamond saw. The sectioned surfaces were ground with 400 and 600 grit SiC paper and polished with 3 µm diamond compound. Both surfaces of each section were examined under a stereomicroscope (Olympus, Tokyo, Japan) at 40x magnification by two examiners. Each examiner independently graded the dye penetration at the incisal and gingival margin using the following ordinal scale:

0 = no marginal leakage

1 = silver nitrate penetration that extended less than or up to half the distance to the DEJ (dentino-enamel junction)

2 = penetration greater than half and up to, but not past, the DEJ

3 = penetration past the DEJ, but not including the pulpal wall

4 = penetration involving the pulpal wall

Two examiners reevaluated all specimens if there were any discrepancies. Statistical analysis of the results of the staining measurement was done using the Kruskal-Wallis non-parametric independent analysis and the Mann-Whitney U-test to evaluate differences between the experimental groups at a significance level of α=0.05.

RESULTS

Flexural Strength and Modulus

For the hybrid composite, flexural strength was decreased with each increase in configuration factor (Table 3). Though there was a trend toward lower flexure strength at the highest C-factor for the microhybrid composite, the difference between groups was not significant.

The elastic modulus decreased when either composite was cured under constraint (Table 4). The elastic modulus of the control groups was significantly higher than other groups, though there was no significant difference between the C-factor of 2.4 and 3.4 for either composite.

SEM Examination

The fracture surface of the hybrid composite control group appeared smooth and homogenous (Figure 2a), while the surface of the composites made with a C-factor of 2.4 and 3.4 showed irregular, rough features (Figures 2b and 2c). The specimen made at a C-factor of 3.4 showed numerous cracks on the fracture surface.

Table 3: *Flexural Strength (MPa ± sd) of the Experimental Groups*

Resin Composite	Control	C = 2.4	C = 3.4
Clearfil AP-X	200.8 ± 25.0^{a}	174.8 ± 9.7^{b}	131.1 ± 15.7^{c}
Esthet-X	117.5 ± 20.7^{A}	112.5 ± 23.7^{A}	93.4 ± 17.7^{A}

Table 4: *Elastic Modulus (GPa ± sd) of the Experimental Groups*

Resin Composite	Control	C = 2.4	C = 3.4
Clearfil AP-X	11.0 ± 0.9^{a}	8.0 ± 0.4^{b}	7.6 ± 1.3^{b}
Esthet-X	7.5 ± 0.8^{A}	5.1 ± 1.0^{B}	4.5 ± 0.5^{B}

Table 5: *Microtensile Bond Strength (MPa ± sd)*

Groups	Hybrid Composite	Microhybrid Composite
C	36.9 ± 4.7^{a}	25.7 ± 7.9
C2	23.7 ± 2.4^{b}	23.7 ± 6.2
C3	25.0 ± 9.0^{b}	22.5 ± 8.0
C4	18.0 ± 10.9^{b}	21.0 ± 6.1

Groups designated with different superscript letters are significantly different (p<0.05).

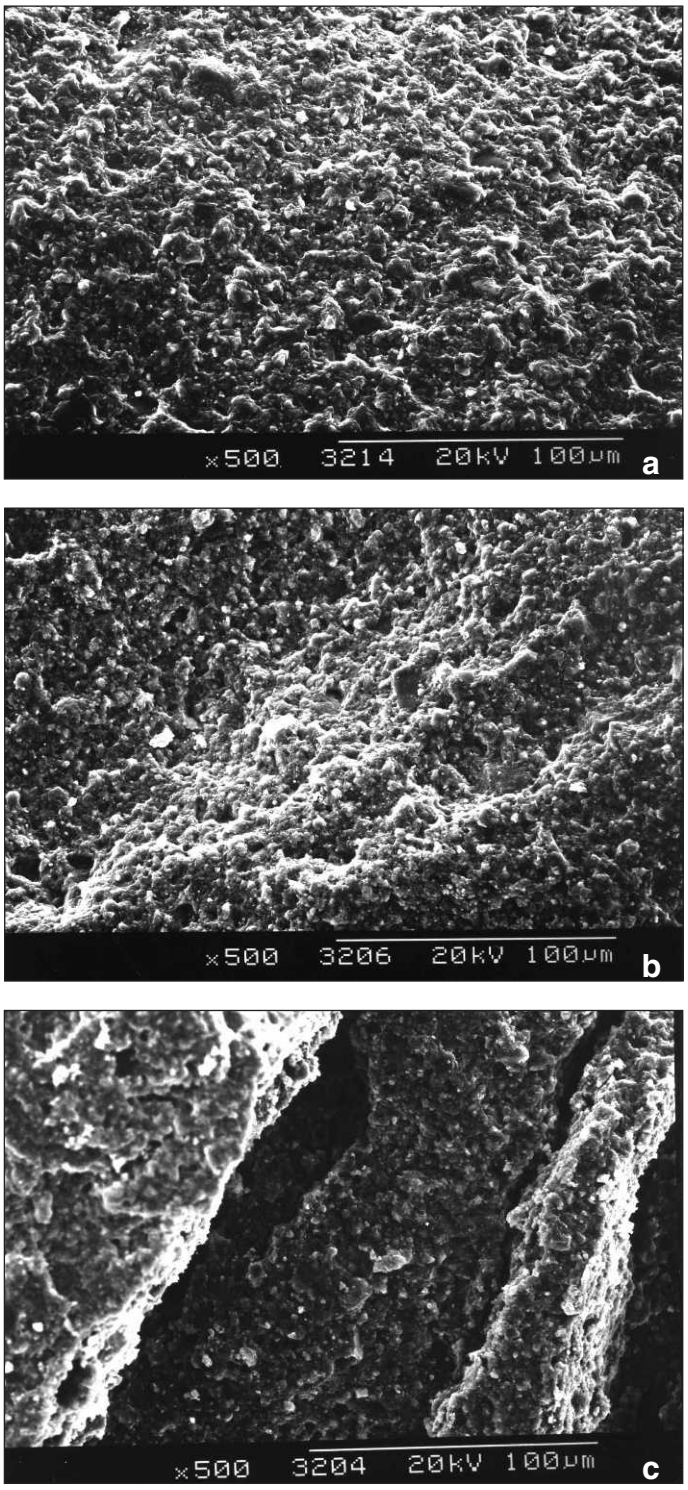

Figure 2. *Fractured surface of the hybrid composite: (a) control group, (b) C-factor; 2.4, (c) C-factor; 3.4.*

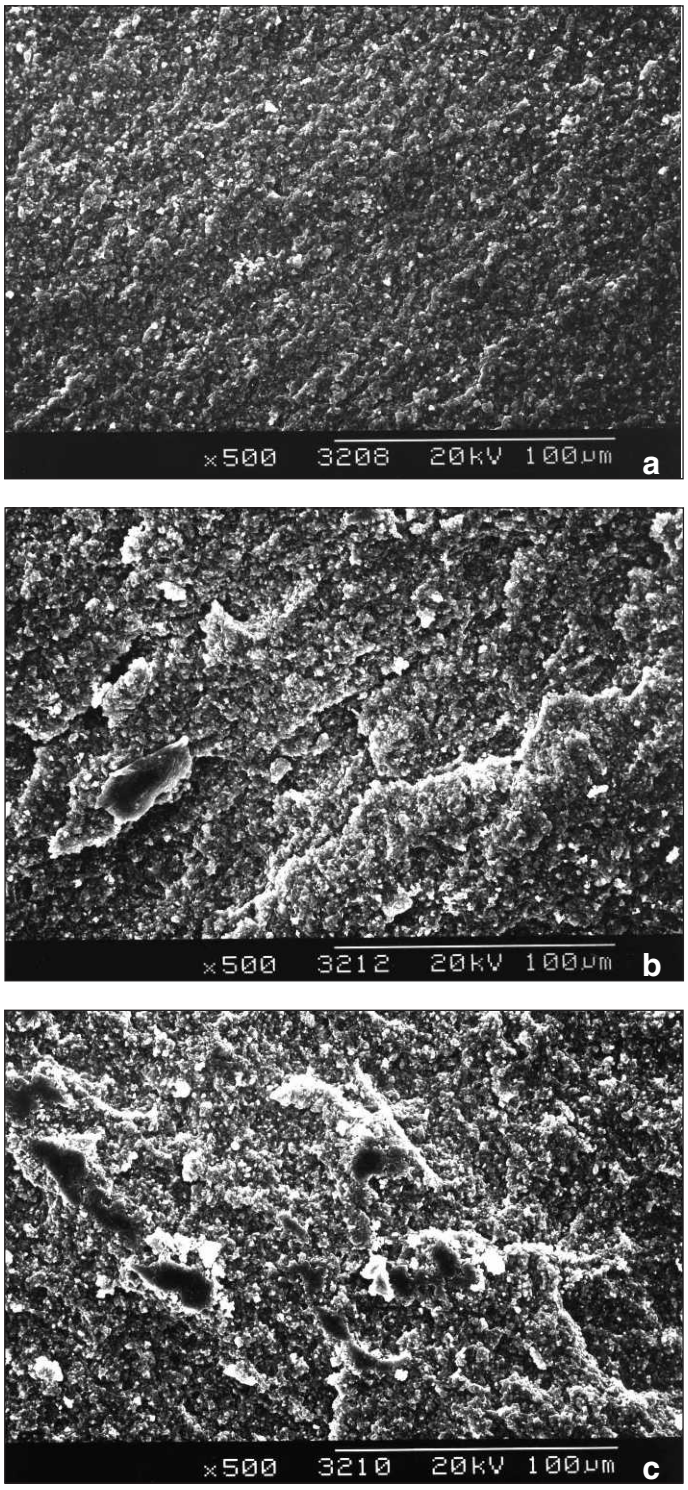

Figure 3. *Fractured surface of the microhybrid composite: (a) control group, (b) C-factor; 2.4, (c) C-factor; 3.4.*

Examination of the fracture surface from the microhybrid composite (Figure 3) was similar to the hybrid composite, but the general features were smoother.

Microtensile Test

The mean microtensile bond strength decreased with increasing C-factor for both the hybrid composite and the microhybrid composite (Table 5). The microtensile

Table 6: *Microleakage Scores of Experimental Groups*

		Clearfil AP-X							Esthet-X						
Groups	Margin (n)	0	1	2	3	4	mean	p	0	1	2	3	4	mean	p
C2	Incisal (12)	0	5	4	3	0	1.83	0.08	0	4	7	1	0	1.75[a]	0.19
	Gingival (12)	0	1	5	6	0	2.42		0	2	7	1	2	2.25	
C3	Incisal (9)	0	3	0	6	0	2.33	1.00	0	3	2	4	0	2.11[a,b]	0.35
	Gingival (9)	0	3	0	6	0	2.33		0	1	3	4	1	2.56	
C4	Incisal (8)	0	1	2	4	1	2.63	0.53	0	0	4	4	0	2.50[b]	0.48
	Gingival (8)	0	1	1	4	2	2.88		0	0	3	4	1	2.75	

Means designated with different superscript letters within incisal groups of Esthet-X are significantly different.

bond strength to flat dentin showed the greatest value of about 37MPa, which was statistically different from the experimental groups produced at higher C-factor that were all statistically similar. Though there was a trend toward lower bond strengths at higher C-factor for the microhybrid composite, the differences among the groups were not statistically different.

Microleakage Test

Table 6 shows the microleakage scores of all experimental groups. No specimens ranked zero in the microleakage experiment. Microleakage scores for the hybrid composite restorations were not statistically different from the microhybrid composite restorations at both the incisal and gingival margins ($p>0.05$). In all experimental groups, there was a trend for the microleakage scores to increase with higher C-factors, though there were no significant differences among the groups. When evaluated at the $p<0.10$ level of significance, there were differences due to C-factor within the incisal groups of Esthet-X (denoted by different superscript letters in Table 6). Leakage at the gingival margin was not statistically different from the incisal margin.

DISCUSSION

Secondary or recurrent caries is regarded as the main cause of failure for dental composites and is primarily related to technical difficulties in placing restorations with sealed margins due to substantial polymerization contraction of the materials. Many factors influence marginal leakage in composite restorations, including polymerization contraction and differences in thermal expansion characteristics (Lutz, Krejci & Barbakow, 1991). Either factor can produce stress within the composite when it is restrained from free shrinkage. Anything that increases the capacity of the resin to flow and relieve stress, such as large, unbonded surfaces, slow curing rates or porosity, results in less contraction stress (Feilzer & others, 1990; Davidson & others, 1991; Feilzer & others, 1993; Davidson & de Gee, 1984).

In this study, the microtensile bond strength of the hybrid composite drastically decreased as the C-factor was increased, while the bond strength of the microhybrid composite was only slightly decreased. This result suggests that the bond strength of a stiffer composite is more affected by the cavity configuration than that of a less stiff composite. Most hybrid composites have higher filler levels than microhybrid composites, which leads to higher elastic modulus (Willems & others, 1992) as was shown in this study. For a given contraction strain, contraction stress will generally be increased for a material with a higher elastic modulus. For the hybrid composite, the bond strength of the control group was highest to the flat dentin surface, possibly because there was little stress on the adhesive bond during polymerization of the composite. The bond strength of the control for the hybrid composite was also higher than the control for the microhybrid, possibly due to the higher physical properties of the former. Miyazaki and others (1991) reported that filler content was one of the most important factors influencing the physical properties of composites in the study of bond strength to bovine dentin. Other studies also have shown that the mechanical properties of dental composites were most highly correlated with bond strengths to dentin or enamel (Zidan, Asmussen & Jorgensen, 1980; Boyer, Chalkley & Chan, 1982).

Stresses large enough to exceed the adhesive forces between the tooth and the composite may be relieved as gaps formed at the margins (Davidson & others, 1984; Lutz & others, 1991). Because the *in vivo* bonding of resin to dentin is more variable than to enamel, cavities with margins in dentin are most at risk (Swift, Perdigão & Heymann, 1995). This trend was apparent in this study. However, the differences in leakage at the gingival and incisal margins were not significant. Optimization of the margins of composite restorations depends on reducing contraction or relieving contraction stresses. In all the experimental groups, the microleakage scores tended to increase with higher C-factors, though the differences did not reach statistical significance for this sample size. Similar microleakage tests in which the C-factor was varied have previously been presented by Choi and others (2000).

The hybrid resin composite showed a higher flexural strength and elastic modulus than the microhybrid composite for all configuration factors. The hybrid composite used in this study had a higher filler content (84.5wt%) than the microhybrid composite (77.0wt%). Generally, it is accepted that an increased filler level should contribute to increased mechanical properties and reduced polymerization shrinkage. While developing contraction stresses can be relieved by the flow capacity of the material in the pre-gel stage, the flow capacity is severely reduced in the post-gel stage, leading to the development of contraction stresses that can cause micro-defects or cracks in the composite. The lower elastic modulus and higher shrinkage of the microhybrid composite is indirect evidence that the flow capacity is achieved mainly by increasing the proportion of monomer in the formulation of the composite pastes. Therefore, despite the reduced polymerization shrinkage that was measured by the Hg dilatometer technique and found to be 2.3% by volume for Esthet-X and 1.5% for Clearfil AP-X, by increasing the C-factor, the hybrid composite was affected more than the microhybrid composite.

SEM analysis of the fracture surfaces of hybrid composite showed a rougher appearance than what was present on the microhybrid composite. This difference was most likely due to the difference in filler particle size of the two composites. The mean filler particle size of the hybrid and microhybrid composite was 3.0 μm and 0.6-0.8 μm, respectively. Another observation was that the fracture surface on the specimens with lower C-factor had a smoother appearance than those created from the higher C-factor. Resin composites that filled in the cavity with higher C-factor experienced severe contraction stresses during polymerization and the forces can cause cracking in the resin mass and create severe residual stresses. Flexural and/or tensile strengths are significantly affected by the presence of defects due to the generation of stress concentrations. In brittle materials, such as dental resin composites or porcelain, micro-cracks that exist on the surface or inside the material decrease strength (Kim & others, 1994). It is hypothesized that as the C-factor of the cavity increased, the flow capacity of the resin composites decreased and more internal stresses occurred in the restricted polymerization environment, which caused a detrimental effect on the mechanical properties of the resin composites.

It has been shown that polymerization shrinkage can cause contraction stress that has a detrimental effect on the bond strength between resin composites and tooth structure (Yoshikawa & others, 1999; Uno & others, 1999; Kinomoto & others, 1999). However, there have been few studies that examine the effect of contraction stresses on the mechanical properties of resin composites. In this study, the flexural strength and elastic modulus of resin composites had a tendency to decrease with an increase in the constraint imposed by the "cavity" during polymerization, as depicted by the C-factor. The flexure strengths of the hybrid composite were significantly reduced as the constraint increased, while those of the microhybrid composite were not significantly different. This may be due to the differences in filler content between the two composites. The hybrid composite with higher filler content and higher elastic modulus may show an earlier emergence of the gel-point, which substantially decreases flow capacity of the material. Therefore, contraction stresses are produced earlier and to a greater extent in the more heavily filled hybrid composite, resulting in the material being more sensitive to cavity constraints. Thus, the contraction stress of hybrid composites, which results from polymerization shrinkage, affects both the bond strength to tooth structures and the mechanical properties of the composites.

CONCLUSIONS

The mechanical properties of a composite can be affected by the constraint under which it polymerizes. In this study, a hybrid composite showed greater sensitivity compared to a microhybrid composite with increasing constraint, that is, C-factor. These results suggest that adequate selection of materials and control of polymerization contraction stress are very important factors for successful composite restoration.

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Clinical Technique/Case Report

Polytetrafluoroethlyene (PTFE) Tape as a Matrix in Operative Dentistry

WJ Dunn • JT Davis • JA Casey

INTRODUCTION

The most commonly used matrix for anterior restorations involving proximal contact is the clear plastic matrix (Murchison, Chan & Cooley, 2001). These matrices are usually made of Mylar, an extraordinarily strong polyester film that grew out of the development of Dacron in the early 1950s Dupont (2003). Clear matrices possess an advantage over metallic matrices in that they allow visualization of the composite restorative material as the matrix is being manipulated, ensuring that no voids have been created during the placement process. Another obvious advantage of the clear matrix is that it makes light polymerization through the matrix possible. The downside of clear matrices is that they are thicker than metal matrices. Metal matrix bands are available in 0.0015 and 0.0010-inch thicknesses, and clear matrices are typically manufactured as a 0.0020-inch film. Furthermore, there are situations where it may be advantageous to have unencumbered access to proximal areas for composite contouring without the loose ends of a matrix getting in the way. In these situations, a polytetrafluoroethylene (PTFE) matrix technique may prove useful.

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The use of PTFE thread seal tape, otherwise known as plumber's tape, is not new to dentistry, but a review of the literature yields only sparse references (Chan, 2003; Brown, 2002). Polytetrafluroethylene tapes are made from viscoelastic polymers coated with tetrafluoroethylene. The thickness of PFTE tape can vary drastically, but Federal Specification T-27730A stipulates that the average thickness should be 0.0025-inches. Generally, the 1/2-inch wide variety is 0.075-millimeter thick, or approximately 0.003-inches. Initially, this is thicker than metal or Mylar, but PFTE can be stretched to more than 300% of its original length, producing a matrix much thinner than with any other available material. When stretched, PFTE tape will also adhere and conform to dry tooth structure. This paper demonstrates the expedient clinical application of PFTE tape used as a matrix in a Class IV resin-based composite restoration.

TECHNIQUE

Figures 1 through 7 illustrate the use of PFTE tape to restore a failing resin-based composite restoration in tooth #9 (Figure 1). The patient reported no symptoms, all diagnostic tests were within normal limits and there was no radiographic evidence of periapical pathology. After appropriate anesthesia, a #212 retractor was used to facilitate rubber dam isolation for access to tooth #9. The composite restoration was removed, revealing a threaded pin and recurrent caries (Figure 2). The visible portion of the pin and all infected caries were removed. A Vitrebond base (3M/ESPE, St Paul, MN, USA) was placed over the site of the pin and a generous bevel placed around the periphery of the entire

preparation (Figure 3). After etching, rinsing and priming, a layer of adhesive was cured for 20-seconds and the first layer of composite was placed, simulating the dentin portion of the central incisor. This was accomplished without a matrix in place to facilitate unencumbered access to the preparation (Figure 4). At this point, a single thickness of PFTE tape was applied and stretched across the mesial aspect of tooth #10 (Figure 5). Composite was added and sculpted to the first cured increment without a wedge. Because the PFTE matrix was wrapped around the adjacent tooth, complete control of restoration placement and contour of the tooth #9 was possible. Following polymerization of the composite layer simulating enamel, the PFTE was removed. Any interproximal remnants of PFTE were removed by passing floss through the contact. A restoration with appropriate anatomical contours and proximal contact was accomplished

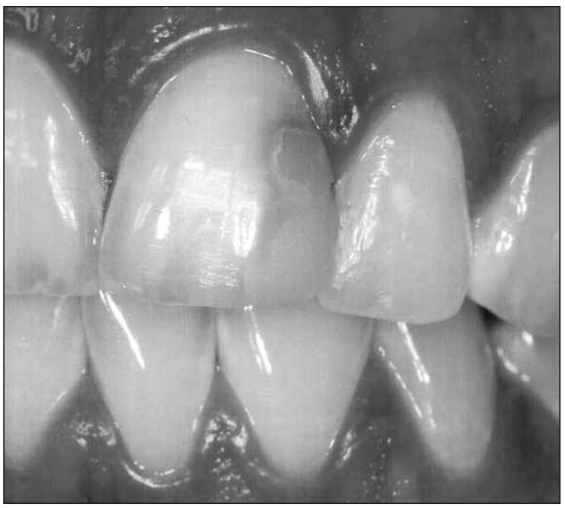

Figure 1. *Failing resin-based composite restoration, pre-op.*

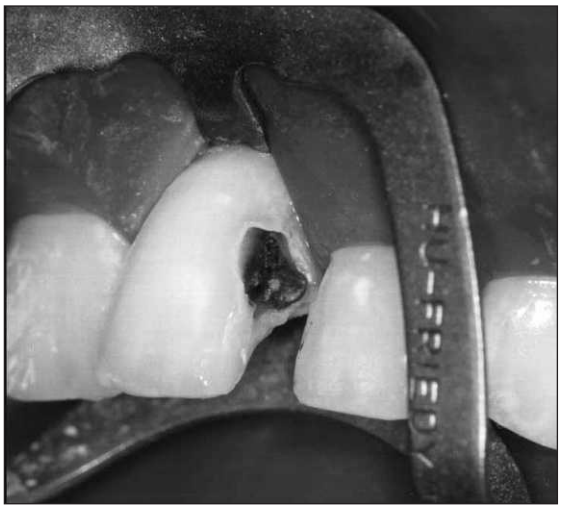

Figure 2. *Removal of failed composite restoration revealing pre-existing threaded pin and recurrent caries.*

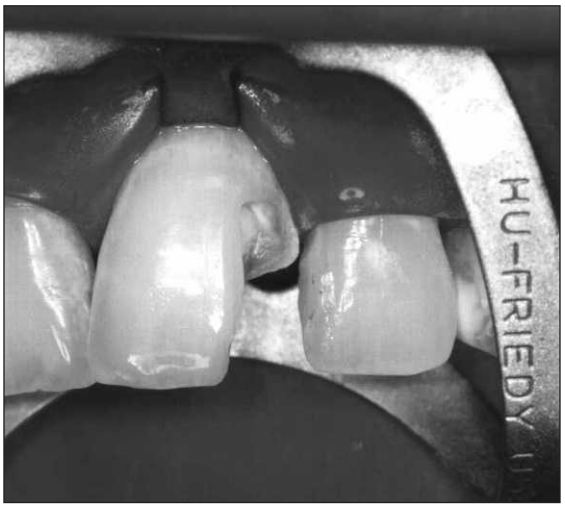

Figure 3. *Completed Class IV preparation with circumferential bevel.*

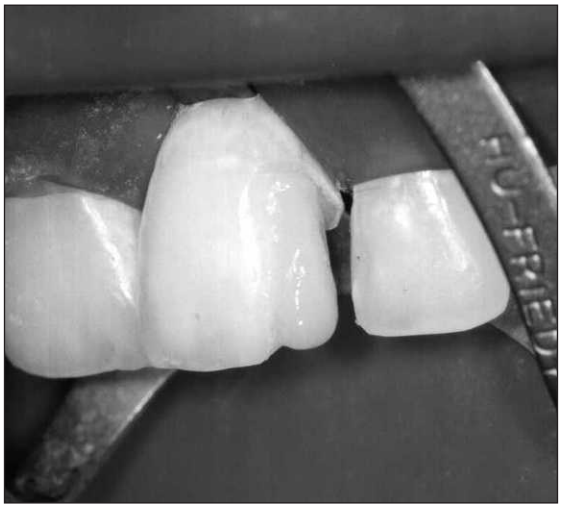

Figure 4. *First increment of composite placed, simulating dentin.*

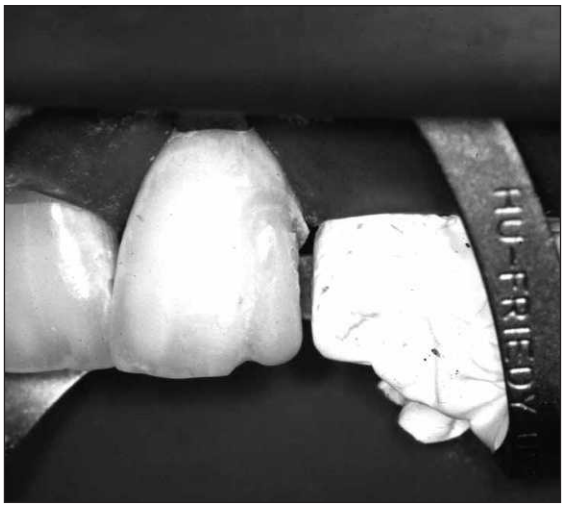

Figure 5. *PFTE tape applied and stretched across adjacent tooth.*

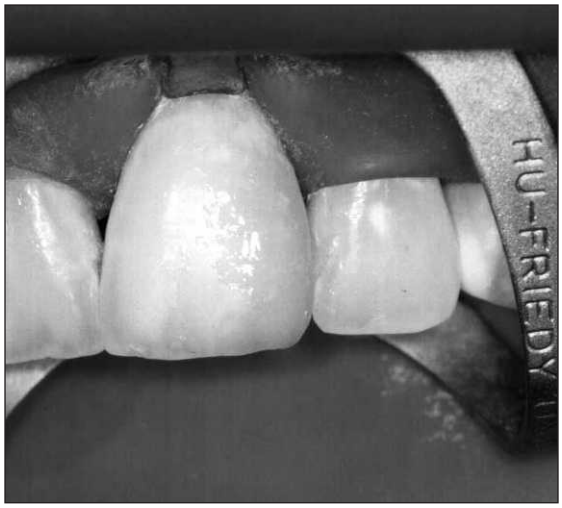

Figure 6. *Completed restoration.*

without the use of a wedge (Figures 6 and 7). The PFTE tape technique can also be adapted for direct and indirect veneers.

SUMMARY

A method for using PTFE tape as a matrix to prevent the etching and/or bonding of adjacent tooth structure was presented. This technique is simple, quick and inexpensive. PFTE tape in the form of plumber's tape is readily available at any hardware store. Despite manufacturers' varying thicknesses of PTFE tape, it can be stretched, yielding a matrix thinner than other matrix systems. The tape will also adhere and conform to adjacent tooth structure, offering the operator an unhindered access to perform sculpting of the restorative material.

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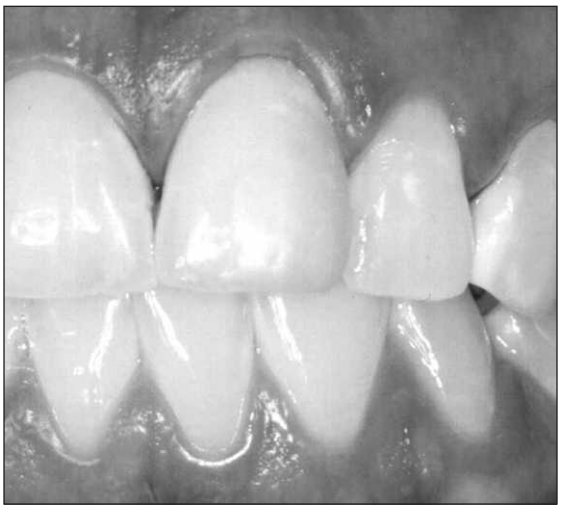

Figure 7. *Post-operative view with rubber dam removed.*

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Establishing Proximal Contacts with Pre-polymerized Composite Inserts

WJ Dunn

Clinical Relevance

Tight, anatomically correct proximal contacts are still difficult to achieve in posterior composite restorations. A technique is presented that may help the clinician to obtain good proximal contacts and limit the overall volumetric shrinkage of the restoration.

INTRODUCTION

Resin-based composite restorations for posterior teeth have become an accepted procedure in modern dental practice. While there is still disagreement on the use of composite in extensively damaged posterior teeth, there is no doubt that in incipient lesions, composite restorations are successful and the preparations are more conservative (Hilton, 2001). Early trials with posterior composite were disappointing; poor wear resistance, microleakage, secondary caries and inadequate proximal contacts were common (Leinfelder, 1995). Improvements in resin-based composite interparticle spacing and resin matrix formulation have resulted in a decrease in wear from an annual rate of more than 100 microns to less than 10 microns (Mazer & Leinfelder, 1999). However, other problems with the material and technique still confound the practitioner. The organic resin matrix contracts during polymerization, when monomers are converted from an aggregate of freely flowing molecules to a rigid network of cross-linked polymer chains, resulting in an overall volumetric shrinkage of 2% to 4% (Rawls & Esquivel-Upshaw, 2003). If the bond between composite and tooth is weak, this shrinkage may lead to bacterial penetration and recurrent caries; if the bond holds, undesirable internal shrinkage stresses can occur. Another problem with posterior composites is the difficulty in obtaining anatomically correct and appropriately tight proximal contacts. The rheologic properties and viscoelastic nature of unpolymerized resin-based composite make it impossible to condense and unsuitable for a packing technique in a cavity preparation. When using a matrix band, the concept of applying occlusal force to achieve proximal contact makes sense only if the restorative material will resist displacement. Attempts have been made to create a resin-based composite material that will resist displacement. These materials contain a higher percentage of glass filler particles to increase their viscosity (Cobb & others, 2000; Leinfelder, Bayne & Swift, 1999), but the clinical performance and physical properties of "packable" composites are no better than conventional resin-based composite materials (Hilton, 2001; Cobb & others, 2000; Nash, Lowe & Leinfelder, 2001). Peumans and others (2001) demonstrated that the quality of the proximal contact area in Class II restorations was greatly influenced by the type of matrix system used. A sectional, contoured steel matrix band in combination with a bitine ring gave superior results. That study also revealed that the type of composite used did not play a significant role in obtaining an adequate contact. Klein and others (2002) concluded that even high viscosity hybrid composites and compos-

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ites with modified filler particles did not result in higher proximal contact strengths.

Various reports describing techniques to manipulate the composite material to form tighter contacts against adjacent teeth have been published (Nash & others, 2001; Peumans & others, 2001; Klein & others, 2002; Keogh & Bertolotti, 2001). Some involve devices that attach to the guide tip on light curing units to put a force on the matrix while composite is being cured (Keogh & Bertolotti, 2001; Von Beetzen & others, 1993) or they use a hand instrument to apply pressure against the contact area (El-Badrawy & others, 2003); others prefer a sectional matrix and bitine ring (Peumans & others, 2001) and some have advocated the use of glass inserts in combination with composite (Donly & others, 1989). This paper describes a technique for achieving broad, tight proximal contacts with resin-based composite in posterior teeth using a pre-polymerized composite insert.

TECHNIQUE

The patient is a 39 year-old male in good health with no contraindications to dental treatment. Tooth #19 was diagnosed with mesial and occlusal caries. The patient exhibited no symptoms. The proximal caries were diagnosed radiographically and the occlusal caries were diagnosed by direct vision, transillumination, and by laser fluorescence (KaVo Diagnodent 2095, KaVo America Corporation, Lake Zurich, IL, USA). Mandibular block anesthesia was delivered and the mandibular left quadrant isolated with a rubber dam (Figure 1). A conservative proximal preparation was made to gain access to the mesial caries. This preparation was designed to accept a resin-based composite material, so only enough tooth structure was removed to allow access and removal of the caries with no additional retentive features added. The same concept was applied for the occlusal caries. After all caries was removed, a metal sectional matrix (0.0014 inches thick, Composi-Tight, Garrison Dental Solutions, Spring Lake, MI, USA) and plastic wedge (Hawe Adapt System Luciwedge, sds/Kerr, Orange, CA, USA) were inserted into the mesial area of #19 to create a proximal matrix, then a bitine ring (Composi-Tight) was applied to facilitate spreading between teeth #19 and 20 (Figure 2). Next, a bead of hybrid resin-based composite (Gradia Direct shade A2, GC America, Alsip, IL, USA), small enough to easily fit inside the proximal preparation, was polymerized against the internal aspect of another sectional matrix band (Figures 3 and 4) using a light curing unit with an adequate power output. In this case, a corded light emitting diode curing unit was used (Ultra-Lume LED 2, Ultradent Products, South Jordan, UT, USA). This resulted in a custom composite insert with a rounded, broad contact area that is smooth and not air-inhibited. Any accepted

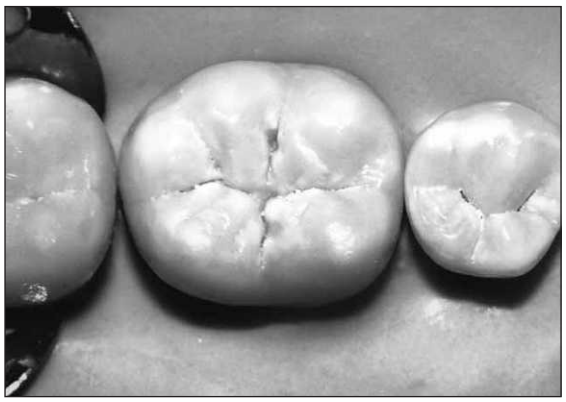

Figure 1. *Pre-operative view of tooth #19.*

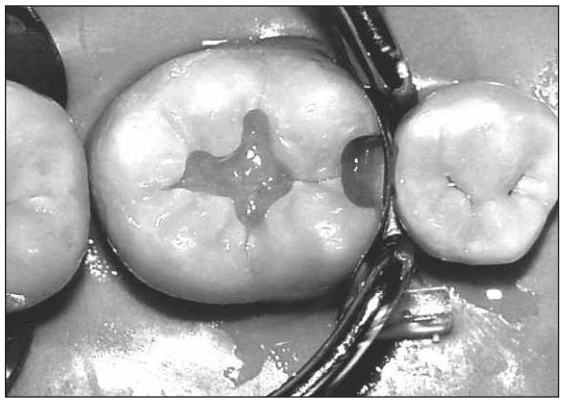

Figure 2. *Completed occlusal and mesial preparations with sectional matix, wedge and bitine ring applied.*

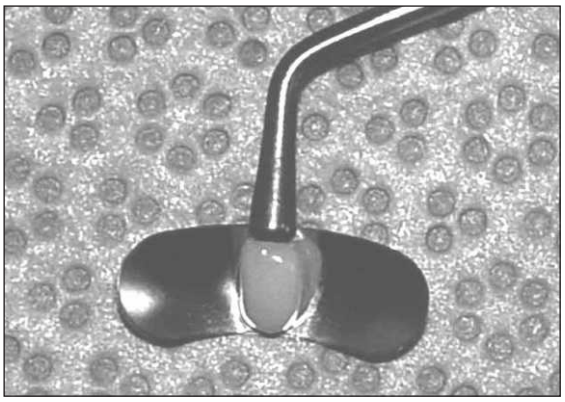

Figure 3. *Bead of unpolymerized composite, small enough to fit inside the mesial preparation, is adapted next to the inner surface of a similar-sized matrix.*

Figure 4. *The bead of composite is polymerized outside the mouth.*

bonding procedure can be used to bond the composite insert in the cavity. In this case, a self-etching primer system (Clearfil SE Bond, Kuraray America, New York, NY, USA) was used according to manufacturer's recommendations. A small amount of unpolymerized composite was injected into the preparation (Figure 5) and the pre-polymerized insert was tacked on to the end of a condenser to facilitate the transfer and application of the insert into the preparation (Figure 6). Some clinicians may prefer to inject a low viscosity resin-based composite material into the preparation to ensure that the insert will seat and minimize the chances of creating voids. Even though it will not displace as easily as a flowable composite, many clinicians will opt for the superior physical properties of a conventional hybrid composite to bond the pre-polymerized insert. Most resin-based composite materials will flow enough to be displaced if they are kept at room temperature. Materials specifically designed as packable composites are too viscous to predictably allow for insertion and displacement of the insert and should not be used in this technique. After the insert was seated into the displaced unpolymerized composite and an apical stop was felt, a mesial-occlusal force was applied to the insert, pushing it against the matrix band and the adjacent tooth (Figure 7). The restoration was polymerized for 40 seconds from the occlusal direction as pressure was being applied to the insert. Typically, another increment of composite is necessary to completely fill the preparation. After the occlusal and mesial restorations were finished and polished, they were sealed with a surface sealant (Fortify, BISCO, Schaumburg, IL, USA). The completed restoration is presented in Figure 8.

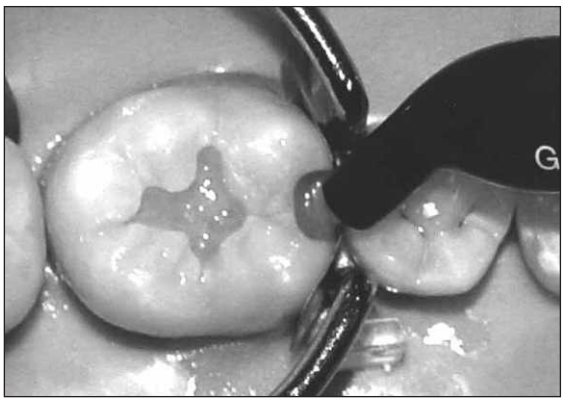

Figure 5. *After etchant, primer, and adhesive have been applied, resin-based composite is syringed into the cavity preparation.*

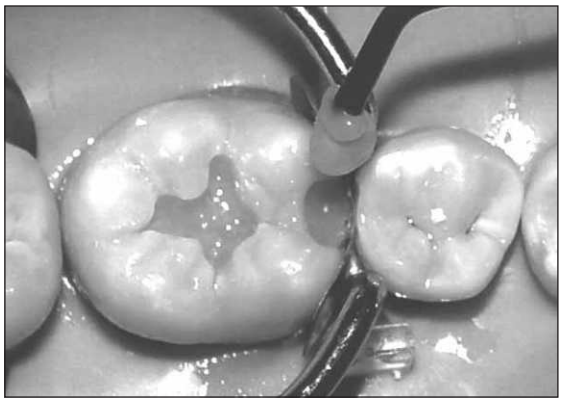

Figure 6. *The pre-polymerized composite insert is tacked on the end of a condenser and inserted inside the preparation, displacing some of the unpolymerized composite.*

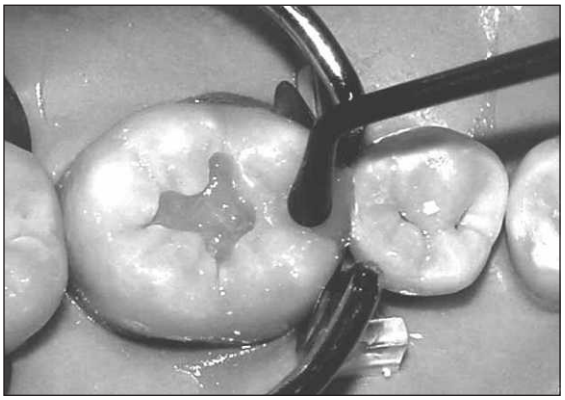

Figure 7. *Pressure is applied to the insert, forcing it apically and mesially against the matrix and adjacent tooth, as the restoration is photopolymerized.*

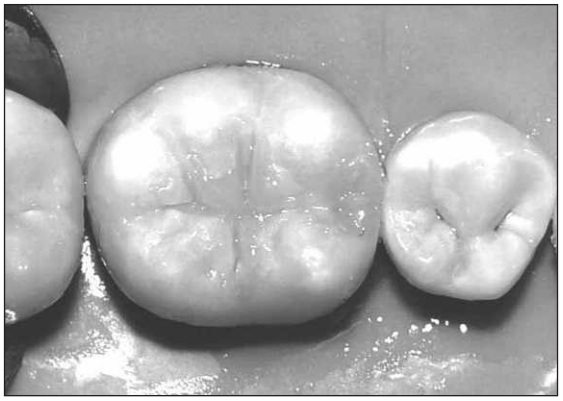

Figure 8. *The completed restoration.*

SUMMARY

A technique of restoring Class II posterior restorations with resin-based composite and a pre-polymerized composite insert was presented. This technique is intended to aid the practitioner in obtaining tight, broad, proximal contacts without having to purchase special instruments or materials. This method is not time-consuming, nor technically difficult. Another benefit of this technique is that it reduces the total amount of volumetric shrinkage of restorative material inside the cavity preparation, as the composite insert is pre-polymerized before placement.

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Salvaging a Compromised Tooth Using a Combination Amalgam Core/Composite Window Technique

JC Meiers

Clinical Relevance

Severely debilitated teeth can be economically, esthetically and functionally restored using a combination of amalgam and resin composite, which takes advantage of the strength of both materials. This article describes the use of an amalgam/composite window technique to salvage a badly broken down premolar.

INTRODUCTION AND DESCRIPTION OF PROBLEM

An 80-year old patient presented at an emergency visit with a total crown fracture of a maxillary second premolar, Figure 1. The tooth was asymptomatic, vital and with no pulp exposure. The patient was interested in salvaging the tooth but did not want to invest much time or money in the process. This was the most posterior tooth in that quadrant and the patient had no interest in either implants or a removable partial denture to provide additional occlusal support and masticatory function on that side. Possible treatment options for this tooth included intentional endodontics with a cast or prefabricated post and core and crown or a pin amalgam restoration. The patient decided on the pin amalgam to restore function, which could be managed in the time remaining at this visit, then a veneering of the buccal surface of the core with resin composite at a second visit to provide a more esthetic appearance. The use of an amalgam/resin composite combinational approach to provide function and esthetics is not a new technique (Durnan, 1971; Barkmeier, 1979; Anglis & Fine, 1982; Gourley & Ambrose, 1982; St Arnault & Coury, 1983; Lambret, Scrabeck & Robinson, 1983; Quiroz & Swift, 1986; Albers, 1996) but may not be considered today as a possible treatment choice in this situation because of the plethora of tooth colored materials that have much more exposure in journals and advertisements. The following describes this procedure.

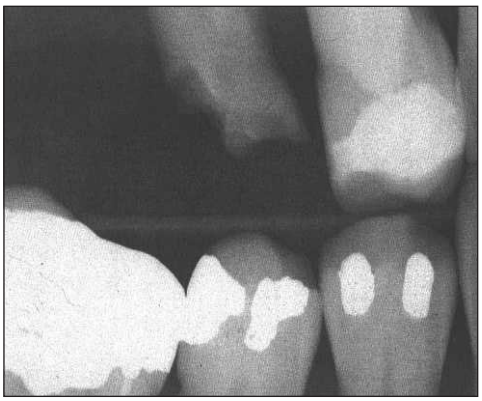

Figure 1. *Pre-op radiograph indicating the extent of coronal tooth loss of maxillary second premolar at presentation.*

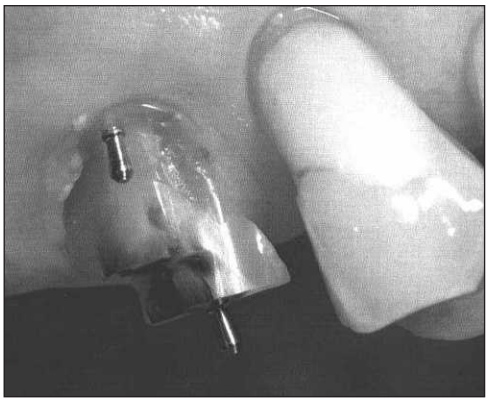

Figure 2. *Facial view of prepared premolar with pins in place on the buccal and palatal faces.*

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Initial Core Placement

The tooth was prepared to receive an amalgam core. The challenge was to work with the remaining tooth structure to develop a preparation design that would be retentive to a large volume of amalgam and withstand the occlusal and lateral forces exerted on this core during function. This was accomplished with the preparation shown in Figure 2. Mesial and facial gingival steps were placed along with a short slot on the mesial gingival and pulpal floor. Pins were placed on the facial and lingual faces for added retention and resistance form. Matricing this type of situation can be challenging. Neither a traditional tofflemeier matrix retainer and standard matrix band technique nor automatrix approach would be successful in this situation, because of the gingival contour of the remaining crown. A custom matrix was shaped to fit the gingival form using a copper band and placed on the tooth, Figures 3 and 4. An admixed amalgam alloy (Valiant PhD, Ivoclar/Vivadent USA, Amherst, NY, USA) was condensed into this preparation and the band removed by cutting a slot up the facial aspect. The amalgam was carved to an initial shape that provided some contour and a positive occlusal stop, Figure 5. The patient was presented with the option of having this core veneered with a resin composite to make it blend with the remaining dentition. The patient agreed to this additional treatment and was reappointed for a second visit.

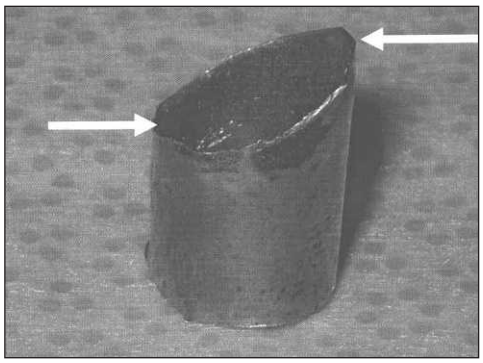

Figure 3. *Customized copper band for matrixing. The gingival portion reflects the height discrepancy between the facial and palatal aspects of the remaining tooth structure, as noted by the white arrows.*

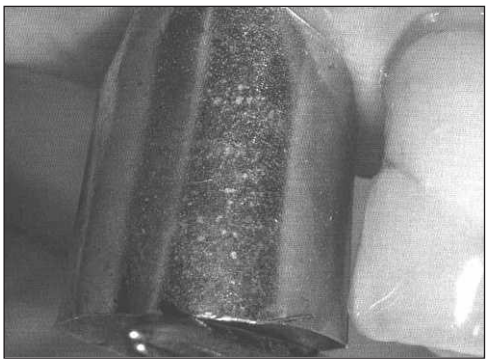

Figure 4. *Copper band placed on premolar.*

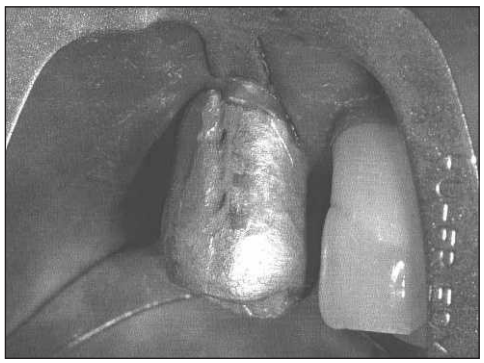

Figure 5. *Amalgam is carved and tooth is isolated for composite window procedure.*

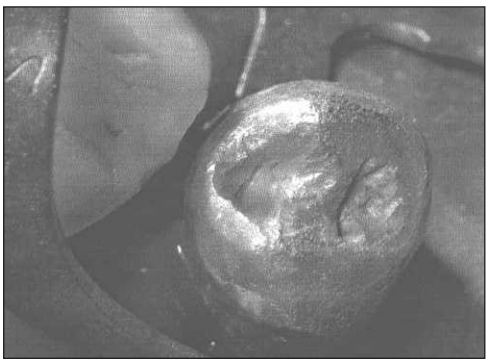

Figure 6. *Occlusal view of isolation prior to facial reduction for the composite veneer. Use this view as a starting point to compare the subsequent veneer sequence steps.*

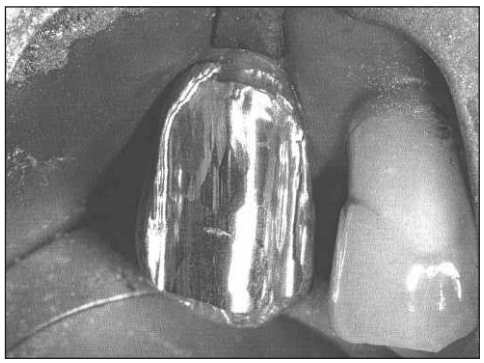

Figure 7. *The buccal-facial aspect of the amalgam core is reduced approximately 1.5 – 2 mm and a chamfer margin is placed on the exposed root surface.*

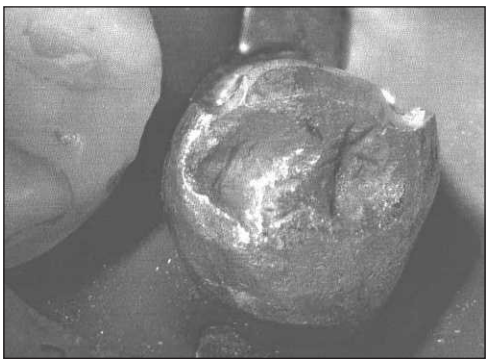

Figure 8. *Occlusal view of facial reduction–compare to Figure 6.*

Composite Window Veneer

On the second appointment, the tooth was isolated, Figures 5 and 6, and the facial aspect of the amalgam core reduced approximately 2 mm to receive a resin composite veneer and a definite chamfer was placed on the mesial, distal, gingival and occlusal portions of the core, Figures 7 and 8. This reduced surface was then roughened by placing horizontal grooves and pot holes to help mechanically retain the resin composite, Figure 9. The amalgam and exposed dentin were treated with a self-

etching primer (AdheSE, Ivoclar/Vivadent USA) and this surface was coated with an initial, thin opaque liner (Tetric Color, Ivoclar/Vivadent USA) to mask the amalgam, Figures 10 and 11. A 0.5-mm layer of dentin shaded small particle resin composite (4 Seasons, Ivoclar/Vivadent, USA) was placed, contoured and followed by a final layer of the appropriate enamel shade (4 Seasons, Ivoclar/Vivadent, USA), Figures 12 and 13. The resin composite veneer was then shaped, polished, the rubber dam removed and the occlusion and cuspal shape adjusted. The final result can be very esthetic as shown in Figure 14.

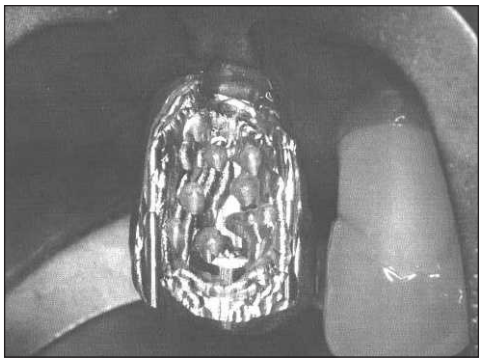

Figure 9. *The facial aspect is roughened with grooves and holes to help mechanically lock the resin composite to the amalgam core.*

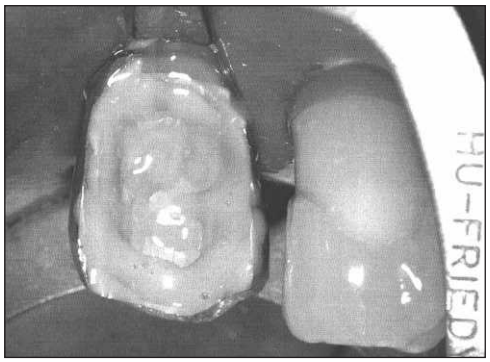

Figure 10. *An initial thin layer of opaque is placed to mask the color of the amalgam.*

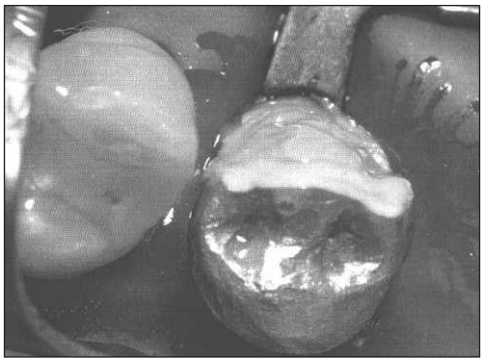

Figure 11. *Occlusal view of opaque placement compare to Figure 8.*

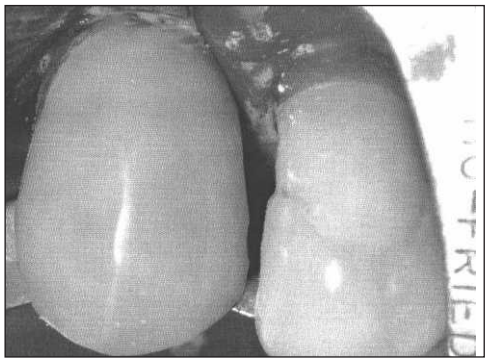

Figure 12. *An approximately 0.5 mm layer of dentin shade resin composite is placed over the Opaque and a final layer of enamel shade resin composite is added and the veneer is shaped to proper contour and polished—facial view.*

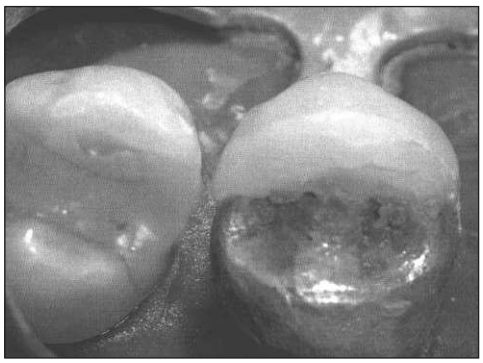

Figure 13. *Occlusal view of shaped and polished veneer–compare to Figures 6, 8 and 11.*

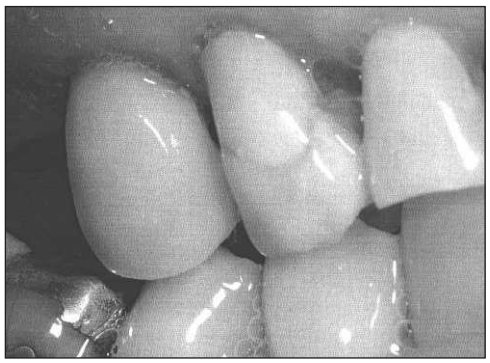

Figure 14. *Buccal view of finished amalgam core/composite window in occlusion.*

DISCUSSION

This technique provides the clinician the ability to restore mutilated teeth at a reasonable cost for the patient and provides the potential for durable occlusal wear, with a stable vertical stop and acceptable esthetics. This approach utilizes the best mechanical/physical properties of both restorative materials—the strength of amalgam to withstand occlusal forces and wear over time and the ability to blend in with the adjacent natural tooth structure provided by the resin composite facial veneer. With more patients living longer and maintaining their natural teeth, which, in many cases are extensively restored, the type of situation described in this clinical case may become a common presentation. The ability to restore adequate function and esthetics using this approach will permit many of these patients to retain teeth that otherwise would be lost, because of the inability or desire to pay for more involved and expensive reconstructive techniques.

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