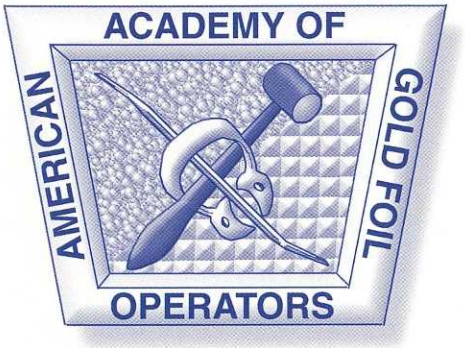
OPERATIVE DENTISTRY



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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

Oxymoron

ox-y-mo-ron (äk' si môr' än) n., pl. -mo'ra
A figure of speech in which opposite or contradictory ideas or terms are combined.
(Ex: thunderous silence, sweet sorrow)

Webster's New World Dictionary of the American Language **(1984)**
2ND Edition, pg 1016, Simon & Schuster, Inc Cleveland, OH

An oxymoron is generally used to create an epigrammatic effect by combining incongruous terms. Oxymora can be humorous (jumbo shrimp), sarcastic (military intelligence) or thought provoking (mournful optimist), and most of us have used one at some time in our lives to elicit a response or make a point. I would like to offer a new oxymoron that incorporates all of the attributes above, one that, unfortunately, is having tremendous impact on today's academic community. That oxymoron is "CORPORATE COLLEGIALITY."

In my opinion, academic collegiality has been the cornerstone of professional education as well as it being one of the most enjoyable aspects of an academic career. The stimulation of sharing ideas, exploring diverse philosophies and conducting research to answer questions has made teaching dentistry, for most of us in academics, a life-style rather than an eight-to-five "job." It has been my experience that dental faculty do not choose an academic career for the financial gain (since most could enjoy a much higher income in private practice). They teach because they love the challenges and stimulation of the educational process and feel they are making a definitive contribution to the future of the dental profession. Working within a collegial atmosphere encouraged and supported by the university administration results in faculty who are willing to put in countless overtime hours to ensure that their students receive the most current information so that excellence becomes the foundation on which their clinical practice is based. The bottom line is that knowing you are considered a valued colleague and collaborator rather than merely an employee or "warm body" makes all the attitudinal difference in the world.

The problem we face today, however, is that the skyrocketing costs of education, coupled with the shameful lack of financial support from local, state and federal government, has placed academic institutions in the position of having to base most decisions and policies on income generation. Because of fiscal constraints, institutions of higher learning have been forced to adopt the traditional corporate model where the educational process becomes a business, faculty are merely "workers" and the dollar is the only parameter by which success can be measured. Some of the more obvious negative results are the limitation of scientific investigation to "fundable" research only, loss of a percentage of qualified students who cannot afford the escalating tuition costs, difficulty in attracting and maintaining high-quality teaching faculty and an evaporation of the collegial atmosphere.

We are experiencing a severe shortage in both teachers and researchers who are entering our academic institutions (Robertson, 1999). Although there has been a tremendous effort to update and improve our teaching and curricular offerings with more emphasis on integration of basic science into clinical instruction and implementation of problem-solving techniques, these procedures have proven more costly and faculty-intensive and have magnified both the financial and personnel problems. Existing faculty are pushed to the limit in an effort to continually provide more instruction, training and mentoring with less time, equip-

ment, facilities and support. The lack of time for collegial interaction and the feeling of being nothing more than worker drones severely erode the dedication and commitment that are essential to a thriving academic environment.

Can this pendulum swing be reversed? Yes, but only through a concerted effort to improve funding for education at every level. As a profession, we lobby enthusiastically and successfully for various types of legislation that affect our practices. That's not enough. We need to also focus our efforts on supporting the institutions that have provided us with the training that allows us to practice our chosen profession. Every member of the dental health care team, each constituent, component, state and national society and our myriad professional academies should be highly pro-active in supporting funding for education.

Potential avenues include:

- Contacting the development offices or deans of your local educational institutions or your alma mater and ascertain their needs and goals for the future. They may have suggestions on how you can help.
- Contacting local, state and national political representative and voicing your support for education funding (two Internet addresses in the US that are very useful are: www.congress.org and www.votesmart.org).

I challenge each of you to do your part to alleviate the financial pressures faced by schools of dentistry and help remove the "corporate collegiality" oxymoron from our vocabulary.

Michael A Cochran
Editor

Reference

Robertson PE (1999) Guest Editorial—Where is the next generation of dental academics? *Operative Dentistry* **24(5)** 257.

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Clinical Research

One-Year Clinical Evaluation of Posterior Packable Resin Composite Restorations

AD Loguercio • A Reis
LE Rodrigues Filho • ALS Busato

Clinical Relevance

Clinical evaluation of four packable posterior composites and a control showed some significant differences after one year.

SUMMARY

This study evaluated the clinical performance of four packable resin composite restorative materials in posterior teeth (Class I and II) compared with one hybrid composite after one year. Eighty-four restorations were placed in 16 patients. Each patient received at least five restorations. The tested materials were: (1) Solitaire + Solid Bond; (2) ALERT + Bond-1; (3) Surefil + Prime & Bond NT; (4) Filtek P60 + Single Bond and; (5) TPH Spectrum + Prime & Bond 2.1. All restorations were made using rubber dam isolation, and the cavity design was restricted to the elimination of carious tissue. Deeper cavities were covered with calcium hydroxide and/or glass ionomer cement. In shallow and medium cavities, no protection was performed except for the respective adhesive system used in each group. Each adhesive system and resin composite was placed according to the manufacturer's instructions. One week later, the restorations were finished/polished and evaluated according to the USPHS modified criteria. All patients attended the one-year recall, and the 84 restorations were evaluated at that time based on the same evaluation criteria. The scores were submitted to statistical analysis (Chi-square test, $p<0.05$). Solitaire and TPH showed some fractures at marginal ridges. Solitaire, ALERT and TPH showed some concerns related to color match and surface texture. Surefil and Filtek P60 showed an excellent clinical performance after one year.

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INTRODUCTION

Despite the excellent long-term results obtained with amalgam restorations, speculation about the possible health dangers associated with mercury (Roulet, 1997), and the demand for esthetic materials have contributed to the increased use of resin composites in posterior applications.

When resin composite was first used for restorations in posterior teeth (Phillips & others, 1973), several authors questioned its wear resistance. Composites introduced in the early 1970s had a generalized wear rate of about 100-150 µm/year (Leinfelder, Wilder & Teixeira, 1986). This was due to transference of masticatory stresses through the filler particle and into the resin matrix, resulting in microcracking of the polymeric matrix with subsequent chemical hydrolysis of the vinyl-silane radicals (Bayne, Taylor & Heymann, 1992).

Today, the majority of resin composites on the market have submicron-sized fillers (<1 µm) and are referred to as universal hybrid resin composites. The improved esthetics provided by these materials due to the smoother surface obtained after polishing, as well as higher wear resistance (<10 µm/year), led to their being recommended for placement in both anterior and posterior teeth. Several hybrid resin composites with these characteristics have shown excellent clinical performance in many clinical studies (Leinfelder, 1995; Abdalla & Alhadainy, 1996; Smith & others, 1996; Perry & others, 1997).

Greater success of resin composites in posterior teeth resulted from improvements in mechanical properties via modification in size, shape, composition and amount of filler loading (Leinfelder, 1985; Suzuki & others, 1995). Other variables, such as location, size and design of the cavity, light curing procedure and finishing and polishing procedures also contributed to the dramatic reduction in wear rate of direct posterior composite restorations (Busato & others, 1996).

Nevertheless, the degree of complexity of resin composite restoration placement and curing is blamed for the perceived higher levels of secondary caries and postoperative sensitivity. Compared with placing a Class II amalgam restoration, composite techniques are appreciably more technically demanding. Each increment of composite must be carefully placed to intimately adapt it to the cavity walls. Furthermore, each individual increment must be light cured for approximately 40 seconds. In many instances, developing appropriate proximal contours and contact can be difficult; therefore, special wedging techniques or instruments are commonly required. Finishing and polishing procedures are more difficult and time-consuming for resin composites than for amalgam (Leinfelder, Bayne & Swift, 1999).

Packable resin composites were introduced into the market due to a strong interest in developing dental composites that are less technique-sensitive and handle like amalgam (Leinfelder & others, 1999). The nomenclature for these new composites is controversial since some manufacturers usually refer to them as condensable. However, materials can only be considered condensable if their volume is reduced under a condensable pressure, which does not occur with any of these composites (Sturdevant & others, 1995).

Table 1: *Description of the Groups (Materials and Manufacturers)*

Groups	Materials		Manufacturers
	Adhesive Systems	**Resin Composites**	**Manufacturers**
(1)	Solid Bond (Multi-bottle)	Solitaire (Packable)	Heraeus Kulzer, Dormagen, Germany
(2)	Bond-1 (One-bottle)	ALERT (Packable)	Jeneric Pentron, Wallingford, CT, USA
(3)	Prime & Bond NT (One-bottle)	Surefil (Packable)	Dentsply Konstanz, Germany
(4)	Single-Bond (One-bottle)	Filtek P-60 (Packable)	3M Dental Products St Paul, MN, USA
(5)	Prime & Bond 2.1 (One-bottle)	TPH Spectrum (Hybrid)	Dentsply Konstanz, Germany

Table 2: *Description of the Adhesive Systems Used in This Study*

Adhesive Systems	Composition (*)	Batch Number
(1) Solid Bond	1. Esticid-20 FG: 20% phosphoric acid with coloidal silica; 2. Solid Bond P–HEMA, acetone and maleic acid; 3. Solid Bond S—Bis-GMA and 25% filler (**)	34 CEO123
(2) Bond-1	1. Conditioner: 35% Phosphoric acid, water soluble polymer thickening agent; 2. Adhesive: PMGDM, HEMA, light-cured initiator and acetone.	780962 790980
(3) **Prime & Bond NT**	1. Conditioner: 36% phosphoric acid with coloidal silica; 2. Adhesive: PENTA, UDMA, Resin R5-62-1,T-resin, D-resin, nanofiller, cetylaminehydro-fluoride and acetone.	971202 9806001075
(4) Single-Bond	1. Conditioner: 36% phosphoric acid with coloidal silica; 2. Adhesive: Bis–GMA, HEMA, dimethacrylates, polyalkenoic acid copolymer, initiator, water, ethanol.	7JA 8BX
(5) Prime & Bond 2.1	1. Conditioner: 36% phosphoric acid with coloidal silica; 2. Adhesive: UDMA, PENTA, R5-62-1 resin, Bisphenol A dimethacrylate, butylated hydroxytoluene, camphoroquinone, 4 ethyl dimethyl aminobenzoate, cetylamine hydrofluoride, acetone.	971202 9705000001

(*) Perdigão & Lopes (1999); (**) Tanumiharja, Burrow & Tyas (2000)

Table 3: *Description of the Resin Composites Used in This Study*

Materials	Filler Type and Particle Size*	Filler Volume and Weight (%)	Matrix Type	Batch Number
(1) Solitaire	Si-F-B-Al glass and glass filaments 0.7-20 µm (0.8 µm average)	60% vol 45% wt***	Polyglass monomers	34 CEO123
(2) ALERT	Ba-Al-Si glass, SiO_2 and glass fibers 0.7 µm (fibers - 60-80 µm)	80-84% vol 62-70% wt**	Bis-GMA ethoxilated	860960
(3) Surefil	Ba-B-F-glass, SiO_2 plus nanofiller 0.8 µm	77-82% vol 58-66% wt**	UDMA	990216
(4) Filtek P60	Similar to Z100 0.01-3.5 µm (0.6 µm average)	83% vol 61% wt	Bis-GMA, UDMA with Bis-EMA	9AG
(5) TPH Spectrum	Ba glass 0.8 µm**	75% vol 57% wt	Bis-GMA with UDMA	28632/2

(*) Manufacturers' instructions (ALERT, Surefil and Filtek P60); (**) Farah & Powers (1998); (***) Manhart & others (2000)

Table 4: *Number of Evaluated Restorations by Location (tooth) and Extension (Class), Divided into Different Groups*

Groups	Number of Evaluated Restorations	TOOTH		CLASS	
		Premolars	Molars	I	II
(1)	18	05	13	02	16
(2)	14	03	11	02	12
(3)	21	07	14	04	17
(4)	17	05	12	02	15
(5)	14	04	10	02	12
TOTAL	84	24 (24%)	60 (76%)	12 (14%)	72 (86%)

Actually, these products do not require condensation to guarantee a coherent, void-free mass with minimal reaction matrix in the same way as amalgam. These materials are simply stiffer and less sticky than traditional composites, which allows for their easier placement. Therefore, a better description of their unique handling characteristics would be to refer to them as packable composites.

Improvements in the rheological characteristics were not obtained by adding a larger amount of filler particle. Manufacturers have eliminated stickiness by altering the filler characteristics (Solitaire; ALERT and Surefil) and, at the same time, reducing the matrix viscosity by using a variety of matrix monomers (Definite, Prodigy Condensable and Filtek P60). In the past 30 years, there have been no fundamental changes in the monomer systems since the introduction of dimethacrylate (Peutzfeldt, 1997; Manhart & others, 2000).

This one-year study compared the clinical performance of four packable resin composites (Solitaire, ALERT, Surefil and Filtek P60) with a hybrid resin composite (TPH Spectrum) in Class I and II posterior restorations.

METHODS AND MATERIALS

In 1998/1999, one operator placed 84 restorations in 16 patients. Each patient required at least five Class I or Class II restorations. All patients had complete and normal occlusion. Patients with rampant caries, bruxism or clenching, xerostomia and periodontal problems were not included in the patient selection. After patient consent was obtained, the restorative procedure was initiated. Using rubber dam isolation, the cavity design (restricted to the elimination of carious tissue guided by 0.5% basic fucsin) was prepared using stainless steel burs (#329, 330 and/or 245 KG Sorensen, Barueri, São Paulo). The dentin in deeper cavities was covered with calcium hydroxide (Dycal, Caulk-DeTrey Dentsply, Konstanz, Germany) and/or glass ionomer cement (Vitrebond, 3M Dental Products, St Paul, MN 55144, USA) (Tables 1 and 2).

In Class II restorations, the adhesive system and first increment of resin composite were applied to guarantee a better cure of the composite in the gingival margin before placing the pre-contoured metal matrices and wood wedges for proximal occlusal restorations. Tables 1 and 3 show the resin composites used in this study.

The restorative materials were randomized, taking into consideration variables such as tooth type and position, restoration class and size and occlusion in a way that minimized the influence of those factors (Bryant & Hodge, 1994). Although all the restorations were moderate-to-large, as defined by Wilson, Smith & Wilson (1986), fewer than 5% of the restorations extended less than one quarter of the way up the culpal slopes.

The adhesive systems were used according to the manufacturers' instructions. Placement of the resin composites followed the incremental technique (2 mm thick layers). The resin composite was adapted with a flat-faced or elliptical condenser and light-cured for 40 seconds using a XL-1500 light-curing unit (3M Dental Products, St Paul, MN 55144, USA), with light output of 550 mW/cm^2. A post-occlusal adjustment was performed with carbon paper and fine-grit diamond burs,

Table 5: *Number of Evaluated Restorations in Each Criteria for Each Group*

Evaluation Criteria	Scores ↓	BASELINE					01 YEAR				
	Materials→	1	2	3	4	5	1	2	3	4	5
Retention	**A**	18	14	21	17	14	18	14	21	17	14
	B	--	--	--	--	--	--	--	--	--	--
	C	--	--	--	--	--	--	--	--	--	--
Anatomic Form	**A**	18	14	21	17	14	16	14	21	17	10
	B	--	--	--	--	--	2	--	--	--	3
	C	--	--	--	--	--	--	--	--	--	1
Marginal Adaptation	**A**	18	14	21	17	14	18	14	21	17	14
	B	--	--	--	--	--	--	--	--	--	--
	C	--	--	--	--	--	--	--	--	--	--
Interfacial Staining	**A**	18	14	21	17	14	18	14	21	17	14
	B	--	--	--	--	--	--	--	--	--	--
	C	--	--	--	--	--	--	--	--	--	--
Surface Texture	**A**	18	8	21	17	14	18	07	21	17	14
	B	--	6	--	--	--	--	07	--	--	--
	C	--	--	--	--	--	--	--	--	--	--
Color Match	**A**	18	10	21	17	14	8	6	21	17	8
	B	--	4	--	--	--	10	8	--	--	6
	C	--	--	--	--	--	--	--	--	--	--
Postoperative Sensitivite	**A**	18	14	21	17	14	18	14	21	17	14
	B	--	--	--	--	--	--	--	--	--	--
	C	--	--	--	--	--	--	--	--	--	--
Secondary Caries	**A**	18	14	21	17	14	18	14	21	17	14
	B	--	--	--	--	--	--	--	--	--	--
	C	--	--	--	--	--	--	--	--	--	--

A = *Alpha* B = *Bravo* C = *Charlie*

and the quality of the interproximal contact was checked with dental floss. Finishing and polishing were carried out after one week using fine-grit diamond burs (KG Sorensen Ind, Barueri, SP, Brazil) and aluminum oxide polishing paste (Kerr Manufacturing, Romulus, MI 48174, USA) in rubber cups on the occlusal surfaces. Abrasive strips (3M Dental Products) were used in the interproximal surface when necessary.

All restorations were evaluated after one week (baseline) and one year for the following characteristics: retention, color match, interfacial staining, secondary caries, postoperative sensitivity, anatomical form, marginal adaptation or integrity and surface texture (Leinfelder, 1987).

They were clinically evaluated by two investigators using the USPHS modified criteria as first described by Cvar & Ryge (1971) and adapted by Barnes & others (1995). The examiners were unaware which material had been used, creating a double-blind study.

When disagreements arose during evaluations, consensus evaluations were obtained between examiners (Wendt & Leinfelder, 1994). The data was statistically analyzed using the Chi-square test at a confidence level of 95%.

RESULTS

The results are summarized in the Tables 4 and 5. All patients attended the one-year recall, summing 84 evaluated restorations.

No cavosurface discoloration, marginal adaptation defects or lack of retention were found in any of the tested groups after one year. None of the patients complained of any symptoms, either after placement of the resin composite (*baseline*) or after one year. Also, no secondary caries was found.

After one year, the following restorations were recorded as Bravo: anatomic form (Solitaire 11% and TPH Spectrum 28%), surface texture (ALERT 50%) and color match (ALERT 57%, Solitarie 56% and TPH Spectrum 43%). Considering anatomic form, a total of four restorations (28%) out of 14 placed with TPH Spectrum had small fractures. This was statistically significant ($p<0.05$) (Figure 1). In the same way, two small fractures were found with Solitaire. All fracture cases occurred in the marginal ridges, but only one, recorded as Charlie (TPH Spectrum resin), had to be replaced.

The surface texture of six ALERT restorations were rated as Bravo in the baseline and this situation was aggravated after one-year (Figure 2). Despite ALERT, Solitaire and TPH's initial color match, significant dis-

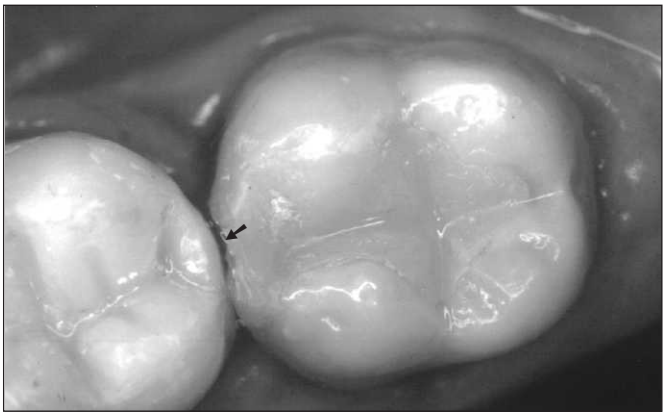

Figure 1. *Lower right second molar restored with Prime & Bond 2.1 adhesive system plus TPH Spectrum resin after one year. Note the small fracture at the marginal ridge (arrow). The restoration was classified as Bravo in color mismatch.*

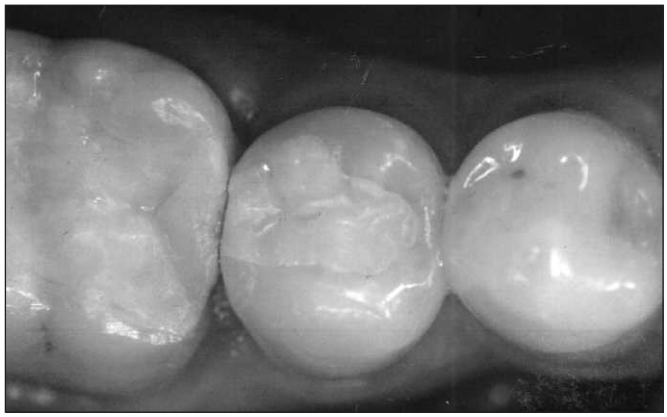

Figure 2. *Lower right second premolar and first molar restored with Bond-1 plus ALERT after one year. The surface texture of the restoration was classified as Bravo.*

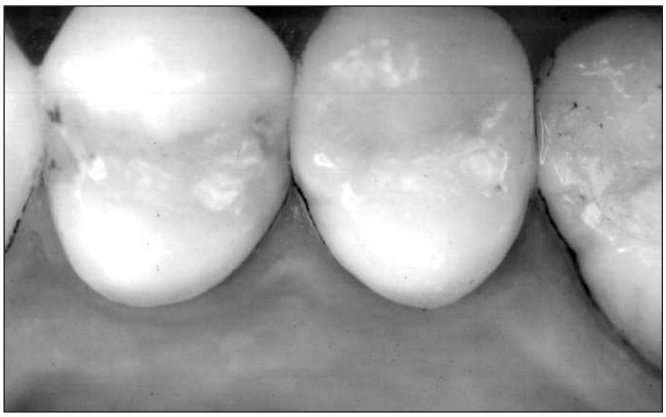

Figure 3. *Upper left first and second premolar restored with Solid Bond and Solitaire after one year. Both restorations were classified as Bravo in color mismatch.*

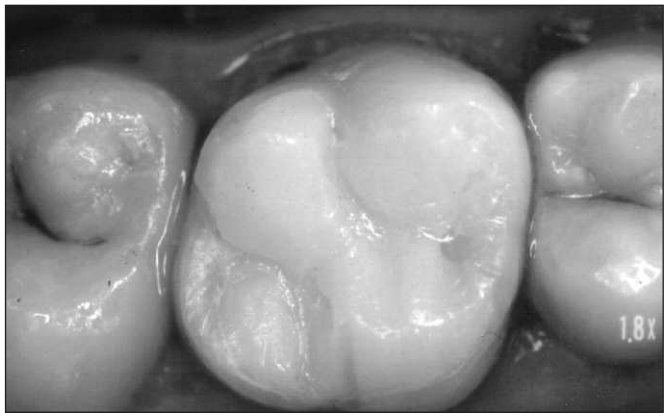

Figure 4. *Upper right first molar restored with Single Bond and P60 after one year. Note the excellent clinical performance after one year.*

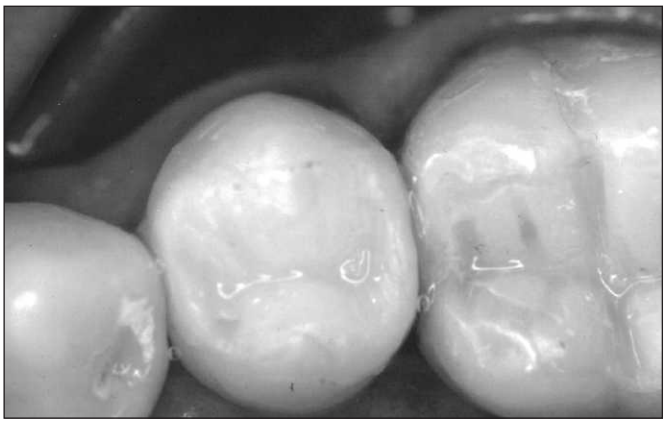

Figure 5. *Lower right second premolar restored with Prime & Bond NT and Surefil after one year. Note the excellent clinical performance of this material.*

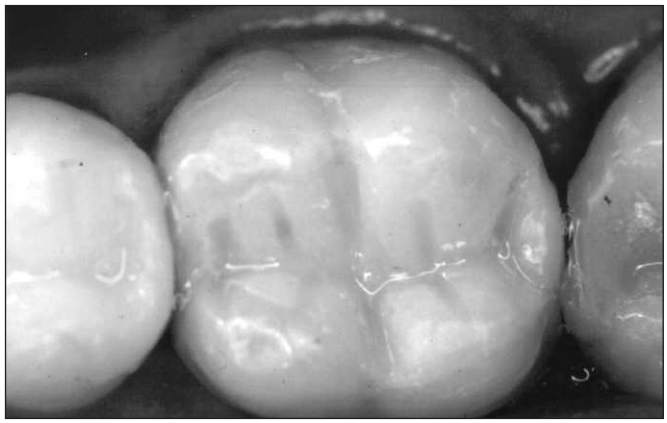

Figure 6. *Lower right first molar restored with Prime & Bond NT and Surefil with excellent clinical performance after one year.*

coloration was observed after one-year (Figures 1, 2 and 3). The statistical analysis revealed significant differences among the tested materials relating to color match and surface texture ($p<0.05$). All Surefil and Filtek P60 restorations evaluated showed Alpha ratings (Figures 4, 5 and 6) in all categories.

DISCUSSION

Performance of these materials after one year showed minor changes compared to the baseline. This fact is not surprising, since several studies have already shown a satisfactory performance of hybrid composites in posterior teeth during initial periods of evaluation (Leinfelder, 1995; Abdalla & Alhadainy, 1996; Smith & others, 1996; Perry & others, 1997).

Only TPH had been evaluated for more extended periods (Wendt & Leinfelder, 1994; Perry & others, 1997), which demonstrated a good clinical performance in posterior teeth. This material was released in 1993/1994 as a substitute for the Prisma APH (Dentsply, Konstanz, Germany). According to Leinfelder (1995), the manufacturer reduced the particle size and increased the percentage of filler. Apart from these changes, laboratory studies have shown that this composite still exhibits greater wear than the other composites released in the same period. According to the results of this study, four out of 14 restorations with TPH lost their anatomic form after one year and one of them required replacement. These observations demonstrate that this material may be weaker than the other resin composites used. Another important finding is the lack of color match that occurred with this material after one year (Figure 1). This fact was not observed in the Perry & others (1997) study.

Due to the recent release of the packable resin composites tested (Solitaire, 1997; Surefil and ALERT, 1998; Filtek P60, 1999), only a few studies have analyzed the clinical performance of these materials. In the case of Filtek P60, no clinical study was found. The 3M technical profile showed a few differences in composition compared to Z100 resin. No changes in the amount, size and distribution of the filler particle were made (Technical profile). This appears to be a good predictor of the clinical performance of Filtek P60, since several studies with Z100 have demonstrated good results in posterior teeth (Smith & others, 1996; Busato & others, 2000).

In the Surefil brochure (Dentsply Caulk, 1998), there are references of short clinical studies that showed good performance of this material. Perry & others (1999) and Perry, Kugel & Aboushala (2000) evaluated 25 Class II restorations in molar teeth. The restorations were evaluated using the USPHS criteria and wear was indirectly measured after 3, 6, 9, 12 and 24 months, showing good behavior in posterior teeth. Nevertheless, the two-year evaluation showed some restorations classified as Bravo in the following categories: color match and cavosurface discoloration.

These observations confirmed the results of this study in relation to Filtek P60 and Surefil (Figures 4, 5 and 6). However, some concerns were observed in Solitaire and ALERT restorations. Concerning ALERT, the study conducted by Fay & others (2000) must be noted. They placed 51 posterior restorations in 26 patients. After six months, 42 restorations were analyzed using the modified USPHS criteria and the indirect cast method of wear. Even in the baseline, some problems relating to marginal integrity, color match and surface texture were detected. After six months, all of these problems had increased slightly and some demonstrated discoloration at the margins. Despite these findings, the authors concluded that this material had a satisfactory performance. This study agreed with the current authors' findings. Some concerns regarding texture surface as well as color match observed in the baseline were aggravated after one year (Figure 2). This may be due to the presence of filamentous filler with 60-80 μm presented in ALERT (Table 3), which causes some difficulties during the finishing and polishing procedure. Roeder, Tate & Powers (1999) confirmed the higher roughness of ALERT, which seems to aggravate with loading cycling (Klautau, 2000).

According to Bayne, Taylor & Heymann (1992), the presence of these big particles may theoretically cause greater wear of the restorative material and the antagonist enamel. When the restoration is under masticatory function, the stress concentration through the filler particle into the resin matrix will lead to easy removal of these particles in the surface, thus, exposing the organic matrix and accelerating the wear process even more.

Consequently, Jeneric Pentron released another version of ALERT that aimed to improve handling characteristics and surface texture. However, a recent study showed no change in surface roughness, compared to the old version (Cardoso & others, 2000).

Some controversial results relating to Solitaire resin have been published. Farah & Powers (1998) in a one-year clinical evaluation showed that despite three fracture cases and color mismatches (34%), the Solitaire resin showed good performance. However, Klinge & others (2000), after evaluating 82 restorations in a one-year period, observed color mismatch (37%), poor marginal adaptation (72%) and integrity (20%) and finally several fractures. Thus, the authors concluded that this material should not be used in posterior teeth.

Apart from these differences, both studies found fractures and color mismatches (Figure 3). All reports from the manufacturers and several *in vitro* studies indicated that Solitaire has the lowest diametral tensile strength, flexural strength, flexural modulus and fracture toughness of the packable resins tested (Leinfelder & others, 1999; Manhart & others, 2000; Kelsey & others, 2000). According to Manhart & others (2000), this is attributed to the greater range of particle size (2-20 μm) compared to Surefil and Filtek P60.

No problems regarding postoperative sensitivity or interface discoloration were found after one year for all materials tested in this study. These results confirmed the good performance of the adhesive systems used in several other laboratory studies, (Santini, Plasscharet & Mitchell, 2000; Tanumiharja, Burrow & Tyas, 2000), as well as the good performance of the ionomer cement used as a base in deep cavities (van Dijken, Kieri & Carlén, 1999).

CONCLUSIONS

Based on the results obtained in this study, it seems reasonable to conclude that the packable resin composites Filtek P60 and Surefil exhibit excellent clinical performance after one year. It is also necessary to emphasize that the timeframe for this study was not of such a duration to indicate long-term suitability of the tested materials, but it may provide an indication concerning their future performance.

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Color Perception Among Different Dental Personnel

CPC Sim • AUJ Yap • J Teo

Clinical Relevance

For teeth with very dark shades, shade selection should be done in conjunction with dental technicians, whenever possible.

SUMMARY

This study investigated the differences in color perception among distinct groups of dental personnel. Four groups of dental personnel (10 dental technicians, 15 final-year dental students, 15 general practitioners and 10 prosthodontists) were asked to match seven test tabs of shades A1, A4, B2, B3, C2, C4 and D3 (Z100 shade guide, 3M Dental Products, St Paul, MN 55144, USA) against a standard Vita shade guide under similar lighting conditions. The results obtained were computed into L*a*b* values using a small-area colorimeter (Dental Colorimeter, Minolta Camera Pte Ltd). The data were analyzed using one-way ANOVA/post-hoc Scheffe's test at significant level $p<0.05$. The results showed significant differences in ΔE (color difference) between the dental technicians and the clinicians for shade C4. The significant difference that was observed in ΔE for dark shades between dental personnel was mainly contributed to a disparity in L* values. A significant difference in ΔL^* was observed between dental technicians and prosthodontists for shade C4.

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INTRODUCTION

Accuracy in shade selection is an integral part of restorative dentistry. The demand for aesthetic dental restorations has increased exponentially over the last few years due to the development of new aesthetic materials and increased patient awareness. This has led to an increased need for accurate shade matching of the tooth being restored to that of the adjacent teeth. This minimizes the loss of clinical time, avoids additional cost resulting from repeat restorations and ensures patient satisfaction.

Many factors influence shade determination in clinical practice. Shade matching is highly affected by the viewing conditions. Light sources in the operatory and laboratory, the amount of sunlight, the color of the walls, the patient's clothing and make-up and the viewing angle of the tooth all can affect shade matching. Fluorescent light tends to accentuate the blue range of the color system, whereas incandescent light accentuates the yellow-red range (Rosenstiel, Land & Fujimoto,

1995). Hence, color-corrected lights with a color-rendering index of at least 90 should be used by clinicians, patients and other personnel involved in shade selection (Preston, Ward & Bobrick, 1978).

Another factor influencing shade selection is the color-vision status of the person selecting the shade, be it the dentist or the dental technician. Several studies have shown males as having a greater propensity for color-vision anomalies than females (Moser & others, 1985; Wasson & Schuman, 1992). In a survey of 670 dentists, Moser & others (1985) found color-vision anomalies in 9.7% of males and 0.1% of females.

Other factors influencing shade selection include training in color education (O'Brien & Nilsson, 1997), differences in color perception among individual dentists and their experience. It has been shown that even individual dentists could not duplicate their shade selection at different times (Culpepper, 1970). However, there have been conflicting results related to the influence of clinical experience on accuracy of shade selection (Barna & others, 1981; McMaugh, 1977; Davison & Myslinski, 1990). Few studies in the field of color in dentistry have looked at the proficiency of shade matching of different dental personnel.

This study aimed to determine the differences in color perception among the different groups of dental personnel.

METHODS AND MATERIALS

Seven different plastic shade tabs taken from a commercial composite shade guide (Z100 shade guide, 3M Dental Products, St Paul, MN 55144, USA) were used as test tabs for this study. The Z100 shade tabs were selected as they were keyed to the Vita Lumin shade guide (Vita Zahnfabrik, Bad Sackingen, Germany). To ensure that a whole spectrum of values were investigated, shades A1, A4, B2, B3, C2, C4 and D3 were selected. The test tabs were masked with black opaque plastic tape, leaving only the tooth form visible for shade matching. The test tabs were randomly arranged, and 50 dental personnel were asked to match the mid-third or body of each test tab to a tab on the Vita shade guide. The 50 dental personnel consisted of four groups: Group (DT): 10 dental technicians; Group (DS): 15 final-year dental students; Group (GP): 15 general practitioners and Group (PD): 10 prosthodontists. They were not informed of possible repeated shades and were blinded to the actual shades of the test tabs but not to the Vita shade guide. The tabs on the Vita shade guide were randomized with respect to their values. Shade matching was carried out under similar color-corrected lighting conditions (Trucolor TLM 40W/33RS, Phillips, Le Mans, France).

The color of the test and Vita shade tabs were computed into L*a*b* values by using a small-area (3 mm in diameter) colorimeter (Dental Colorimeter, Minolta Camera Pte Ltd, Tokyo, Japan), where L* indicates lightness and a* and b* are the chromaticity co-ordinates. The a* and b* co-ordinates designate positions on a red/green and yellow/blue axis, respectively (+a* = red, -a* = green; +b* = yellow, -b* = blue). The average L*a*b* values were calculated from three colorimetric measurements taken at the bodies of each test and Vita shade tab. After each reading, the colorimeter was removed from the test/Vita shade tab and repositioned back before taking the next reading. The colorimeter was calibrated using a white calibration tile supplied by the manufacturer. Illumination corresponding to "average" daylight (CIE Illuminant D65) from a pulsed xenon light source was used in the colorimeter.

The color difference between a test tab and its matched Vita tab was calculated using the equation

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

where ΔL^*, Δa^* and Δb^* are the mathematical differences between the test tab and its matched Vita tab.

These values were then used to compare color differences among the four dental personnel groups. Statistical analysis was carried out using one-way analysis of variance to determine significant differences among groups at $p<0.05$. Pair-wise comparisons were then determined using post-hoc Scheffe's tests.

RESULTS

Table 1 reflects the mean ΔL^*, Δa^*, Δb^* and ΔE values for the seven test tabs for each group of dental personnel. The largest and smallest ΔL^* values were seen in Group DT for shade C4 and Group DS for shade B3, respectively. In Group DT, the largest and smallest Δa^* values were observed for shades D3 and B2, respectively. The largest Δb^* value was observed in Group DS with shade A4, while the smallest Δb^* value was observed in Group PD with shade A1.

One-way analysis of variance showed that there was no significant difference in ΔL^*, Δa^*, Δb^* and ΔE values among the different groups of dental personnel except for shade C4 (Table 2). For test tab shade C4, there was a significant difference in ΔL values between dental technicians and prosthodontists ($p<0.05$) and a highly significant difference in ΔE values between the dental technician group (DT) and clinicians (DS, GP and PD) ($p<0.01$). Mean ΔE values for all individual shades evaluated in the four dental personnel groups ranged from 2.03 (shade B3 with Group GP) to 6.95 (shade C4 with Group DT).

When the results of the test tabs were pooled, there was a significant difference in ΔE values between the dental technicians and general practitioners. Ranking of the mean pooled ΔE values from the smallest to the greatest by groups is as follows: GP<DS<PD<DT.

Table 1: *Mean and (SD) ΔL, Δa, Δb and ΔE Values*

Shade Tab		DT	DS	GP	PD
1 (A1)	ΔL*	4.86 (0.58)	4.65 (0.93)	4.23 (1.76)	4.62 (0.38)
	Δa*	0.42 (0.19)	0.45 (0.24)	0.51 (0.30)	0.34 (0.13)
	Δb*	0.91 (1.30)	1.34 (2.19)	1.18 (1.37)	0.37 (0.85)
	ΔE	5.07 (0.91)	5.26 (1.17)	4.81 (1.11)	4.70 (0.59)
2 (A4)	ΔL*	3.14 (2.17)	3.25 (1.12)	4.67 (1.50)	4.07 (2.11)
	Δa*	0.73 (0.52)	0.97 (0.29)	0.68 (0.42)	0.54 (0.52)
	Δb*	3.31 (1.32)	4.25 (0.99)	4.13 (1.18)	3.69 (1.54)
	ΔE	4.98 (1.71)	5.52 (1.17)	6.47 (0.98)	5.87 (1.63)
3 (B2)	ΔL*	4.68 (1.22)	3.74 (2.32)	2.63 (2.45)	3.42 (2.45)
	Δa*	0.29 (0.14)	0.51 (0.42)	0.49 (0.22)	0.45 (0.20)
	Δb*	1.65 (1.55)	0.84 (0.54)	1.14 (1.17)	1.07 (1.17)
	ΔE	5.31 (0.22)	4.10 (1.95)	3.30 (2.20)	3.99 (2.05)
4 (B3)	ΔL*	1.58 (1.15)	1.22 (0.44)	1.23 (0.54)	1.71 (1.04)
	Δa*	0.71 (0.28)	0.78 (0.32)	0.87 (0.34)	1.14 (0.72)
	Δb*	3.83 (2.85)	2.21 (2.20)	1.37 (0.49)	2.92 (3.22)
	ΔE	4.42 (2.73)	2.83 (2.00)	2.03 (0.80)	3.70 (3.30)
5 (C2)	ΔL*	4.25 (2.33)	3.23 (2.43)	2.47 (1.90)	2.31 (1.30)
	Δa*	0.74 (0.41)	0.41 (0.32)	0.51 (0.26)	0.56 (0.31)
	Δb*	2.51 (1.81)	2.58 (1.16)	1.88 (0.66)	3.64 (2.63)
	ΔE	5.22 (2.50)	4.32 (2.41)	3.29 (1.78)	4.40 (2.87)
6 (C4)	ΔL*	5.50 (2.64)#	3.89 (1.11)	3.89 (1.11)	3.60 (0.00)#
	Δa*	0.73 (0.26)	0.68 (0.74)	0.68 (0.75)	0.70 (0.00)
	Δb*	3.61 (1.71)	3.76 (0.54)	3.76 (0.54)	3.90 (0.00)
	ΔE	6.95 (2.23)#	5.53 (0.71)#	5.53 (0.71)#	5.35 (0.00)#
7 (D3)	ΔL*	4.26 (2.73)	3.48 (3.16)	3.57 (2.81)	4.19 (3.66)
	Δa*	1.30 (0.69)	0.99 (0.65)	0.96 (0.60)	1.26 (0.64)
	Δb*	1.71 (1.23)	2.28 (3.16)	1.69 (1.42)	1.84 (1.78)
	ΔE	4.89 (2.86)	4.81 (3.90)	4.18 (3.04)	5.19 (3.47)
All shades	ΔL*	4.04 (2.26)	3.35 (2.08)	3.24 (2.12)	3.42 (2.11)
	Δa*	0.70 (0.49)	0.69 (0.42)	0.67 (0.38)	0.71 (0.53)
	Δb*	2.50 (1.98)	2.46 (2.08)	2.16 (1.54)	2.49 (2.23)
	ΔE	5.26 (2.13)#	4.62 (2.27)	4.23 (2.18)#	4.74 (2.35)

 # = statistically significant differences between dental personnel groups at p<0.05 using post-hoc Scheffe's tests.

DISCUSSION

Shade selection of aesthetic restorative materials is usually conducted by visual matching of a shade sample. Light from the test tab enters the eye and acts on the receptors (rods and cones) in the retina. Impulses from this area are then passed to the optical center of the brain, where an interpretation is made. Different people will interpret the same given stimulus differently, hence the shade selection process becomes a subjective assessment. This accounts for the broad standard deviation seen in all the dental personnel groups. Color vision is dependent on the cones of the retina, which are active under higher lighting conditions. The exact mechanism of color vision is not known, but it has been demonstrated that there are three types of cones which are sensitive to red, blue and green light (Land, 1977). They form an image similar to the additive effect of pixels in color television pictures.

The small-area colorimeter uses photodetectors to measure the reflectance of the light source from the test sample. The reflectance data obtained were then transformed into color dimensions via a microprocessor. Several research studies have used colorimeters to provide quantitative color measurements (Johnston & Kao, 1989; Seghi, 1990; Lund, Aquilino & Dixon, 1991) and the CIELAB system is a well-accepted mode of providing numerical colorimetric information that relates well to actual visual responses (Seghi, Hewlett & Kim, 1989). The CIELAB system is arranged in such a manner that the a* and b* axes corresponds to the red-green and yellow-blue axes of the visual color space, respectively. Therefore, a positive a* value relates to the amount of red and a negative a* value relates to the amount of green in the color sample. A positive b* value relates to the amount of yellow and a negative b* value relates to the amount of blue in the color sample.

Errors may occur in absolute color measurements due to the curved surfaces of both the test and Vita shade tabs. Also, each Vita shade tab is composed of gradation in shades, while the test shade tab is matched to the middle-third of the corresponding Vita shade tab. To minimize errors, measurements were made against the middle-third of both the test and Vita shade tabs.

The results of this study showed that the dental technician group tended to perceive the value of a dark shade, such as C4, as being higher than what it should be. It is postulated that when a dentist gives a laboratory instructions for a porcelain restoration to be fabricated in a dark shade of a low value, the technician may doubt whether the shade is truly that dark and may err in fabricating a restoration of a lighter shade and value. This provides leeway for modification of shade during the try-in of the porcelain restoration, as it is easier to increase the chroma or lower the value by surface staining than to lighten a dark restoration. This habit was observed during the shade matching exercise carried out in this study.

Studies by previous authors have shown that there is a varied response in shade matching ability among individuals (Culpepper, 1970). Dental education related to color also influences shade matching capabilities in dental personnel such that they are more discriminating

Table 2: *Comparison of Differences in Color Parameters Among Personnel Groups by Shade Tabs*

Shade Tab		Difference
1 (Shade A1)		NS
2 (Shade A4)		NS
3 (Shade B2)		NS
4 (Shade B3)		NS
5 (Shade C2)		NS
6 (Shade C4)	ΔL*	DT > PD
	Δa*	NS
	Δb*	NS
	ΔE	DT > DS, GP, PD
7 (Shade D3)		NS
All shades	ΔL*	NS
	Δa*	NS
	Δb*	NS
	ΔE	DT > GP

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

in color matching than non-dental personnel (O'Brien & Nilsson, 1997). However, even among dental personnel, variations in shade matching abilities exist. A study by Barrett, Anusavice & Moorehead (1996) had 116 dental students and faculty match a set of 12 Vita porcelain shade discs to a set of 13 Vita shade discs. The participants repeated the matching exercise. The results showed that 36.35% of the paired discs had ΔE > 3.4, where human visual perception of color differences are no longer correlated with colorimetric instrumental values.

Under controlled conditions, an average difference of one ΔE unit is visually just perceptible (Kuehni & Marcus, 1979; Seghi & others, 1989). However, the average color difference rated as a match in the oral environment was 3.7 (Johnston & Kao, 1989). Tashkandi & O'Brien (1997) found in their study that the mean percentage of correct selection of best matching shade was 65%. In this study, all the dental personnel groups showed ΔE values larger than 3.7 for all test tabs except for the general practitioner group which showed ΔE values less than 3.7 for shades B2 and C2 and the three clinical dental personnel groups for shade B3.

This study also showed that there was no difference in shade matching ability among the clinical groups, that is, dental students, general practitioners and prosthodontists. The additional training that the prosthodontists had undergone, with presumably more experience in color matching, did not appear to give the prosthodontists' group any additional advantage. This concurred with the study by Davison & Myslinki (1990) that showed no significant improvement in shade selection between the prosthodontists' group and that of the dental students and general practitioners. However, in another study by Draper, Walters & Jasinevicius (1997) that compared dental students and dentists, experience was shown to improve shade selection. This was also noted in a study by McMaugh (1977) that showed prosthodontists as giving better shade selection than first-year dental students. However, the dental students in this study were final-year students who, by then, already had some practical clinical training in shade selection, unlike first-year dental students who had no didactic or clinical training in shade selection.

CONCLUSIONS

A significant difference in color perception among very dark shades was observed between dental technicians and clinicians. The significant difference in ΔE was mainly due to the large disparity in L* values.

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Laboratory Research

SEM Evaluation of the Interaction Between A Three-Step Adhesive and Dentin

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Clinical Relevance

The profuse penetration of Scotchbond Multi-Purpose results in numerous resin tags and microtags that establish intimate contact with collagen fibrils of dentin.

SUMMARY

Interaction between resin tags and microtags of adhesive systems and dentinal collagen fibrils is a poorly understood aspect of adhesion. This study evaluated this interaction in 25 recently extracted human third molars. Each tooth was embedded in an epoxy resin and cross-sectioned to obtain two 1-mm-thick dentin disks. The outer dentin surfaces were polished with wet 600-grit sandpaper to create a uniform smear layer. After etching with 35% phosphoric acid for 15 seconds, the primer and adhesive of Scotchbond Multi-Purpose and the resin composite Z100 (3M Dental Products, St Paul, MN 55144, USA) were placed on the dentinal surfaces according to the manufacturer's instructions. The disks were left in distilled water at 37°C for two weeks, then fractured perpendicular to the bonded surfaces in order to obtain two hemi-disks. The fractured surfaces were treated with 2N-chloridric acid and processed for scanning electron microscopy. Gold-coated specimens were examined with a JEOL 6100 scanning electron microscope. Results showed a hybrid layer with resin tags of approximately 100 µm in length and numerous and fine branching resin microtags. The tags and microtags created by this three-step adhesive system were observed in intimate contact with the collagen fibrils of dentin, even in deeper zones which were not affected by acid etching. It suggests that adhesion to dentin may include both micromechanical and chemical aspects.

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INTRODUCTION

Most adhesive systems for dentin bonding require acid etching that removes or alters the smear layer and decalcifies the underlying dentinal structures. Decalcification of the dentin surface includes exposing the collagen network from the intertubular dentin up to a depth of 5 µm (Pashley & others, 1993). Acid etching

also opens the dentinal tubules, which acquire a funnel-shaped appearance due to the partial removal of the peritubular dentin. Penetration of the resin monomers into the exposed collagen network results in the so-called hybrid layer or inter-diffusion zone (Nakabayashi & others, 1982). In addition, penetration of resin monomers through the enlarged dentinal tubules and their lateral branches (canaliculae), form resin tags and microtags, respectively (Titley & others, 1995).

The penetration of resin through the tubular/canalicular system of dentin may be important for mechanical coupling that may increase the bond to dentin (Chappell & others, 1994). Diffusion of resin monomers into the collagen network of intertubular dentin has been considered important for enhancing the bond strength as a whole (Van Meerbeek & others, 1992). In recent years, numerous micromorphological studies of the resin-dentin interface of various adhesive systems have been published (Eick & others, 1993; Perdigão & Swift, 1994; Vargas, Cobb & Armstrong, 1997). However, these studies focused mainly on the structure of the hybrid layer and little has been reported on the relationship between resin tags/microtags and dentinal collagen fibrils.

Since Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144, USA) adhesive has been shown to penetrate etched dentin, the authors analyzed the interaction between the resin tags and microtags of this three-step adhesive system and the collagen fibrils of dentin. High-resolution scanning electron microscopy was used to verify the relationship between these structures.

METHODS AND MATERIALS

Twenty-five recently extracted human third molars stored in distilled water at 4°C were used in this study. The teeth were embedded in an epoxy resin, and the occlusal third was removed using a Labcut 1010 (Extec Corp, Enfield, CT, USA) slow-speed cutting machine equipped with a diamond-impregnated disk under coolant with copious water. Subsequently, the remaining surface was polished with 180, 240 and 600-grit silicon carbide sandpaper until no enamel remained. This was confirmed by examination under a Nikon stereomicroscope (Nikon Corporation, Japan). The teeth were then cross-sectioned in the same slow-speed cutting machine to obtain two 1 mm-thick dentin disks. The outer surface of each disk was polished for three minutes with wet 600-grit silicon carbide sandpaper to create a uniform smear layer. After etching with 35% phosphoric acid for 15 seconds and washing with air-spray water for 15 seconds, the primer and adhesive (Scotchbond Multi-Purpose, 3M Dental Products) and resin (Z100, 3M Dental Products) were placed on the dentin surfaces according to the manufacturer's instructions. One coat of primer was applied to the dentin surface and gently air-dried for five seconds. Then, the adhesive was applied and photo-activated for 10 seconds. Finally, a 2-mm increment of resin was placed and photo-activated for 40 seconds using a Curing Light XL 1500 unit (3M Dental Products) with 450mW/cm^2 intensity. The dentin disks were left in distilled water at 37°C for two weeks, then fractured perpendicular to the bonded surfaces to obtain two hemi-disks. The fractured surfaces were treated with 2N-chloridric acid for two minutes, washed with distilled water, transferred to 70% ethanol and dehydrated in increasing concentrations of ethanol. To avoid shrinkage of specimens during air drying, the hemi-disks were immersed in 100% hexamethyldisizilane (Electron Microscopy Sciences, Fort Washington, PA, USA), for 10 minutes and left under a fume hood equipped with an exhaust system for complete evaporation of HMDS. Specimens were mounted on aluminum stubs with their treated surfaces face up, using a colloidal silver adhesive and sputter-coated with gold in a Balzers SDC-050 apparatus (Bal-Tec AG, Liechtenstein). The hemi-disks were examined under a JEOL 6100 scanning electron microscope (JEOL LTD, Tokyo, Japan), operating to 10-15 kV.

RESULTS

The resin-dentin interface showed penetration of resin material into the dentinal tubules and canaliculae. Long projections of resin (resin tags), 100 µm in length, were observed occupying the dentinal tubules. In addition, numerous fine, long and anastomosed lateral branches (resin microtags) were seen as penetrating the canaliculae through the intertubular dentin. In the region immediately under the hybrid layer, numerous resin microtags were observed around the base of the resin tags (Figure 1). The base of the resin tags was larger and appeared more conical, or funnel-shaped (Figure 2).

In general, the resin tags exhibited a smooth texture. However, in some regions resin-infiltrated collagen fibrils were observed in intimate contact with the tags (Figures 3 and 4).

Resin microtags were observed in all extensions of resin tags. They were numerous, very fine and profusely anastomosed, filling the canaliculae lumen (Figure 5). The resin microtags appeared close to the mineralized collagenous matrix of intertubular dentin (Figure 6). Interaction between dentinal collagen fibrils and the resin microtags was also evident very near their origin from the resin tags (Figure 7).

DISCUSSION

This study showed that monomers of the three-step adhesive Scotchbond Multi-Purpose (3M Dental Products) largely penetrate through dentinal tubules and canaliculae, establishing an intimate contact with

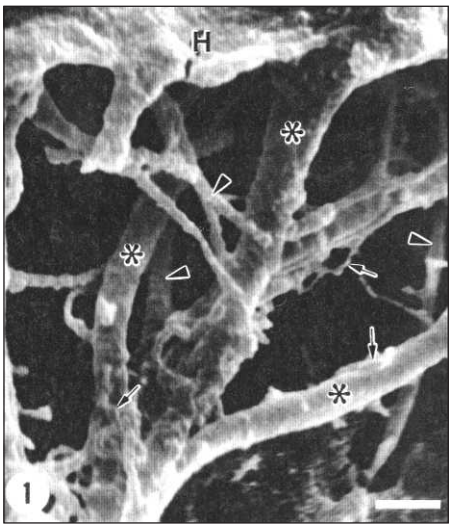

Figure 1. *Scanning electron micrograph showing a region underneath the hybrid layer (H). Several resin tags (asterisks) are seen exhibiting their funnel-shaped base. Numerous lateral branches or resin microtags (arrowheads) may be also observed. Some resin-infiltrated collagen fibrils (arrows) are identified in association with the resin tags. Bar: 2 µm.*

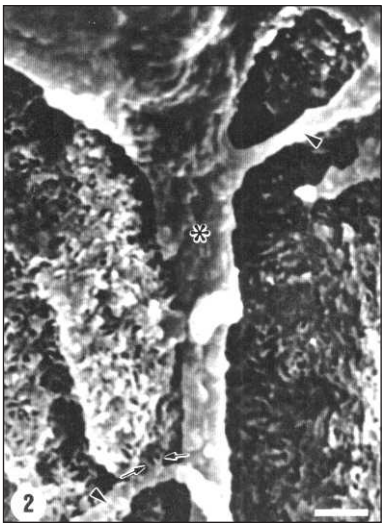

Figure 2. *Scanning electron micrograph of the funnel-shaped base of a resin tag (asterisk). Two resin microtags (arrowheads) appear arising from the resin tag. The lower microtag appears in contact with mineralized collagen fibrils (arrows) of the intertubular dentin. Bar: 1 µm.*

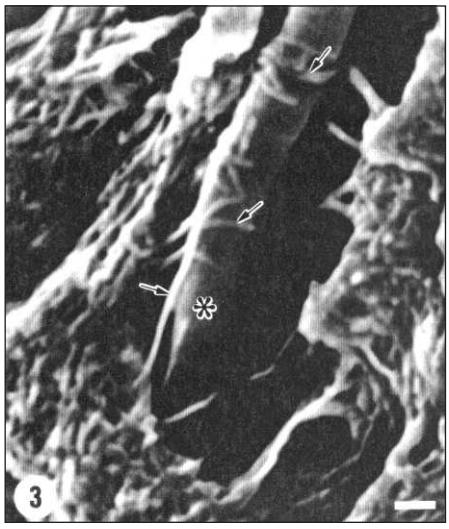

Figure 3. *Scanning electron micrograph showing a resin tag (asterisk) within the dentinal tubule. Various resin-infiltrated collagen fibrils (arrows) are observed in contact with the resin tag. Bar: 0.5 µm.*

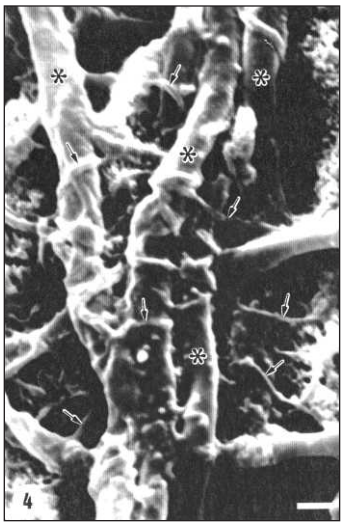

Figure 4 *Scanning electron micrograph showing a region in which various resin tags (asterisks) are observed in close proximity one to another. Numerous resin-infiltrated collagen fibrils (arrows) appear embracing the resin tags. Bar: 1 µm.*

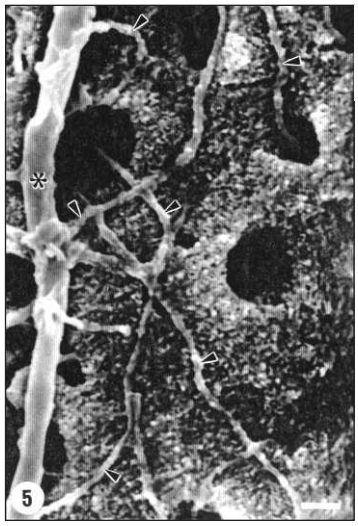

Figure 5. *Scanning electron micrograph showing a resin tag (asterisk) and numerous microtags (arrowheads). The resin microtags are seen in contact with the mineralized collagen fibrils of the underlying intertubular dentin. Bar: 1 µm.*

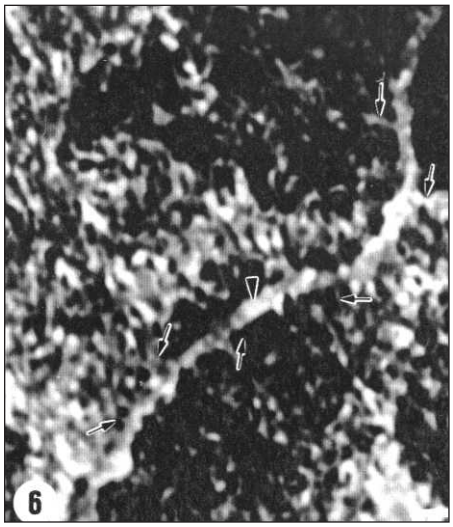

Figure 6. S*canning electron micrograph showing a higher magnification view of a resin microtag (arrowhead), which appears in contact with collagen fibrils (arrows) of the intertubular dentin. Bar: 0.5 µm.*

the dentinal collagen fibrils. Careful processing for scanning electron microscopy and high-resolution examination permitted the authors to evaluate the relation between resin and the main organic constituent of dentin—its collagenous fibrilar component. Chloridic acid removed the mineral component and collagen of the dentin with which it reacted. In subjacent areas not affected by the acid, the collagen was left mineralized. In these non-exposed areas, the authors examined the relationship between the mineralized collagen fibrils and resin tags/microtags.

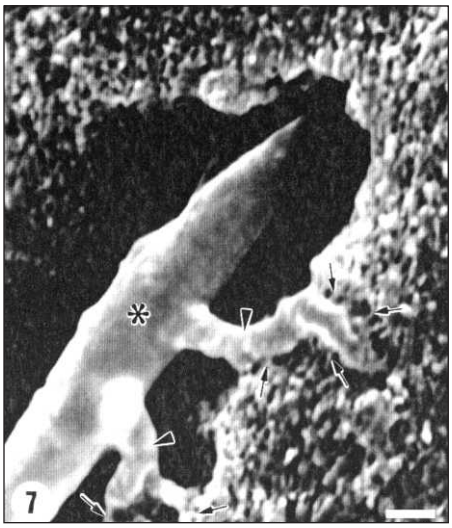

Figure 7. *Scanning electron micrograph showing a resin tag (asterisk) within a dentinal tubule. Two resin microtags (arrowheads), which are seen arising from the resin tag, appear in intimate contact with collagen fibrils of the intertubular dentin (arrows). Bar: 1 µm.*

Results showed that resin lateral branches or microtags were numerous and profusely penetrated the dentinal canalicular system. The adhesive monomers of the resin microtags established close proximity with the collagen fibrils of the intertubular dentin. The dentinal canaliculae are numerous, anastomosed and run through the intertubular dentin. They have no wall of peritubular dentin, except for less than one micrometer near its origin from the dentinal tubules (Mjör & Nordahl, 1996). The presence of numerous microtags formed by Scotchbond Multi-Purpose (3M Dental Products) and other adhesive systems was previously reported (Chappell & others, 1994; Titley & others, 1995; Prati & others, 1998; Prati & others, 1999).

Since acid etching of dentin was reported to occur up to 5 µm deep (Pashley & others, 1993), this study's results showed an intimate contact between resin and collagen fibrils also occurred in regions where dentin was not acid etched. For this reason, the resin microtags that penetrated the intertubular dentin did not diffuse within a collagen network because localization of these regions was deeper than the acid etched area. Adhesive monomers of microtags, therefore, established an intimate contact with the mineralized collagen fibrils of intertubular dentin walls of canaliculae.

In addition to microtags, resin tags also interacted with collagen fibrils. Peritubular dentin is known to hyper-mineralize compared to intertubular dentin. Peritubular dentin possesses a rare organic matrix with a few of collagen fibrils that are contained within its mineral bulk. Some collagen fibrils reach the periodontoblastic space and embrace the odontoblast process *in vivo* (Dai & others, 1991). Thus, when resin monomers penetrated through the dentinal tubules, they impregnated the collagen fibrils that reached the tubular lumen.

The profuse diffusion of adhesive monomers into dentin that forms the hybrid layer (interdiffusion zone), resin tags and numerous microtags may improve the micromechanical coupling of dentin bonding (Nakabayashi & Pashley, 1998). On the other hand, this study's results suggest that two types of interaction may occur between the resin and collagen of dentin. At the hybrid layer, which was not focused on in this study, adhesive monomers infiltrate the collagen network of the acid etched intertubular dentin. These collagen fibrils are free from mineral (hydroxyapatite) that was removed by the previous etching. In these regions, therefore, bonding may be micromechanical and chemical (Nakabayashi & Pashley, 1998). On the other hand, as has been shown here, resin microtags establish an intimate contact with the collagen of the intertubular dentin wall of canaliculae. These collagen fibrils remain mineralized because acid etching did not reach these deeper zones. Polyalkenoic acid copolymer that has been suggested to establish calcium-polyalkenoate complexes (Smith, 1992), is a component of the primer of Scotchbond Multi-Purpose (3M Dental Products). It suggests that in regions with microtags and mineralized collagen contact, bonding may be chemical, thus, enhancing adhesion to dentin as a whole.

Regions examined in this study included superficial dentin at the occlusal side, where distance between dentinal tubules is greater than in deep regions. At superficial dentin, dentinal canaliculae are numerous and very anastomosed, forming an intricate canalicular system, as reported by Mjör & Nordahl (1996). In addition to resin tags, sealing of restorative material may be improved by the presence of numerous and anastomosed microtags. Microleakage may, therefore, be diminished by higher penetration of adhesive monomers through dentinal tubules and canaliculae. However, it should be considered that density, orientation and diameter of dentinal tubules, as well as the canaliculae, are different at various regions of dentin (Mjör & Nordahl, 1996). In addition, clinical factors that include the state of dental pulp, aging and others, may produce partial or total obliteration of dentinal tubules and canaliculae by forming sclerotic dentin (Pashley, 1996). In these situations, Prati & others (1999) report that penetration of adhesive monomers could be diminished. Thus, the presence and extension of resin tags and microtags and transdentinal permeability, in general, may be altered.

CONCLUSIONS

This scanning electron microscopic study showed that monomers of tags and microtags of the three-step adhesive Scotchbond Multi-Purpose (3M Dental Products) establish intimate contact with dentinal collagen fibrils. The lateral branches or microtags were

numerous and profusely penetrated the canalicular system of dentin, establishing an intimate relationship with the mineralized collagen fibrils of intertubular dentin. In addition, the resin monomers of tags also impregnated the collagen fibrils of tubular lumen. These observations suggest that adhesion to dentin may have a chemical component in the deeper non-etched zones of dentin.

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Effect of Adhesives on the Inhibition of Secondary Caries Around Compomer Restorations

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Clinical Relevance

For compomer restorations, use of an adhesive that does not contain Bis-GMA resin may be beneficial for adhesion to dentin without reducing the contact potential for secondary caries inhibition.

SUMMARY

This study evaluated the effect of adhesives on the inhibition of secondary caries around compomer restorations in vitro**. Two adhesive systems with a Bis-GMA resin, Scotch bond Multipurpose (MP) and Single Bond (SB), and one adhesive system with no Bis-GMA resin, F2000 compomer primer/adhesive (PA), were used prior to placement of the compomer (F2000), and non-fluoride releasing resin composite (Z100) was used as a control. Class V cavities prepared on extracted human premolars were restored with various combinations of materials: F2000/MP, F2000/SB, F2000/PA, Z100/MP, Z100/SB and Z100/PA. The restored teeth were incubated in bacterial medium containing sucrose with** Streptococcus mutans **for two weeks after storage for 14 days. On microradiographs, the radio-opaque layers adjacent to the F2000 restorations were thick and clear, while the layers in the Z100 restorations were unclear. In the F2000 restorations, the mean thickness of the radio-opaque layers in the PA group was significantly greater than that of the MP and SB groups. In fluoride-releasing measurement, F2000 coated with PA showed a significantly higher amount of fluoride release than MP and SB, and no significant difference in the amount of fluoride release from uncoated F2000.**

These results indicated that applying an adhesive without Bis-GMA resin to compomer restoration has no suppressive effect on the fluoride release from compomer and might be beneficial for inhibiting secondary caries in vitro**.**

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INTRODUCTION

Glass ionomer cements are reported to be effective for secondary caries inhibition *in vitro* (ten Cate & van Duinen, 1995). These materials are expected to inhibit secondary caries by releasing fluoride ions. Fluoride ions released from glass ionomer cements easily pene-

trate and diffuse into the cavity wall dentin because these cements directly contact the cavity wall. In fact, Nagamine & others (1997) detected fluoride ions released from glass ionomer cements in cavity wall dentin. Fluoride ions penetrating dentin produced mineralization of the dentin and reduced demineralization (Damen, Buijs & ten Cate, 1998). Therefore, dentin penetrated by fluoride ions offers resistance against secondary caries attack. However, glass ionomer cements produce poor adhesion to tooth substances compared to resin composite restorations.

Recently, new fluoride-releasing resin composites containing fluorosilicate glass filler, called compomers, have been developed and commercialized. Compomers have been reported to inhibit caries-like lesions around restorations (Dionysopoulos & others, 1998). However, the bonding of compomers did not occur without using adhesives (Tate, You & Powers, 1999). Therefore, the use of adhesive systems is indispensable for the compomer to achieve good adhesion to dentin. Although adhesives lead to good adhesion of compomer to dentin, the adhesive layer may inhibit fluoride uptake into the cavity wall dentin around the compomer restoration because the compomer is not directly in contact with the cavity dentin. Castro & others (1994) reported that various surface coatings inhibited the fluoride release from glass ionomers. Therefore, the adhesive layer might regulate fluoride release from the compomer and affect the inhibitory effect of secondary caries around the compomer restoration.

This study determined the relationship between fluoride release from compomers through adhesives with and without a Bis-GMA resin and the inhibitory effect of secondary caries around the restorations using these adhesive systems *in vitro*. In addition, tensile bond strength of the compomer to dentin using these adhesive systems was evaluated.

METHODS AND MATERIALS

Tensile Bond Strength Test

Two adhesive systems with a Bis-GMA resin, Scotch Bond Multi-Purpose (3M Dental Products, St Paul, MN 55144, USA) and Single Bond (3M Dental Products), and one adhesive system with no Bis-GMA resin, F2000 compomer primer/adhesive (3M Dental Products), were used prior to placing the compomer (F2000; 3M Dental Products) and the non-fluoride releasing resin composite (Z100; 3M Dental Products) as a control. Table 1 lists the components of the adhesives. The flat dentin surfaces of 78 bovine incisor teeth were ground with a silicone carbide paper (#600) under water. The teeth were randomly assigned to six groups (n=13) of adhesive systems and restorative materials. Cylindrical rings with an inner diameter of 3.7 mm and a height of 3 mm were attached on the dentin surfaces, and the surfaces were treated with the three adhesive systems. The dentin surfaces in MP and SB systems were etched with 35% phosphoric acid gel for 15 seconds, rinsed for 10 seconds and blotted with cotton pellets. In the MP system, the primer was applied to the surfaces for 30 seconds and gently air dried for five seconds. The adhesive was coated and light cured for 10 seconds using a visible light unit (Visilux 2; 3M Dental Products). The adhesive in the SB system was applied twice on the moist surfaces and light cured for 10 seconds. The PA system was applied to the surfaces without etching and light cured for 10 seconds. The restorative material filled each tube and was light cured for 40 seconds. After storing the specimens for 24 hours in distilled water at 37°C, the tensile bond strength was measured using a universal testing machine (Autograph AGS-10kND, Shimadzu, Kyoto, Japan) at a crosshead speed of 0.5mm/min.

Measurement of Fluoride Release

Thin layers of the three adhesives were applied in cylindrical Teflon plastic molds with an inner diameter of 6 mm and a depth of 2.5 mm, followed by thinning with a gentle stream of air, then light cured for 10 seconds. Two restorative materials were placed in the coated or non-coated (control) molds, pressed on the top by glass plates, then light cured for 40 seconds. Five disc specimens were prepared for eight groups. The top surfaces of the specimens were coated with nail varnish to prevent fluoride release from the uncoated surface. After storage at 37°C and 100% humidity for 24 hours, the specimens were immersed in 5 ml distilled water at 37°C and changed to fresh distilled water on the last day of every week for 10 weeks. A mixture of 0.5 ml of each storage solution and 0.05 ml of acetic buffer solution (TISAB III; Orion Research Inc, Boston MA 01915-6199, USA) and the fluoride concentration were measured using a fluoride-specific electrode attached to an ion meter (F-23, Horiba Ltd, Kyota, Japan). The results were calculated as the amount of fluoride release per surface area of specimens ($\mu g/cm^2$).

Artificial Secondary Caries Procedure Around Restorations

Eighteen human extracted upper permanent premolars free of caries and other defects were selected and randomly assigned to three groups. The teeth were mechanically cleaned, the roots cut off and the pulp tissues removed. Class V cavities were prepared at the cemento-enamel junction on the buccal and palatal surfaces of each tooth using a high-speed diamond point with water coolant. The depth of each cavity was standardized at 1.5-2.0 mm. The palatal and buccal cavities of six teeth in three groups, respectively, were treated with three the adhesive systems according to the manufacturer's instructions. The palatal cavities

Table 1: *Adhesive Systems Used in This Study*

System	Composition
Scotch Bond Multi-Purpose (MP)	
Etchant	35% phosphoric acid
Primer	HEMA, polyalkenoic copolymer, water
Adhesive	Bis-GMA, HEMA
Single bond (SB)	
Etchant	35% phosphoric acid
Adhesive	HEMA, Bis-GMA, dimethacrylate, water, ethanol, polyalkenoic copolymer
F2000 compomer primer/adhesive (PA)	
Side A	methacrylated polycarboxylic acids, HEMA, water, ethanol
Side B	maleic acid, water

Abbreviations:
HEMA;2-hydroxyethyl methacrylate, Bis-GMA;bisphenyl glycidylmethacrylate
All materials were produced by 3M Dental Products, St Paul, MN 55144 USA

Table 2: *Tensile Bond Strength to Dentin (MPa±SD)*

Restoration	**Adhesive Systems**		
	SB	MP	PA
F2000	12.3±5.0	10.7±2.7	12.7±2.8
Z100	12.5±4.3	10.1±3.5	7.7±3.8

Horizontal lines connect means that are not significantly different ($p>0.05$).

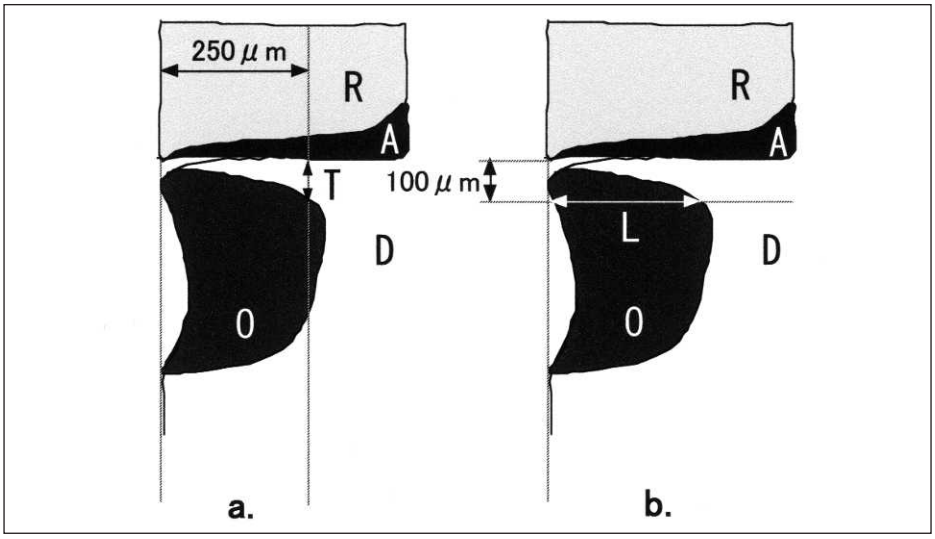

Figure 1. *Measurements of the thickness of radio-opaque layers (a) and the depth of outer lesions (b). A=adhesive resin, D=dentin, O=outer lesion, R=restorative material, T=thickness of radio-opaque layer and L=depth of outer lesion.*

of all teeth were restored with F2000 and the buccal cavities were restored with Z100. Then, the restorative materials that filled in the cavity were light-cured for 40 seconds. The restorations were polished with a white carborundum point with water coolant after storage at 37°C and 100% relative humidity for 24 hours. The specimens were individually mounted on plastic tubes and stored for an additional 14 days at 37°C and 100% relative humidity. Hanks' balanced salt solution (Nakarai Tesque, Kyoto, Japan) was poured into each tube and changed every seven days. After storage, each tooth surface was coated with nail varnish except for a 0.5 mm peripheral zone around the restoration, then sterilized with ethylene-oxide gas for 24 hours. Hanks' balanced salt solution was again poured into each tube, and the specimens were incubated in Brain Heart Infusion broth (Difco Laboratories, Detroit, MI 48232-7058, USA) containing 1% sucrose inoculated with *Streptococcus. mutans* IFO 13955 at 37°C for 14 days. The medium was replaced every three or four days and Hanks' balanced salt solution was changed every seven days. After incubation, the specimens were removed from the tubes and embedded in epoxy resin. The specimens were sectioned through both restorations using a rotary diamond cutting machine (Isomet, Buehler Ltd, Evanston, IL 60204) and ground sections 80 μm thick were prepared. Contact microradiographs were taken with a soft x-ray source (SoftexCMR, Softex Co, Tokyo, Japan) at 15 KVp, 3 mA, and the artificial secondary carious lesion at the gingival margin in the root was observed with a microscope at 100x (V-12, Nippon Kougaku, Japan). To evaluate the inhibitory effect of the restorations, the lesions were measured with a micrometer at sites shown in Figure 1: (1) the thickness of the radio-opaque layer adjacent to the gingival wall at a depth of 250 μm under the surface of the restorative material, and (2) the depth of the outer lesion at a distance of 100 μm from the restoration margin.

Statistical Analysis

All data were statistically analyzed using ANOVA and the *t*-test for comparison between means at a significance level of 0.05.

RESULTS

Table 2 summarizes the mean tensile bond strengths of F2000 and Z100 to dentin treated with three adhesive

Table 3: *Mean Cumulative Amount of Fluoride Release From F2000 Coated with Adhesives (μg/cm² ± SD)*

	Immersion Time		
Adhesive Systems	**1 Week**	**5 Weeks**	**10 Weeks**
MP	16.9+4.9	30.7+6.7	49.9+11.3
SB	20.6+9.3	39.4+8.9	58.0+10.6
PA	31.7+8.6	62.4+15.8	87.7+21.6
uncoated	30.8+4.8	70.1+7.3	104.2+ 9.0

Vertical lines connect means that are not significantly different ($p>0.05$).
No fluoride release was detected from Z100 coated with any adhesives.

Table 4: *The Thickness of the Radio-Opaque Layers in Each Group (μm ± SD)*

Restoration	**Adhesive Systems**		
	MP	SB	PA
F2000	13.0 ± 4.8	15.8 ± 3.3	20.7 ± 3.3
Z100	2.2 ± 3.1	2.8 ± 3.6	3.1 ± 3.6

Horizontal lines connect means that are not significantly different ($p>0.05$).

Table 5: *The Depth of the Outer Lesions in Each Group (μm + SD)*

Restoration	**Adhesive Systems**		
	MP	SB	PA
F2000	355 ± 60	396 ± 35	422 ± 48
Z100	436 ± 42	477 ± 69	514 ± 70

Horizontal lines connect means that are not significantly different ($p>0.05$).

systems. The mean bond strength to dentin in the F2000/PA group was 12.7 MPa and was significantly higher than that of the Z100/PA group (t-test, $p<0.05$). The mean bond strength of F2000 and Z100 to dentin treated with SB system were 12.3 MPa and 12.5 MPa, respectively, and almost the same as that of the F2000/PA group. The bond strength of the MP systems with F2000 and Z100 were 10.7 MPa and 10.1 MPa, and the same as those of the SB and PA systems.

Table 3 indicates the mean cumulative amounts of fluoride release from F2000 specimens coated with various adhesives at 1, 5 and 10 weeks. No fluoride release was detected from Z100 coated with any adhesives. The amounts of fluoride release of F2000 coated with PA at 5 and 10 weeks were 62.4 μg/cm² and 87.7 μg/cm², respectively, and were significantly higher than F2000 coated with MP and SB (t-test, $p<0.05$). However, F2000 coated with PA showed no difference from the uncoated F2000 at all test periods. Although the fluoride release from F2000 coated with SB was higher than that of F2000 coated with MP, there was no difference between them at 10 weeks.

Figure 2 shows typical microradiographs of caries-like lesions at the gingival margins of cavities restored with F2000 or Z100 after pretreatment with various adhesive systems. In all specimens, there were outer lesions on the exposed tooth surface but no wall lesions were observed in the root. In the outer lesions, radio-opaque layers were observed in the walls adjacent to all restorations. Particularly, the layers adjacent to the F2000 restoration groups were thick and clear (Figure 2a, c and e), while those adjacent to the Z100 restoration groups were unclear (Figure 2b, d and f).

Table 4 presents the mean thickness of radio-opaque layers adjacent to the gingival walls at a depth of 250 μm under the surfaces of the restorations. The mean thickness of this layer in the F2000 groups ranged from 13.0 μm to 20.7 μm, while the Z100 groups ranged from 2.2 μm to 3.1 μm. The thickness of the layer in the F2000/PA group was significantly greatest among all groups (t-test, $p<0.05$).

Table 5 shows the mean depth of outer lesions at a distance of 100 μm from the restoration margins. The depths of outer lesions in the Z100 groups were significantly deeper than those of the F2000 groups (t-test, $p<0.05$). However, there was no significant difference in lesion depth among the three adhesive groups restored with F2000 or Z100.

DISCUSSION

Compomers are known to possess fluoride releasing ability (Shaw, Carrick & McCabe, 1998; Verbeeck & others, 1998). However, these reports have shown only the amount of fluoride release from compomers uncoated with adhesives. Therefore, the fluoride release from compomers through adhesives should be evaluated, even *in vitro*, because the adhesion of compomers to dentin requires the use of adhesive systems. Castro & others (1994) reported that various surface coatings inhibited the fluoride release from glass ionomers. This finding shows that the cumulative amount of fluoride release is influenced by the kind of surface coating material. In this study, PA system resulted in a higher amount of fluoride release from F2000 coated with adhesives than did MP or SB. The PA system, an acidic primer/adhesive, contains HEMA

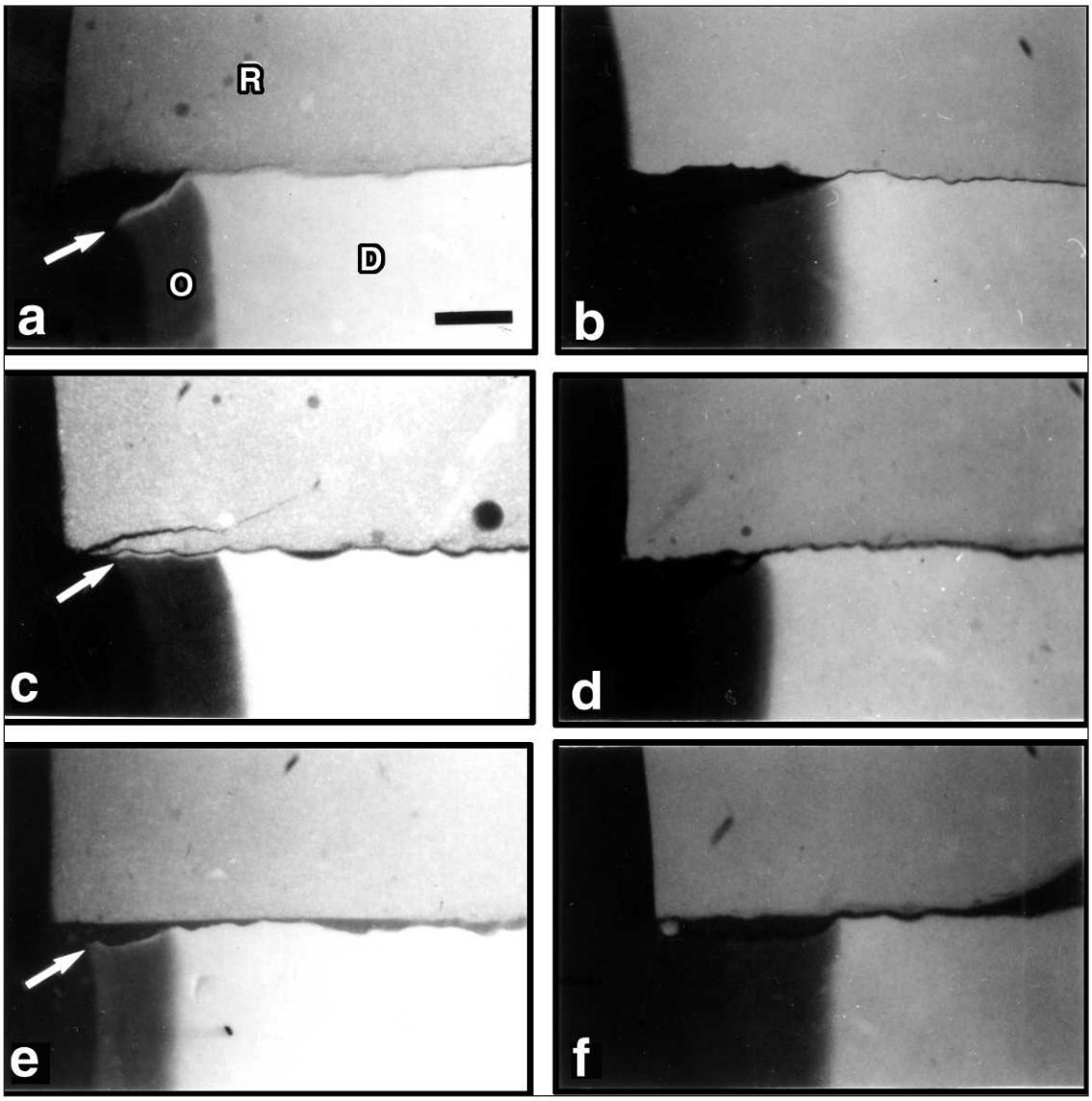

Figure 2. *Typical microradiographs of the lesions in root margins of cavities restored with compomers and resin composites that used various adhesive systems. a=F2000/PA group, b=Z100/PA group, c=F2000/SB group, d=Z100/SB group, e=F2000/MP group and f=Z100/MP group. The arrows show the radio-opaque layer in F2000 compomer restorations. D=dentin, O=outer lesion and R=restorative material. All microradiographs are same magnification. Bar=200 μm.*

and not Bis-GMA monomer. On the other hand, MP and SB, both of which are traditional three-step adhesive and wet bonding adhesive systems, contain HEMA and Bis-GMA monomer. Generally, HEMA monomer with its hydrophilic nature increases water absorption (Arima, Hamada & McCabe, 1995), and Bis-GMA monomer, with its hydrophobic property, decrease the uptake of water into the copolymer that contains it (Kalachandra & Turner, 1987). As the adhesives in MP and SB contain Bis-GMA resin as a base monomer, these adhesives have higher hydrophobia than PA. The adhesives containing Bis-GMA might thus inhibit fluoride release from the compomer by regulating water absorption. The use of the PA system in the compomer restoration is advantageous for the fluoride-releasing ability of F2000 because the PA system without a Bis-GMA resin does not prevent fluoride release from F2000 when compared to MP and SB systems.

Although compomers produce a low-level and no initial burst of fluoride release (Verbeeck & others, 1998; Shaw & others, 1998), the authors could observe a radio-opaque layer in the gingival lesion adjacent to F2000 as a compomer. Many investigators have shown radio-opaque layers around various glass ionomers (Pereira, Inokoshi & Tagami, 1998; Tam, Chan & Yim, 1997; Nagamine & others, 1997). Dionysopoulos & others (1998) reported that compomer restorations had been shown to have an inhibitory effect on secondary caries. The fluoride release from fluoride-containing materials changes hydroxyapatite to fluoroapatite or hydroxy-fluoroapatite with resistance ability against acid attack. Therefore, this radio-opaque layer would be formed by fluoride ions released from compomers and resist acid-attack during artificial caries formation at the cavity wall.

However, it is doubtful whether this radio-opaque layer provides resistance to a clinical caries challenge. Randall & Wilson (1999) reported that there was no conclusive evidence for or against a treatment effect of the inhibition of secondary caries by glass ionomer restoratives that released a large amount of fluoride *in vivo*. This effect, supported by this study, may be of the-

oretical interest only, however, the effect should be evaluated *in vivo*.

In this study, the thickness of the radio-opaque layer of the restoration with no Bis-GMA resin was thicker than that of the restoration with a Bis-GMA resin. This finding suggests that a Bis-GMA resin in adhesives inhibits fluoride penetration to cavity wall dentin. The conditioning step used in adhesive systems with a Bis-GMA resin may also decrease or inhibit formation of a radio-opaque layer. The adhesive system with the total etching step produces the thick hybrid layer when compared to the adhesive system with self-etching primer (Prati & others, 1998). Therefore, this thick layer in adhesive systems with the conditioning step might prevent the penetration of fluoride to dentin. On the other hand, a few micrometers of the radio-opaque layer were observed around Z100 restorations in spite of no fluoride release from them. The authors reported that a radio-opaque layer was observed in the cavity wall adjacent to composite resin restoration (Itota & others, 1995). The results of this study showed that adhesion of resin composites had little effect on the thickness of layers, although the hybrid layer within the cavity wall dentin had an inhibitory effect against caries.

Also, there was no significant difference in the lesion depths among the three adhesive groups restored with F2000. The outer lesion was inhibited by the uptake of fluoride to the tooth surface (Dijkman & Arends, 1992). As the restored teeth were immersed in a liquid culture medium, fluoride released from F2000 compomer might diffuse into the medium and the concentration of fluoride might have a low-level at the root surface in all groups. Therefore, the use of adhesives would not affect the depth of the outer lesion.

This study showed no significant difference among bond strengths of the three adhesive systems in F2000. Therefore, it is suggested that use of these adhesives produces good adhesion to dentin in F2000 regardless of a Bis-GMA resin.

CONCLUSIONS

This *in vitro* study examined the effects of three different adhesives on a) fluoride release, b) inhibition of artificial secondary caries and c) tensile bond strength to dentin of a compomer restorative material. The adhesive that did not contain Bis-GMA showed the highest amount of fluoride release from a compomer and produced the thickest radio-opaque layers and best adhesion to dentin for compomer restoration in the three adhesives. The use of the compomer adhesive that does not contain Bis-GMA is recommended in order to provide optimal adhesion without a reduction in the potential for contact inhibition of secondary cavity wall caries.

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The Effect of Flexural Load Cycling on the Microleakage of Cervical Resin Composites

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Clinical Relevance

Occlusal forces, specifically those that generate tensile stresses on cervical restorations, may also affect long-term marginal integrity.

SUMMARY

Although several in vitro **studies have attempted to investigate the microleakage of Class V resin composites under loading, the effect of load cycling on marginal seal is still unclear. This may be due to the fact that axial loads were applied to the specimens. This study investigated the effect of flexural loads on marginal sealing of cervical resin composites. One hundred and fifty cervical wedge-shaped cavities were restored with Clearfil Photo Bond, Clearfil Liner Bond 2, Scotchbond Multi-Purpose with 10% maleic acid, Scotchbond Multi-Purpose with 35% phosphoric acid or Mac-Bond 2 according to the manufacturers' instructions. After the restorations were finished, 10 specimens from each group were immersed in 0.5% basic fuchsin solution to examine microleakage. Prior to dye solution immersion, 20 specimens were subjected to flexural load cycling (1 mm labio-lingual or linguo-labial displacement at the incisal edge, 10,000 cycles, 1 cycle/second). The data were analyzed using the Kruskal-Wallis test and the Mann-Whitney U-test ($p<0.05$). When the flexural loads were not applied, both the incisal and apical margins showed good marginal sealing, regardless of the adhesive system used. Labio-lingual loading significantly deteriorated the marginal integrity at the incisal enamel margins, except for those restored with Clearfil Photo Bond. However, only Clearfil Photo Bond demonstrated a significant increase in microleakage along the apical dentin margins. Linguo-labial loading had no significant effect on the marginal seal.**

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INTRODUCTION

Non-carious cervical lesions are often restored for esthetic reasons or because of hypersensitivity, even when caries is not clinically detected. Unfortunately, gingival margin discoloration and/or dislodgment of these restorations are more frequently observed in these restorations than in Class III and IV restorations (Davidson & Kemp-Scholte, 1989; Smales & Gerke, 1992; Browning & Dennison, 1996). These clinical prob-

lems may result from gap formation and subsequent microleakage between the restorative material and the cavity walls. According to current knowledge, gaps occur when contraction stresses exceed bond strength of a resin composite to a cavity wall (Davidson, de Gee & Feilzer, 1984). As a bonding substrate, dentin is less reliable than enamel. Non-carious cervical lesions often have both enamel and dentin margins, and therefore, resin composite restorations of these lesions tend to have poor clinical performance.

Progress in dentin adhesive technology has improved clinical performance of cervical resin composite restorations (Van Meerbeek & others, 1994). Therefore, considerable effort has gone into developing adhesive systems that can provide sufficiently strong and stable bond to dentin. Many *in vitro* studies have indicated that fourth generation adhesive systems show high bond strength to dentin as well as to enamel (Gwinnett & Yu, 1994; Fortin & others, 1994; Triolo, Swift & Barkmeier, 1995; Yokota & others, 1996). In addition, these adhesive systems have been found to improve the marginal sealing of cervical resin composite restorations (Holtan & others, 1993; Gwinnett & Yu, 1994; Vargas & Swift, 1994; Davidson & Abdalla, 1994).

It has been reported that occlusal stresses are concentrated in the cervical region (Spranger, 1995; Palamara & others, 2000). *In vivo* studies on Class V resin composite restorations have revealed that occlusal stresses affected their clinical performance (Qvist, 1983; Heymann & others, 1991; Van Meerbeek & others, 1993). However, most previous *in vitro* microleakage studies have not taken occlusal load stresses into consideration. Although several *in vitro* studies have been attempted to investigate the microleakage of Class V resin composite restorations under mechanical loading (Munksgaard, Itoh & Jörgensen, 1985; Mandras, Retief & Russell, 1991; Rigsby & others, 1992; Davidson & Abdalla, 1994), the effect of load cycling on marginal integrity remains unclear. This may result from vertical loads being applied to specimens along the long axes of the teeth. It is important to closely simulate clinical conditions in order to predict, as accurately as possible, the *in vivo* performance of materials. For *in vitro* microleakage studies of cervical lesions, lateral loads should also be applied, since the etiology of cervical lesions is probably more closely related to eccentric occlusal forces that induce flexure preferentially at the cervical regions (Lee & Eakle, 1984; Spranger, 1995).

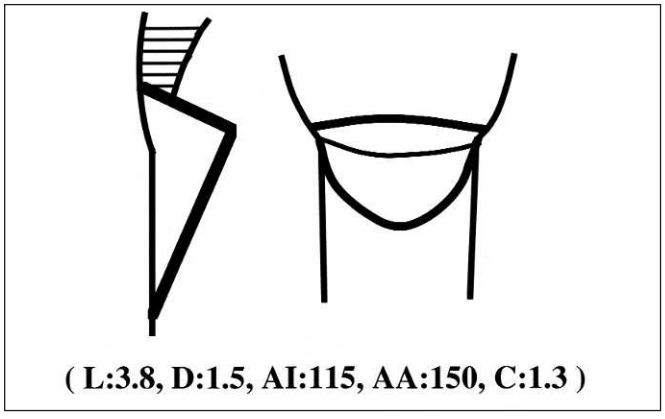

Figure 1. *Schematic drawing of the wedge-shaped cavity. L=inciso-apical width (mm), D=cavity depth (mm), AI=cavosurface angle at the incisal enamel margin (degree), AA=cavosurface angle at the apical dentin margin (degree), C=C-factor.*

This study investigated the effects of flexural load cycling on microleakage of cervical resin composite restorations.

METHODS AND MATERIALS

It has been reported that bovine teeth can be used in lieu of human teeth for *in vitro* bond strength and microleakage studies (Nakamichi, Iwaku & Fusayama, 1983; Reeves & others, 1995). Bovine incisors are preferable for this study because they are larger and easier to acquire than human teeth. After thawing the teeth under running water, soft tissues, such as gingiva and periodontal ligament attached to the teeth, were removed with a knife.

Cavity Preparation

One hundred and fifty wedge-shaped cavities (Figure 1), simulating typical cervical non-carious tooth surface loss, were prepared at the cemento-enamel junction on the labial surfaces of bovine incisors. The inciso-apical width of the cavity was approximately 3.8 mm and the depth was 1.5 mm. The cavosurface angles at the incisal and apical margins were 115° and 150°, respectively. In addition, the C-factor (the ratio of bonded surface area to unbonded surface area) of the cavity was approximately 1.3. The cavities were prepared with diamond burs (#202, Shofu Inc, Kyoto, Japan) at high speed with water coolant. Protect Varnish (Kuraray Co, Osaka, Japan) was then applied around the cavity to highlight the margins. Finally, the cavities were finished with the same diamond burs at low speed.

Restoration of the Cavities

Tables 1 and 2 list the adhesive systems and resin composites used in this study. The cavities were treated with these adhesive systems according to manufacturers' instructions.

For Clearfil Photo Bond (Kuraray Co, Osaka, Japan), all cavity walls were etched with K-etchant (37% phosphoric acid) for 30 seconds. The cavities were then rinsed for 15 seconds with a dental syringe, and dried thoroughly for 15 seconds with oil-free compressed air. Subsequently, a mixture of Photo Bond Universal and Catalyst adhesive resin was applied to the cavity walls.

Table 1: *Adhesive Systems Used in This Study*

Materials	Batch No.	Manufacturer	Components	Chemical Composition	pH of Conditioners
Clearfil Photo Bond	11157	Kuraray Co, Osaka, Japan	K-etchant Photo Bond univ Photo Bond cat	{37% phosphoric acid} {HEMA, ethanol} {MDP, Bis-GMA, HEMA}	0.06
Clearfil Liner Bond 2	11279G	Kuraray	LB Primer A LB Primer B LB Bond	{Phenyl-P, 5-NMSA, HEMA, ethanol} {HEMA, water} {MDP, Bis-GMA, HEMA, micro filler}	1.4
Scotchbond Multi-Purpose	510301	3M Dental Products, St Paul, MN 55144, USA	Etchant (Green) Etchant (Blue) Primer Adhesive	{10% maleic acid} {35% phosphoric acid} {HEMA, polyalkenoic acid copolymer, water} {Bis-GMA, HEMA}	1.2 0.6
Mac-Bond 2	430657	Tokuyama Co, Tokyo, Japan	Primer A Primer B Bonding Agent	{Mac-10, phosphate, acetone} {ethanol, water} {Mac-10, Bis-GMA, HEMA}	1.9

Abbreviations: HEMA= 2-hydroxyethylmethacrylate; MDP= 10-methacryloyloxydecyl dihydrogen phosphate; Bis-GMA= bispheny glycidyl metacrylate; Phenyl-P= 2-methacryloxyethyl phenyl hydrogen phosphate; 5-NMSA= N-methacryloyl 5-aminosalicylic acid; and Mac-10= 11-methacryloyloxy-1,1-undecanedicarboxylic acid

Table 2: *Resin Composites Used in this Study*

Materials	Batch No.	Manufacturer	
Clearfil AP-X	0526A	Kuraray	Filler content: 84.5 W%, Mean particle size: 3.0 μm, Elastic modulus: 10 GPa
Z100	6MW	3M	Filler content: 84.5 W%, Mean particle size: 0.6 μm, Elastic modulus: 13 GPa
Estelite	160Y7	Tokuyama	Filler content: 70.0 W%, Mean particle size: 0.2 μm, Elastic modulus: 10 GPa

After the adhesive was subjected to gentle air thinning, it was light cured for 10 seconds using a New Light VL-II curing unit (GC Co, Tokyo, Japan).

For Clearfil Liner Bond 2 (Kuraray Co, Osaka, Japan), the enamel and dentin walls were simultaneously treated with a mixture of LB Primer A and B for 30 seconds. After gentle air drying to evaporate the solvent, LB Bond was applied to the cavity and thinned with a gentle stream of air. This was followed by 20 seconds of light curing.

For Scotchbond Multi-Purpose with maleic acid (3M Dental Products), the entire cavity was etched with 10% maleic acid for 15 seconds, rinsed with water for 15 seconds and gently dried with compressed air for 10 seconds. Scotchbond Multi-Purpose Primer was then applied to enamel and dentin and gently air-dried. Finally, Scotchbond Multi-Purpose Adhesive was applied, gently air-thinned and light cured for 10 seconds.

For Scotchbond Multi-Purpose with phosphoric acid (3M Dental Products), the entire preparation was etched with 35% phosphoric acid for 15 seconds, rinsed with water for 15 seconds and gently dried with compressed air for 10 seconds. Scotchbond Multi-Purpose Primer was applied to enamel and dentin, and gently air dried. Scotchbond Multi-Purpose Adhesive was then applied, gently air thinned and light cured for 10 seconds.

For Mac-Bond 2 (Tokuyama Co, Tokyo, Japan), all cavity walls were conditioned with a mixture of Primer A and B for 20 seconds, then dried with a mild stream of air. Subsequently, Bonding Agent was applied as uniformly as possible and light cured for 10 seconds.

All treated cavities were filled with a single increment of proprietary resin composite (Clearfil AP-X for the Clearfil system; Z100 for the Scotchbond system; Estelite for Mac-Bond 2). They were then light cured for 60 seconds. Thirty restorations were prepared for each restorative system. After 24-hour storage in tap water, the excess restorative materials and Protect Varnish were removed with diamond burs (103R, Shofu Inc, Kyoto, Japan), and the restorations were finished with ultrafine diamond burs (A03ff, GC Co, Tokyo, Japan) at low speed under wet conditions.

Experimental Design

Ten restored teeth of each restorative system were then coated with a nail varnish up to 1 mm from the restoration margins and immersed in 0.5% basic fuchsin solu-

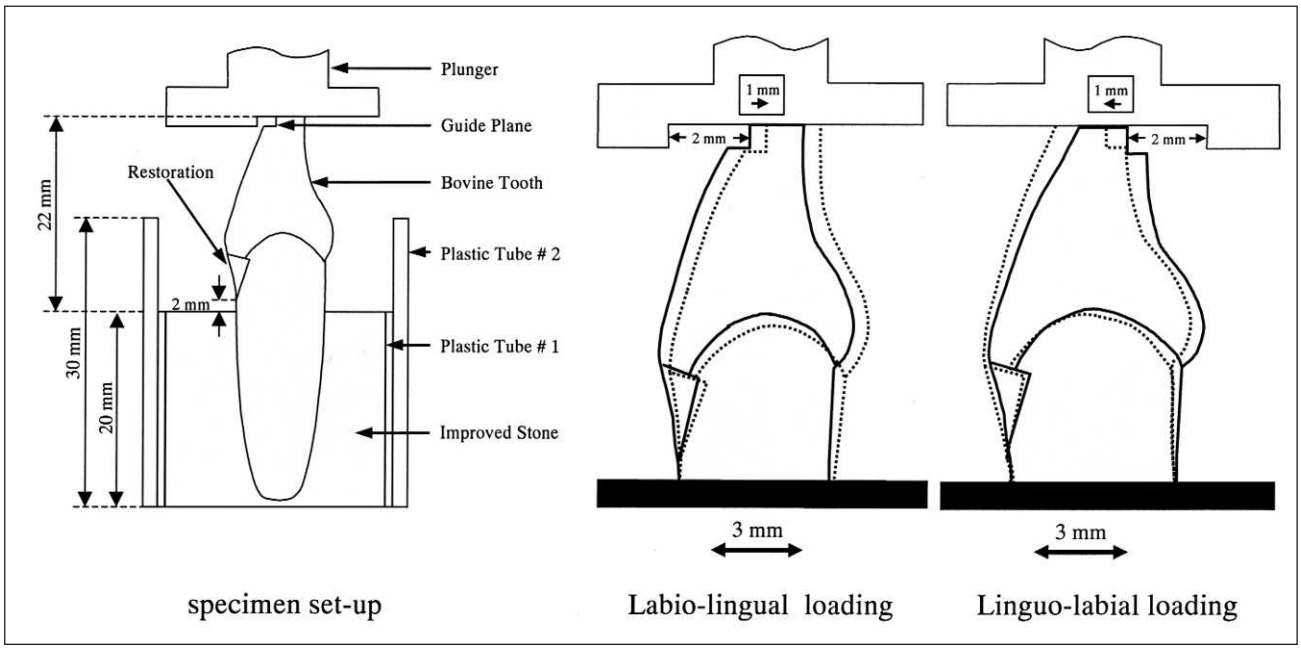

Figure 2. *Schematic drawing of the specimen set-up and flexural loading. The specimens were set on a testing machine so that the guide plane was located approximately 2 mm away from the vertical plane of the plunger. The table was repeatedly moved in a labio-lingual direction 3 mm against the stationary plunger. As a result, a lateral (labio-lingual or linguo-labial) displacement of approximately 1 mm was applied to the guide plane.*

tion for 24 hours. To avoid gap formation by dehydration of the tooth, the varnishing procedure was completed within 10 minutes. These specimens were classified as the control group.

Twenty specimens were subjected to flexural load cycling, as shown in Figure 2, prior to immersion in the dye solution. The root of the tooth was mounted in an upright position in a plastic tube (tube #1) up to 2 mm below the apical margin of the restoration with an improved dental stone (New Fujirock, GC Co, Tokyo, Japan). The height of the tube was 20 mm. The specimens were then kept in a container for 24 hours in which the relative humidity was 100%. The incisal enamel (approximately 22 mm above the upper surface of the tube) was sectioned perpendicular to the tooth axis with a low-speed diamond saw (Isomet, Buehler, Ltd, Lake Bluff, IL, 60044, USA). Subsequently, a guide plane, 1.7 mm in height, was prepared at the labial or lingual surfaces with a cylindrical diamond bur (B12, GC Co, Tokyo, Japan) mounted in a milling machine (EM Paralellometer, Royal, Tokyo, Japan). Each mounted specimen was placed in a plastic tube (tube #2), 30 mm in height, and a paper soaked in water was packed into the remaining space to prevent tooth dehydration. These prepared specimens were then set on a testing machine (Wagoseiki, Nagasaki, Japan) so that the guide plane was located approximately 2 mm away from the vertical plane of the plunger. The table was repeatedly moved in a labio-lingual direction 3 mm against the stationary plunger. As a result, a lateral (labio-lingual or linguo-labial) displacement of approximately 1 mm was applied to the guide plane. The magnitude of lateral load was approximately 110N and strain at the cemento-enamel junction was approximately $2.2x10^{-3}$. The loading was repeated 10,000 times at a rate of 1 cycle/second. Upon completion of cyclic loading, the teeth were removed from the improved stone, coated with the nail varnish and immersed in dye solution. Ten specimens were prepared for each loading group.

Evaluation of the Marginal Sealing

After 24-hour storage in the dye solution, the teeth were longitudinally sectioned through the center of the restoration with a low speed diamond saw. The sectioned surfaces were ground with SiC papers up to #1500 grit and examined under a light microscope at a magnification of 50x or 100x. The degree of dye penetration at the incisal enamel and apical dentin margins was scored according to the following criteria:

Incisal enamel margins;

0= No evidence of dye penetration

1= Dye penetration just at the cavity margin

2= Dye penetration up to dentino-enamel junction

3= Dye penetration beyond dentino-enamel junction

Apical dentin margins;

0= No evidence of dye penetration

1= Dye penetration just at the cavity margin

2= Dye penetration up to 1/3 of the cavity depth

3= Dye penetration greater than 1/3 of the cavity depth

Table 3: *Microleakage Scores at the Incisal Enamel Margins (n=10)*

Adhesive Systems	Subgroups	Microleakage Score 0	1	2	3	Sum of Scores	Median Score
	control	10				0	0
Clearfil Photo Bond	labio-lingual	10				0	0
	linguo-labial	10				0	0
	control	8	2			2	0
Clearfil Liner Bond 2	labio-lingual			9	1	21	2*
	linguo-labial	7	1	2		5	0
Schotchbond Multi-	control	7	3			3	0
Purpose with maleic	labio-lingual			5	5	25	2.5*
acid	linguo-labial	7	2	1		4	0
Schotchbond Multi-	control	10				0	0
Purpose with	labio-lingual	2	1	3	4	21	2*
phosphoric acid	linguo-labial	8	2			2	0
	control	9	1			1	0
Mac-Bond 2	labio-lingual	4		3	3	15	2*
	linguo-labial	9	1			1	0

*: Significantly different from control at $p<0.05$.

Table 4: *Microleakage Scores at the Apical Dentin Margins (n=10)*

Adhesive Systems	Subgroups	Microleakage Score 0	1	2	3	Sum of Scores	Median Score
	control	7	3			3	0
Clearfil Photo Bond	labio-lingual	2	6	2		10	1*
	linguo-labial	7	3			3	0
	control	10				0	0
Clearfil Liner Bond 2	labio-lingual	9	1			1	0
	linguo-labial	10				0	0
Scotchbond Multi-	control	8	2			2	0
Purpose with Maleic	labio-lingual	6	4			4	0
Acid	linguo-labial	5	5			5	0.5
Scotchbond Multi-	control	7	3			3	0
Purpose with	labio-lingual	5	5			5	0.5
Phosphoric Acid	linguo-labial	6	4			4	0
	control	10				0	0
Mac-Bond 2	labio-lingual	10				0	0
	linguo-labial	9	1			1	0

*: Significantly different from control at $p<0.05$.

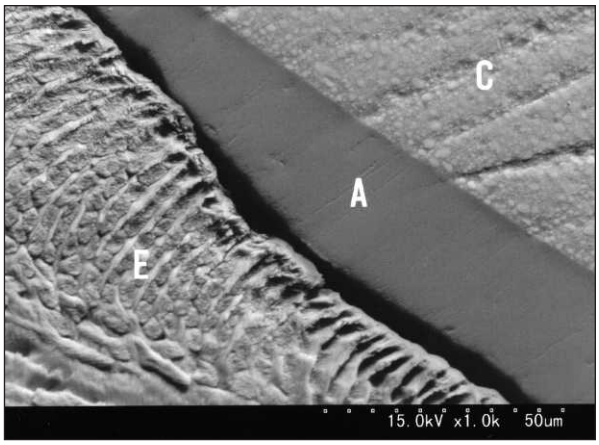

Figure 3. *SEM image of the resin-enamel interface restored with the Scotchbond Multi-Purpose with phosphoric acid system after repeated labio-lingual loading. The sectioned surface was polished and briefly treated with 37% phosphoric acid for five seconds. C=composite resin, A=adhesive resin, E=enamel. A gap occurred between the adhesive resin and enamel. The thickness of the adhesive resin layer gradually decreased as going up to the cavity margin.*

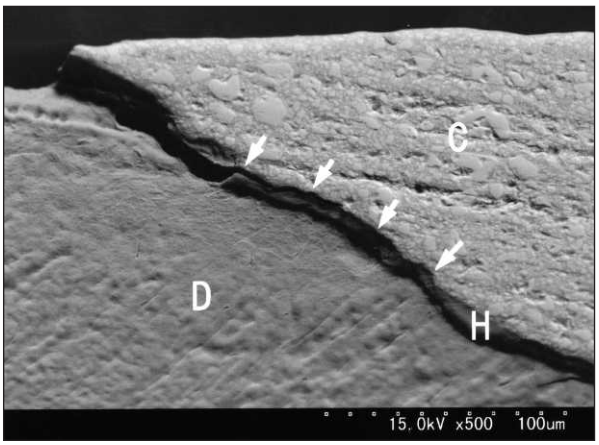

Figure 4. *SEM image of the resin-dentin interface restored with the Clearfil Photo Bond system after labio-lingual loading. The sectioned surface was polished and treated with 37% phosphoric acid for five seconds. C=composite resin, H=hybrid layer, D=dentin. A small gap (arrows) occurred between the hybrid layer and the composite resin.*

Statistics

Both halves of each sectioned tooth were examined. If these scores were found to be different, the higher score was recorded. The data were then statistically analyzed using the Kruskal-Wallis test and the Mann-Whitney U-test ($p<0.05$).

Scanning Electron Microscopic Inspection of Adhesive Interfaces After Load Cycling

Sectioned surfaces of the typical specimens were polished with increasingly fine diamond pastes (6, 3, 1 µm; Buehler Ltd). The polished surfaces were treated with 37% phosphoric acid (K-etchant) for five seconds, air-dried, coated with gold and observed with a scanning electron microscope (SEM) (3500 N, Hitachi, Tokyo, Japan).

RESULTS

Tables 3 and 4 summarize the microleakage scores at the incisal enamel and apical dentin margins. When no flexural loads were applied to the specimens (control group), both the incisal and apical margins showed good marginal sealing regardless of the adhesive system used. Statistical analysis revealed that labio-lingual loading had a significant effect on the marginal integrity of cervical resin composite restorations. The integrity of marginal sealing at the incisal enamel margins was significantly impaired by loading ($p<0.05$), except when Clearfil Photo Bond was used. SEM observation revealed gap formation between the adhesive resin and enamel (Figure 3). With regard to the apical dentin margins, only Clearfil Photo Bond showed a significant increase in microleakage scores ($p<0.05$). A small gap between the resin composite and the hybrid layer created by Clearfil Photo Bond was confirmed by SEM examination (Figure 4). On the other hand, linguo-labial loading did not significantly affect the marginal sealing of the cervical resin composite restorations.

DISCUSSION

The control group specimens demonstrated good marginal sealing. Table 5 lists the tensile bond strengths of the adhesive systems that were used. These tensile bond strengths to bovine enamel and dentin were determined by using the authors' laboratory methods (Yokota & others, 1996, 1999; Sata & others, 1999). Clearfil Photo Bond is a second-generation adhesive system, and its bond strength to dentin is relatively poor; however, even this adhesive system showed good marginal sealing. Polymerization contraction of a resin composite generated at the adhesive interface has been reported to increase as the C-factor increases (Feilzer, de Gee & Davidson, 1987). In addition, the magnitude of contraction stress depends on the volume or thickness of the resin composite layer (Hosoda & others, 1989). The cavity used in this study had a small C-factor (approximately 1.3) as well as a thin layer of resin composite at the apical portion. Therefore, the magnitude of polymerization contraction stress generated around the apical dentin margins might be less than the dentin bond strength of Clearfil Photo Bond. In addition, hygroscopic expansion of the resin composite may have been able to close any gap, if it occurred.

Axial load cycling has been reported as not impairing the good marginal sealing of the fourth generation adhesive systems (Davidson & Abdalla, 1994). However, flexural loads have never been applied to

Table 5: *Tensile Bond Strengths (MPa)*

Adhesive Systems	Enamel	Dentin	Significance
Clearfil Photo Bond	16.6 (4.6)	4.1 (2.3)	$p<0.05$
Clearfil Liner Bond 2	17.7 (3.1)	19.0 (2.2)	NS
Scotchbond Multi-Purpose with Maleic Acid	15.7 (3.5)	14.9 (2.0)	NS
Scotchbond Multi-Purpose with Phosphoric Acid	17.3 (3.0)	11.2 (2.6)	$p<0.05$
Mac-Bond 2	18.3 (3.9)	16.5 (3.4)	NS

All values are mean (S.D.). NS: not significantly different (n=10)

These data quoted from our previous studies (Yokota & others, 1996, 1999; Sata & others, 1999).

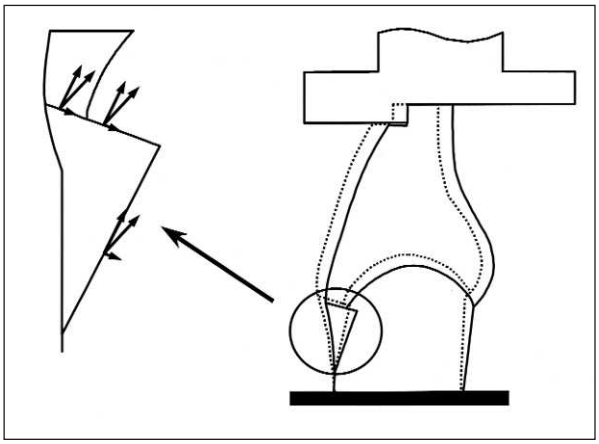

Figure 5. *Schematic drawing of the stresses induced by labio-lingual loading. It is assumed that greater normal stress is induced on the adhesive interface of the incisal wall rather than that of the apical wall. This is likely because the angle between the incisal wall and the direction of stress is closer to 90°.*

investigate the microleakage of cervical resin composite restorations in *in vitro* experiments. Lee & Eakle (1984) and Spranger (1995) have suggested that eccentric occlusal forces could possibly cause non-carious cervical lesions. Heymann & others (1991) reported that factors related to tooth flexure, such as stressful occlusion, were significantly associated with retention failures of Class V resin composite restorations. They indicate that flexural loads would be more useful and reasonable in the assessment of microleakage, especially for non-carious cervical lesions. This study first showed that repeated labio-lingual loading led to deterioration in the marginal integrity of all the adhesive systems used. Labio-lingual loading could possibly generate greater tensile stress at the adhesive interface than axial loading, which may result in bond degradation. It should be noted that a lateral displacement of approximately 1 mm is much greater than that encountered in clinical situations. However, this magnitude of displacement was applied in order to magnify the effect of flexural loading. In addition, there may be no significant difference in the stress distribution pattern under loading between human and bovine incisors despite differences in cavity and tooth size.

In the case of Clearfil Photo Bond, microleakage occurred only at the apical margins. When induced tensile stress exceeds bond strength, bond disruption and gap formation subsequently occurs. Even if tensile stress does not exceed bond strength, a fatigue bond fracture could result from frequent load application. Fatigue bond fracture is likely to occur at the adhesive interface, where the greatest discrepancy exists between induced stress and bond strength. Clearfil Photo Bond shows significantly higher bond strength to enamel than dentin. The leakage pattern of this system may be attributed to its adhesive property.

In the case of Clearfil Liner Bond 2, Scotchbond Multi-Purpose with maleic acid and Mac-Bond 2, microleakage mainly occurred at the incisal enamel margins. Preparation of the enamel bevel, pretreatment of the enamel wall with phosphoric acid or prolonged application of self-etching primer has been demonstrated to significantly reduce microleakage at the incisal enamel margins of these adhesive systems (Ferrari, Goracci & Garía-Godoy, 1997; Yokota & others, 1999; Sata & others, 1999). In addition, it has also been reported that enamel etching using acids of higher pH, shorter application periods or lower concentration of acids may not adequately etch the enamel (Swift & Cole, 1993; Triolo & others, 1993; Saunders & Saunders, 1996). In turn, this may result in weaker bond strength than conventional treatment with phosphoric acid (30-40%). Single Bond is an advanced version of Scotchbond Multi-Purpose. For this system, the manufacturer advises total etching with 35% phosphoric acid. With regard to this adhesive system, the marginal integrity at the incisal margins did not deteriorate in spite of labio-lingual loading (Kubo & others, 1998). These results support this study's hypothesis that the microleakage pattern was caused by the decrease in bond strength to enamel. Another possible explanation is the increase in bond strength to dentin. Enamel and dentin bond strengths for these adhesive systems do not differ significantly. It has been indicated that the relationship between enamel and dentin bond strengths has an effect on the microleakage pattern (Kubo & others, 1994; Fortin, Perdigão & Swift, 1994; Saunders & Saunders, 1996). Generally, induced stress at the adhesive interface may significantly decrease immediately after a bonding fracture has occurred. The stress induced at the incisal walls for these adhesive systems might be greater than that for Clearfil Photo Bond, since good adhesion was maintained at the apical dentin walls. From the results of

this study, the authors believe that greater normal stress was induced on the adhesive interface of the incisal wall rather than the apical wall. This is likely because the angle between the incisal wall and the direction of stress is closer to 90° (Figure 5). Therefore, the incisal margins might be more susceptible to microleakage. However, further studies are necessary to demonstrate the detail of stress distribution.

Contrary to the authors' expectations, Scotchbond Multi-Purpose with phosphoric acid, which also has significantly higher bond strength to enamel than to dentin, had a different leakage pattern from that of Clearfil Photo Bond. This may be due to the decrease in enamel bond strength. It is reported that Scotchbond Multi-Purpose showed a significant decrease in enamel bond strength when etched enamel was coated with dentin primer (Woronko, Germain & Meiers, 1996). In addition, owing to the lower viscosity of adhesive resin, the thin adhesive layer around the incisal enamel margin may lead to a decrease in bond strength. The increase in dentin bond strength could also have an effect on the microleakage pattern.

When the load is applied linguo-labially, compressive and shear stresses may be induced at the adhesive interfaces. Compressive and shear stresses may cause bonding fractures between a resin composite and cavity walls. However, compressive and shear stresses may have considerably less effect on debonding than tensile stresses. The prevailing results indicated that under current experimental conditions, load cycling with only 10,000 repetitions did not generate fatigue bond fractures.

CONCLUSIONS

The overall findings of this study suggest that occlusal forces that generate tensile stress on cervical restorations may affect the marginal integrity of cervical resin composite restorations. It is important for *in vitro* studies on microleakage of cervical lesions to take flexural loads into consideration.

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Influence of Light Energy Density on Effectiveness of Composite Cure

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Clinical Relevance

Light energy density influences the effectiveness of composite cure. Use of low light intensities with soft-start polymerization and pulse-delay techniques must be compensated for with higher intensity light phases.

SUMMARY

This study investigated the influence of light energy density (intensity x time) on the effectiveness of composite cure in view of the curing profiles of new light-polymerization units. This investigation used a digital microhardness tester to evaluate the hardness of the top/bottom surfaces and hardness ratio of 2 mm thick composite specimens after exposure to different light energy densities. Parameters included five light intensities (200, 300, 400, 500 and 600 mW/cm^2) and nine irradiation times (10, 20, 30, 40, 60, 80, 100, 120 and 180 seconds). Six samples were evaluated for each light energy density. KHN values and the hardness ratio obtained with 40 seconds cure at 400 mW/cm^2 was used as control. Results were analyzed with one-way ANOVA and Scheffe's post-hoc test at significance level (0.05). Correlation between curing time and hardness values and ratio was done using Pearson's correlation at significance level 0.01. Results showed that the adequate hardness for surface finishing could be obtained with 20 seconds irradiation at lower intensities of 200 or 300 mW/cm^2. Optimal cure of the bottom surfaces could not be achieved with 200 mW/cm^2, but was attained with 300 mW/cm^2 only after 120 seconds of irradiation. Optimal cure of the bottom surfaces was possible with 30 and 20 seconds irradiation at 500 and 600 mW/cm^2, respectively. Effective cure was not achieved with low light intensities (200 to 300 mW/cm^2) but could be achieved with high intensities (500 and 600 mW/cm^2) after 30 seconds of irradiation.

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INTRODUCTION

Light-activated resin composites, introduced in the 1970s, revolutionized clinical dentistry by maximizing working time and minimizing setting time. Over the last few years, composite restoratives and adhesive techniques have become the foundation of modern dentistry. The hardening of a dental composite results from a chemical reaction between dimethacrylate resin monomers that produces a rigid and heavily cross-linked polymer network surrounding the inert filler particles (Ferracane, 1995). The extent of this reaction, often referred to as the degree or effectiveness of cure, is very important in that it dictates many physical and mechanical properties of the composite restoration (Asmussen, 1982a). It is also vital to ensuring that clin-

ical problems do not arise from cytotoxicity of inadequately polymerized materials (Caughman & others, 1991). Effectiveness of composite cure may be directly or indirectly assessed. Direct methods that assess degree of conversion, such as infrared spectroscopy and laser Raman spectroscopy, have not been accepted for routine use because these methods are complex, expensive and time-consuming (Rueggeberg & Craig, 1988). Indirect methods have included visual, scrapping and hardness testing. Incremental surface hardness has been shown to be an indicator of the degree of conversion (Asmussen, 1982b), and a good correlation between Knoops hardness and infrared spectroscopy has also been reported (DeWald & Ferracane, 1987).

An inherent disadvantage of resin composites is that they shrink during light polymerization (Sakaguchi & others, 1991; Yap & others, 2000). Commercial composite materials contract by 2 to 5 volume percent during polymerization (Ferracane, 1992). This shrinkage results in significant stresses in the composite-tooth bond and surrounding tooth structure that may lead to bond failure and formation of microcracks in tooth (Feilzer, de Gee & Davidson, 1987; Bowen, Nemoto & Rapson, 1983). To overcome the problem of polymerization shrinkage, several approaches have been introduced. The first and most common approach involves the incremental placement of composites and allowing composite to contract freely to the adhesive surface (Davidson, 1986). The second is the application of liners (Kemp-Scholte & Davidson, 1990). The last and most recent approach is to slow down the polymerization process by initial reduction of resin conversion (Davidson & Feilzer, 1997).

High intensity lights may provide higher values for degree of conversion, but they also produce higher contraction strains during composite polymerization (Sakaguchi & Berge, 1997). A slower curing process that permits composite flow may allow for stress relaxation to take place during photopolymerization (Sakaguchi & Berge, 1998). As the polymerization process is dependent on total light energy rather than light intensity alone (Miyazaki & others, 1996), a slower curing process with an equivalent degree of conversion can be obtained by applying a lower intensity light for a longer time or using variable intensities over a given time period. Examples of the latter include soft-start polymerization and pulse-delay cure. The soft-start polymerization technique involves a step-wise modulation of light energy from low-to-high intensities, while the pulse-delay cure consists of an initial low-energy dose, a waiting period where surface finishing is done, followed by curing at a high intensity. Central to both these techniques is the light energy density (intensity x time).

The objective of this research was to investigate the influence of light energy density on the effectiveness of composite cure in view of the curing profiles of these new light-polymerization units. The information gained will help clinicians optimize the use of these new curing lights and maximize chairside productivity. In addition, the data obtained serves as the foundation for further research on the pulse and pulse-delay cure techniques.

METHODS AND MATERIALS

A mini-filled resin composite (Z100; 3M Dental Products, St Paul, MN 55144, USA) of A2 shade and a commercial light-cure unit that allowed for independent command over light intensity and time (VIP; BISCO Inc, Schaumburg, IL 60193 USA) were selected for this research. VIP (Variable Intensity Polymerizer) was engineered to provide high-intensity light in situations demanding rapid intense polymerization such as sealants and veneers and to deliver multiple-curing intensities for composite restorations. VIP has an output wavelength range of 400 to 500 nm and is programmed with preset exposure times of 2 to 5, 10, 20 and 30 seconds and a continuous mode of up to 225 seconds. The programmed intensity or power settings are 100, 200, 300, 400, 500 and 600 mW/cm^2. This allows clinicians to manually select any time and intensity combinations or use pre-programmed values, customizing the curing procedures specific to the composites being used. VIP also incorporates a radiometer that permits auto-calibration.

The current study used a digital micro-hardness tester (FM7; Future-Tech Corp, Tokyo, Japan) to evaluate the hardness of the top/bottom surfaces and hardness ratio of 2 mm thick composite specimens after exposure to different light energy densities. Parameters investigated included five light intensities (200, 300, 400, 500 and 600 mW/cm^2) and nine irradiation times (10, 20, 30, 40, 60, 80, 100, 120 and 180 seconds). Before beginning the experiment, the light intensities were checked with both the in-built radiometer and another commercial radiometer (CureRite; EFO Inc, Ontario, Canada). Readings from both radiometers were similar and the programmed light intensities (200 to 600 mW/cm^2) were found to be accurate. The composites were placed in black Delrin molds with square cavities 2 mm deep and 4 mm wide/long and confined between two opposing acetate strips (Hawe-Neos Dental, Bioggio, Switzerland) to ensure smooth surfaces and to minimize inhibition of polymerization by oxygen (Finger & Dreyer Jørgensen, 1976). A glass slide (1 mm thick) was then placed on the molds, and excess material was extruded by application of pressure. The composites were then irradiated from the top through the glass slide and acetate for 10 seconds at the different light intensities (that is, 200 to 600 mW/cm^2). Immediately after light polymerization, the acetate strips were removed, and the speci-

mens in their molds, were positioned centrally beneath the micro-hardness tester to assess Knoops hardness number (KHN) of the top and bottom surfaces. A 500g load was applied through the indenter with a dwell time of 15 seconds. KHN was computed by the microprocessor from the equation KHN = 14.2 (F/d^2), where F is the test load in kg and d is the longer diagonal length of an indentation in millimeters. Six specimens were made for each light intensity. KHN readings after 10 seconds were recorded, and the composites were then further irradiated in 10 seconds increment up to 40 seconds, for a total of 60, 80, 100, 120 and 180 seconds through the glass slide and acetate strip. Hardness readings were taken at each time increment and mean hardness ratio was calculated using the following formula: Hardness ratio = KHN of bottom surface/KHN of top surface.

Based on the control intensity of 400 mW/cm^2 and the manufacturer's recommended irradiation time of 40 seconds, two classification of cure was defined. Adequate cure of surfaces is achieved when surface hardness statistically compares with that obtained with 400 mW/cm^2 for 40 seconds. Optimal cure is attained when surface hardness is equal to or greater than that obtained with 400 mW/cm^2 for 40 seconds (that is, top surface KHN ≥ 73 and bottom surface

Table 1: *Mean KHN at the Top/Bottom Surfaces and Hardness Ratio*

Intensity (mW/cm^2)	Curing Time (Seconds)	Treatment	KHN Top	KHN Bottom	Hardness Ratio
200	10	1	49.48 (1.54)	21.45 (0.96)	0.43 (0.01)
	20	2	62.09 (5.52)	28.57 (2.57)	0.46 (0.06)
	30	3	69.60 (2.42)	37.80 (3.05)	0.54 (0.04)
	40	4	70.47 (1.04)	40.65 (2.39)	0.58 (0.03)
	60	5	71.35 (2.86)	43.45 (3.80)	0.61 (0.05)
	80	6	70.62 (2.75)	46.28 (4.82)	0.66 (0.07)
	100	7	71.58 (2.53)	50.17 (2.58)	0.70 (0.05)
	120	8	71.93 (3.06)	49.73 (6.73)	0.69 (0.10)
	180	9	79.00 (2.65)	51.18 (4.13)	0.65 (0.05)
300	10	10	55.68 (1.32)	26.85 (2.28)	0.48 (0.05)
	20	11	64.67 (2.52)	35.25 (2.47)	0.55 (0.03)
	30	12	69.10 (0.72)	43.25 (2.39)	0.63 (0.02)
	40	13	70.82 (1.59)	45.80 (1.81)	0.65 (0.02)
	60	14	70.95 (2.48)	49.93 (3.82)	0.70 (0.05)
	80	15	72.63 (3.49)	52.02 (2.48)	0.72 (0.05)
	100	16	73.78 (3.86)	54.43 (2.41)	0.74 (0.04)
	120	17	76.02 (4.78)	57.83 (2.59)	0.76 (0.06)
	180	18	78.65 (3.98)	58.47 (1.81)	0.75 (0.03)
400	10	19	58.52 (1.93)	32.43 (4.10)	0.55 (0.06)
	20	20	67.28 (2.93)	45.35 (3.55)	0.68 (0.06)
	30	21	70.28 (1.85)	53.55 (5.55)	0.76 (0.07)
	40	22	73.35 (0.80)	57.45 (5.44)	0.78 (0.07)
	60	23	74.60 (1.52)	58.68 (3.87)	0.79 (0.05)
	80	24	74.83 (2.72)	61.67 (3.53)	0.82 (0.02)
	100	25	77.92 (4.05)	60.85 (3.34)	0.78 (0.02)
	120	26	78.90 (3.62)	63.27 (3.96)	0.80 (0.05)
	180	27	81.03 (1.89)	64.30 (2.11)	0.79 (0.03)
500	10	28	62.70 (2.08)	44.58 (2.55)	0.71 (0.03)
	20	29	68.72 (2.44)	54.27 (3.87)	0.79 (0.05)
	30	30	73.23 (1.11)	62.13 (2.51)	0.85 (0.03)
	40	31	77.38 (2.22)	63.98 (2.57)	0.83 (0.03)
	60	32	78.92 (0.92)	66.08 (1.46)	0.84 (0.02)
	80	33	81.48 (0.97)	69.35 (2.06)	0.85 (0.02)
	100	34	82.42 (1.32)	72.02 (1.13)	0.87 (0.02)
	120	35	80.18 (2.71)	71.80 (1.60)	0.90 (0.04)
	180	36	83.73 (1.15)	75.45 (1.78)	0.90 (0.02)
600	10	37	63.68 (2.28)	43.77 (2.19)	0.68 (0.02)
	20	38	69.63 (1.68)	56.77 (3.10)	0.82 (0.05)
	30	39	74.15 (1.15)	62.72 (2.06)	0.85 (0.02)
	40	40	76.72 (1.40)	66.83 (0.98)	0.87 (0.01)
	60	41	80.27 (1.74)	70.27 (2.08)	0.88 (0.03)
	80	42	82.48 (1.34)	71.83 (1.97)	0.87 (0.03)
	100	43	83.35 (0.92)	73.52 (1.49)	0.88 (0.02)
	120	44	84.47 (1.27)	75.87 (1.62)	0.90 (0.02)
	180	45	87.13 (3.19)	77.98 (1.92)	0.90 (0.03)

KHN ≥ 57). Polymerization is deemed to be effective if optimal cure is achieved for both top and bottom surfaces and hardness ratio is ≥ 0.78. The results were analyzed with one-way ANOVA and Scheffe's post-hoc test at significance level 0.05. Correlation between curing time and hardness values and ratio was done using Pearson's correlation at significance level 0.01.

RESULTS

Table 1 shows the mean KHN at the top/bottom surfaces and hardness ratio. Results of statistical analysis is shown in Table 2, and the correlation between curing time and KHN at the top/bottom surfaces and hardness ratio is reflected in Table 3. Figures 1 to 3 show the mean KHN of the top/bottom surfaces and hardness ratio with increase cure time.

At the top surface, the control group (T22) was significantly harder than irradiation at 200, 300 and 400 mW/cm² (T1, T10 and T19) for 10 seconds. This means that adequate cure can be achieved for surface finishing with just 20 seconds irradiation at 200 mW/cm². A significant increase in surface hardness, as compared to the control, was only attained after irradiation for 180 seconds at 600 mW/cm² (T45). Although this may increase the degree of conversion and physico-mechanical properties of composite restorations, it is not clinically viable and may result in greater polymerization shrinkage. Optimal cure (KHN ≥ 73) was accomplished after 180 seconds of irradiation at 200 mW/cm² (T9) and greater than 80 seconds of irradiation at 300 mW/cm² (T15 to T18). With higher intensities (500 and 600 mW/cm²), optimal cure at the top surface was attained with 30 seconds of irradiation (T30-36 and T39-45).

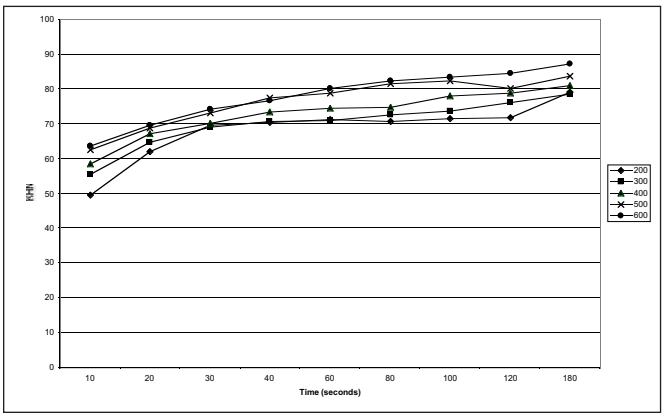

Figure 1. *Mean KHN of the top surface with increase cure time.*

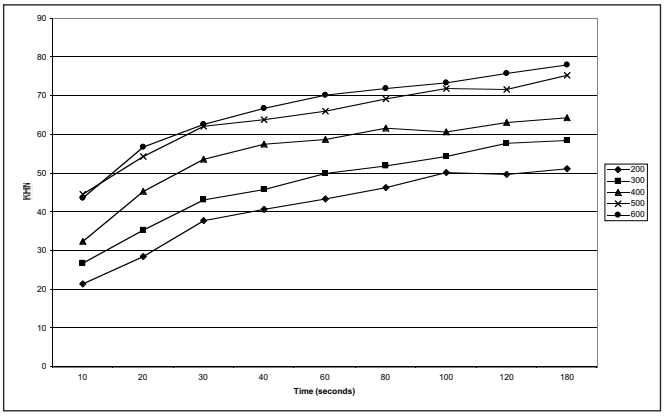

Figure 2. *Mean KHN of the bottom surface with increase cure time.*

At the bottom surfaces, adequate cure can be achieved with 80 seconds irradiation at 200 mW/cm² (T6), 40 seconds irradiation at 300 mW/cm² (T13) and 20 seconds irradiation at 400 mW/cm² (T20). Significant differences in hardness of the bottom surface, as compared to the control, was observed only after 100 seconds irradiation at 500 mW/cm² (T34-36) and 80 seconds irradiation at 600 mW/cm² (T42-45). Optimal cure of the bottom surface (KHN ≥ 57) could not be achieved with an intensity of 200 mW/cm² and was attained only after 120 seconds of irradiation at 300 mW/cm² (T17). At intensities of 500 and 600 mW/cm², optimal cure was attained after 30 and 20 seconds of irradiation, respectively.

Significant differences in hardness ratio as compared to the control are reflected in Table 2. Effective cure was not achieved with lower light inten-

Table 2: *Results of Statistical Analysis*

Variables	Differences
KHN Top	T1, T10 and T19 < Control (T22) < T45
KHN Bottom	T1-5, T10-12 and T19 < Control (T22) < T34-36 and T42-45
Hardness Ratio	T1-3, T10-11 and T19 < Control (T22)

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

Table 3: *Correlation Between Curing Time and KHN at the Top/Bottom Surfaces and Hardness Ratio*

Intensity (wM/cm²)	Variable	KHN Top	KHN Bottom	Hardness Ratio
200	**Curing Time**	0.72 (S)	0.79 (S)	0.67 (S)
300		0.77 (S)	0.84 (S)	0.75 (S)
400		0.80 (S)	0.71 (S)	0.52 (S)
500		0.79 (S)	0.83 (S)	0.71 (S)
600		0.86 (S)	0.81 (S)	0.60 (S)

Results of Pearson correlation (p<0.01); S indicates statistical significance.

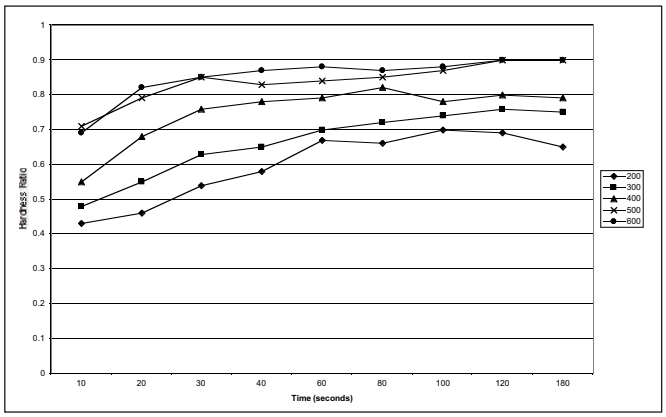

Figure 3. *Mean hardness ratio with increase cure time.*

sities (200 and 300 mW/cm^2) but was attained with high light intensities (500 and 600 mW/cm^2) after 30 seconds of irradiation. Correlation between curing time and KHN at the top/bottom surfaces and hardness ratio was significant for all light intensities.

DISCUSSION

Polymerization of resin composites generally decrease from the surface of the restoration inwardly. As a result, apparent hardness of the top or external surface is not an adequate indicator of complete material polymerization (Tate, Porter & Dosch, 1999). The introduction of soft-start polymerization and pulse-delay cure techniques to reduce photopolymerization shrinkage had further complicated the aforementioned issue. It is generally accepted that an intensity of 300 mW/cm^2 or greater in the wavelength range of 450 to 500 nm (peak absorption at 470 nm) is needed for complete polymerization of composite up to 2 mm in depth (Lee & others, 1993; Bayne & Taylor, 1995). However, several authors have suggested a minimum intensity of 400 mW/cm^2 for routine polymerization (Rueggeberg, Caughman & Curtis, 1994; Manga, Charlton & Wakefield, 1995). This light intensity (400 mW/cm^2), together with an irradiation time of 40 seconds (manufacturer's recommended cure time), was used as the control for this study. Both soft-start polymerization and pulse-delay cure techniques utilize a low-intensity light phase that is subsequently compensated for by a high-intensity light phase. There are several possible permutations and combinations of light energy density (intensity x time) to achieve effective cure. Before developing new light curing profiles involving multiple combinations of densities, it is important to establish the effectiveness of each light energy density. This had not been comprehensively reported in the literature and was the focus of this study. Composite specimens 2 mm thick were used, as it ensured uniform and maximum polymerization (Yap, 2000). At depths greater than 2 mm, the polymerization of composite is very susceptible to changes in light energy density (Rueggeberg & others, 1994). A2 shade was selected to minimize the effects of colorants on light penetration (Bayne, Heymann & Swift, 1994).

Optimal cure is essential for the top surface to produce stable, strong and durable composite restorations (Brosh & others, 1997; Condon & Ferracance, 1997). At the top surface, adequate cure for surface finishing can be achieved with just 20 seconds irradiation at 200 mW/cm^2. The light energy density recommended by BISCO during the pulse phase of the pulse-delay technique is three seconds at 100 mW/cm^2 for Z100 of A2 shade. This is followed by a waiting time of three to five minutes, where finishing is done and a final cure of 30 seconds at 500 mW/cm^2. Usage of such low pulse energy may result in a softer surface that may be prone to damage and excessive removal during finishing and polishing procedures. Optimal cure for the top surface was reached only after 180 seconds of irradiation at 200 mW/cm^2 and greater than 80 seconds irradiation at 300 mW/cm^2. With higher intensities (500 and 600 mW/cm^2), optimal cure was attained with just 30 seconds of irradiation. This was in agreement with BISCO's high-intensity light-phase regimen. ESPE Highlight (ESPE, Norristown, PA 19404, USA), a two-phase soft-start polymerization light system, also employs 30 seconds irradiation at high intensity (700 mW/cm^2) that was preceded by a 10 second curing phase at 150 mW/cm^2.

The top surface was not as susceptible to the effects of light intensities as compared to the bottom surface. This finding is in agreement with those of Rueggeberg & others (1994) and Sakaguchi & Berge (1998), who concluded that at the top surface of composites, only irradiation time is a significant factor contributing to monomer conversion. For the bottom surface, only optimal cure should be considered, as pulpal tissues are affected by the leaching of unpolymerized components. The latter cannot be guaranteed with just "adequate" cure. An *in vitro* evaluation of resin composites found that unreacted bis (phenol-A-glycidyl-methacrylate), trace amounts of benzophenone light stabilizer and a benzoyl peroxide initiator fragment leached from composites and were the source of toxic reactions in cell cultures (Rathburn & others, 1991). Removal of these extracts decreased the toxicity of resin composites by 90% in cell culture. Optimal cure of the bottom surface could not be achieved with an intensity of 200 mW/cm^2 and was attained only after 120 seconds of irradiation at 300 mW/cm^2. Therefore, light sources with intensity values between 200 and 300 mW/cm^2 should not be clinically used due to their poor cure characteristics. When used with soft-start polymerization and pulse-delay techniques, usage of such low intensities must be compensated with higher intensity light phases. Optimal cure of the bottom surface can be achieved with 30 seconds irradiation at 500 mW/cm^2 and 20 seconds irradiation at 600 mW/cm^2. Significant difference in cure of

the bottom surface was observed only after 100 seconds irradiation at 500 mW/cm^2 and 80 seconds irradiation at 600 mW/cm^2. Although higher light energy densities results in decreased residual monomer levels and rate of elution (Tanaka & others, 1991), they may result in increased shrinkage (Venhoven, de Gee & Davidson, 1996; Sakaguchi & Berge, 1997).

In the ideal situation, the degree of composite polymerization should be the same throughout its depth, and the hardness ratio should be one or very close to it as the hardness of the bottom surface should be identical to that of the top surface. As light passes through the bulk of composite, light intensity is greatly reduced due to light scattering, thus decreasing the effectiveness of cure (Ruyter & Øysæd, 1982). This scattering of light accounts for the difference in hardness between the top and bottom surfaces. The hardness ratio should not exceed 10 to 20% (that is, the hardness ratio should be approximately ≥ 0.8) for visible light-cured composites to be adequately polymerized (Pilo & Cardash, 1992). This was achieved with the control (40 seconds irradiation at 400 mW/cm^2). Despite the realization of optimal cure for both top and bottom surfaces with extended light irradiation, effective cure was not achieved with lower light intensities, as the hardness ratio was less than 0.78. Effective cure was achieved with 30 seconds irradiation at 600 and 500 mW/cm^2. Hence, these are the recommended light energy densities for the high intensity light phase for both soft-start polymerization and pulse-delay cure techniques. Correlation coefficient between curing time and KHN at the top/bottom surfaces and hardness ratio was significant and positive for all light intensities. When the duration of irradiation time is considered, over-curing of composites is not possible, only under-curing. The effectiveness of composite cure for combined light energy densities is currently being undertaken, together with polymerization shrinkage assessment. As the influence of light-energy density on composite cure may be both material and shade dependent, more research is required prior to establishing of new curing profiles.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. Adequate hardness for surface finishing could be obtained with 20 seconds irradiation at lower intensities of 200 or 300 mW/cm^2.
2. At 200 mW/cm^2, optimal cure of the top surface was achieved after 180 seconds of irradiation. Optimal cure of the bottom surface could not be achieved.
3. At 300 mW/cm^2, optimal cure of the top and bottom surfaces was achieved after 80 and 120 seconds of irradiation, respectively.
4. At 500 mW/cm^2, optimal cure of the top/bottom surfaces was achieved after 30 seconds of irradiation.
5. At 600 mW/cm^2, optimal cure of the top and bottom surface was achieved after 30 and 20 seconds of irradiation, respectively.
6. Effective cure was not achieved with low light intensities (200 to 300 mW/cm^2) but could be achieved with high intensities (500 and 600 mW/cm^2) after 30 seconds of irradiation.

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Influence of Veneering Composite Composition on the Efficacy of Fiber-Reinforced Restorations (FRR)

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M Shehata • P Marquis

Clinical Relevance

This investigation assessed the influence of storage time, up to six months, on the flexural properties of four commercially available fiber-reinforced veneer composites. In addition, two experimental composites were used to assess the influence of varying filler loading and resin matrix chemistry on the efficacy of fiber reinforced composites. The results demonstrated that the chemical composition of veneer composites is a critical factor in terms of the degree of reinforcement.

SUMMARY

This study investigated the influence of fiber reinforcement on the flexural properties of four commercial (Artglass, Belleglass HP, Herculite XRV and Solidex) veneering composites (Series A) and two experimental composites (Series B&C). This study investigated how the composition of the veneering composites influenced the enhancement of strength and modulus produced by fiber reinforcement. The formulation of the experimental composites were varied by changing the filler load (Series B) or the resin matrix chemistry (Series C) to assess the effect these changes would have on the degree of reinforcement.

In Series A, the commercial veneering composites were reinforced by an Ultra-High-Molecular-Weight Polyethylene fiber (UHMW-PE/Connect) to evaluate flexural properties after 24 hours and six months. In Series B, experimental composites with the same organic matrix but with different filler loads (40% to 80% by weight) were also reinforced by Connect fiber to evaluate flexural properties. In Series C, experimental composites (Systems 1-4) with the same filler load (76.5% by weight) but with different organic matrix compositions were reinforced by Connect fiber to evaluate flexural properties. For Series B and C, flexural properties were evaluated after 24 hours water storage.

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All the samples were prepared in a mold 2 mm x 2 mm x 25 mm and stored in distilled water at 37°C until they were ready for flexural testing in an Instron Universal Testing Machine using a crosshead speed of 1 mm/minute. The results showed no significant differences in the flexural strength (FS) between any of the commercial reinforced composites in Series A. The flexural modulus (FM) of the fiber-reinforced Belleglass HP group was significantly higher than for Artglass and Solidex. Water storage for six months had no significant ($p>0.05$) effect on the flexural strength of three of the four reinforced veneering composites. The flexural strength for Artglass was significantly reduced ($p<0.05$) by six-month water storage. In Series B, however, increasing the amount of filler loading improved the flexural modulus of the reinforced experimental composite but had no effect on its flexural strength. In Series C, changing the organic matrix formulation had no affect on flexural strength but affected the flexural modulus of the reinforced experimental composite.

INTRODUCTION

Fiber reinforcement of dental resins has been reported since the 1960s, but only within the last few years have systems have been marketed for use with fixed partial dentures. Continuous fiber-reinforced composites have a number of applications in restorative dentistry, including splinting, restoration of endodontically-treated teeth and bridgework (Freilich & others, 1999). Many factors affect the efficiency of reinforcement. One variable is the composition of the overlying veneering composite, especially the type of inorganic matrix (filler type, size) and the nature of the resin (organic) matrix. Properties of unreinforced resin composites can be markedly changed by variations in the composition of the resin matrix, the size and distribution of filler particles as well as the curing method employed for the system (Braden & others, 1997).

Fillers are incorporated for various reasons, such as improving strength, handling properties and conferring radiopacity, thus, reducing the coefficient of thermal expansion and minimizing polymerization shrinkage. In addition, Whiting & Jacobsen (1980) have shown that composite materials have higher elastic moduli and lower damping compared with unfilled resins.

Single filler additions may not provide as many improvements, however, several filler types used together may compensate for this. Fillers should be resistant to the chemical environment in the mouth, be colorless, non-toxic, match the refractive index of the polymer matrix, be relatively hard and have a reinforcing effect on the matrix phase. Among the substances that can fulfill these criteria, glass, glass ceramics, some silicates and silicon dioxide are available (Braden & others, 1997). A wide variety of inorganic-filled polymers have been characterized in terms of particle size, structure, density and porosity of filler. The property "polymer-filler interaction" is even more difficult to characterize. Ziegel & Romanov, (1973)

Table 1: *Description of the Four Veneering Composites Used in Series A*

Composite	Shade/Batch #	Organic Matrix	Inorganic Matrix	Curing Time	Curing Unit	Batch #	Mftr
Artglass (A)	D/104 DA2	Multifunctional methacrylic acid ester 30% by weight	Silicon dioxide and silanized barium-aluminum-silicate glass Average particle size 1µm 70% by weight	180 seconds	Unixs	30103	Kulzer, Germany
Belleglass HP (B)	TD/806056	Bis-GMA/TEGDMA	Barium glass fillers 78.7 % weight/and 65 % volume	140°C for 20 minutes/ under 60-80 psi nitrogen pressure	Belleglass unit	2800011	Kerr, USA
Herculite XRV (Laboratory) (H)	A3/3604-22876	Bis-GMA/TEGDMA	Barium glass fillers (78.5% by weight)	60 seconds	Spectrum/ Dentsply	02265	Kerr, USA
Solidex (S)	T/104 DA2	Co-polymers with multi-functional resin, 22% by weight. Conventional resins/ photo initiators 25% by weight	Inorganic ceramic micro-fillers 53% by weight	10 minutes	Solidilte EX	98129538	Shofu, Japan

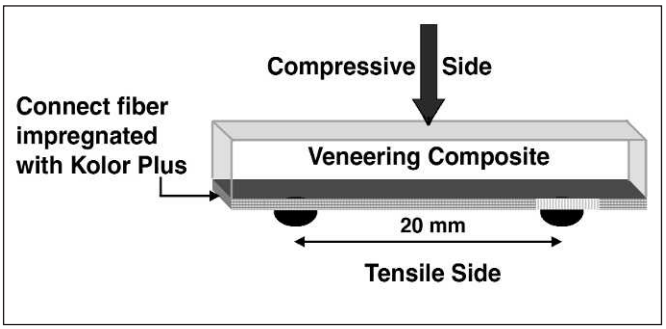

Figure 1. *A schematic diagram showing placement of fiber at the tensile side in Series A, B and C. The specimen was centrally loaded in the middle of the span.*

introduced this term to the dental literature. This property includes interfacial forces between the filler and the polymer and orientation of the polymer in the vicinity of the surface of the filler.

This study investigated the influence of commercial veneering composite composition on the flexural properties of fiber reinforced composites (FRCs). In addition, two experimental composites were used to assess the effects of varying filler loading and organic matrix composition of experimental composites reinforced by Ultra-High Molecular Weight Polyethylene Fiber.

METHODS AND MATERIALS

Series A

All flexural strength specimens were prepared in a polytetrafluoroethylene (PTFE) split mold with the dimensions 2 mm x 2 mm x 25 mm. Four types of commercial veneering composite (Table 1) were used to prepare groups of control and fiber-reinforced specimens for flexural testing. From each veneering composite, two unreinforced control groups (10 specimens/group for each of the two test time intervals) were prepared for three-point bend testing. Two fiber-reinforced groups (Connect fiber, Kerr, Orange, CA 92867, USA) were prepared for each veneering composite. Fiber was placed at the bottom of the mold (tensile side/Figure 1) after impregnation with Kolor Plus (Batch No 23401 Kerr, Orange, CA 92867, USA). Then, the overlying veneering composite was applied, taking care not to displace the impregnated fiber from the base of the mold. All samples were cured according to manufacturers' instructions (Table 1). All groups prepared in this series were stored for 24 hours or six months in distilled water at 37°C before testing. One hour after the specimens were removed from the incubator they were tested dry at room temperature by applying load at a rate of 1 mm/minute using an Instron Testing Machine (Instron Corp Model TM 5565, Canton, MA, USA).

A specially designed jig, supplied by the manufacturer of the universal testing machine, supported the samples during testing (Figure 1).

Series B

An experimental composite (supplied by 3M Dental Products, St Paul, MN 55144, USA) was used for this series of experiments. The resin matrix formulation and filler-type were based on the commercial product Z100. Connect fiber was used to reinforce the experimental composite with different filler loadings (40-80% by weight filler loading) and placed, as mentioned, in Series A. The composition of the experimental composite used in this series consisted of Bisphenol-A glycidylmethacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA). The filler was a synthetic material of zirconia/silica, its mean particle size being approximately 0.6 µm in diameter. Three control groups, without any fiber reinforcement (n=5 per group) of experimental composite (40, 60 and 80% by weight filler loading) were prepared for three-point bend flexural testing as previously described. Seven groups (n=5 per group) of experimental composite (40, 60, 70, 72, 74, 76 and 80% filler loading by weight) and reinforced with Connect fiber (tensile side) after wetting with Kolor Plus were also prepared for flexural property testing. The group size had to be restricted to five in this and Series C due to the limited availability of the batch of experimental materials. The samples were stored wet for 24 hours at 37°C prior to testing at room temperature.

Series C

Four experimental composites systems (Hereaus Kulzer, Wehrheim, Germany) were used (Table 2). All systems had the same amount of filler (76.5% by weight) and initiator concentrations. The only difference between them was in the relative proportion of TEGDMA, Bis-GMA and UDMA by weight in the resin matrix composition. From each system, two groups (five specimens/group) were prepared for flexural test-

Table 2: *Composition % by Weight of the Experimental Composite*ß *with Different Organic Matrices Used in Series C*

Component	System 1	System 2	System 3	System 4
UDMA	0.0	0.0	0.0	17.5
Bis-GMA	17.5	13.1	8.7	0.0
TEGDMA	4.4	8.7	13.1	4.4
Fillers*	76.5	76.5	76.5	76.5
Initiators	1.7	1.7	1.7	1.7
Total %	100.0	100.0	100.0	100.0

*Barium-aluminum-silicate glass, silanized, average particle size 1 µm.
ß Experimental composite supplied by Kulzer, Wehrheim, Germany.

ing. One group was reinforced with Connect fiber after impregnation with Kolor Plus and placed at the bottom of the mold. The other group served as the unreinforced control group.

All samples prepared in Series B and C were cured in a Unixs curing oven (Kulzer) for 180 seconds. Samples were stored in distilled water for 24 hours at 37°C before testing.

The mean and standard deviation of each group were calculated. The flexural test results for Series A were subjected to statistical analysis using separate three-way ANOVA's for the strength and modulus data (the independent variables being material [4 levels], storage time [two levels] and fiber [two levels]). Supplementary two-tailed, unpaired Student's *t*-tests were performed to compare specific pairs of means to test whether storage time (24 hours or six months) had any influence on strength or modulus. Series B and C data were analyzed by one-way analyses of variance (ANOVA) and post-hoc Tukey paired group comparison tests ($p<0.05$).

Table 3: *Series A Results: The Mean Flexural Strengths (FS) MPa & Moduli (FM) GPa (± SD) of Veneering Composites Without (Control) and with Connect Fiber Reinforcement Storage in Distilled Water at 37°C for 24 Hours (h) or 6 Months (m)*

FS	Artglass (A)	Belleglass HP (B)	Herculite XRV (H)	Solidex (S)
24h/Control	82.7 (12.7)^{b,1}	109.7 (15.9)^{a,1}	102.73 (11.6)^{a,1}	65.6 (7.9)^{b,1}
6 m/Control	68.0 (12.6)^{a,2}	80.6 (28.2)^{a,2}	88.5 (24.2)^{a,1}	69.8(12.6)^{a,1}
24 h/Fiber	261.6 (29.1)^{a,1}	242.1 (64.5)^{a,3}	239.2 (37.8)^{a,2}	265.2 (39.6)^{a,2}
6 m/Fiber	212.8 (32.0)^{a,2}	235.3 (59.1)^{a,3}	265.3 (60.5)^{a,2}	257.8 (35.5)^{a,2}
FM				
24 h/Control	6.1 (0.4)^{a,1}	8.3 (1.0)^{b,1}	7.6 (1.5)^{b,1}	4.9 (0.6)^{a,1}
6 m/Control	3.2 (1.2)^{a,2}	9.2 (0.7)^{b,1}	7.2 (1.0)b,1	5.2 (0.6)^{c,1}
24 h/Fiber	5.3 (0.6)^{a,1}	8.3 (1.5)^{b,1}	7.75 (1.2)^{b,1}	5.3 (0.5)^{a,1}
6 m/Fiber	5.4 (0.8)^{a,1}	8.6 (0.8)^{b,1}	8.1 (0.7)^{b,1}	5.8 (1.5)^{a,1}

For each row of FS and FM results, means with the same horizontal superscript letter were not significantly different ($p>0.05$) according to post-hoc Tukey test comparisons.
For each of the four separate blocks of FS and FM results, means with the same paired superscript number were not significantly different ($p>0.05$) according to two-tailed, unpaired Student's *t*-tests.

Determination of Flexural Results

The flexural strength and modulus were calculated using the following equations:

$$\text{Flexural strength (s) MPa} = \frac{3\,W\,I}{2\,b\,d^2}$$

$$\text{Flexural modulus (E) MPa} = \frac{SI^3}{4\,bd^3}$$

W is the maximum load, in Newtons, exerted on the specimen.

I is the distance, in millimeters, between the supports.

b is the width, in millimeters, of the specimen measured immediately prior to testing.

d is the height, in millimeters, of the specimen measured immediately prior to testing.

S is the slope of the initial straight-line portion of the load-extension curve, N/mm of extension.

RESULTS

Series A

Table 3 and Figures 2 and 3 list the flexural results and their statistical analysis. Results of the three-way

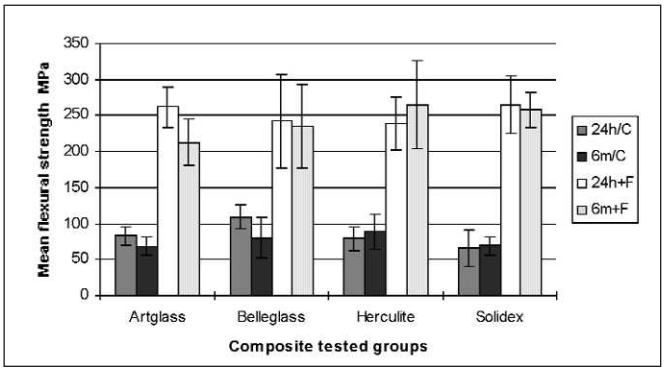

Figure 2. *Series A: The mean flexural strength (MPa) of unreinforced/reinforced commercial veneering composites after storage for 24 hours or six months in distilled water at 37°C. Error bars represent ± one standard deviation. C=control without fiber reinforcement, F=fiber reinforcement.*

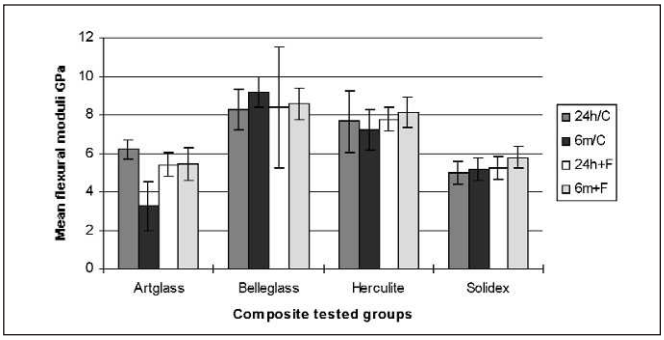

Figure 3. *Series A: The mean flexural moduli (GPa) of unreinforced/reinforced composites after storage for 24 hours or six months in distilled water at 37°C. Error bars represent ± one standard deviation.*

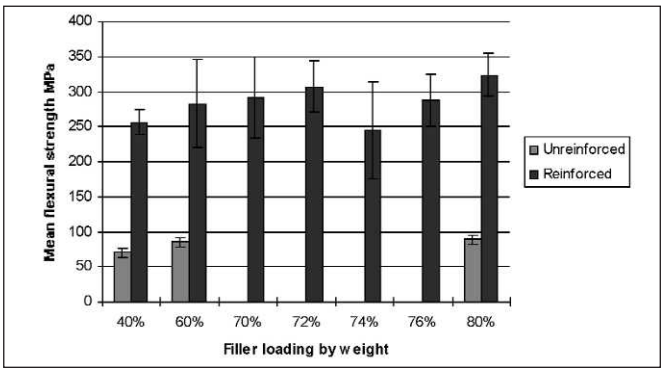

Figure 4. *Series B: The mean flexural strengths (MPa) of unreinforced/ reinforced experimental composites after storage for 24 hours in distilled water at 37°C. Error bars represent ± one standard deviation.*

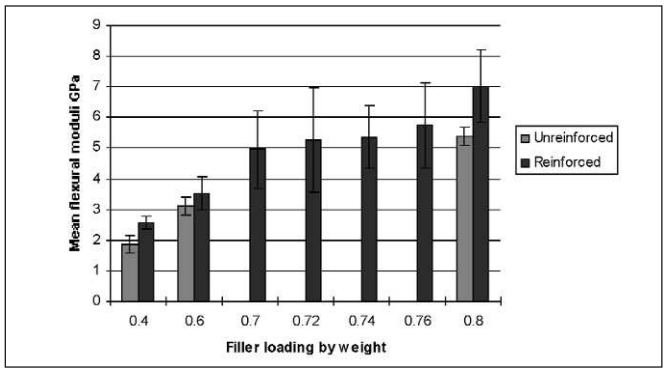

Figure 5. *Series B: The mean flexural moduli (GPa) of unreinforced/ reinforced tested experimental composites after storage for 24 hours in distilled water at 37°C. Error bars represent ± one standard deviation.*

Table 4: *Series B Results: The Mean Flexural Strength (FS) MPa & Modulus (FM) GPa (± SD) of the Experimental* Veneering Composites with Different Filler Loadings by Weight, Before and After Reinforcing with Connect Fiber Specimens Stored for 24 Hours in Distilled Water at 37°C Before Testing*

	FS		FM	
Filler Loading % by Weight	**Without Fiber**	**With Fiber**	**Without Fiber**	**With Fiber**
40	70.4 (13.8)[a]	256.8 (17.8)[a]	1.9 (0.2)[a]	2.6 (0.2)[a]
60	85.8 (9.0)[b]	282.8 (62.8)[a]	3.1 (0 .4)[b]	3.5 (0.5)[a,b,c,d,e]
70	------	290.9 (58.1)[a]	------	4.9 (1.3)[b,c,d,e,f]
72	------	307.2 (36.1)[a]	------	5.3 (1.7)[c,d,e,f]
74	------	245.0 (69.6)[a]	------	5.4 (1.0)[d,e,f]
76	------	287.4 (37.9)[a]	------	5.8 (1.4)[e]
80	89.3 (6.7)[b]	324.1 (30.6)[a]	5.4 (0.3)[c]	7.0 (1.2)[f,e]

Means with the same vertical superscript letter were not significantly (p>0.05) different according to post-hoc Tukey test comparisons.

* Experimental composite supplied by 3M Dental Products.

ANOVA on strength data revealed that the factor "fiber" was highly significant (p<0.001) and "time" had also just reached significance (p=0.04). The three-way ANOVA on the modulus data revealed that the only significant factor was "material" (p<0.001).

Unreinforced Groups

After 24 hours water storage, the flexural strength of the tested materials ranked as follows: BelleglassHP (B)>Artglass (A) & B>Solidex (S) p<0.05 and B=Herculite (H). Water storage between one day and six months did not affect the flexural strength for two of the four composite materials. For Artglass & Belleglass, there was a significant reduction in flexural strength (p<0.05) after six months. After six months water storage, the mean flexural strengths of the four products did not differ significantly (p>0.05).

After 24 hours water storage, there were significant differences in the flexural modulus of the veneering composites as follow as B=H>A=S. Water storage between one day and six months significantly reduced (p<0.05) the flexural modulus of Artglass but had no statistically significant effect on the flexural modulus of the other products (p>0.05). After six months water storage, the flexural modulus of Artglass was significantly lower than for the other groups (Table 3/Figures 2 and 3).

Reinforced Groups

Water storage for six months had no significant (p>0.05) effect on the flexural strength of three of the four reinforced veneering composites. The flexural strength of Artglass was reduced significantly (p<0.05) by six-month water storage. The flexural strength of the reinforced veneering composites after fiber reinforcement and water storage for six months was approximately three times greater for the matching groups (Table 3 and Figures 2 and 3).

After 24 hours water storage, the flexural modulus of the four reinforced veneering composites tested was B=H>A=S (Table 3).

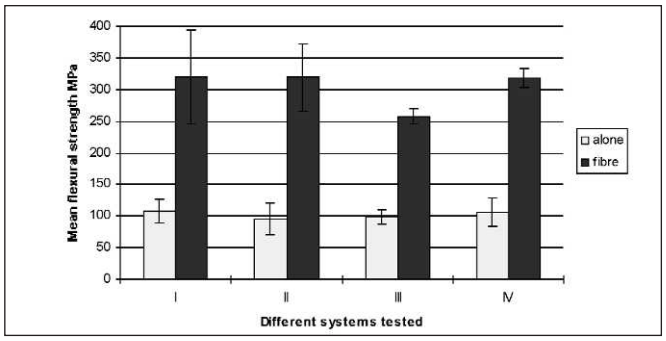

Figure 6. *Series C: The mean flexural strengths (MPa) of unreinforced/reinforced tested experimental composite groups stored for 24 hours in distilled water at 37°C. Error bars represent ± one standard deviation.*

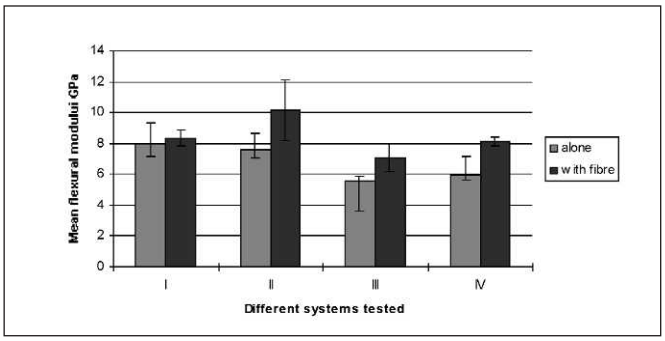

Figure 7. *The mean flexural moduli (GPa) of unreinforced/reinforced tested experimental composite groups stored for 24 hours in distilled water at 37°C. Error bars represent ± one standard deviation.*

Table 5: *Series C Results: The Mean Flexural Strength (FS) MPa & Modulus (FM) GPa (± S.D) of Experimental Veneering Composites, Before and After Reinforcing with Connect Fiber. Stored for 24 Hours in Distilled Water at 37°C*

	FS		FM	
System #	Without Fiber	With Fiber	Without Fiber	With Fiber
I	107.7 (18.6)[a]	320.7 (74.5)[b]	8.0 (1.3)[a]	8.3 (0.5)[a.b.c]
II	95.6 (25.1)[a]	319.1 (52.8)[b]	7.6 (1.1)[a]	10.2 (1.9)[a]
III	98.1 (11.2)[a]	257.3 (11.9)[b]	5.5 (0.3)[b]	7.1 (0.9)[b]
IV	106.7 (22.1)[a]	317.7 (14.9)[b]	5.9 (1.2)[c]	8.2 (0.2)[c]

Means with the same vertical superscript letter were not significantly ($p>0.05$) different according to post-hoc Tukey test comparisons.

After six months water storage, the flexural modulus of the four reinforced veneering composites tested was B=H=S>A (Table 3/Figure 3).

Water storage for six months had no effect ($p>0.05$) on the flexural modulus of all the reinforced groups.

Series B

Results of the flexural properties and their statistical analysis are listed in Table 4 and Figures 4 and 5. Changing the filler loading of the reinforced experimental composite test groups did not effect the flexural strength (Table 4, Figure 4) but significantly improved the flexural modulus (Table 4, Figure 5) ($p<0.05$).

The filler loading increase from 40% to 80% by weight resulted in increases in the mean flexural strength for both the unreinforced (27%) and fiber reinforced (79%) experimental groups as well as much greater increases in the flexural modulus for both the unreinforced (289%) and reinforced (272%) test groups.

Series C

Flexural property results and their statistical analysis are listed in Table 5 and Figures 6 and 7.

Unreinforced Groups

There was no significant difference in the flexural strength of the four composite controls that were tested. The flexural modulus of System 1 was significantly greater ($p<0.05$) than that of Systems 3 and 4. The mean flexural modulus of System 2 was significantly greater ($p<0.05$) than Composition 3.

Reinforced Groups

There was no significant difference ($p>0.05$) in the flexural strength (Table 5, Figure 6) of any of the four trial composite systems.

The flexural modulus of System 2 was significantly greater ($p<0.05$) than Systems 3 and 4. Flexural modulus results revealed that fiber reinforcement was responsible for a 134% increase in the flexural modulus of System 2 (Table 5, Figure 7). Fiber reinforcement was responsible for a 171% increase in the flexural modulus of Systems 2 and 3, compared to the unreinforced control.

DISCUSSION

Metal-free crowns and bridges are becoming popular among dental practitioners (Leinfelder, 2000). Fiber reinforcement of resin composite is one approach used to improve the strength of composites. Fibers differ in properties according to type and architecture. The nature of the overlying composite may also affect the degree of reinforcement. The strength and rigidity of the overlying composite, its wear resistance and its aesthetic qualities are the main factors influencing the effectiveness of fiber-reinforced composite systems in restorative dentistry (Freilich & others, 1999).

This research assessed the effect of changes in veneering composite formulation in regard to efficiency of reinforcement. Glass fillers in dental composites provide limited reinforcement because of their brittleness and relatively low strength. One aim of this research was to identify the best combination of UHMW-PE fiber and overlying composite from the systems studied in regard to their strength and rigidity.

Placement of fiber during reinforcement at the tensile side, where most tensile stresses are located (Figure 1), has been shown to be critical in regard to the efficiency of reinforcement (Ellakwa & others, 2001). In addition, the bonding agent used to impregnate the UHMW-PE fiber will form a complete system with the overlying composite (Ellakwa & others, 2000). Each component will have a synergistic role in the ultimate efficacy of reinforcement. Studying the effect of overlying veneering composite on the efficiency of reinforcement requires standardization of the remaining two factors (fiber and bonding agent).

The Artglass and Belleglass veneering dental composites selected for this study have been proposed to be substantially more wear resistant than other currently available polymer-based restoratives (Leinfelder, 1997). Artglass has been identified by the manufacturer as a non-conventional polymer. The high flexural results of Artglass after reinforcement, combined with the favorable clinical wear resistance results obtained in a study conducted at the University of Alabama (Leinfelder, 1997), suggest that this material may be suitable for metal-free bridge work in certain situations. The results of this study show that fiber reinforcement significantly improves the flexural strength of Artglass and also prevents the drop in flexural modulus that occurs with unreinforced material after six months water storage. The difference in flexural moduli after reinforcement among Artglass, Belleglass HP and Solidex may be attributed to differences in the composition of these materials. The physical and chemical principles associated with Belleglass HP are substantially different from those of other veneering composites selected for this study. In addition, the mechanism for curing Belleglass HP (as shown in Table 1) is considerably different from other commercial products that were evaluated and may be partially responsible for the difference in flexural strength of unreinforced Belleglass HP compared to the Artglass and Solidex groups that were tested after 24 hours. Also, the higher flexural modulus of the unreinforced and reinforced Belleglass HP groups may principally be related to chemical composition (Table 1) and partially related to fiber reinforcement. The results of this investigation, combined with the wear results of Gerbo & others (1990), suggest that this material may also be suitable as a veneering composite for metal-free bridges. This study showed no significant difference in the flexural properties of the Herculite XRV tested groups and Belleglass HP, presumably because of their similar chemical composition. However, many studies have shown that heat treatment of dental composites will improve their degree of conversion, which is supposed to be reflected in their mechanical properties (Ferracane & Condon, 1992).

The difference in flexural modulus at six months for the fiber reinforced Artglass, compared to the unreinforced control may be attributed to the influence of UHMW-PE fiber.

The lower flexural modulus of unreinforced Solidex compared to Belleglass HP may be related to the lower filler loading of the former product.

Changes in the flexural moduli results of Series A, especially after reinforcement, was relatively minimal compared to the increase in flexural strength results on reinforcement. Fiber reinforcement maintained the flexural moduli of all the commercially-tested composites after six months water storage, whereas this was not always so with their unreinforced counterparts.

With regard to stress resistance, Connect fiber impregnated with Kolor Plus resulted in a distinct improvement compared to the unreinforced control samples.

Fiber-reinforced composites are less likely to fail under stress. Summarizing the results of Series A, once the overlying veneering composites were reinforced with UHMW-PE fiber, no significant difference was detected in the strength of all the veneering composites after storage from one day to six months. This is possibly due to fiber reinforcement. The current findings are not consistent with the results of Vallittu, Ruyter & Ekstrand (1998), who reported a reduction in flexural properties of fiber-reinforced composites after six months water storage. This difference may be attributed to differences in bonding agents, fiber types and the veneering composites investigated in the different studies. The findings of this study are consistent with those of Ledizesky, Chow & Cheng (1994) and Samadzadeh & others (1997), who reported significant improvements in the flexural properties and fracture toughness of polymers after UHMW-PE fiber reinforcement.

From the results of this study, water storage up to six months had no significant effect ($p<0.05$) on flexural properties of three of the four fiber-reinforced materials. This finding may be attributed to the hydrophobic nature of the polyethylene fibers compared to the hydrophilic resin they replaced and/or the water resistance of the fiber resin interface.

Ladizesky & Chow (1992) examined the effects of interfacial adhesion, noting that water storage had little effect on the mechanical properties and interface strength when using UHMW-PE as a reinforcement.

The results of the tests described in Series B demonstrate the effect of changing filler loading on the flexural properties of a fiber-reinforced experimental composite. The significant improvement in flexural modulus of both the unreinforced and the fiber-reinforced groups may be attributed to the increase in filler loading. These findings were consistent with those of Braem & others, (1989), who reported a similar finding for unreinforced composites using acoustic spectroscopy. The difference in flexural properties between the reinforced groups versus the unreinforced groups in Series B may again be attributed to the influence of fiber reinforcement.

Series C investigated the effects of changing the proportion of resin monomers in the organic matrix of an experimental composite after standardization of filler loading. The significant difference in flexural modulus of unreinforced Systems 1 and 2 versus 3 and 4 may possibly be attributed to changes in the relative proportions of TEGDMA and Bis-GMA in the first two systems and the difference between the properties of Bis-GMA and UDMA (Table 2). It has previously been demonstrated that the greater the amount of TEGDMA in a Bis-GMA/TEGDMA copolymer, the greater the degree of conversion due to an increase in mobility of the molecules (Asmussen, 1982 & Ferracane & Greener, 1986). Compared with TEGDMA, the aromatic monomer of Bis-GMA is much more rigid. As a consequence, the degree of conversion in Bis-GMA/TEGDMA copolymers has been found to decrease with an increase in Bis-GMA content (Ferracane & Greener, 1986). Despite the resultant decrease in the degree of conversion, an increase in content does not result in a reduction in strength or hardness (Asmussen, 1982). This lack of correlation between conversion and hardness or strength may be explained by the fact that flexible TEGDMA is substituted by the much stiffer Bis-GMA in the polymer network (Asmussen, 1982). The flexibility of TEGDMA is related to ether linkages of the molecule, which gives rise to only slight barriers to free rotation about the bonds (March, 1977). The relative stiffness of Bis-GMA is related to the bulky, aromatic groups of the central part of the molecule, causing much larger barriers to rotate about the bonds (March, 1977). The difference in rigidity between Systems 4 and 2 can be explained by the fact that UDMA is less viscous compared to Bis-GMA, yet more flexible. This may improve the toughness of the final composite (Peutzfeldt, 1997). Thus, the nature of monomers in the polymer effects the mechanical properties of the dental composite. However, the flexural strength results of the four reinforced trial products were not significantly different. This may be explained by the fact that they have the same fiber reinforcement.

Within the limitations of this study, reinforcing different veneering composites (different composition or/and different method of curing) with UHMW-PE fibers did not affect the flexural strength of the reinforced veneering composite. This finding can mainly be attributed to fiber reinforcement placed at the tensile side. Applied load will transmit through the overlying veneering composite and stress will transfer to the fiber-matrix interface. The differences in the moduli of reinforced veneering composite groups may be attributed to differences in filler loading and organic matrix compositions of the products tested.

It is difficult to generalize the results of this study to all FRC systems, as different fibers may have different influences on the efficiency of reinforcement that differ from that of UHMW-PE fiber.

CONCLUSIONS

Fiber reinforcement of different veneering composites improved their flexural properties. After reinforcement, no significant difference in flexural strength was found among the four veneering composites tested in Series A after storage for 24 hours or six months in distilled water at 37°C. The only difference was in the flexural modulus of Belleglass HP. That was higher than both Artglass and Solidex. Increasing filler loading of an experimental veneering composite improved its flexural modulus but did not affect flexural strength after reinforcement. Varying the amount and type of monomer in a second experimental veneering composite did not affect its flexural strength but had an effect on its flexural modulus after reinforcement.

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Effects of Nd:YAG Laser, Air-Abrasion and Acid-Etching on Human Enamel and Dentin

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Clinical Relevance

Nd:YAG laser and air-abrasive systems created more surface irregularity in less time than acid etchant when applied to enamel and dentin surfaces.

SUMMARY

The effects of the Nd:YAG laser, air-abrasion and acid-etching systems on mineral content and surface morphology of cut dentin and enamel were examined in 10 extracted human teeth. Enamel specimens were lased for two seconds at a fluence of 0.75 J and a frequency of 15 Hz, air-abraded for two seconds with 50 micron Al-oxide and etched for 60 seconds with 37% ortho-phosphoric acid. Dentinal specimens were subjected to the same procedure for half the time. Untreated areas of the same specimens served as the control. Morphologically, the lased dentin showed an apparently melted surface with partial obstruction of the dentin tubules, as well as cracks along the lased surface. Air-abrasion created very irregular surfaces on enamel and dentin. Dentin tubules were observed on the acid-etched dentin samples but not the air-abraded surfaces. The Nd:YAG laser created the most surface irregularity on both enamel and dentin. Laser treatment appeared to alter the chemical structure and surface morphology of the dentin and enamel.

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INTRODUCTION

Although acid etching is routinely used to condition or roughen dental surfaces prior to using bonding agents, lasers can also be used. Ruby lasers were developed in the early 1960s (Maiman, 1960). Since then, a variety of lasers have been used experimentally and clinically in dentistry. Stern & Sognnaes (1964) and Goldman & others (1964) were the first to investigate the potential uses of the ruby laser in dentistry. These authors began their studies on hard dental tissues by investigating the use of a ruby laser to reduce subsurface demineralization. A reduction in permeability to acid demineralization of enamel after laser irradiation was found. The major types of lasers used in dentistry are Neodymium: Yttrium-Aluminum-Garnet or Nd:YAG, argon and carbon dioxide lasers; Erbiyum:YAG, Erbiyum, Chronmium: Yttrium-Scandium-Gallium-Garnet or ErCr:YSGG lasers (Salama, 1998; Kimura, Wilder-Smith & Matsumoto, 2000). Recently, the Nd:YAG laser has been proposed for a variety of dental hard tissue applications, including dentinal hypersensitivity treatment (Anic & others, 1998; Lan, 1999), etching procedures (Tagomori & Morioka, 1989; Bahar & Tagomori, 1994;

Cox, Pearson & Palmer, 1994; Ariyaratnam, Wilson & Blinkhorn, 1999) and caries removal and cavity preparation (Myers, 1991; Bassi, Chawla & Patel, 1994; Levy, Koubi & Miserendino, 1998).

Another innovative roughening method is the kinetic cavity preparation (air-abrasive system) technique. Air-abrasion was developed in the 1940s as an alternative to the slow-speed, belt-driven handpieces that were used. It was first used clinically by Robert B Black in 1943 (Black, 1945). The SS White Company introduced the Airdent air-abrasive unit in 1951. Since its recent re-emergence, air abrasive technology again offers an alternative to conventional handpieces. Using a pressurized stream of microscopic non-toxic abrasive powder, the technology provides a new means for rapidly removing enamel, dentin, decay and previous restorations. Although not appropriate for every clinical situation, the air-abrasive system minimizes heat, vibration and bone-conducted noise associated with conventional means of caries removal since the cutting is accomplished by air pressure. Also, patients treated with the air-abrasion system rarely request anesthesia (Black, 1945; Goldstein & Parkins, 1995; Rinaudo, Cochran & Moore, 1997). Also, study results (Los & Barkmeier, 1994; Goldstein & Parkins, 1995; Moritz & others, 1998) have shown this method to be an alternative for roughening enamel and dentinal surfaces.

This study (a) compared the morphologic effects of these innovative systems on enamel and dentin with the conventional acid-etch technique using SEM and (b) investigated the effects of these techniques on the mineral content of enamel and cut dentin using energy dispersive spectrometry (EDS).

METHODS AND MATERIALS

Ten freshly extracted, intact third-molars were stored in a 10% solution of formalin at pH 7.0 for a maximum of one month. Their enamel surfaces were cleaned by brushing with non-fluoridated toothpaste and washed and stored in distilled water.

The teeth were randomly divided into two groups, enamel and dentin. They were sectioned transversally at the cemento-enamel junction using a low-speed diamond disk. Four enamel and dentinal slices were obtained from each crown, producing a total of 40 surfaces. They were allocated to the control, acid-etched, lased and air-abraded treatment groups. In the enamel group, two longitudinal cuts of the molar crowns were made, producing four segments with enamel surfaces. In the dentin group, half the occlusal parts of the crowns were transversally sectioned and discarded to access the dentin. Two longitudinal cuts were then made to produce four dentinal segments. For handling convenience, the slices were embedded in self-curing acrylic blocks.

The following treatment parameters were applied to the enamel and dentin groups except for exposure times, which were twice as long for the enamel group as the dentin group.

- **Control Group:** No treatment.
- **Acid-Etched:** The enamel surfaces were etched with 37% ortho-phosphoric acid (3M Dental Products, St Paul, MN 55144, USA). Exposure times: 60 seconds (enamel) and 30 seconds (dentin). These times were applied according to the prospectus and literature (Liberman & others, 1984) by using a chronometer. Following etching, the surfaces were washed with water and dried with an air syringe.
- **Lased:** The Nd:YAG laser (American Dental Technologies Inc, Propulse Dental Laser System, Corpus Christi, TX 78405, USA) used in this study had a 1.064 nm wavelength and operated under "Pulse Master 600 LE" mode. The beam is delivered via a 320 µm coated silica fiber contact handpiece connected to the laser. The application parameters were selected according to the manufacturer's recommendations for etching (0.75 J, 15 pps). Before Nd:YAG laser exposure, the enamel surfaces were painted with black India ink for better absorption of the laser light, which was moved over a circular area of the sample. Exposure times: two seconds (enamel) and one second (dentin).
- **Air-Abraded:** A KCP 1000 Whisperjet (American Dental Technologies Inc) was used according to the manufacturer's recommendations for etching: (60 psi, with 50 µm Al-oxide powder). Exposure times: two seconds (enamel) and one second (dentin). During the application of air-abrasion, the nozzle distance was stable at 2 mm from sample surfaces.

The specimens were then coated with carbon and their surface morphology examined under SEM (JEOL JSM T 330, Tokyo, Japan) at 20 kV. Assessment of surface roughness was conducted based on research done by Los & Barkmeier, 1994; Dankner & others, 1997 and Anic & others, 1998. The calcium (Ca), phosphorus (P), sulphur (S) and potassium (K) content of each enamel and dentin specimen were measured using SEM and an EDS machine (Tracor Northern Inc, X-Ray Detectors, WI 53562, USA), together. Each specimen was irradiated at a voltage of 20 kV for 200 seconds and mineral content was measured in weight % after applying the ZAF-4 correction method. Differences in mineral contents between the control and treatment groups were analyzed using the Mann-Whitney U test.

RESULTS

In the laser group, SEM revealed extensive surface roughening of enamel (Figure 1A). At higher magnification (Figure 1B), it was shown that there was a central melt region (at the center of beam contact

Figure 1. *Photomicrographs of treated enamel.*

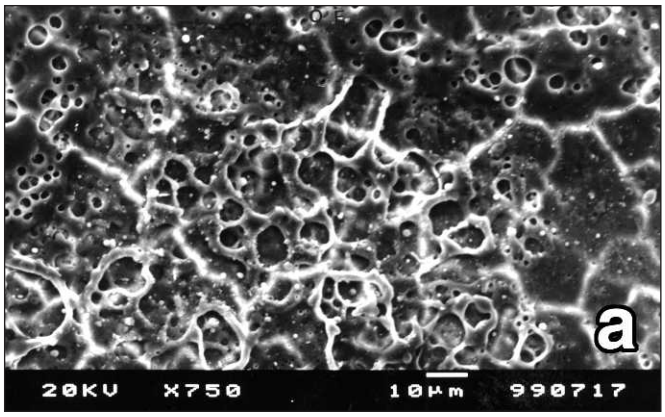

Figure 1A. *Lased with 0.75 J at 15 pps for two seconds showing extensive surface roughening. (magnification x750)*

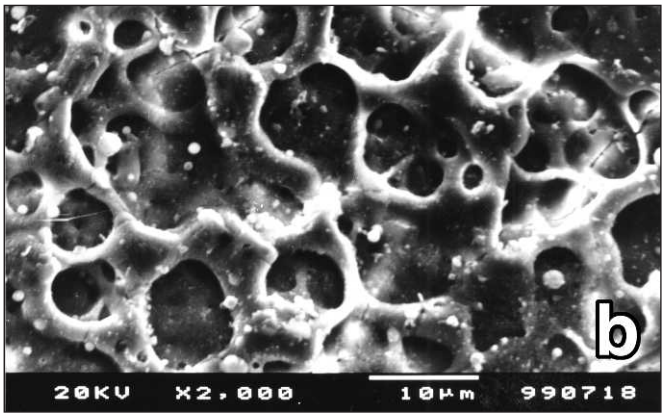

Figure 1B. *Lased: At higher magnification, showing blister formation and some microcracks. (magnification x2000)*

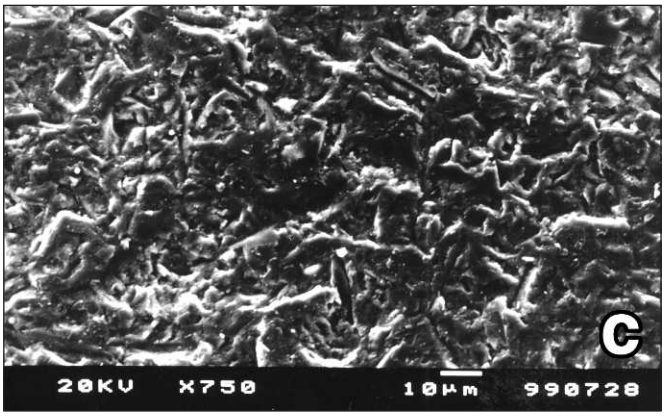

Figure 1C. *Air-abraded with 50 µm Al-oxide powder for two seconds showing a very irregular surface with smear layer. (magnification x750)*

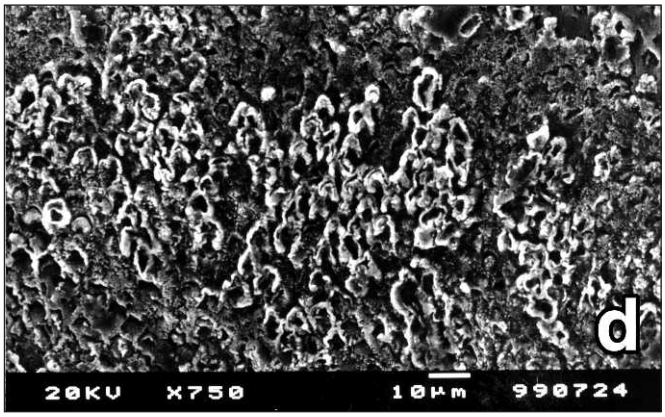

Figure 1D. *Etched with 37% ortho-phosphoric acid for 60 seconds showing whitening and chalky microporosity. (magnification x750)*

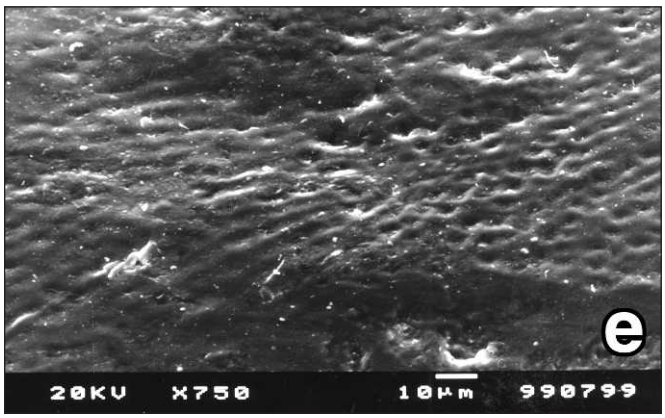

Figure 1E. *Control specimen-no treatment. (magnification x750)*

with the surface) which, although rough, was covered by a fused, blister formation. Some microcracks were also observed on the enamel surface.

Air abrasion created a very irregular surface on the enamel (Figure 1C) and dentin surface (Figure 2C), both similar in appearance. A smear layer was observed but no dentin tubules were observed.

The acid-etched enamel surface (Figure 1D) showed a chalky microporosity.

The lased dentinal surfaces (Figure 2A) revealed the exposed orifices of tubules composed of melted material and spread uniformly across the surface melting. Resolidification of the dentinal smear layer caused a sponge-like appearance on the surface. At higher magnification (Figure 2B), some microcracks were clearly observed.

On the acid-etched dentinal surface (Figure 2D), the orifices of the dentinal tubules were open. No smear layer was observed.

The most roughened enamel and dentinal surfaces were observed in the laser group. The morphological appearance of enamel (Figure 1E) and dentin (Figure 2E) surfaces in the control group was typical. However, the appearance, like the orientation of

Figure 2. *Photomicrographs of treated dentin.*

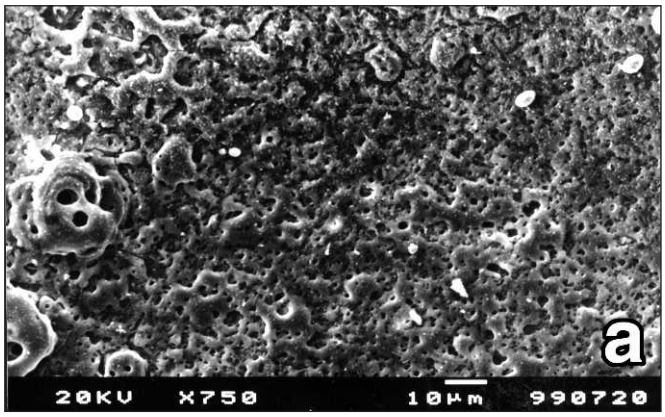

Figure 1A. *Lased with 0.75 J at 15 pps for one second showing exposed orifices of dentinal tubules with a sponge-like appearance. (magnification x750)*

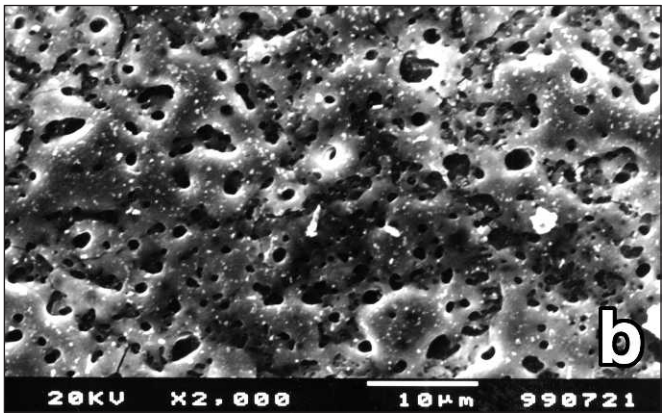

Figure 2B. *Lased: At higher magnification, clearly showing some microcracks. (magnification x2000)*

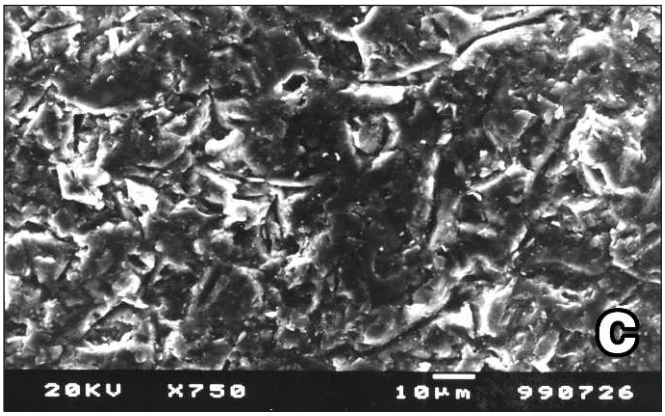

Figure 2C. *Air-abraded with 50 µm Al-oxide for one second showing a very irregular surface and smear layer. (magnification x750)*

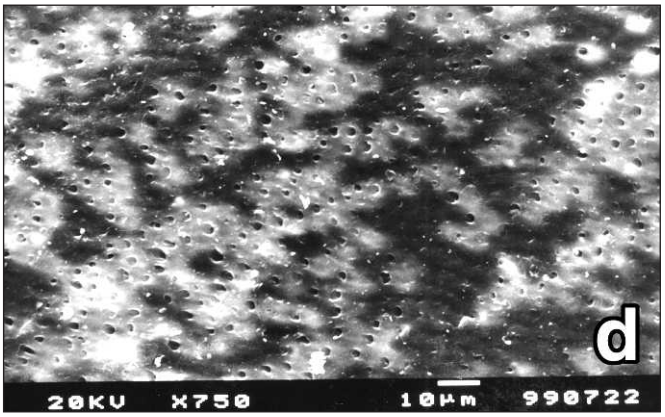

Figure 2D. *Etched with 37% ortho-phosphoric acid for 30 seconds showing no smear layer and open dentinal tubules orifices. (magnification x750)*

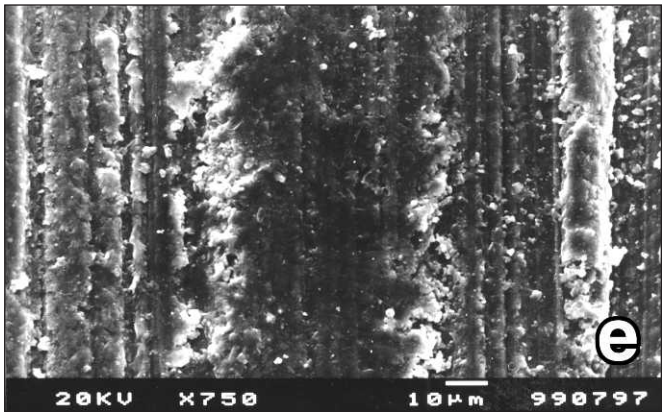

Figure 2E. *Control specimen. (magnification x750)*

dentinal tubules in Figure 2E, was really the transversal cutting trace of dentin and the smear layer appearance.

Table 1 shows the Ca, P, S and K content of lased, air-abraded, etched and control group of enamel and cut dentin. The phosphorus content of the lased dentin and the calcium content of the lased enamel were higher than the controls, although not significantly. The only significant change in element content with respect to the controls was a reduction in calcium (Ca) in the lased dentin ($p<0.01$).

DISCUSSION

Acid-etch is the accepted preparation method for adhesion of composite materials to enamel or dentin. However, it has disadvantages (Liberman & others, 1984): (a) it damages tooth structure (pulp, dentin), (b) clinical manipulation involves drying, wetting, then drying again, (c) removal of the etchant with an air-syringe causes spillage damages involving areas of enamel or surrounding soft tissues and (d) its treatment times are relatively long (60 seconds for enamel and 30 seconds for dentin).

Recently, new innovative methods, such as laser and air abrasion, have been suggested for creating retentive

Table 1: *Mineral Content of Treated Enamel and Dentin*

	ENAMEL				DENTIN			
Mineral	Lased	Air-Abraded	Acid-Etched	Control	Lased	Air-Abraded	Acid-Etched	Control
Ca	67.14	65.01	67.77	64.65	63.74*	66.86	68.02	67.59
P	32.28	34.18	31.52	34.28	35.83	32.97	28.45	32.18
K	0.01	0.34	0.02	0.02	0.11	0.17	0.00	0.22
S	0.57	0.47	0.69	1.05	0.31	0.00	3.53	0.01

*Significant difference with respect to control ($p<0.01$)

areas for resin bonding (Liberman & others, 1984; Featherstone & Nelson, 1987; Cox & others, 1994; Los & Barkmeier, 1994; Goldstein & Parkins, 1995; Rinaudo & others, 1997; Moritz & others, 1998; Ariyaratnam & others, 1999). Many investigators (Kuroda & Fowler, 1984; Liberman & others, 1984; Featherstone & Nelson, 1987; Tagomori & Morioka, 1989; Morioka, Tagomori & Takahiko, 1991; Bahar & Tagomori, 1994) have indicated that laser etching with or without fluoridizing treatment with low fluences could increase the acid resistance of tooth enamel. Some investigators (Liberman & others, 1984; Featherstone & Nelson, 1987; Los & Barkmeier, 1994; Rinaudo & others, 1997; Moritz & others, 1998; Ariyaratnam & others, 1999) have also demonstrated that laser irradiation or air abrasion to roughen enamel or dentin surfaces produced higher composite bond strengths than acid etching. However, while applying for etching purposes, these systems have disadvantages: some powder particles remain on the tooth surface following the application of air-abrasion (Goldstein & Parkins, 1994; Christensen, 1996). The Nd:YAG laser beam causes increases in heat, scattering and reflection on the tooth surface (Dederich, 1993).

The laser etching effect is a function of laser type, operational mode and energy output. In this study, the laser had abraded the dentin surfaces more than enamel. The efficiency rate of ablation with this laser increases exponentially with laser fluence (Levy & others, 1998; Ariyaratnam & others, 1999). Lasers with the same parameters as those used in this study have been found to do no thermal damage to the pulp when applied to enamel or dentin surfaces despite the high temperature they reach (Kuroda & Fowler, 1984; Tagomori & Morioka, 1989).

Los & Barkmeier (1994) found that air-abrasion of dentin with the much harder Al_2O_3 created more surface irregularity than with hydroxyapatite. Dentin surfaces that were air abraded with aluminum oxide, then treated with conditioners to remove the smear layer appeared more irregular than flat ground dentin surfaces treated with the same conditioners. In addition, Bery & Ward (1995) found that tensile bond strengths of resin composite to air-abraded and acid etched enamel were significantly greater than of those to air-abraded, unetched enamel. There was also no statistically significant difference between any combination of tip diameter, powder flow rate or air pressure.

On the other hand, Rinaudo & others (1997) reported that air abrasion, alone, significantly lowered the shear bond strengths of dentin bonding agent systems ($p<0.01$) compared to acid etching. However, they also found that air abrasion plus conditioning of the dentin surface resulted in bond strengths similar to conditioned-only specimens ($p<0.01$). Roeder, Bery & Powers (1995) reported air-abrasion treatment of enamel and dentin, alone, to result in lower *in vitro* bond strengths than those due to etching and preparation with dentin primer. Moritz & others (1998) also found laser irradiation with certain devices and the air-abrasive technique to yield results similar to those with acid etching.

Reducing the calcium (Ca) and phosphorus (P) contents of the lased dentin and enamel surfaces, respectively, indicated laser-induced changes in the organic components of the hydroxyapatite crystals. These changes may be indicators of the melting and re-crystallization process of the dentin surface reported by Stabholz & others (1993) and Dankner & others (1997). However, the increase in Ca content of the lased enamel and P level of lased dentin was an unexpected result. This may be due to differences in the organic-inorganic contents of enamel and dentin and laser exposure time. Dankner & others (1997) also determined a significant decrease in P levels following XeCl-308 nm excimer laser treatment. A decrease in the Ca levels also occurred but was not statistically significant. Non-significant changes in sulphur (S) and potassium (K) levels were also noted. But Ariyaratnam & others (1999) concluded that morphologically, lased dentin showed an apparently melted surface with partial obstruction of the dentin tubules as well as cracks along the lased surface. Although laser irradiation of dentin produced a favorable surface for mechanical bonding of resin composite, laser etching of dentin with Nd:YAG laser did not produce superior bonding when compared with conventional dentin bonding.

CONCLUSIONS

The Nd:YAG laser and air abrasive systems created more surface irregularity in less time than ortho-phosphoric acid etchant for conditioning enamel and dentin

surfaces. However, this laser technique causes changes in the mineral content of enamel and dentin surfaces. Further study is required to determine the exact relationship of the degree of surface irregularities, bond strength and microleakage.

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Relationship Between Nanoleakage and Long-Term Durability of Dentin Bonds

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M Nakajima • J Tagami

Clinical Relevance

The bond strength of single bottle adhesive systems to dentin gradually decreases over time.

SUMMARY

This study tested the hypothesis that long-term durability of resin bonds to dentin would directly relate to the nanoleakage of dentin bonding systems. Twenty extracted third molars were ground flat with #600 grit SIC paper under running water to expose middle dentin. One-Step or Single Bond was applied to the dentin surface according to the manufacturer's instruction. A crown was built-up with Clearfil AP-X resin composite and the specimens were stored in water for 24 hours at 37°C. The bonded assemblies were cut mesio-distally perpendicular to the interface in approximately 0.7 mm thick slabs and trimmed for microtensile bond strength testing. All slabs were immersed in individual bottles containing 37°C water that was changed daily. Specimens were randomly assigned to four groups (one day, three, six and nine months), and at the specified time period, the specimens to be tested were randomly divided into two subgroups for testing: 50% $AgNO_3$ and the control. In the 50% $AgNO_3$ subgroup, the slabs were coated with fingernail varnish except for approximately 0.5 mm around the bonded interface and immersed for one hour in 50% $AgNO_3$, followed by exposure in a photo developing solution for 12 hours just prior to debonding. The specimens in the control subgroup were soaked in water until they were debonded. Then, all specimens were subjected to microtensile bond testing. Micrographs of the fractured surfaces of the debonded specimens in the $AgNO_3$ subgroup were taken using light microscopy. They were then subjected to image analysis by NIH Image PC (Scion, Fredrick, MD, USA), and the area of silver penetration was quantitated. The fractured surface was further analyzed under the SEM. Bond strength data and the silver penetration areas were subjected to two and three-way ANOVA and Fisher's PLSD test at the 95% level of confidence. Regression analysis was used to test the relationship between bond strengths and the silver penetra-

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tion area at each time period. The tensile bond strength of both materials gradually decreased over time. Specimens bonded with One-Step showed less silver nanoleakage at one day compared to three, six and nine months ($p<0.05$), but there were no significant differences between the nanoleakage measured at three, six and nine months. In contrast, for specimens bonded with Single Bond, there were no statistically significant differences in the silver nanoleakage among the four time periods tested ($p>0.05$). No correlation was observed between bond strength and nanoleakage for either bonding system. Nanoleakage occurred in both adhesive systems, and bond strengths gradually decreased over time. However, there was no correlation between bond strength and nanoleakage for either adhesive system in this study.

INTRODUCTION

Current adhesive systems use acidic conditioners to remove the smear layer, resulting in demineralization of the dentin subsurface. This removes the smear layer and produces resin monomer penetration in the demineralized dentin to create a hybrid layer. After polymerization *in situ*, the hybrid layer (Nakabayashi, 1985) provides sealing of the dentin and good retention of resin composites.

The long-term durability of bonds between adhesive resins and dentin is of critical importance to the longevity of bonded restorations. High early bond strengths of current adhesive systems to dentin have been reported (Nakajima & others, 2000). However, few reports regard long-term adhesive-dentin bond durability (Kiyomura 1987; Burrow, Satoh & Tagami, 1996; Shono & others, 1999). These reports, although *in vitro*, have indicated that resin-dentin interfaces have degraded as a result of long-term water storage. Degradation of the dentin bond may result from water sorption by the bonded constituents and/or by hydrolysis of the adhesive resin (Burrow & others, 1996). Recent *in vivo* studies have demonstrated degradation of resin-dentin bonds and increased porosity at the bonded interface after one or three years (Sano & others, 1999; Hashimoto & others, 2000). These morphological changes at the interface might be caused by extracting resinous materials by hydrolytic attack (Sano & others, 1999).

Recently, the term nanoleakage has been used to define the diffusion of silver ions through nanometer-sized channels within the hybrid layer, partially or fully demineralized dentin or within the adhesive resin (Sano & others, 1995). Fluid penetration through nanoleakage pathways may cause degradation of the dentin bond (Sano & others, 1999).

To date, most leakage studies and bond tests have been performed in different specimens because the specimens needed to be sectioned in order to measure leakage. Since recently developed microtensile bond tests permit the creation of 8-10 specimens per bonded tooth, it has become possible to evaluate bond strengths and leakage studies using the same specimen (Pereira & others, in press). These authors compared the microtensile bond strength and nanoleakage of silver particles on alternate specimens prepared from the same tooth and concluded that there was no correlation between early bond strength and nanoleakage using a total-etch single bottle and self-etching priming adhesive systems (Pereira & others, in press). However, concern remains regarding the relationship between nanoleakage and bond strength during a long-term period since degradation of the resin-dentin interface from hydrolytic attack may slowly occur through nanoleakage pathways. This study tested the hypothesis that long-term durability of resin bonds to dentin is directly related to nanoleakage of dentin bonding systems. The null hypothesis was that there is no correlation between resin-dentin bond strengths and nanoleakage over time.

METHODS AND MATERIALS

Twenty extracted human third molars that were stored frozen were used in this study. The teeth were thawed, cleaned of debris and the occlusal surface was ground flat to remove the enamel and exposed middle dentin. The dentin surfaces were inspected to ensure that there were no remnants of enamel. They were then polished with #600 grit silicone carbide paper under running water.

The bonding procedures were carried out as recommended by the manufacturers. The adhesive systems used in this study were Single Bond (3M Dental Products, St Paul, MN 55144, USA) and One-Step (BISCO, Inc, Schaumburg, IL 60193, USA), both of which used phosphoric acid etchants and the moist bonding technique (Table 1). Ten teeth were prepared for each material. The dentin surfaces were etched with

Table 1: *Materials Used in This Study*

System	Ingredient	Code/Batch #
One-Step (BISCO)		
Etchant	32% phosphoric acid (Uni-etch)	#089077
Adhesive	BPDM Bis-GMA, HEMA, Acetone, Photoinitiator	#079107
Single Bond (3M)		
Etchant	35% phosphoric acid	#7423
Adhesive	Polyalkenoic acid-copolymer, Bis-GMA, HEMA, Photoinitiator Ethanol, Water	#3411

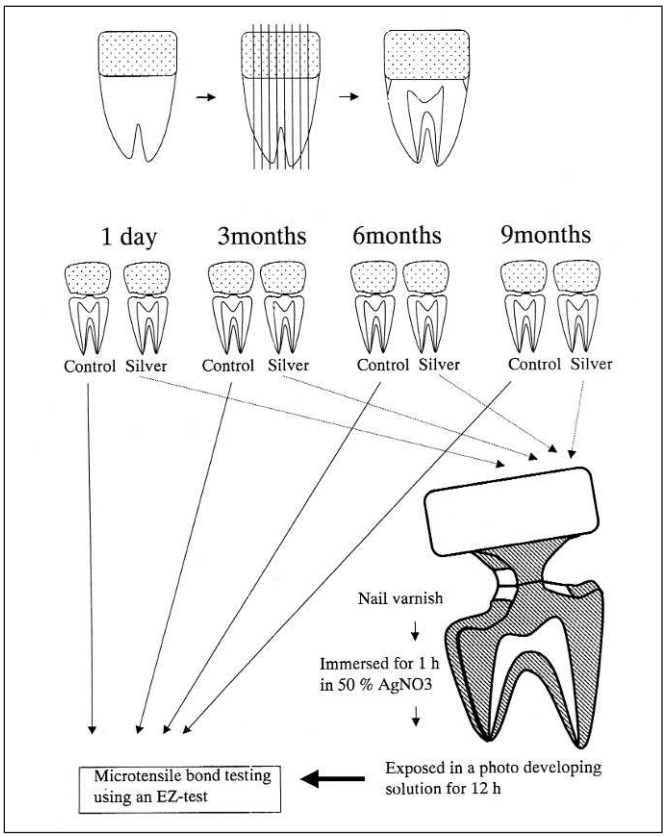

Figure 1. *Sample preparation for microtensile bond test and nanoleakage.*

the respective phosphoric acid gel for 15 seconds and rinsed for at least 15 seconds. The excess water was removed with a damp Kimwipe, leaving a visibly moist surface. Two consecutive coats of each adhesive resin were applied with a brush, gently air-thinned with oil-free compressed air for five seconds and light-cured for 10 seconds. The crown was then built-up incrementally over the adhesive resin with Clearfil AP-X (Kuraray Co, Ltd, Osaka, Japan) resin composite. The bonded assemblies were stored in tap water at 37°C for one day, then sectioned perpendicular to the bonded interface into approximately 0.7 mm thick slabs with a diamond saw. The adhesive-dentin interface was trimmed to an approximate width of 1.4 mm with a fine diamond bur to produce a cross-sectional surface area of approximately 1 mm^2 for microtensile bond testing. Eight or nine slabs were cut perpendicular to the bonded interface of each tooth. After pooling all the slabs from each bonding system, they were immersed in individual bottles containing water at 37°C. The water was changed every day until testing.

Specimens were randomly assigned to four groups (one day and three, six and nine months). At the specified time period, the specimens to be tested were randomly divided to two subgroups: in one subgroup, the slabs were coated with fingernail varnish except for approximately 0.5 mm around the trimmed bonded interface and were immersed for one hour in 50% $AgNO_3$, followed by exposure in a photodeveloping solution for 12 hours. The specimens in the other subgroup were soaked in water for 13 hours. Then, all specimens were subjected to microtensile bond testing using a tabletop material tester (EZ-test, Shimadzu Co, Kyoto, Japan) at a crosshead speed of 1 mm/min (Figure 1). All debonded specimens were fixed in 10% neutral formalin for at least eight hours.

The debonded specimens in the $AgNO_3$ subgroup had micrographs taken of the fractured surfaces using light microscopy at 64x magnification. The images

Table 2: *Microtensile Bond Strength MPa ± SD (The Number of Specimens)*

(Control Group)				
Periods	**1 Day**	**3 Months**	**6 Months**	**9 Months**
Adhesive				
SB	45.5 ± 15.2^{a} (12)	33.4 ± 11.9^{b} (10)	26.2 ± 8.6^{b,c} (10)	22.6 ± 8.5^{c} (12)
OS	35.3 ± 9.8^{a,b} (8)	26.4 ± 8.4^{b,c} (9)	19.2 ± 5.7^{c} (8)	17.2 ± 7.1^{c} (8)

Table 3

($AgNO_3$ group)				
Periods	**1 day**	**3 months**	**6 months**	**9 months**
Adhesive				
SB	39.9 ± 10.9^{d} (9)	30.2 ± 10.9^{d,e} (10)	39.0 ± 12.5^{d} (9)	28.7 ± 11.8^{e} (11)
OS	42.5 ± 9.8^{d} (10)	24.7 ± 10.6^{e} (9)	22.9 ± 6.0^{e} (7)	22.0 ± 7.7^{e} (12)

Mean figures with the same superscript letters are not significantly different (p>0.05) using Fisher's PLSD test. Groups identified by different superscript letters are significantly different (p<0.05).

Table 4: *The Area of Silver Penetration (Mean mm^2 SD)*

Periods	**1 day**	**3 months**	**6 months**	**9 months**
Adhesive				
SB	0.144 (0.023)^{a}	0.150 (0.026)^{a}	0.149 (0.052)^{a}	0.147 (0.036)^{a}
OS	0.093 (0.037)^{b}	0.154 (0.017)^{a}	0.131 (0.028)^{a}	0.137 (0.023)^{a}

Mean figures identified by the same superscript letter are not significantly different (p>0.05) using Fisher's PLSD test.

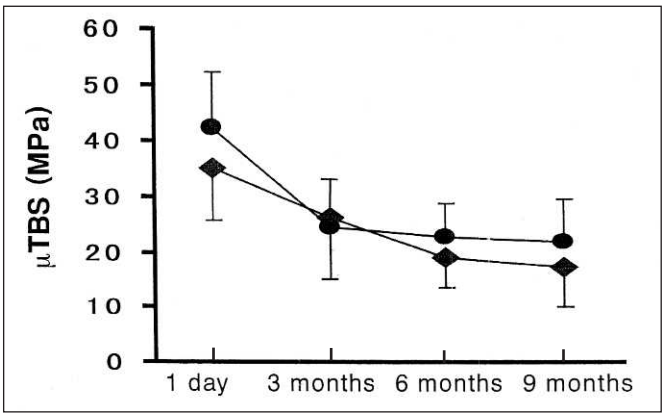

Figure 2A. *Microtensile bond strength (μTBS) of One-Step adhesive system. Diamond symbols designate control group data and round symbols represent the silver nitrate data. Brackets indicate plus or minus 1 SD.*

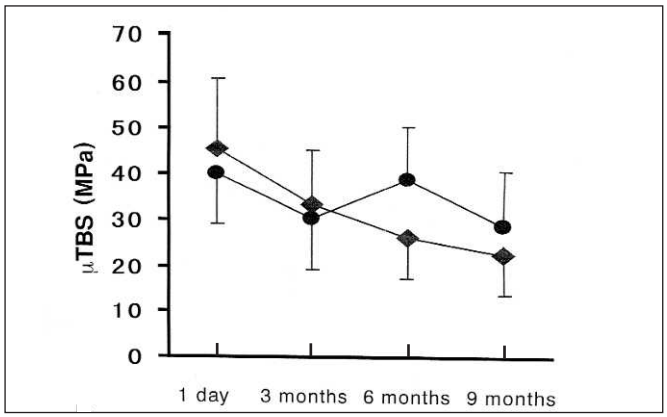

Figure 2B. *Microtensile bond strength (μTBS) of Single Bond adhesive system. Diamond-shaped symbols designate control group data, while round symbols identified the mean values of the silver nitrate exposed subgroup.*

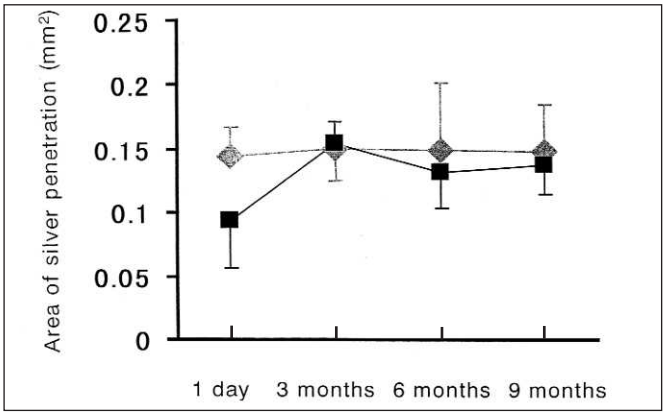

Figure 3. *Silver penetration area for One-Step and Single Bond at each time period. Square symbols designate One-Step subgroups and diamond-shaped symbols designate Single Bond subgroups.*

were scanned to convert them from analog to digital format, were subjected to image analysis by NIH Image PC (Scion, Fredrick, MD, USA) and the area of silver penetration was quantitated. Means and standard deviations of silver penetration areas were calculated at each time period (one day and three, six and nine months).

Bond strength data and the silver penetration areas were subjected to two and three-way ANOVA and Fisher's PLSD test at the 95% level of confidence. Regression analysis was used to test the relationship between bond strengths and silver penetration area at each time period. All fractured specimens were placed on SEM stubs and allowed to air dry. The specimens were gold sputter-coated and observed with a scanning electron microscopy (JXA-840, JEOL, Tokyo, Japan) so that microscopic fracture patterns and the morphology of the debonded interfaces could be assessed.

RESULTS

Means and standard deviations of the microtensile bond strengths for One-Step and Single Bond are summarized in the Table 2 (Control group), Table 3 ($AgNO_3$ group) and Figure 2A and B.

The tensile bond strengths of both materials gradually decreased over time. The ANOVA indicated no interaction between materials with or without silver penetration and time periods ($p>0.05$). The bond strengths of the control and $AgNO_3$ subgroup were not significantly different ($p>0.05$). However, the bond strength of Single Bond was significantly higher compared to One-Step ($p<0.05$). The tensile bond strengths in the Single Bond control subgroup became significantly lower after three, six and nine months ($p<0.05$) than one day, and the bond strengths after nine months were about one-half the value of the one day group, 22.6 ± 8.5 and 45.5 ± 15.2 MPa, respectively. The tensile bond strengths in the One-Step control subgroup became significantly lower after six and nine months ($p<0.05$) and were approximately half the bond strength measured after one day. For the $AgNO_3$ subgroups, the tensile bond strength of both materials decreased over time, except for the Single Bond six month results, and there were no significant differences between the bond strength of the control and $AgNO_3$ subgroups each time, except for the six month results of Single Bond.

Table 4 and Figure 3 summarize the mean and standard deviation of the silver penetration area for One-Step and Single Bond. More silver nanoleakage in specimens bonded with Single Bond was found compared to One-Step at one day. Specimens bonded with One-Step showed less silver nanoleakage (penetration area) at one day compared to three, six and nine months ($p<0.05$), but there were no significant differences between the nanoleakage measured at three, six and nine months. In contrast, for specimens bonded with Single Bond, there were no statistically significant differences in the silver nanoleakage among the four time periods tested ($p>0.05$).

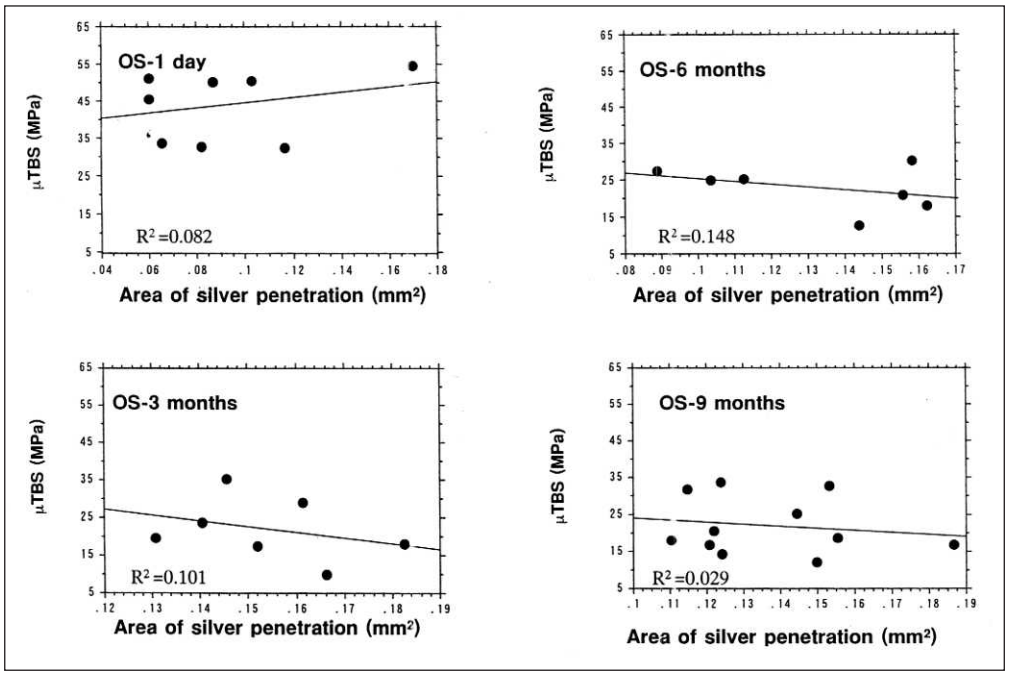

Figure 4. *Relationship between bond strength and nanoleakage (silver penetration area) at each time period for One-Step. μTBS=microtensile bond strength in megapascals.*

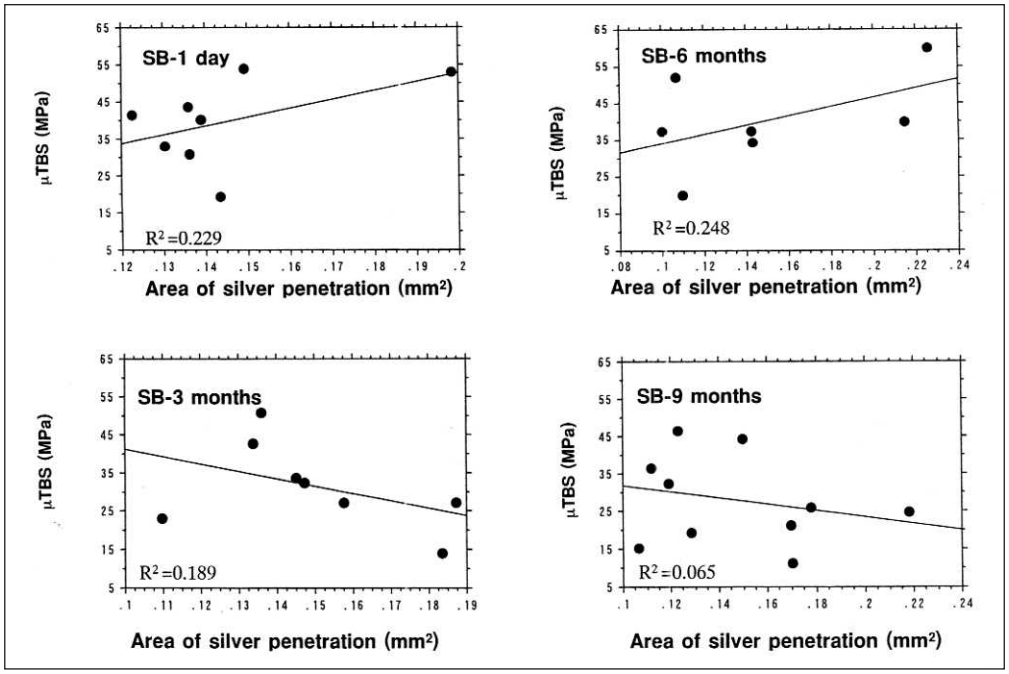

Figure 5. *Relationship between bond strength and nanoleakage (silver penetration area) at each time period for Single Bond. Note that there were no correlation between microtensile bond strength and nanoleakage for both adhesive systems.*

Regression analysis of the relationship between the microtensile bond strength and nanoleakage failed to produce any consistent correlation with either adhesive system. During the same time periods, the correlations were positive and at other times, they were negative. R^2 values never exceeded 0.248 (Figures 4 and 5).

SEM observations of fractured sites of specimens bonded with One-Step showed morphological changes over time. Failures occurred within the resinous component at the top of the hybrid layer in the one-day group (Figure 6A). However, in the three and six-month groups, there was a mixed fracture pattern of cohesive failures within the adhesive resin and hybrid layer (Figures 6B,C). Moreover, in the nine-month group, SEM observations showed that failures involving the bottom of the hybrid layer predominated (Figure 6D). SEM observations of fractured sites of specimens bonded with Single Bond showed nearly identical appearances over time (Figure 7A-D). All fracture modes were mainly classified as a mixture of interface and cohesive failure including adhesive resin and the top and middle of the hybrid layer.

DISCUSSION

The durability of bonds between adhesive resin and dentin is of critical importance for the longevity of bonded restorations. A dramatic decrease in dentin bond strength after a five year storage in water has been reported (Kiyomura, 1987). In another study that determined the effect of long-term water storage on the bond strength of an adhesive system to dentin, with and without priming, it was revealed that priming doubled early bond strength. This bond strength remained stable over the first year for the primed group; however, after three years, the bond strength became similar to those of the unprimed controls (Burrow & others, 1996). On the other hand, it was recently reported that storage conditions influenced the long–term durability of dentin bonding of resin cements

Figure 6. *SEM micrographs of dentin side of a specimens that were bonded with One-Step, and then tested for bond strength.*

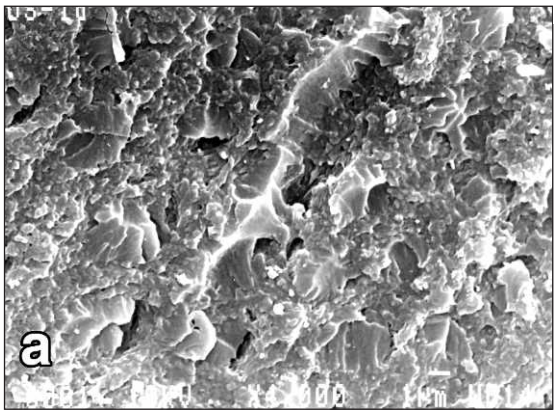

Figure 6A. *One day later. Fracture occurred within the resinous component at the top of the hybrid layer in one day group. (magnification x4000)*

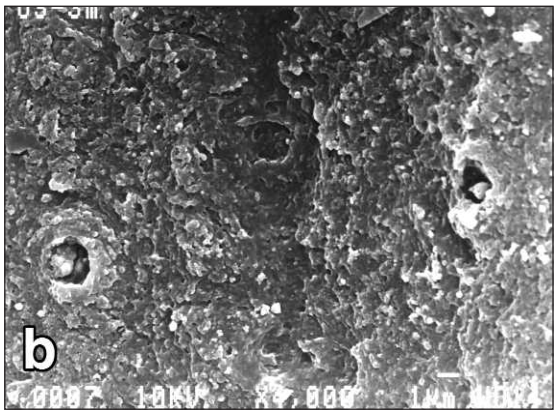

Figure 6B. *Three months later. Mixed fracture pattern of cohesive failures occurred within the adhesive resin and hybrid layer in three and six months group. (magnification x4000)*

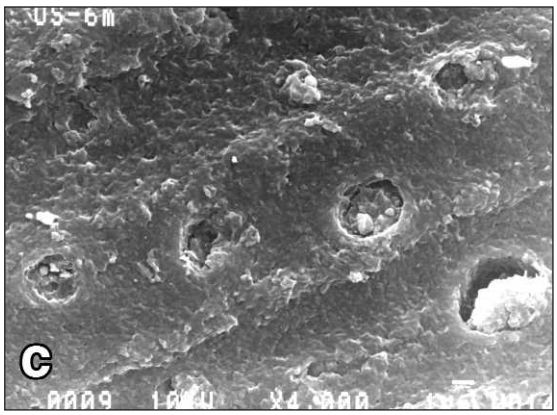

Figure 6C. *Six months later. Mixed fracture pattern of cohesive failures occurred within the adhesive resin and hybrid layer in three and six months group. (magnification x4000)*

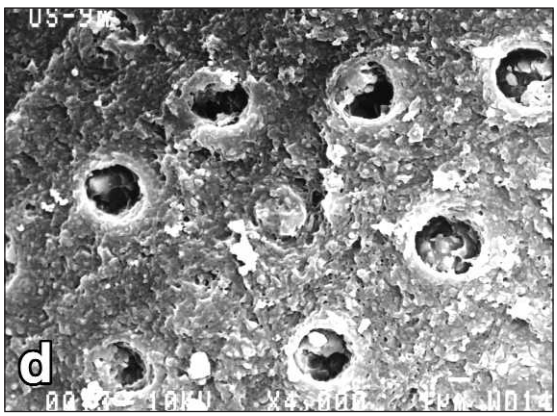

Figure 6D. *Nine months later. Fracture occurred within the bottom of the hybrid layer in nine months group. (magnification x4000)*

and that changing the storage medium every day might be useful to accelerate long-term durability tests (Kitasako & others, 2000). Moreover, Shono & others (1999) found that a smaller cross-sectional area of resin-dentin interface, as used in the microtensile bond test, accelerated the deterioration of bond strength over time. In this study, the water that was used as a storage medium was changed every day and the specimens were reduced to a 1 mm^2 cross-sectional area for microtensile bond testing prior to storage to maximize hydrolytic stresses over time.

The tensile bond strengths for both total-etch adhesive systems dramatically decreased after three months, and the bond strengths after six months were about one-half the value of the one day specimens (Figure 2A,B). The decrease in bond strength is thought to result from the effect of hydrolysis at the interface of the bonding resin and hybrid layer (Burrow & others, 1996; Armstrong & others, 2000). Shono & others (1999) reported that the bond strengths of One-Step to superficial dentin did not change over three months in a storage solution that was not changed during test periods. It was reported that changing the solution may also have accelerated hydrolysis at the interface between the hybrid layer and dentin and also between the hybrid layer and resin cement (Kitasako & others, 2000). This study's different methods may have been reasonable for the greater fall in bond strength of One-Step over three months compared to Shono & others (1999).

It is believed that microleakage occurs via gaps between the restoration and tooth. Gap-free restorations should not permit leakage between the restoration and cavity wall. Current adhesive systems often produce gap-free restorations but with some leakage (Ferracane, Condon & Mitchem, 1992). Recently, another pathway for leakage that occurred within porosities in the hybrid layer revealed using silver nitrate (Sano & others, 1994). Silver penetration was observed beneath the adhesive resin in the absence of gap formation along the interface. To distinguish this leakage from typical microleakage, the term nanoleakage has been suggested (Sano & others, 1995). The most important pathway for nanoleakage is a hybrid layer that has not been fully penetrated by resin, leaving spaces for fluid penetration that may cause degradation of resin-dentin bonds. In a previous study, no correlation was observed between short-term resin-dentin bond strength and nanoleakage of total etch and self etching primer bonding systems (Pereira & others, in press).

Figure 7. *SEM micrographs of dentin side of a specimens that were bonded with Single Bond, and then tested for bond strength. All fracture modes were classified as a mixture of interface and cohesive failure included adhesive resin and the top and middle of the hybrid layer.*

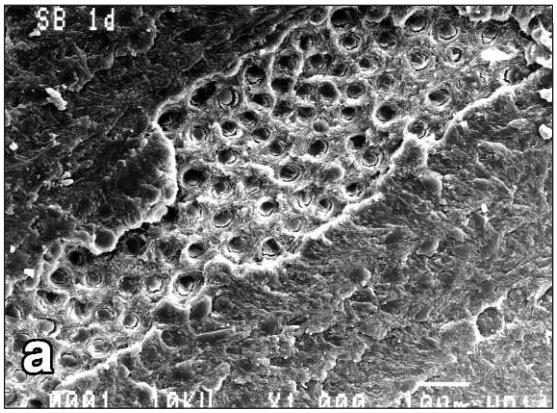

Figure 7A. *One day later. Fracture pattern showed a mixture within adhesive resin and hybrid layer. (magnification x1000)*

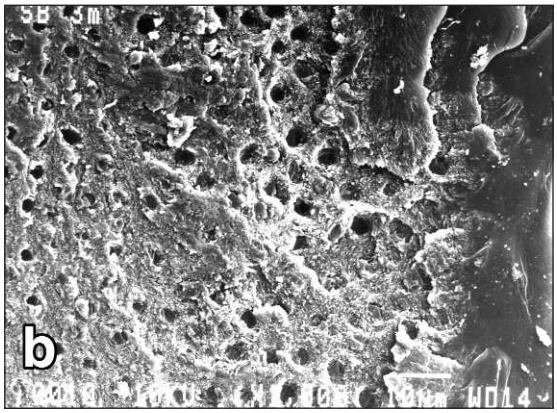

Figure 7B. *Three months later. Fracture pattern showed a mixture within adhesive resin and hybrid layer. (magnification x1000)*

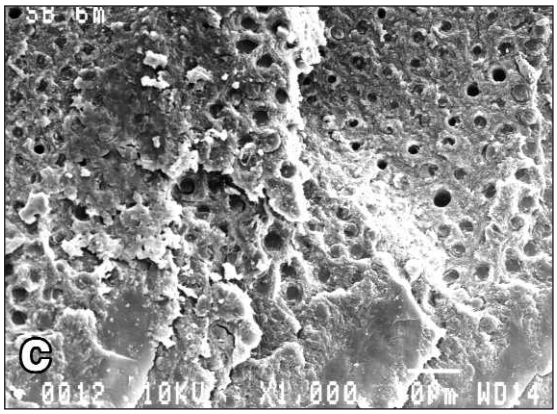

Figure 7C. *Six months later. Fracture pattern showed a mixture within adhesive resin and hybrid layer. (magnification x1000)*

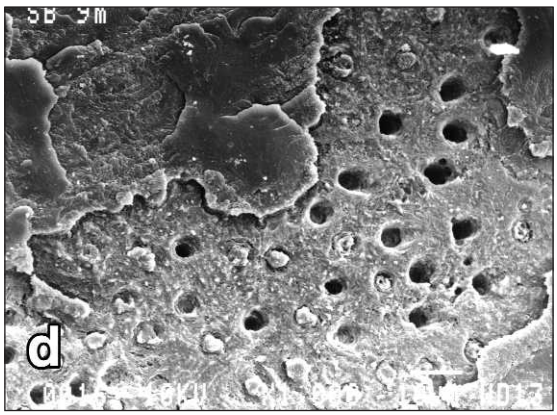

Figure 7D. *Nine months later. Fracture pattern showed a mixture within adhesive resin and hybrid layer. (magnification x1000)*

Pereira & others (in press) also reported that using silver nitrate for identifying microporosities within resin dentin bonds produced a small but significant increase in bond strength. Their scanning electron micrographs showed that silver ions were converted to metallic silver grains. If these grains grew larger than the original microporosities, the collagen fibrils may have become prestrained, thereby, altering the local stress concentrations during testing. This could decrease stress around the edge of the specimen, leading to less pronounced stress concentration effects. This, in turn, could raise the load needed to cause failure and could result in an increase in apparent bond strength (Pereira & others, in press). On the other hand, except for the six month data for Single Bond specimens, this study's results revealed that the tensile bond strengths of the control and silver groups were not significantly different ($p>0.05$) (Table 2, 3). The technique, used to measure bonding defects or microporosities, does not influence bond strength. These results may be influenced by the direction of infiltration of silver nitrate. In this study, $AgNO_3$ only infiltrated the bonded interface from two directions, (that is, only from the lateral trimmed surfaces), while in the previous study (Pereira & others, in press), it infiltrated from all four directions (that is, from all around the interface). Therefore, the total area of silver nitrate infiltration was less in this study, which explains why significant differences between the control and silver nitrate groups did not exist.

In this study, specimens bonded with One-Step showed less ($p<0.05$) silver penetration for the one day group than the longer time periods. However, after three months, the area of penetration did not significantly change ($p>0.05$) (Table 4, Figure 3). Bond strengths of One-Step gradually decreased with time, which became significantly lower after six months ($p<0.05$) and were approximately half the strength measured after one day. In contrast, with Single Bond there were no statistically significant differences ($p>0.05$) in the area of silver penetration among the four time periods tested (Table 4, Figure 3), while the bond strengths gradually decreased with time, falling from 46 MPa to 23 MPa in the control subgroup and 40 MPa to 29 MPa in the $AgNO_3$ subgroup.

SEM observations of fractured sites of specimens bonded with One-Step showed morphological changes over time. Failures occurred within the resinous component at the top of the hybrid layer in the one-day group (Figure 6A). However, in the three and six-month groups, there was a mixed fracture pattern of cohesive

failures within the adhesive resin and hybrid layer (Figure 6B,C). Moreover, in the nine-month group, SEM observations showed that failures predominantly involved the bottom of the hybrid layer (Figure 6D). This change of fracture pattern may indicate degradation of the adhesive interface over time. In a previous study, Shono & others (1999) reported porosities in the intertubular regions of deep dentin that was incubated for 90 days prior to bond testing of One-Step. The loss of intertubular mass may result from a loss of resin and collagen fibrils because of the hydrolysis of these two phases.

SEM observations of fractured sites of specimens bonded with Single Bond appeared almost identical over time (Figure 7A-D). All fracture modes were primarily classified as a mixture of interface and cohesive failure including adhesive resin and the top and middle of the hybrid layer. It was difficult to find differences in the fracture patterns among all groups. Burrow & others (1999) reported that bonding resin absorbs a significant amount of water, which may adversely affect longevity of restorations. The susceptibility of resin to hydrolysis probably results from a low degree of conversion and cross-linking during polymerization (Shono & others, 1999). Failure is initiated at and propagates from the weakest point of the bonded assembly (Kato & Nakabayashi, 1998). This study speculates that in the case of Single Bond, the decrease in the physical properties of bonding resin occurred at a faster rate than degradation of the interface between the hybrid layer and dentin.

No correlation existed between bond strength and nanoleakage (that is, silver uptake) for either adhesive system (Figures 4 and 5). However, for specimens bonded with One-Step, the resin-dentin bond strength significantly decreased with time and the silver penetration area was significantly greater at three months than at one day, thus, a relationship may have existed between nanoleakage and long-term bond strength. On the other hand, after three months, the silver infiltrated area became stable but the bond strengths continued to fall. In the case of Single Bond, the resin-dentin bond strength gradually decreased, whereas, the area of silver penetration was stable over time. Moreover, the fracture pattern did not change over time. The relationship between nanoleakage and long-term bond strength was unclear in this study.

It is believed that nanometer-sized spaces within the hybrid layer may result from incomplete resin infiltration into the demineralized dentin, poor polymerization of adhesive resin and the existence of low molecular weight oligomers (Sano & others, 1999). This nanoleakage pathway may allow fluid penetration along the interface, which may result in a hydrolytic breakdown of either the adhesive resin or collagen within the hybrid layer, thereby, compromising the stability of the resin-dentin bond (Sano & others, 1995). Within the limitations of this *in vitro* study, it was concluded that while nanoleakage obviously occurred at the dentin interfaces of the total etch systems evaluated, the relationship between bond strength and nanoleakage remains unclear. Bond strength decreased significantly, however, it seems that the factors that contribute to durability are more complicated *in vivo*. Sano & others (1999) demonstrated *in vivo* that after one year the fractured interfaces exhibited an increased porosity over time. The change in the bonded interface *in vivo* may be caused by flexure of the restored tooth under occlusal stresses. If water absorption occurs at the interface, there may be bulk fluid movement at the junction of the adhesive resin and the hybrid layer during flexation of the restoration under function. This may promote mechanical and chemical degradation of the cured resin and may accelerate the washout of water-soluble monomers and oligomers. Carvalho & others (2000) reported that storage of demineralized dentin in saline for 48 months did not cause any decrease in its tensile properties. According to previous studies, the weakest portion of the hybrid layer, which causes degradation for longevity, seems to be resin within the inter-fibrillar space, rather than collagen fibrils.

The cervical margin of Class V restorations is often within dentin. It has been reported that the collagen fibrils were not completely infiltrated by the adhesive resin at the CEJ level along the cavosurface margin of restorations (Prati & others, 2000). This external marginal hybrid layer is exposed in oral environmental conditions with dental plaque formation, where pH falls to low values and bacterial enzymes are produced. These conditions may be more severe than this experimental condition. These environmental challenges may jeopardize the durability of the bond (Prati & others, 2000). Further research is needed to evaluate the influence of acid-cariogenic solution and saliva proteolitic enzyme on dentin bonds and to gain a better understanding of the durability of resin-dentin bonds.

CONCLUSIONS

Within the limitations of this *in vitro* study, the tensile bond strength of single bottle adhesive systems gradually decreased over time and nanoleakage occurred in both materials at any period. However, the area of silver penetration (nanoleakage) demonstrated almost no change over time. There was no correlation between bond strength and nanoleakage for either adhesive system.

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Microleakage of Class V Resin Composite Restorations After Bur, Air-Abrasion or Er:YAG Laser Preparation

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RP Ramos • A Brugnera, Jr • JD Pécora

Clinical Relevance

Class V cavities prepared by either air-abrasion or Er:YAG laser, with a subsequent phosphoric acid etching, showed microleakage values comparable to conventional dental bur preparation. However, conventional dental bur preparation followed by acid etching produced the best overall seal.

SUMMARY

This in vitro **study compared the microleakage of Class V resin composite restorations placed in cavities prepared with a high-speed dental bur, air-abrasion or Er:YAG laser. Twenty sound extracted human third molars were selected and randomly assigned to four equal Groups (n=10): Group I, cavities were cut by dental drill at high-speed; Group II, aluminum oxide air-abrasion was used for cavity preparation, and in Groups III and IV, cavities were prepared by Er:YAG laser. Following cavity preparation, Groups I and II were acid-etched, Group III was treated only by Er:YAG laser and Group IV was conditioned by Er:YAG laser followed by acid-etching. Cavities were restored (Single Bond + Z-100) and the teeth stored for seven days in distilled water. Then, the restorations were polished and the specimens thermocycled, immersed in a 0.2% Rhodamine solution, sectioned and analyzed for leakage at the occlusal (enamel) and cervical (dentin/cementum) interfaces using an optical microscope connected to a video camera. The images were digitized and software was utilized for microleakage assessment. Upon analyzing the results, statistically significant differences ($p<0.01$) between the occlusal and cervical regions for all groups was observed, and, as a rule, there was better marginal sealing at the**

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enamel margins. The highest degree of infiltration was observed for cavities prepared and treated exclusively by Er:YAG (Group III). The other experimental groups showed statistical similarities in the amount of marginal leakage at the enamel margins. However, at the cervical margins, there was a significant difference ($p<0.05$) between Group I and the remaining groups. None of the techniques completely eliminated marginal microleakage at the dentin/cementum margins.

INTRODUCTION

In recent decades, dental research has produced improved restorative techniques and materials to reproduce the characteristics and appearance of lost dental tissue. The development of adhesive resin restorative systems has minimized the need for resistance form and macro-mechanical retention and enabled cavities to be prepared without extending them into sound tooth structure (Horiguchi & others, 1998).

Today, newer methods for preparing dental hard tissue, such as laser irradiation and aluminum oxide air-abrasion, have become widespread. Air-abrasion technology was first introduced in the 1940s with the expectation that it would replace the low-speed mechanical drills used for tooth preparation. The goal was to provide the same effectiveness, but with freedom from pain, trauma and patient discomfort. However, while this technique offered some remarkable advantages, final cavity preparation still required supplementary mechanical instrumentation. This shortcoming, coupled with the development of high-speed air turbine handpieces, caused air-abrasion technology to be dismissed and only reintroduced in the last decade (Rinaudo, Cochran & Moore, 1997). Modern air-abrasion units employ a high-speed stream of purified aluminum oxide particles propelled by air pressure. The technique has been proposed for potential dental applications, including modification of tooth surfaces, removal of carious lesions and existing restorations and cavity preparation (Laurell, Carpenter & Beck, 1994; Goldstein & Parkins, 1995; Nikaido & others, 1996; Horiguchi & others, 1998; Chan & others, 1999). In a similar manner, laser applications for dental practice have 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 light-activated materials and treating or cutting dental substrate. The most promising wavelength has been the Er:YAG at 2.94 micrometers. Many investigations (Hibst & Keller, 1989; Wigdor & others, 1995; Cozean & others, 1997; Niu & others, 1998; Hatibovich-Kofman, Wright & Braverman, 1998; Zyskind & others, 1998; Wright & others, 1999; Armengol & others 1999) have reported Er:YAG laser's ability to cut or ablate tooth structure for removing carious lesions, cavity preparation and modifying dentin and enamel surfaces.

In addition, both air-abrasion and Er:YAG laser irradiation have been reported to be reliable and safe technologies (Katora, Jubach & Polimus, 1981; Goldstein & Parkins, 1994; Myers, 1994; Laurell & others, 1995; Sekine & others, 1995; Sonntag & others, 1995) that offer improved patient comfort by reducing the pressure, heat, vibration and noise generally associated with rotational methods and, in most cases, eliminating the need for local anesthetic (Rinaudo & others, 1997; Cozean & others, 1997).

However, there is little reported research concerning the effects of laser irradiation and air-abrasion on dental substrates and, consequently, the marginal sealing of cavities prepared by these new technologies.

Therefore, this investigation assessed the degree of marginal leakage of a resin composite in Class V cavities prepared by high-speed dental bur, air-abrasion or Er:YAG laser.

METHODS AND MATERIALS

Twenty sound human third molars extracted within a six-month period and stored in saline solution were selected and cleaned with a water/pumice slurry and a dental prophylactic cup. Forty Class V cavities with the occlusal margins in enamel and the cervical margins located 1 mm apical to the cemento-enamel junction were prepared on the buccal and lingual surfaces of each tooth. Cavity dimensions were standardized utilizing a template to trace an outline on both surfaces with a mesiodistal width and an occluso-gingival measurement of 3 mm. The depth of the cavity was approximately 1.5 mm and was calibrated by measuring with a premarked periodontal probe. Four preparation techniques were utilized, and for each tooth, the bucal and lingual cavities were prepared by different methods. The specimens were randomly assigned to four equal groups (n=10).

For Group I, the cavities were prepared using a #245 carbide bur at high-speed with air/water spray and finished with sharp hand instruments. New burs were used after every five preparations. For Group II, cavities were prepared by the handpiece of the air-abrasive system (Kreativ Mach 4.1- New Image Do Brazil Imp Exp Ltda, São Paulo SP, 04543-000, Brazil) with a 0.011-inch nozzle opening using a 27.5 µm aluminum oxide particles stream at 60 psi air pressure with intensity of 7g/min on enamel and 4g/min on dentin. The treatment was

accomplished at a distance of approximately 2 mm at a 45° angle with the occlusal surface. For Groups III and IV, the cavities were prepared by a short pulsed Er:YAG laser (Fidelis, Fotona Latin Med Inc, Stuart, FL 34994, USA) with density energy of 500mJ at 5Hz, emitted at a wavelength of 2.94 µm under water spray coolant. The diameter of the laser beam at the tooth surface was 1.0 mm and a handpiece with a removable tip was attached to a flexible fiber delivery system. The laser parameters were selected on the control panel based on the procedure to be accomplished, so that high dosimetries were used to cut enamel and dentin and low dosimetries were used to treat tooth surface.

After cavity preparation, the enamel and dentin surfaces were conditioned according to the experimental group. Groups I and II were etched with a 37% phosphoric acid gel (Gel Etchant, Kerr Corporation, Orange, CA 92667, USA) for 15 seconds, rinsed for 20 seconds and gently dried with absorbent paper to keep the tooth surface moist; for Group III, the cavities were treated by a short-pulsed Er:YAG laser (120mJ/pulse at 4Hz) for 30 seconds; for Group IV, laser irradiation (120mJ/pulse at 4Hz) for 30 seconds was followed with acid-etching, rinsing and drying using the material and technique described for Groups I and II.

A uniform layer of a single component bonding system (Single Bond, 3M Dental Products, St Paul, MN 55144, USA) was applied to all specimen preparations, air-thinned and light-cured for 30 seconds with a visible light curing unit with an output of 400 mW/cm^2 (XL 3000, 3M Dental Products). A microhybrid light-activated resin composite (Z-100, 3M Dental Products) was inserted using an incremental placement technique. Each increment was approximately 1 mm thick and was light cured for 40 seconds. The specimens were stored for seven days in distilled water at 37ºC, then the restorations were polished with Super Snap disks (Shofu Inc, Kyoto, 6050983, Japan). The specimens were subjected to a thermocycling regimen of 500 cycles between 5°C and 55°C waterbaths. Dwell time was one minute, with a three-second transfer time between baths.

In preparation for the dye penetration test, the specimens were superficially dried and sealed (including apical region) with epoxy resin and two coats of nail varnish, except for a 2 mm-window around the cavity margins. They were then immersed in a 0.2% Rodhamine B solution for 24 hours. The surface-adhered dye was then rinsed in tap water and the epoxy resin and nail varnish were removed with a sharp instrument. The teeth were embeded in a chemically-activated acrylic resin (JET, Clássico, São Paulo, SP 05458-001, Brazil) and bisected longitudinally in a mesiodistal direction with a water-cooled diamond saw in a Minitom sectioning machine (Struers A/S, Copenhagen, DK-2610, Denmark). The separated buccal and lingual halves were again embedded in blocks of acrylic resin and sectioned in a buccol-ingual direction, providing two to three cuts 1.0 mm thick for each tooth. This approach was utilized because the third molar's accentuated convexity did not allow the buccal and lingual preparations to be centralized, and, therefore, the restorations could not be propriately sectioned in the same slice. Following sectioning, the cuts were initially thinned in a polishing machine (Politriz, Struers A/S, Copenhagen, DK-2610, Denmark) using sandpapers from 180 to 600 grit, then manually smoothed with water sandpapers of 1000 and 1200 grit to obtain a flattened surface and a final thickness of approximately 0.25 mm.

The sections were identified, carefully fixed on microscopic slides and analyzed for leakage by viewing them under a x2.5 magnification optical microscope (Axioskop-Zeiss, Jena, D-07740, Germany) connected to a color video camera with x10 magnification on the lens (TK-1270, JVC, Tokyo, 55473, Japan). The images that were obtained were transmitted to a personal computer, and after digitization, were analyzed using the KS300-v2.0 software (Kontron Elektronik GmbH, Eching bei München, Germany), which allows for standardized assessment and quantitative measurement of microleakage in millimeters. The depth of the cavity and dye penetration along the occlusal and cervical margins towards the axial wall were determined and the percentage of infiltration was calculated. The data were submitted to statistical analysis using the Kruskal-Wallis test.

RESULTS

Table 1 shows the means of tracer agent penetration (percentage) at both regions for the experimental groups.

Analyzing the results, a statistically significant difference ($p<0.01$) between the occlusal (enamel) and cervical (dentin/cementum) margins was observed for all groups. The best marginal sealing in the occlusal region was found in Group I (bur-preparation + acid-etching) and Group IV (laser-preparation + laser and acid-etching).

Table 1: *Means of Tracer agent Penetration at Occlusal and Cervical Margins*

Margin	Bur + Acid Etching (I)	Air-Abrasion + Acid Etching (II)	Laser Preparation + Laser-Etching (III)	Laser Preparation + Laser and Acid-Etching (IV)
Occlusal	0% (± 0%)	3.4% (± 10.7%)	26% (± 32.1%)	0% (± 0%)
Cervical	13.7% (± 29.1%)	25.9% (± 38.4%)	37.2% (± 31.4%)	21.2% (34.6%)

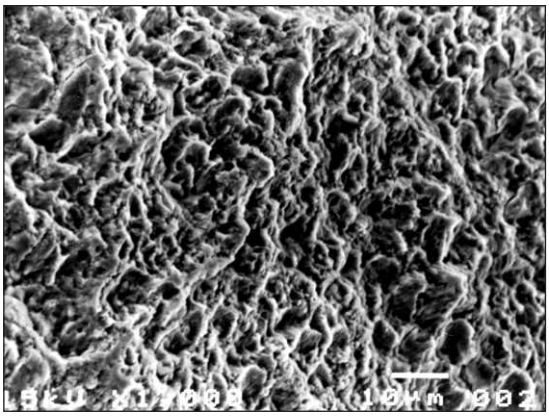

Figure 1. *Representative scanning electron microscopic (SEM) photograph of lased enamel surface (Original magnification x1000, and bar represents 10 µm).*

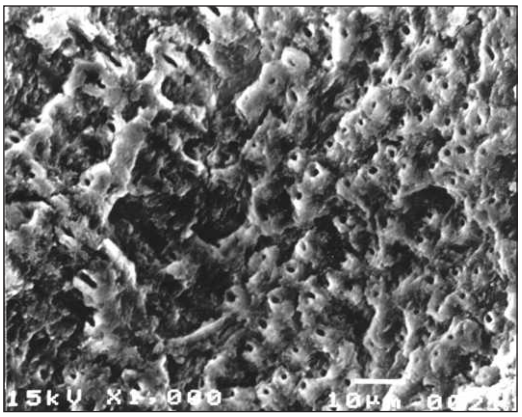

Figure 2. *Representative scanning electron microscopic (SEM) photograph of lased dentin surface (Original magnification x1000, and bar represents 10 µm).*

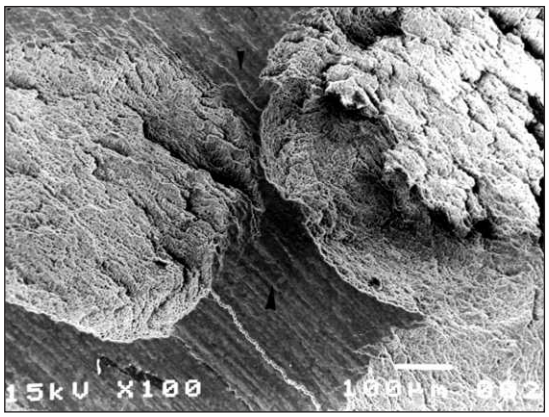

Figure 3. *Representative scanning electron microscopic (SEM) photograph of lased enamel surface showing non-treated areas (arrows). (Original magnification x100, and bar represents 100 µm).*

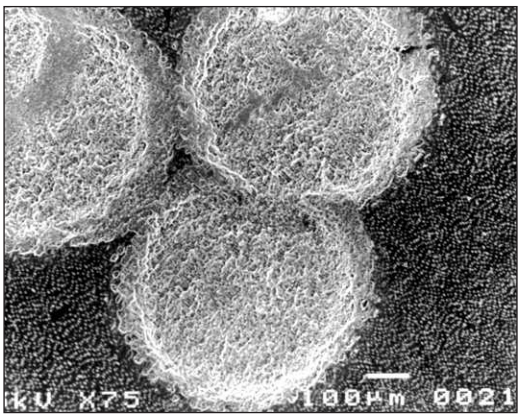

Figure 4. *Representative scanning electron microscopic (SEM) photograph of lased dentin surface showing non-treated areas (arrows). (Original magnification x75, and bar represents 100 µm).*

Comparing the four techniques, Group III (laser preparation + laser-conditioning) had the highest degree of microleakage and showed significant differences at the occlusal ($p<0.01$) and cervical ($p<0.05$) margins. The other experimental groups showed statistical similarities in the amount of marginal leakage at occlusal margins; however, at cervical margins, there was a significant difference ($p<0.05$) between Group I and the remaining groups.

DISCUSSION

It has been demonstrated that air-abrasion used for tooth preparation (Christensen, 1996; Boston, Alperstein, & Boberick, 1997; Guirguis, Lee & Conry, 1999) creates a roughened surface (Laurell & Hess, 1995) depending on the air stream pressure and aluminum oxide particle size. Nevertheless, several authors (Eackle, Wong & Huang, 1995; Guirguis & others, 1999; Ellis, Latta & Westerman, 1999; Nikaido & others, 1996; Fu & Hanning, 1999) observed that air-abrasive treatment does not eliminate the need for acid-etching. The resin materials bonded to non-etched air-abraded surfaces lack the seal obtained with acid-conditioning. Furthermore, acid conditioning is necessary to remove the smear layer created by air abrasion and enhance bonding to the dental substrate (Roeder & others, 1995). Because of these findings, this research combined the air-abrasive system with a phosphoric acid conditioning.

Although the related proceedings provided satisfactory marginal sealing, numerically, it was observed that the bur-prepared group presented lower microleakage values. This could be explained by the cavity type (Class V) since the air-abraded preparations do not present precise, clearly identifiable outlines and, therefore, the irregularity of walls and margins might have interfered with the marginal sealing of the restorations.

It has been reported that treatment with Er:YAG laser creates surfaces similar to acid-etched surfaces (Keller & Hibst, 1993). Other investigations (Visuri & others, 1996; Hibst & Keller, 1994) have shown that when bonding composite to tooth structure, the Er:YAG laser alone or combined with acid-etching produces a surface with bonding strength that is equal to or better than that solely produced by acid-etching. However, Eduardo & others (1996) observed that resin composite shear bond strength to enamel was superior for the acid-etched group compared to the group prepared by Er:YAG laser. They felt the morphological alterations created on the enamel surface by laser irradiation were insufficient to effectively bond composite to dental surface.

This study's findings disclosed that preparing and exclusively treating tooth surface with Er:YAG laser did not result in optimal sealing at either margin. Laser

irradiation did not produce a dye penetration-resistant interface, and the laser group demonstrated the highest degree of microleakage. A possible explanation for such performance could be incomplete ablation of the enamel surface resulting from the difficulty in obtaining a uniform pulse administration. The morphological observation of lased surfaces by scanning electron microscope (SEM) revealed an irregular ablation pattern (Figures 1 and 2) and the existence of unaffected areas (Figures 3 and 4). A previous investigation (Groth & others, 1996) reported similar problems.

However, when laser application was followed by 37% phosphoric acid conditioning, the marginal integrity of the restorations was considerably enhanced. These observations are consistent with preliminary studies (Eduardo & others, 1996, Groth & others 1996) that stated the need for acid-etching following Er:YAG laser irradiation to ensure a complete surface conditioning and effective adhesion of the restorative material to cavity preparation.

Although the laser technique indications for cavity preparation include Class V cavities, there are still a few reports regarding marginal leakage. Niu & others (1998) investigated microleakage after resin filling Class V cavities prepared by a conventional method using air-turbine and by Er:YAG laser with and without acid-etching. When both methods were compared, stereoscope and scanning electron microscopic analysis showed no significant differences in the amount of microleakage. On the other hand, Robles & others (2000) and Ramos (1998) compared Class V cavities prepared by high-speed air turbine and Er:YAG laser associated or not associated with a subsequent acid-etching. They observed a higher degree of marginal leakage when cavities were not acid-etched. These findings are consistent with this study, which demonstrated improved marginal sealing when phosphoric acid-conditioning was accomplished. In another investigation, Khan & others (1998) claimed no significant difference in microleakage when using dye penetration between the cavities prepared by air turbine and Er:YAG laser plus acid-etch. These observations support this study, which statistically found similar results for these techniques.

When Group III was compared with other methods of cavity preparation among occlusal margins, more disparate results were observed in contrast to cervical margins. A possible explanation for this would be that the laser does not create the uniform microporosities characteristic of acid-conditioning on the enamel surface. Instead, it promotes a disorganized destruction of enamel prisms. The resultant micro-retention clearly varies from acid-etching patterns, and this irregular microstructure results in poor sealing and a higher degree of marginal leakage. At the dentin/cementum margins, the absence of enamel may explain the amount of microleakage observed for all groups, although lack of acid-etching for laser-treated cavities (Group III) probably determined the increased values.

Aluminum oxide air-abrasion and laser irradiation are still in the developmental stages compared to the traditional high-speed air-turbine technique, and may be useful as adjunct or replacement methods for some cavity preparation and restorative materials.

Studies have yet to establish the specific type of micro-retention obtained with either air-abrasion or Er:YAG laser and how it differs from that obtained with acid conditioning. Likewise, supplemental research should also determine whether any difference is produced by varying particle size or pressure, as well as using different frequencies and energy outputs.

Further investigation that focuses on the long-term effects of ultrastructural changes observed in enamel and dentin substrates prepared and treated by Er:YAG laser or air-abrasive system may lead to improved microleakage prevention as well as to 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 appropriate to conclude that:

- enamel margins provided better marginal sealing than dentin/cementum margins;
- on enamel margins, Class V cavities prepared by air-abrasion or Er:YAG laser, followed by phosphoric acid-etching, showed microleakage values comparable to cavities prepared by high-speed air turbine followed by phosphoric acid-etching;
- cavities prepared and treated by Er:YAG laser (without acid-etching) showed the highest degree of microleakage and
- conventional dental bur preparation with acid etch resulted in the best overall seal.
- none of the tested proceedings provided optimal sealing and guaranteed consistent elimination of marginal leakage in the margins without enamel.

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Polymerization Shrinkage of Densely-Filled Resin Composites

TC Aw • JI Nicholls

Clinical Relevance

Using densely-filled resin composites can reduce the amount of shrinkage that occurs during light curing of composites.

SUMMARY

A new group of restorative materials called "packable" composites has recently been introduced. These products are essentially highly-filled or densely-filled hybrid resin composites. One of the many claims made about these materials is that they undergo less polymerization shrinkage than their conventional counterparts. This in vitro **investigation compared the amount of linear shrinkage that occurs within a variety of densely filled resin composites (DFC) and conventional hybrid resin composites when cured with a visible halogen light. Six DFC resins (Alert, Ariston, P60, Prodigy, Solitaire and Surefil) and two hybrids (TPH-Spectrum, Z100) were used in this study. Dimensional change was measured in a linear direction using a calibrated light microscope. Eighty samples of resin composite were tested, resulting in eight groups of 10 samples (N=10) each. The one-way ANOVA with Student-Newman-Keuls post-hoc test was used to compare the shrinkage between groups, and Pearson's Correlation was used to test the relationship between filler characteristics and shrinkage. Alert and P-60 had significantly less shrinkage than Solitaire, Ariston, Prodigy, Z-100 and TPH-S. Thus, the shrinkage values of some DFC resins were significantly less and others were no different from conventional hybrid resins. There is a moderate association between filler volume and shrinkage. Filler size and resin chemistry are other factors that may also effect shrinkage.**

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INTRODUCTION

In resin composites, the photoinitiator camphorquinone is sensitive to light in the blue region of the visible spectrum, with optimal wavelength centered around 480 nm (ADA Council, 1985; Cook, 1982). Resin composites undergo polymerization shrinkage after visible light curing (Donly & others, 1990). The shrinkage that occurs in a resin composite is clinically significant in that it can cause postoperative sensitivity (Eick & Welch, 1986), inadequate interproximal contact (Bertolotti, 1991), marginal discrepancy, debonding and stress failures (Puckett & Smith, 1992). The measured linear shrinkage of resin composites seems quite variable. Rees showed values that ranged between 0.9% and 2.24% (Rees & Jacobsen, 1989). Other studies have

found this amount to be between 1.1% and 1.8% (Kullman, 1989) or 1.3% and 3.22% (Puckett & Smith, 1992). Many methods have been used to measure polymerization shrinkage, such as cuspal deflection (Suliman, Boyer & Lakes, 1993; Suliman, Boyer & Lakes, 1994), use of a dilatometer (Kullman, 1989; Bausch & others, 1982; Penn, 1986) and measuring specific gravity (Puckett & Smith, 1992). Aw & Nicholls (1997) described a method of optical measurement of linear shrinkage that does not interfere with physical deformation. Measuring linear shrinkage has been found to be comparable to using a mercury dilatometer (de Gee, Feilzer & Davidson, 1993).

It has been suggested that increasing the filler content of a resin composite may reduce the amount of shrinkage. Results of some studies have shown that densely filled composite (DFC) resins are more viscous, and, therefore, easier to pack and stay in place (Tyas, Jones & Rizkalla, 1998). In a clinical trial of posterior Class II restorations, the amount of wear of DFC resin after three years appears comparable to that of amalgam (Roberts & others, 1992). Use of DFC resin in Class II restorations may also decrease the size of the cervical marginal gap (Ehrnford & Derand, 1984). Changing the filler composition can alter the physical properties of the resulting composite (Li & others, 1985; Feilzer, de Gee & Davidson, 1988).

This investigation compared the amount of immediate post-cure linear shrinkage that occurred when six DFC resins and two hybrid resins were cured with a halogen light.

METHODS AND MATERIALS

Design

A brass receptacle with a groove measuring 2 x 6 x 38 mm was fabricated for this experiment. This groove served as a runner for two brass blocks measuring 2 x 5 x 6 mm, which fit snugly into the groove but were able to slide freely within it. Within each block was a stainless steel rod that protruded lengthwise out of either end in the direction of the groove (Figure 1). The dimensions used simulate the proximal box of an average Class II preparation. At one end the rod protruded 1.5 mm and ended in a flattened stub. At the other end, the rod protruded 9 mm, terminating in a sharpened point. The two blocks were placed in the groove with the flattened ends of the rods facing each other and the pointed ends facing in opposite directions. The length from the point to the opposite end of the brass block was measured for each block, and the total for both was 30.582 mm (Figure 2). Thus, the length of the resin material was the distance between the end points minus this length.

The flattened ends of the rods were separated approximately 4 mm prior to resin placement. The resin composite material was placed in the runner between the two brass blocks, with the flattened ends of the stainless steel rods embedded wholly within the resin (Figure 2). When shrinkage occurred within the resin material, the rods and brass blocks were pulled towards each other with the pointed ends providing consistent points from which to measure dimensional change. The distance between the two pointed ends of the rods was measured prior to curing. After curing, the same distance was measured and the difference between them provided a measure of the linear dimensional shrinkage that occurred within the resin composite during curing.

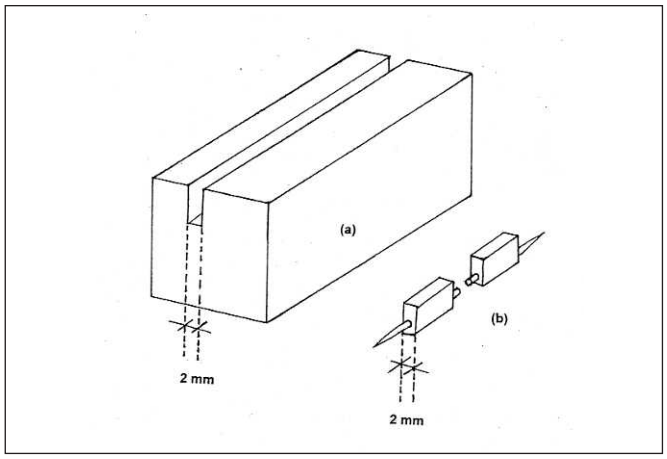

Figure 1. *Schematic drawing of (a) brass receptacle with 2 mm groove, and (b) orientation of brass blocks with steel rods.*

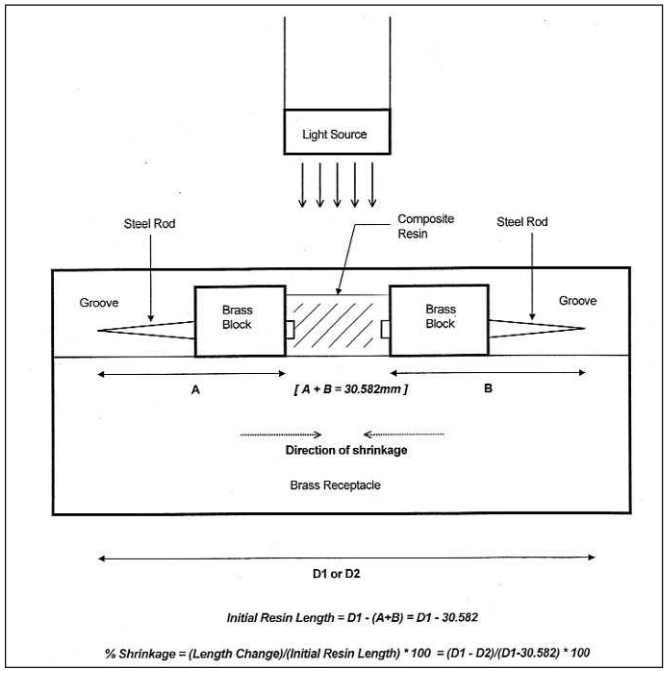

Figure 2. *Cross-sectional diagram of experimental apparatus configuration.*

Materials Characteristics

Each material was handled and cured according to the manufacturer's instructions. The DFC resin materials under consideration were Alert (Jeneric-Pentron, Wallingford, CT 06492, USA), Ariston (Ivoclar, Amherst, NY 14228, USA), P60 (3M Dental Products, St Paul, MN 55144, USA), Prodigy (Kerr, Orange, CA 92867, USA), Solitaire (Kulzer, South Bend, IN 46614, USA) and SureFil (Dentsply Caulk, Milford, DE 19963, USA). TPH-Spectrum (Dentsply Caulk, Milford, DE 19963, USA) and Z100 (3M Dental Products, St Paul, MN 55144, USA) hybrid resin materials were used as controls. Table 1 shows the characteristics of each material.

Procedural Steps

1) The groove in the brass receptacle was coated with a lubricant (Masque, Bosworth Co, Skokie, IL 60076, USA) to eliminate adhesion and possible inhibition of shrinkage.
2) The composite material was dispensed and condensed into the groove in the space between the blocks. Great care was taken to ensure that the flattened ends of the rods were wholly enveloped by the resin composite material and voids were minimized. The blocks were also immobilized during condensation to eliminate compressive or tensile elastic strain on the resin.
3) With an orange UV light shield over the resin (Figure 3) to eliminate premature polymerization, the distance between the two pointed ends of the rods was measured and recorded (D1).
4) The shield was removed and the resin cured in the standard manner with the recommended curing times and increment thicknesses according to the manufacturer's instructions.
5) The distance between the ends of the rods was again measured (D2).
6) The amount of shrinkage was measured by the dimensional change that occurred following curing. The percentage of shrinkage was calculated from the formula (Figure 2):

$$\% \text{ Shrinkage} = \frac{D1 - D2}{D1 - 30.582} * 100\%$$

Table 1

Resin Composite	Shade	Filler Weight (%)	Filler Volume (%)	Average Filler Size µm	Resins	Rec Increment Thickness	Cure Time (Seconds)
Alert	A2	82	67	0.7	BisEMA	5.0	40
P60	A3	83	61	0.6	BisGMA, UDMA, BisEMA	2.5	20
Sure Fil	A	82	66	0.8	U-BisGMA	5.0	40
Solitaire	A30	90	65	2 - 20	Bis-GA, TEGDMA	2.0	40
Ariston	U	79	59	1.3	BisGMA, UDMA, TEGDMA	4.0	40
Prodigy	A3	80	62	0.6	BisEMA, TEGDMA	5.0	40
TPH-S	A3	76.5	57.5	8	BisGMA, BisEMA, TEGDMA	2.5	40
Z100	A3	84.5	66	0.6	BisGMA, TEGDMA	3.0	40

BisEMA Ethoxylated bisphenol-A dimethacrylate
BisGA Bisphenol-A glycidyl diacrylate
BisGMA Bisphenol-A glycidyl methacrylate
U-BisGMA Urethane-modified bisphenol-A glycidyl methacrylate
TEGDMA Triethylene glycol dimethacrylate
UDMA Urethane dimethacrylate

Table 2

Resin Composite	Mean Shrinkage (%)	Standard Deviation	Shrinkage Range (µm)
Alert	0.430	0.041	25 - 36
P60	0.464	0.055	23 - 32
Sure Fil	0.499	0.055	30 – 41
Solitaire	0.545	0.047	30 – 39
Z100	0.565	0.040	35 – 46
TPH-S	0.583	0.051	37 – 47
Ariston	0.603	0.089	28 - 43
Prodigy	0.640	0.092	24 - 47

• Lines connect values that are not significantly different at $p<0.05$.
• ** Materials in bold are DFC resins, hybrid resins otherwise.

This procedure was repeated for 10 samples per resin, with the visible light Optilux 400 (Kerr, Orange, CA 92867, USA) at 600mW/cm², 11 mm spot size. An equivalent amount of material was dispensed for every composite sample tested in each group. The light tip was placed as close as possible between 1 and 4 mm away from the top surface of the sample (depending on recommended increment thickness), simulating curing of resin at the base of the proximal box of an average Class II preparation. As a result, with the light tip placed directly above on the groove, the distance from the curing tip to the bottom surface of every resin sample tested was exactly the same, specifically, 6 mm from the top to the bottom of the groove.

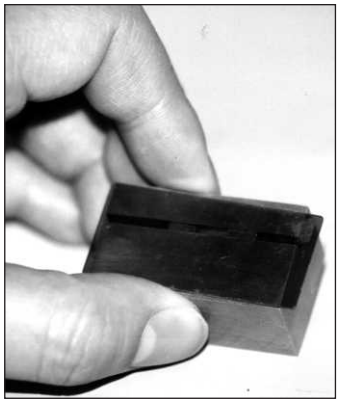

Figure 3. *Orange light shield covering entire groove and resin.*

Dimensional Measurement and Measurement Error

Length measurement was optically performed with a Nikon Measurescope 20 (Nikon Corp, Tokyo, Japan) calibrated light-microscope (Figure 4) whose measurement error was determined for the operator. The microscope table could be translated in the X and Y directions, with the digital readout micrometers having an accuracy of 0.001 mm. To determine measurement error, a given point (rod tip) was selected to be the zero point, with the digital readout being 0.000 in both the X and Y directions. With the X-value at zero, the crosshairs was moved away from zero in the X-direction and re-aligned by the operator. The X-reading was recorded and this process was repeated 10 times so that a measure of the amount of operator reading error could be obtained. The reading error, determined in this manner, was found to be ± 0.002 mm.

Data Collection and Analysis

The dependent variable that was recorded was the amount of linear shrinkage that occurred immediately after light curing. Between the resin groups, this variable was subjected to a one-way ANOVA with the Student-Newman-Keuls post-hoc test used to define significant subsets at the 95% confidence level. Pearson's product moment correlation coefficient determined the relationship between the filler characteristics and linear shrinkage.

RESULTS

Table 2 shows the average percentage of linear dimensional shrinkage (10 samples per group) that occurred

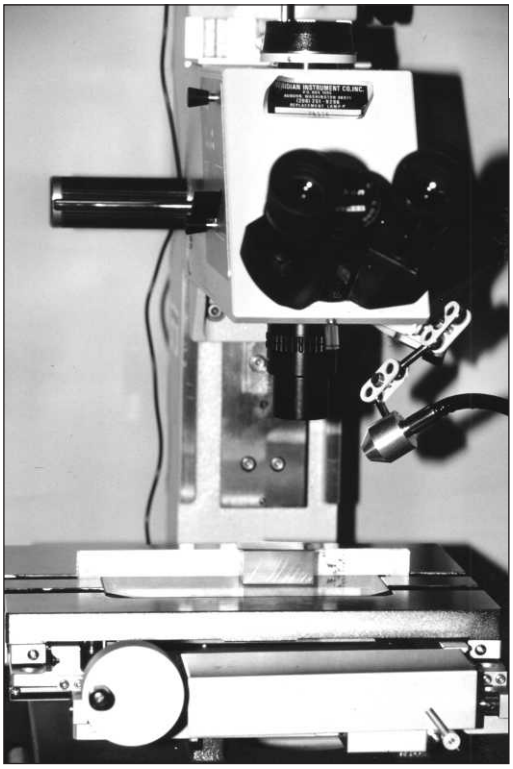

Figure 4. *Experimental apparatus on microscope platform.*

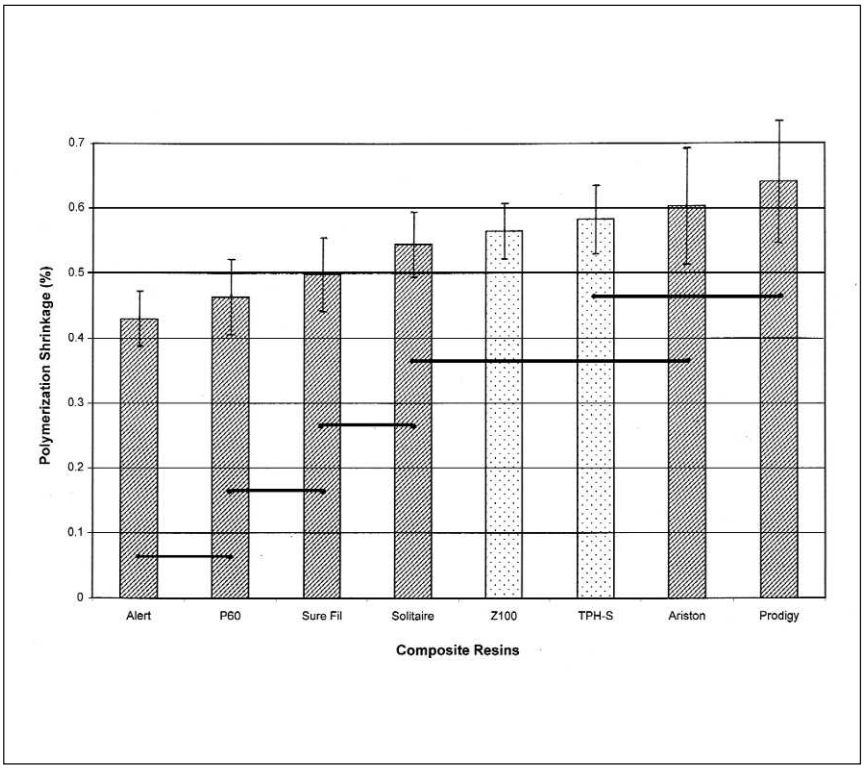

Figure 5. *Graph of immediate post-cure mean linear shrinkage % of various densely-filled and conventional hybrid composite resins. Vertical lines are standard deviations, horizontal lines connect values that are not significantly different at* p<*0.05.*

for the six DFC and two hybrid resins in ascending order with Alert < P60 < Surefil < Solitaire < Z100 < TPH-S< Ariston < Prodigy (Figure 5). The one-way ANOVA test with SNK comparison analysis revealed that the homogenous subgroups were [Alert, P60], [P60, Surefil], [Surefil, Solitaire], [Solitaire, Z100, TPH-S, Ariston], [TPH-S, Ariston, Prodigy], with no significant differences within those groups. Thus, Alert and P60 had significantly less shrinkage than Solitaire, Ariston and Prodigy. Also, the amount of shrinkage of Solitaire, Ariston and Prodigy was not significantly different from conventional hybrid composites such as Z100 or TPH-Spectrum. Visible light curing elicited significantly different shrinkage percentages for some DFC resins. The correlation coefficient between filler volume and shrinkage, r_1 = -0.5759. The correlation coefficient between filler size and shrinkage, r_2 = +0.246.

DISCUSSION

The principal property of DFC resins, as the name suggests, is the increased amount of glass filler loading in the composition of the resin-filler mixture. For some DFC resins, there are different amounts of polymerization shrinkage between them. Some of these differences are significant, some are not, while some are no different from the hybrid composites. It has been demonstrated that an inverse relationship exists between inorganic filler loading and monomer conversion (Mizayaki & others, 1991; Razak & Harrison, 1997; Labella & others, 1999; Barron, Rueggeberg & Schuster, 1992). From the shrinkage results shown in Table 2 and the DFC properties shown in Table 1, the authors observed a trend that the lower the filler % by volume, the greater the mean shrinkage %. A moderate negative correlation (r_1 = -0.5759) exists between filler volume and shrinkage, meaning that more highly filled composites are prone to undergo less shrinkage. This could primarily be explained by the fact that the lower the volume of filler, the higher the volume of resin matrix. Since glass fillers are solids that do not shrink, it is the fluid resin matrix paste that shrinks due to bond formation and physical deformation in the transition from a gel to a solid state. With more resin, more bond formation is possible when polymerized. This results in greater physical deformation and larger shrinkage from one with more filler and less resin that results in smaller shrinkage.

A secondary factor affecting shrinkage would be filler size (Li & others, 1985; Feilzer & others, 1988). From the shrinkage results in Table 2 and the DFC properties in Table 1, the authors observed a trend that the larger the filler particle size, the greater the mean shrinkage %. A weak positive correlation (r_2 = +0.246) exists between filler size and shrinkage, meaning that composites with smaller filler particles may undergo less shrinkage. A small particle has a large surface area-to-volume ratio compared to a large particle, which has a small surface area-to-volume ratio. Therefore, for a given volume of filler, the larger the size of the filler, the less resin is required to envelop the filler particles and the greater the mass of resin matrix in-between. Smaller filler particles result in smaller interparticle distance and smaller masses of resin matrix in-between the filler particles. Smaller continuous mass of composite can result in less bonds and shorter chain formations occurring, which results in decreased shrinkage. Also, with greater spread and dispersion of smaller filler particles in the resin matrix, greater diffraction and diffusion of the curing light beams can occur (Bayne, Heymann & Swift Jr, 1994; Ruyter & Oysaed, 1982), resulting in a less uniform and decreased polymerization of the resin matrix. In contrast, larger filler particles would allow for greater light transmission and penetration through the resin (Li & others, 1985), and hence, more polymerization and shrinkage. However, trying to quantify this relationship using the correlation coefficient may be of limited value since the quoted filler particle sizes are only average figures, with actual particle sizes comprising a wide range of values and amounts and the non-systematic nature of the variation in filler composition between various materials.

Prodigy is the one resin composite that seems anomalous to the expected outcome with high filler volume, low filler size, and, yet, the highest shrinkage values. The fact that the mean shrinkage value has a high standard deviation suggests a resin-filler mixture that may not be homogenous with uneven distribution of filler, which could explain the resulting data spread. Another explanation is that the resin chemistry in this case could be the greater determinant of shrinkage than filler characteristics, which are discussed below.

The third factor affecting shrinkage is attributable to the chemistry of the resin matrix, itself. It has been well demonstrated that differences in the nature of the monomer and catalyst can alter the polymerization of the material, and, thus, the shrinkage as well (Peutzfeldt, 1997; Anseth & others, 1996; Davy & others, 1998). From the shrinkage results in Table 2 and the DFC properties in Table 1, the authors observed that resins containing TEGDMA have a greater mean shrinkage %. TEGDMA is a monomer with lower molecular weight (thus smaller size), compared to the monomer Bis-GMA. Shrinkage occurs by bond formation between monomers during polymerization. The distance between monomers due to van der Waals' forces are transformed into the distance of covalent bonds of the polymer that is formed. Thus, the magnitude of shrinkage is determined by the *number* of covalent bonds formed (degree of conversion) and also by the *size* of the monomers. Smaller monomers are used

to lower the viscosity, but they also have the effect of increasing polymerization shrinkage (Ruyter, 1985; Ferracane, 1995). Adding monomers of large molecular weight to the mixture can minimize the contraction per unit volume of resin. The degree to which each individual factor (filler loading, filler size and resin chemistry) determines the amount of polymerization shrinkage and the effect between them, whether synergistic or additive, is speculative and requires further study.

The values obtained are consistent with data from previous studies on linear and volumetric shrinkage of resin composites (Kullman, 1989; Bausch & others, 1982; Penn, 1986; de Gee & others 1993; Aw & Nicholls, 1997). Since there may be some frictional resistance to shrinkage between the brass receptacle and resin samples, the values obtained do not correspond *exactly* to absolute free shrinkage measurements but serve as comparative values between the experimental groups. However, based on a *percentage* of shrinkage, the effect of this resistance is minimal. Since the various DFCs produced different amounts of polymerization shrinkage, this suggests that different amounts of bond formation have occurred due to the three factors described above. The contraction behavior can be very specific to a given composite due to its unique combination of filler, resin characteristics and formulation. Is there a limit as to how much filler loading, how small the filler particles and how optimal the resin chemistry can be to achieve minimal shrinkage and yet have good physical properties? There probably is, but, as yet, it is unknown and requires further investigation.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The polymerization reaction of densely-filled composite (DFC) resins was accompanied by a dimensional change that results in shrinkage.
2. The amount of polymerization shrinkage of some DFC resins can be significantly less, and with others, it can be no different from that of hybrid resin composites.
3. There exists a moderate association between filler volume and polymerization shrinkage. Other factors, such as filler size and resin chemistry, may also have some impact on shrinkage.

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The Effect of Curing Light Intensity on the Cytotoxicity of a Dentin-Bonding Agent

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Clinical Relevance

A suitable light source should be used to cure dentin bonding agents as completely as possible to avoid any potential for pulpal toxicity.

SUMMARY

Various dentin-bonding agents (DBAs) have been widely used to improve the bonding strength of dental resins and to prevent microleakage at the resin-dentin interface, although DBA may exert potentially detrimental effects upon dental pulp. In this study, a DBA (Scotchbond Multi-purpose) cured at different light intensities (100, 200 and 300-mW/cm^2) for 10 seconds was extracted with Dulbecco's modified Eagle's medium (DMEM) for 24 hours. Thereafter, pulp cells (1 x 10^4 cells/well) were exposed to DMEM with or without DBA extract for 12 hours, 24 hours and five days. Pulp-cell cytotoxicity was measured with a modified 3-(4,5-dimethyl-thiazol -2-yl)-2,5-diphenyl-tetrazolium bromide (MTT) assay. No significant cytotoxicity of DBA eluents on pulp cells was found for the 12-hour exposure group. Following 24-hour exposure of cells to DBA cured at 100-mW/cm^2, pulp cells became rounder, more retracted and lost some cellular processes as compared to controls. Five-day exposure of pulp cells to DBA extract cured by light at levels of 100, 200 and 300 mW/cm^2, respectively, led to a growth retardation of 26%, 48% and 70% as analyzed by the inhibition of mitochondrial dehydrogenase activity. These results indicate that DBA may exert some cytotoxic effects upon dental pulp, especially when DBA-curing is insufficiently complete, as may occur at a low light intensity.

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INTRODUCTION

Numerous dentin adhesives have been developed for bonding restorative resin to dentin (Douglas, 1989). The major reasons for using dentin-bonding agents (DBAs) are to promote the retention of the restoration, to reduce microleakage across the dentin-resin interface and to effectively distribute occlusal stress (Douglas, 1989). Although human- and animal-based experiments have

shown a low incidence of irreversible pulpal damage elicited by DBAs, noted histopathological pulp-tissue changes, including inflammatory-cell infiltration and irregular dentin formation, have been previously reported (Dumsha & Beckerman, 1986; Al-Dawood & Wennberg, 1993; Hebling, Giro & Costa, 1999). These pulpal inflammatory responses are possibly due to pulpal irritation by DBA ingredients, especially when restoration-proximate remnant dentin thickness is thin or when pulp is exposed during cavity preparation procedures (Dumsha & Beckerman, 1986; Hfrsted-Bindslev, 1987; Al-Dawood & Wennberg, 1993; Hebling & others, 1999). Since light curing of DBA is usually not fully complete, leachable components, such as bis-glycidyl methacrylate (Bis-GMA), urethane dimethylacrylate (UDMA), camphor-quinone and 2-hydroxyethyl methacrylate (HEMA), may, therefore, penetrate through dentinal tubules, exert potential pulpal injury and inhibit pulp-tissue repair (Pashley, 1988; Ferracane & Condon, 1990; Hanks & others, 1991; Bouillaguet & others, 1996).

Current DBAs contain many ingredients, interactions between which may explain the variable cytotoxicity obtained from different experiments (Al-Dawood & Wennberg, 1993; Ratanasathien & others, 1995). In addition, a number of factors may influence the pulpal response to DBAs, such factors include remaining dentin thickness, the chemical composition of the particular DBA used, clinical operative procedures and dentin permeability (Söderholm, 1991). In this study, the authors hypothesized that insufficient curing of DBAs may affect the cytotoxicity of DBAs to dental-pulp cells. They, therefore, tested the influence of curing light intensity of a specific DBA, Scotchbond Multi-Purpose (SMP), on *in vitro* human pulp-cell cytotoxicity.

METHODS AND MATERIALS

The Culturing of Human Dental-Pulp Cells

Two strains of human dental-pulp cells were cultured by an explant technique as previously described (Chang & others, 1998a). Briefly, two healthy extracted human third molars were obtained following informed consent. For dental-pulp cell culture, freshly extracted teeth were immediately delivered to the culture room to avoid the likelihood of nutritional deprivation of pulp tissue. The teeth were then carefully broken with a hammer and the pulp tissue removed with a curette. The pulp tissue was gently minced into small pieces by a sharp surgical knife so as to minimize tissue compression. Minced pulp-tissue pieces were transferred to a culture plate and covered sequentially by a small amount of culture medium, then by a coverslip. After 24 hours of tissue adhesion, 10 milliliters of Dulbecco's modified Eagle's medium (DMEM) containing 10% fetal calf serum (FCS), penicillin (100 U/ml) and streptomycin 100 µg/ml (Table 1) was added. Pulp cells usually migrate out from the tissue explant about seven to 10 days later. When the growth of pulp cells approached confluence, they were passaged at a ratio of 1:2. Pulp cells from passage numbers three and eight were used for these studies. Table 1 summarizes the chemicals and materials used in this study.

Table 1: *Materials and Chemicals Used in This Study*

Materials or Chemicals	Source
3-(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyl-tetrazolium bromide (MTT), dimethylsulfoxide (DMSO)	Sigma Chemical Company (St Louis, MO, USA)
Dulbecco's modified Eagle's medium (DMEM), fetal calf serum (FCS), penicillin/streptomycin	Gibco (Life Technologies, Grand Island, NY, USA)
Scotchbond Multi-Purpose (SMP)	3M Dental Products St Paul, MN, USA

Preparation of DBA Extract

The DBA agent used, Scotchbond Multi-Purpose (SMP) Dental Adhesive System, was obtained from 3M Dental Products (St Paul, MN 55144, USA) and was applied into a teflon ring with a diameter of 7 mm and a height of 3 mm. They were covered by a layer of transparent polyester strip (Stripmat, Polydentia, CH-6805 MEZZOVICO, Switzerland) and exposed to a curing light (Curing Light XL 3000, 3M Dental Products) at a distance of 1 mm and a variety of light intensities including 100, 200 and 300 mW/cm^2 for 10 seconds. The light intensity was evaluated with a Cure Rite (Dentsply/Caulk, Milford, DE 19963, USA). Five DBA blocks were immersed in 5 ml of DMEM and extracted for 24 hours. Culture medium (DMEM) was prepared, sterile-filtered and the FCS concentration adjusted to 10% prior to use.

Cytotoxicity of DBA Upon Pulp Cells

Pulp cells were seeded at an initial density of 1 x 10^4 cells/well in 1 ml of DMEM with 10% FCS into 24-well tissue culture plates. After 24 hours in an incubator, the seeding medium was decanted and the cells exposed to 1 ml of fresh medium (DMEM with 10% FCS) containing extracts of DBA block-cured with various light intensities. The cells were then further incubated for various time periods, including 12 hours, 24 hours and five days. Upon completion of incubation, the viable cell number was estimated using a modified 3-(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyl-tetrazolium bromide (MTT) assay as described previously (Chandler, Messer & Ellender, 1994; Chang & others, 1998b). Briefly, at the end of the experiment, the cells were exposed to culture medium containing MTT at a concentration of 0.5 mg/ml for a period of 1.5 hours. Viable cells can reduce MTT to insoluble formazan by mitochondrial dehydrogenase activity. The insoluble formazan so produced was eluted with 0.5 ml of di-methyl sulfoxide (DMSO), and the optical density read against a standard

Figure 1: *Morphology of cultured human dental pulp cells.*

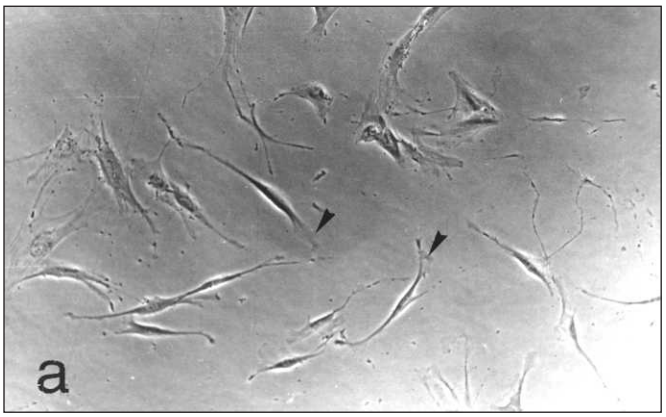

Figure 1A. *Untreated pulp cells appear elongated and spindle-shaped. Extended cellular filopodia and lammelipodia are evident (arrow head).*

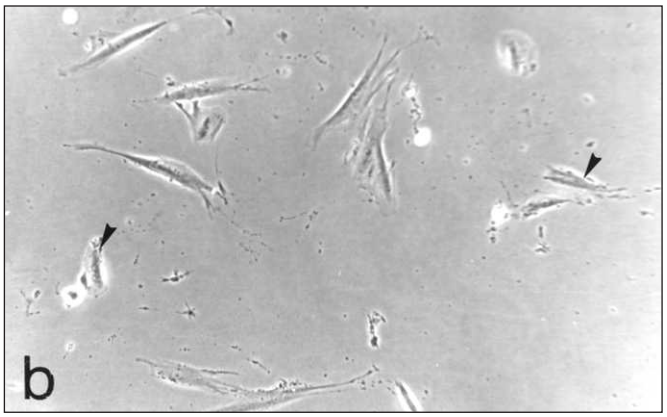

Figure 1B. *Following exposure of pulp cells to medium extract of 200-mW/cm^2 light-cured DBA for 24 hours, cells became retracted and the loss of some cellular processes is noted (arrow head).*

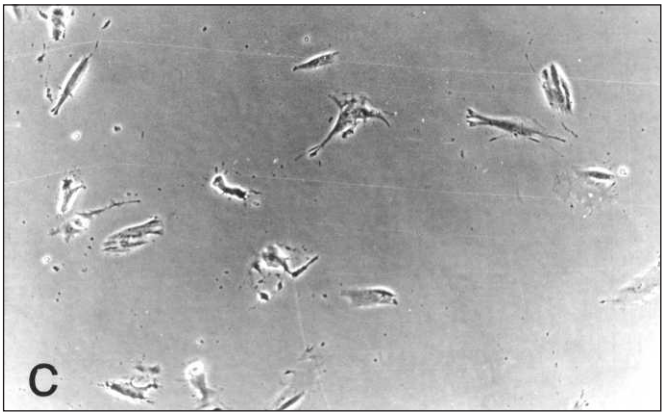

Figure 1C. *Exposure to medium extract of 100-mW/cm^2 light-cured DBA for 24 hours. Retraction and rounding of pulp cells is more evident.*

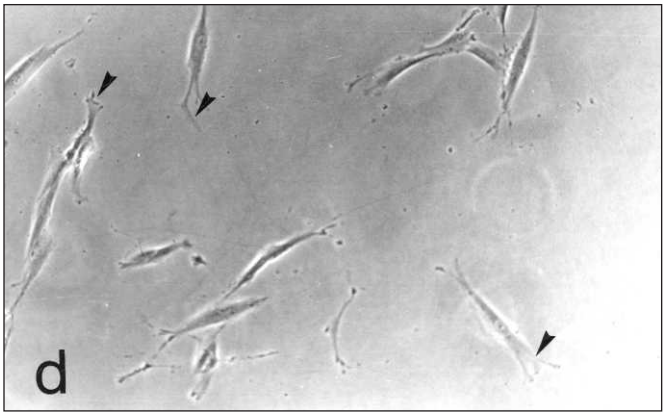

Figure 1D. *Following exposure of pulp cells to medium extract of 300-mW/cm^2 light-cured DBA for 24 hours, no marked morphological changes are noted, as indicated by the presence of marked filopodia (arrow head) (100x, original magnification).*

reagent blank at OD_{540} using a Dias Microplate Well Reader (Dynatech Medical Products LTD, Great Britain). Morphological alterations of the pulp cells detected on microscopic examination were photographed using a Nikon camera under phase contrast microscopy.

Two strains of primary cultured human dental pulp cells with similar cellular susceptibility to toxic effect of DBA were used throughout these experiments. Representative experimental results are shown here. Each experiment was repeated from three to six times. In each experiment, five individual (identical) wells were used for testing the effects of medium and medium containing the various different (intensity) light-cured DBA extracts (100 mW/cm^2-, 200 mW/cm^2- and 300 mW/cm^2) upon the growth of pulp cells. Results were analyzed by StatView 4.0f (Abacus Concepts, Inc, Berkeley, CA, USA) and expressed as Mean ± SD. One-way ANOVA with Fisher's exact test were used for comparisons between the means of control and test samples. A p value < 0.05 was considered as pronounced difference.

RESULTS

Cultured human dental pulp cells appeared elongated and spindle-shaped. Some cells containing filopodia and lammelipodia were noted, suggesting cell proliferation and migration activity (Figure 1A). Following 24-hour exposure of pulp cells to medium containing DBA extract for which the corresponding curing-light intensity was 100 mW/cm^2 and 200 mW/cm^2, pulp cells appeared more retracted than controls, and also exhibited a loss of extended cellular filopodia (Figures 1B & 1C). Exposure of pulp cells to medium extract from 300 mW/cm^2 light-cured DBA for 24 hours induced no marked morphological change for these pulp cells (Figure 1D).

The relative cytotoxicity of DBA extract was evaluated following exposure to medium eluents of SMP cured by three different light intensities over 12 hours. The mean optical density (OD_{540}) value for DMSO eluent from control wells was 0.246 Abs, comparable to that

Figure 2: *Effect of curing-light intensity upon the cytotoxicity of DBA extract to human dental pulp cells. Cell numbers were measured with a modified MTT assay. Optical density (OD) of DMSO eluent was measured at a wavelength of 540 nm. Results are shown as Mean ± SD (shown by bar). *Denotes significant difference (p<0.05) when compared with control.*

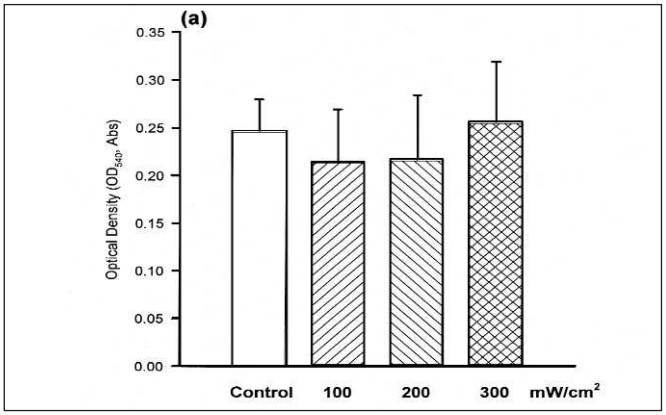

Figure 2A. *Pulp cells (1 x 10⁴ cells/well) were exposed to culture-medium containing DBA extract for 12 hours*

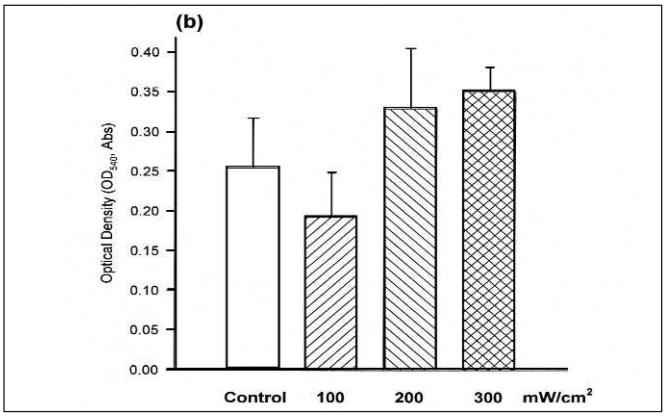

Figure 2B. *Pulp cells (1 x 10⁴ cells/well) were exposed to culture-medium containing DBA extract for 24 hours.*

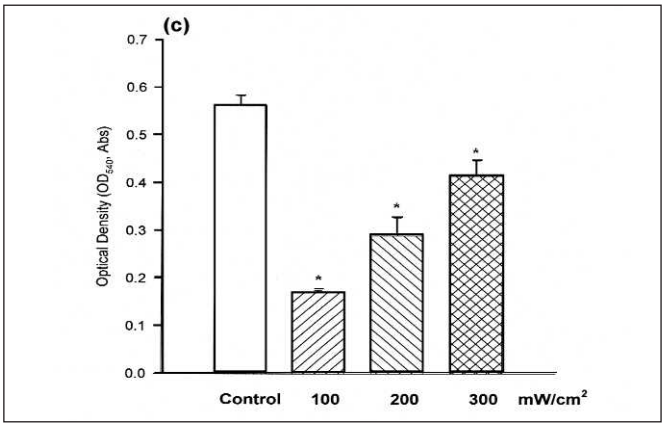

Figure 2C. *Pulp cells (1 x 10⁴ cells/well) were exposed to culture-medium containing DBA extract for five days.*

from cells exposed to medium eluents from the 100-, 200- and 300 mW/cm²-cured DBA categories, these values being 0.214, 0.216 and 0.255 Abs, respectively (Figure 2A). Exposure of pulp cells to medium eluents from 100 mW/cm² light-cured DBA for 24 hours elicited a 25% reduction in the mitochondrial dehydrogenase activity as compared to controls ($p>0.05$). Contrasting this result, exposure of pulp cells to medium eluents from the 200 and 300 mW/cm²-cured DBA categories transiently elevated the mitochondrial dehydrogenase activity by 29% and 37%, respectively ($p>0.05$; Figure 2B). Exposure of pulp cells to medium eluents of 100, 200 and 300 mW/cm²-light-cured DBA categories for five days led to marked cytotoxicity and mitochondrial dehydrogenase activity being inhibited by medium eluents of 100, 200 and 300 mW/cm² light-cured DBA by 26%, 48% and 70%, respectively, as compared to controls (Figure 2C).

DISCUSSION

It is possible that DBAs may exert potentially harmful effects upon dental pulp tissue when placed in contact with unexposed or exposed dental pulp (Franquin & Brouillet, 1988; Hebling & others, 1999)—a possible explanation being that curing of DBA by light is usually not complete. Residual monomers and leachable substances from DBAs have been reported to diffuse through dentinal tubules and induce inflammation, immunogenesis and even necrosis of the dental pulp (Wataha & others, 1994).

In this study, an extract of SMP cured by different light intensities induced morphological changes within cultured human dental pulp cells and also inhibited the growth of such cells *in vitro*, suggesting release of some (presumably) toxic ingredients from the SMP following the curing process. Marked retraction and loss of extended filopodia of pulp cells was noted. Cellular filopodia and lamellopodia are extended cellular processes that mainly contain actin filaments and have been shown to be crucial for cell proliferation and movement during wound-healing and morphogenesis (Sheetz, Wayne & Pearlman, 1992; McClay, 1999). The noted induction of the retraction of pulp cells by SMP suggests that leachable ingredients from SMP may affect the biological functions of pulp cells. The (suggested) toxic effects of DBAs thus may, subsequent to their use *in vivo*, induce inflammation and even necrosis of dental pulp. This may partly explain why intermittent pain or asymptomatic pulp-necrosis is occasionally noted following adhesive-resin restorations.

Meryon & Brook (1989) have consistently found that three DBA materials (Tripton, Scotchbond 2 and

Gluma) are cytotoxic to hamster kidney fibroblasts even in the presence of a 0.1 mm and 0.5 mm dentin barrier. All three DBA materials exerted marked cytotoxicity leading to morphological alterations to cells. Hanks & others (1991) have also found that the monomers present in some resins and DBAs exhibit definite cytotoxicity when placed in direct contact with dental pulp cells (HFrsted-Bindslev, 1987). Using an agar overlay assay, DBA components, such as FO, NPG-GMA, NTG-GMA and PMDM, also exert cytotoxicity upon African green-monkey kidney cells and human embryonic lung (WI-38) cells *in vitro* (Dumsha & Sydiskis, 1985). Hanks & others (1992) have found that some DBAs (for example, Gluma and Scotchbond 2) exert cytotoxicity to Balb/c 3T3 cells, although the presence of a dentin disc barrier decreased the toxic effects of DBAs.

In vivo experiments, however, have also shown that applying Scotchbond adhesive (Silux) to dentin can result in an acceptable pulpal response as indicated by the presence of tertiary dentin adjacent to the cavity preparation, the presence of an intact layer of odontoblasts and evidence of normal dentinogenesis (Franquin & Brouillet, 1988). Acid etching of a tooth cavity and subsequent application of Scotchbond adhesive may, however, induce differing severities of pulpal inflammation for human teeth in the presence of residual dentin (Franquin & Brouillet, 1988). Promoting the penetration of bacteria and DBA into dentinal tubules and dental pulp by acid etching may explain these detrimental pulpal effects and similar effects observed by other researchers (for example, HFrsted-Bindslev, 1987; Franquin & Brouillet, 1988). By contrast, Hanks & others (1992) have reported that DBAs exert minor toxic effects upon animal dental-pulp tissues. Such reported discrepancies may possibly be due reasons such as including the specific DBA used by researchers, the presence or absence of a dentin barrier between the restoration adhesive and the tooth pulp tissue, restoration-proximate remnant dentin thickness and variation in experimental conditions, such as the time of DBA exposure and the type of cells used.

Different brands of DBA that contain different ingredients have been developed, therefore, the toxicity of DBAs may vary depending on the included components. This may partly explain why different DBAs exert differential toxic effects upon tooth pulp (Meryon & Brook, 1989; Hanks & others, 1992). Scotchbond Multi-Purpose is a fourth-generation DBA, the primer for which mainly contains HEMA, polyalkenoic acid copolymers and others, whereas the bonding agent contains Bis-GMA, HEMA and others. In this study, even extract of 300-mW/cm^2 light-cured SMP may interfere with the growth of pulp cells *in vitro*, indicating that ingredients of SMP may leach from light-cured SMP. Furthermore, SMP has been shown to initially release greater quantities of its constituent components, and its cytotoxicity has been reported to be more substantial than was the case for other DBA materials, such as Aelitebond, Optibond and Prisma Universal Bond, even in the presence of a dentin barrier (Bouillaguet & others, 1998). In this study, the observed cytotoxicity was more evident when pulp cells were exposed to medium extract from 100 and 200 mW/cm^2 light-cured DBA than when exposed to extract from 300 mW/cm^2 light-cured DBA. Clinically, this suggests that the DBA material used should be cured by light as completely as possible to prevent its potential pulpal irritation.

CONCLUSIONS

(1)DBAs may be a significant factor in inducing pulpal reactions, especially when curing of the DBA material is not complete.

(2)To reduce any possible pulpal damage following operative restoration involving the use of DBAs, curing conditions, such as the time of curing, the curing light intensity and the thickness of the resin restoration, should be taken into consideration during clinical operative procedures.

Acknowledgements

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Fracture Resistance of Teeth Restored with the Bonded Amalgam Technique

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CTS Dias • LAMS Paulillo

Clinical Relevance

Bonding amalgam technique in mesio-occlusal-distal (MOD) cavities within 2/5 the intercuspal distance width and 3/5 the height of the crown depth did not increase the fracture resistance of maxillary premolars.

SUMMARY

This study evaluated the fracture resistance of maxillary premolars with MOD Class II cavity preparations restored with silver amalgam (G1), Scotchbond Multi Purpose Plus and silver amalgam (G2) and Panavia F and silver amalgam (G3). After the restorations were made, the specimens were stored at 37ºC for 24 hours at 100% humidity and submitted to the compression test. Statistical analysis of the data (ANOVA and Tukey Test) revealed no significant differences among the three groups that were studied.

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INTRODUCTION

Sound teeth rarely fracture during normal masticatory stress. However, cuspal fracture can frequently occur in teeth that have been weakened by caries, large cavity preparations (Jagadish & Yogesh, 1990; Mondelli & others, 1980) and reduced dental structure from erosion or abrasion (Eakle, Maxwell & Braly, 1986; Khers & others, 1990). Studies have shown that teeth with cavity preparations become weaker as the occlusal isthmus is widened, and they fracture more easily than intact teeth (Cavel, Kelsey & Blankenau, 1985; Eakle, 1986; Gelb, Barouch & Simonsen, 1986; Jagadish & Yogesh, 1990; Liberman & others, 1990). Therefore, it is important to preserve the integrity of the dental structure to maintain its resistance (Diefenderfer & Reinhardt, 1997; Eakle & others, 1986). When enamel is supported by dentin good clinical results can be obtained. However, there are cases in which the enamel walls have no support, resulting in a tendency to fracture (Espinosa, 1978; Franchi & others, 1994). In these situations, the unsupporterd enamel must be removed or a resilient material must be used to strengthen the weakened margins (Franchi & others, 1994).

Among direct restorative materials, silver amalgam has been clinically used for more than 160 years (Craig, 1971; Santos & Meiers, 1994; Staninec & Holt, 1988) due to its favorable mechanical properties and easy handling characteristics. Silver amalgam is also frequently chosen for posterior restorations since it resists masticatory stress (Gwinnett & others, 1994). However, its high modulus of elasticity (Skinner & Philips, 1993) does not allow it to reinforce weakened cusps (Boyer & Roth, 1994). This limits its use in cavities where the enamel is not supported by dentin (Gelb & others, 1986; Santos & Meiers, 1994). In addition, lack of adhesiveness to dental structures requires cavity design with mechanical retention at the expense of healthy tooth structure, which increases fracture susceptibility (Bagley, Wakefield & Robbins, 1994; Gwinnett & others, 1994; Staninec & Holt, 1988).

With the development of adhesive systems, bonding of dental amalgam to tooth structure became possible (Staninec & Holt, 1988; Staninec, 1989; Gwinnett & others, 1994; Oliveira, Cochran & Moore, 1996). With this technique, the alloy is condensed against an adhesive resin before polimerization (Vargas, Denehy & Ratananakin, 1994). This technique reduces the need for mechanical retention and allows more conservative cavity preparations (Bagley & others, 1994; Gwinnett & others, 1994; Staninec, 1989). Bonding alloy to enamel and dentin (Boyer & Roth, 1994; Staninec & Holt, 1988) may increase fracture resistance due to splinting of the anatomical crown (Gwinnett & others, 1994; Santos & Meiers, 1994).

Filled adhesive systems offer advantages in the bonded amalgam technique compared to unfilled agents (Bagley & others, 1994). Despite the progress made with this procedure, some limitations have been cited, such as increased chair time, increased cost and the practioners' learning curve for a new technique (Gwinnett & others, 1994; Christensen, 1994; Oliveira & others, 1996). It is, therefore, important to determine whether the proposed advantages of this technique offset the disadvantages.

This study evaluated two adhesive systems for the bonded amalgam technique—a dentin adhesive system and a resin cement—in terms of fracture resistance of maxillary premolars with standardized MOD cavities, and restored teeth with silver amalgam as a control group.

METHODS AND MATERIALS

Thirty unrestored, non-carious, extracted maxillary premolars were stored in 10% formalin solution (pH=7.0) at room temperature. After cleaning with periodontal curettes, the teeth were mounted in polystyrene resin cylinders, exposing 2 mm of root surface below the cementum-enamel junction. They were then stored in physiological saline.

The intercuspal distance on the occlusal surface and the distance from the buccal cusp tip to the cemento-enamel junction of each tooth were measured using a digital caliper to standardize the cavity preparations.

MOD cavities were prepared with parallel walls and no approximal boxes. A FG 3145 diamond bur was used in a high-speed water cooled handpiece that was fixed in a specially designed jig (Figure 1) that allowed their bucco-lingual (Figure 1A) and mesio-distal (Figure 1B) dimensions to be accurately prepared. The isthmus width was 2/5 the distance between the cusp tips, and the pulpal depth was 3/5 the height of the crown. The cavity preparation's width was checked in the occlusal portion and the pulpal depth was measured with a digital caliper in relation to the buccal cusp tip. The preparations were finished with the same diamond bur in a low speed handpiece. The teeth were rinsed with an air-water spray, then randomly divided into three groups (n=10). Group 1: teeth restored with silver amalgam, using alloy Permite C (SDI, São Paulo, Brazil 05421-030) and a conventional restoration technique (Gwinnett & others, 1994). Group 2: dentin adhesive system Scotchbond Multi-Purpose Plus (3M Dental Products, Campinas, Brazil 13001-970) was applied before inserting amalgam. Group 3: the resin cement Panavia

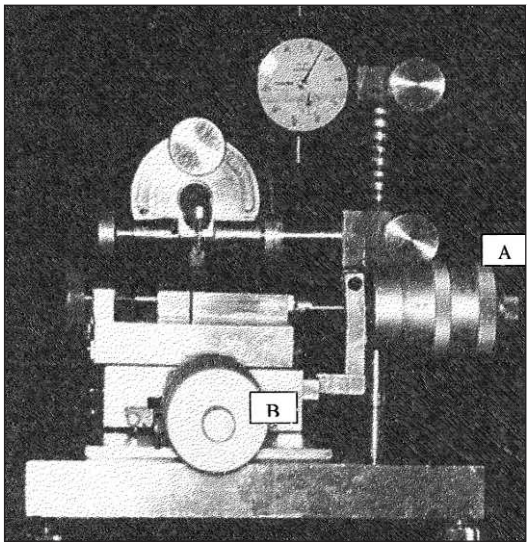

Figure 1. *Precision instrument utilized to prepare the cavities. 1A and 1B: Precision instruments to move the samples to prepare the cavities.*

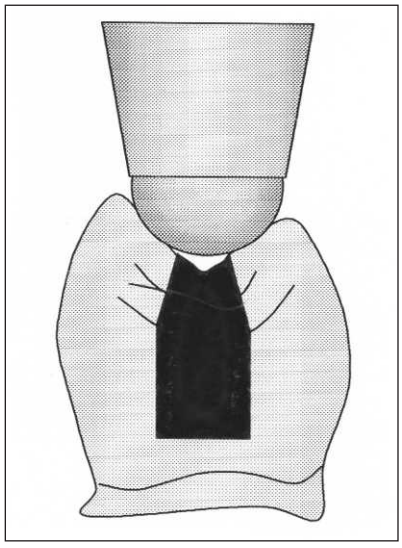

Figure 2. *Diagram of the 4 mm steel sphere contacting the cusps of a restored specimen.*

Table 1: *Means and Standard Deviations*

Group	N	Mean (Kgf) and SD	Tukey
G1	10	94.16 (+ 19.3865)	a
G2	10	104.43 (+ 24.8655)	a
G3	10	98.77 (+ 25.6181)	a

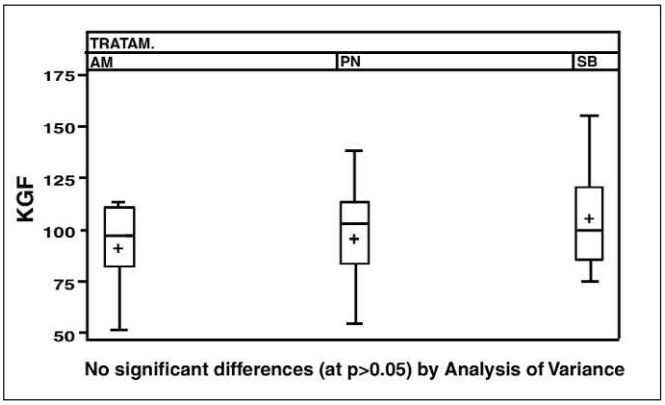

Figure 3. *Box-Plot diagram of the fracture resistance test (AM=Amalgam; PN=Panavia F; SB=Scotchbond Multi-Purpose Plus; TRATAM=Treatment).*

F (Kuraray Co, Osaka, Japan 1-12-39) was used before the teeth were restored with Permite C. The bonding agents' components used in the adhesive amalgam technique were applied according to the manufacturer's instructions.

The specimens were stored for 24 hours in 100% relative humidity at 37°C and the fracture test was conducted in an Instron testing machine (Instron Corp, Canton, England 02021-1089) with 500 Kgf load. A 4 mm diameter steel sphere contacted the buccal and lingual cusps of the tested teeth at a crosshead speed of 0.5mm/min until fracture occurred (Figure 2).

RESULTS

The values obtained in this study were subjected to Analysis of Variance (ANOVA), which revealed no significant differences among the experimental groups (p>0.05). The fracture resistance average for the experimental groups were: G1: 94.16 Kgf; G2: 104.43 Kgf; G3: 98.77 Kgf. To document these results, the Tukey test was applied (Table 1 and Figure 3).

DISCUSSION

Ideally, a restorative material should strengthen the tooth and protect against further fracture (Jagadish & Yogesh, 1990). Extensive cavity preparations weaken tooth walls and increase fracture susceptibility (Pilo, Brosh & Chweidan, 1998). Therefore, Eakle, Staninec & Lacy (1992) suggested that using an adhesive under amalgam restorations can increase the fracture resistance of restored teeth.

The results of this study showed no statistically significant differences between the bonded amalgam techniques that used Scotchbond Multi-Purpose Plus or Panavia F and the conventional technique that only used amalgam. Such results suggest that using bonding agents associated with silver amalgam do not prevent cuspal fracture, which is contrary to other researchers' studies (Oliveira & others, 1996; Pilo & others, 1998). However, this study's findings can be explained by the cavity preparation size, with the isthmus width of 2/5 the distance between the cuspal tips, a pulpal depth of 3/5 the heigth of the crown and parallel walls, in which a significant amount of dentin was still observed under the cusps. The dentin low modulus of elasticity might have supplied considerable flexure resistance to the remaining walls, resulting in statistically similar fracture resistance values. This study's findings agree with Santos & Meiers (1994) and Pilo & others (1998), who also found no significant differences among the groups restored with adhesive amalgam and the group restored with only amalgam. However, Pilo & others' (1998) comparison of the different dentin bonding systems found lower results for Scotchbond Multi-Purpose Plus, whose performance was justified by the absence of filler particles. According to Eakle (1986), reinforcement of dental structure is directly related to using an adhesive system since reinforcement was found only in the group in which the adhesive agent for enamel and dentin was applied. Therefore, Panavia F was expected to produce better results because, in addition to the presence of filler, the material adhesively bonds to enamel and dentin. However, this system uses an acidic primer that incorporates the smear layer instead of removing it. This produces a narrow hybrid layer and reduces the adhesion values (Nishida & others, 1993), which could explain the results of the Panavia F cement.

A one year clinical study (Mahler & others, 1996) found many technical problems and few benefits for the bonded amalgam technique. There were no statistical differences in post-operative sensitivity or marginal integrity.

The results of this research demonstrated high standard deviation values for the three groups studied. According to Jagadish & Yogesh (1990), individual variations in tooth morphology may occur, and the cusp's angulation, enamel thickness, inherent weaknesses and slight variations of the contact of the metal sphere with the cusp during testing may contribute to the large standard deviations. In addition, differences exist between fractures that occur clinically and those induced by a testing machine. Forces generated intraorally during function vary in magnitude, application speed and direction, whereas forces applied *in vitro* are at a constant direction and speed and continually increase until fracture occurs. Bell, Smith & de Pont

(1982), in their study of cuspal failures in teeth restored with MOD amalgams, concluded that cusp fracture occurs as a result of brittle tooth structure fatigue caused by the propagation of microcracks. *In vivo*, only 38% of the fractures occur on the functional lingual cusp (Cavel & others, 1985). In this study, where force was applied with constant direction and increasing load, fracture of the functional cusp occurred in 100% of the specimens.

It should be noted that the bonded amalgam technique is not only used to reinforce the remaining tooth structure. When amalgam is packed into the cavity against an unset resin, a mechanical interlocking of resin and amalgam occurs (Eakle & others, 1992). This interlocking is probably a significant factor in the retention of amalgam in the cavity (Lacy & others, 1989), reducing the need for additional retentive devices in already weakened teeth. Another advantage of the adhesive-amalgam technique is the significant reduction in marginal leakage (Gwinnett & others, 1994) due to sealing that occurs between the dental structure and the adhesive system (Diefenderfer & Reinhardt, 1997).

According to Christensen (1994), it is important that the adhesive amalgam technique be studied widely because, if amalgam restorations are improved by bonding, then the procedure should be routinely done. If not, this rather expensive and time-consuming task should not be used. According to the technique's limitations and the results found in this study, adhesive amalgam should not be commonly employed as a means of preventing dental fracture.

CONCLUSIONS

Study results indicate that when cavity preparations were restored with bonded amalgam techniques using Scotchbond Multi-Purpose Plus and Panavia F, no increase in fracture resistance was observed when compared to conventional amalgam restorations.

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Temperature Transmission of High-Output Light-Curing Units Through Dentin

RW Loney • RBT Price

Clinical Relevance

Light-curing units with concentrating light guides or plasma arc light sources can significantly affect thermal transfer through dentin.

SUMMARY

Light-curing units used for polymerizing restorative resins produce heat during operation. Newer curing units with concentrating light guides or different light sources may require shorter curing times, however, the effect of such modifications on temperature transfer to the pulp is unknown. This study examined the effect of high output light-curing units on temperature transfer through resin composite and dentin.

Temperature rise was measured for 40 seconds for one curing light (Optilux 401 Curing Light) with either a standard 8 mm light guide tip or a light-concentrating tip (Turbo Light Guide), and for three seconds with a plasma arc lamp (Apollo 95E Curing Light). Temperatures were directly recorded at the tip of the light guide and through a sandwich composed of a 1 mm thick pre-cured cylinder of resin composite and dentin (dentin thickness either 0.58 mm or 1.45 mm).

The mean temperature rise ranged from 1.8°C, measured through the sandwich of 1 mm of composite and 1.45 mm of dentin with the plasma arc unit, to 26.4°C measured directly on the Turbo light guide. For each light guide, the temperature increase was greatest when measured directly on the curing tip and least when measured through the composite and 1.45 mm dentin specimens. When measured through the composite/dentin sandwich, the plasma arc unit produced the lowest temperature increase (0.58 mm thick dentin specimen = 5.1°C; 1.45 mm thick dentin specimen = 1.8°C). For a given thickness of resin, the differences in temperature change for all comparisons among the three curing unit/light guides were significant at the 95% level of confidence. Also, for a given light, the differences in temperature for all comparisons among the dentin thicknesses were significant at the 95% level of confidence. However, there were three comparisons of light unit and dentin thickness interaction that were not significant at the 95% level of confidence. For all other comparisons of interaction, significant differences were found at the 95% level of confidence. The temperature increased by 42% to 56% when the Turbo Light Guide was used compared to the standard light guide for thick and thin dentin specimens, respectively.

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INTRODUCTION

Depending on the magnitude of the temperature increase and the duration of the applied heat, varying degrees of pulpal injury can result from applying external heat to a tooth (Lisanti & Zander, 1952; Zach & Cohen,

1965), although the interpretation of the temperature rise required to cause irreversible changes has been questioned (Lloyd, Joshi & McGlynn, 1986). Zach & Cohen (1965) found that a 5.5°C increase in temperature could cause histological changes in the pulp and that 60% of teeth with vital pulps failed to recover from an 11°C temperature increase. Thermal transfer is affected by dentin thickness (Goodis & others, 1989), which can have more of an influence on thermal transfer to the pulp than the thermal conductivity or the type of restoration placed on a tooth (Takahashi, Kitagami & Komori, 1977).

Studies have demonstrated that light-curing units can cause a temperature increase that could damage pulp (Goodis & others, 1990; Hussey, Biagioni & Lamey, 1995). Pulpal temperature rises caused by light-curing units can be affected by the shade of the restorative resin, the degree of porosity in the material, the initial resin temperature, the material thickness (McCabe, 1985) and the duration of light exposure (Goodis & others, 1989). Thermal transfer to the pulp varies with the type of unit used during curing (Goodis & others, 1990; Goodis & others, 1997; Hannig & Bott, 1999). Both the light source and resin contribute to the temperature increase that occurs during curing of resin composites, although contribution of the latter is minimal (Lloyd & others, 1986). The depth of cure (Shortall, Harrington & Wilson, 1995) and surface microhardness (Shortall & Harrington, 1996) have been related to the energy output of the light-curing unit. Newer light-curing units have been designed to increase the light energy output (Curtis, Rueggeberg & Lee, 1995; Dental/ Medical Diagnostic Systems, 1998), but increasing the light intensity could increase thermal transfer to the pulp.

This study determined the effect of a concentrating light guide on a quartz tungsten halogen light-curing unit and a plasma arc unit on the thermal transfer through resin and two thicknesses of dentin. The null hypothesis was that differences in curing units/light guide tips and dentin thickness would have no effect on the temperature transfer measured through the specimens.

METHODS AND MATERIALS

Temperature rise was measured for two curing light sources. The temperature increase produced by a Optilux 401 curing light (Demetron/Kerr Corp, Danbury, CT 06810-7377, USA) was measured with a standard 8 mm light guide tip and also with an 8 mm concentrating light guide, which is claimed to increase light output by 50% (Turbo Light Guide, Demetron/ Kerr Corp). An Apollo 95E Curing Light (DMD, West Lake Village, CA 91362, USA) using a plasma arc lamp that claims to cure resin composites in one to three seconds was also tested. Output of the Optilux curing light was measured prior to the experiment for the standard light guide with and without an intervening Mylar strip (.002", DuPont Mylar, Wilmington, DE 19880-0027, USA) for the standard light guide (663.0mW/cm^2, SD=3.5 and 720.7mW/cm^2, SD= 17.1, with and without Mylar, respectively) and also for the concentrating light guide (973mW/cm^2, SD=9.2 and 1037mW/cm^2, SD= 0, respectively). The light output of the plasma arc unit could not be measured because it was beyond the upper limit of the light output-measuring device (Cure Rite digital radiometer, Dentsply/Caulk), but it has been reported to have an output of 1930 mW/cm^2 (Christensen & others, 1999).

The light guides had Mylar strips covering their surface for all measurements. Temperatures were recorded directly at the surface of the light guide and also through a combined sandwich of a pre-cured cylinder of resin composite and a cylindrical specimen of dentin. Ten specimens of resin composite (Prodigy Condensable resin composite, shade A1, Lot #810876, Kerr, Orange, CA 92867, USA) approximately 1 mm in thickness (1.08 mm, SD = 0.03) were used in combination with one of two dentin specimens (thin = 0.58 mm, and thick = 1.45 mm). To ensure uniform specimen thicknesses and diameter, only two specimens of dentin were used. All dentin specimens were kept in physiologic saline solu-

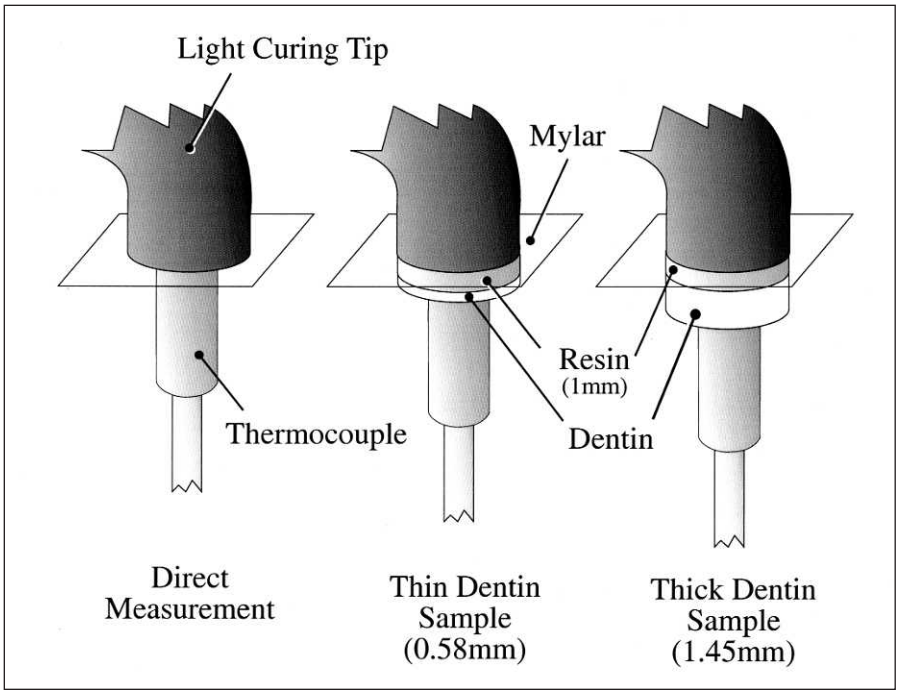

Figure 1. *Technique for measuring temperature changes directly and through thick and thin specimens.*

tion and dried by blotting immediately prior to testing. Temperatures were recorded using a thermocouple (Barnant Thermocouple Thermometer Model 600-1040, Barrington, IL, 60010-2392, USA) that was in direct contact with either the Mylar strip or the surface of the dentin furthest away from the light guide tip (Figure 1). The curing times used were those recommended by the manufacturers (40 seconds for the Optilux, three seconds for the Apollo). The Apollo unit was also tested with a six-second cure because some reports have suggested that increasing the curing times can improve the depth of cure. Since the Apollo unit does not allow continuous curing for more than three seconds, additional curing time was begun as soon as the unit would permit (approximately 1.5 seconds between curing cycles). There was intimate contact among all components for all tests when the measurements were recorded. Pilot testing revealed no difference in mean temperature changes whether or not an intervening conducting medium (silicone paste) was used.

For each curing unit/light guide, the temperature measurements were made in random order for the 20 resin specimens (10 thin, 10 thick). Maximum temperatures were recorded up to the point where the temperatures began to fall rather than the exact moment that a light unit shut off. Measurements were sequentially made with sufficient time between tests for the thermocouple to register a constant temperature for a minimum of 30 seconds. The ambient temperature of the specimens ranged from 26.4°C to 27.2°C (SD=0.3).

RESULTS

The mean temperature changes are given in Table 1 and Figure 2. The ANOVA table and post-hoc Scheffe F test comparisons are given in Tables 2 and 3, respectively. The greatest temperature changes occurred when measured directly on the light guide of the curing light through the Mylar matrix. The temperature increase was lowest when measured through the 1 mm composite and the 1.45 mm dentin sandwich ($p<0.001$).

When measured through the combined composite/ dentin sandwich, the plasma arc unit, used for three seconds, produced the lowest temperature increases (0.58 mm dentin specimen = 5.1°C, 1.45 mm dentin specimen = 1.8°C), even though it caused a slightly higher temperature rise when measured directly on the light guide compared to the Optilux unit with the standard light guide used for 40 seconds. There were no significant differences in the temperature increases recorded directly on the light guide of the plasma arc unit for the three second (15.36±1.32°C) or six second (15.68±0.79°C) curing times ($p>0.999$). Therefore, only the three-second cure recommended by the manufacturer was used in the subsequent temperature measurements.

For a given resin thickness, measured temperature changes were greatest for the Turbo light guide (40 seconds) and least for the Apollo 95E (3 seconds). The temperature increased by 42% to 56% when the Turbo Light Guide was used, compared to the standard light guide, for thick and thin dentin specimens, respectively.

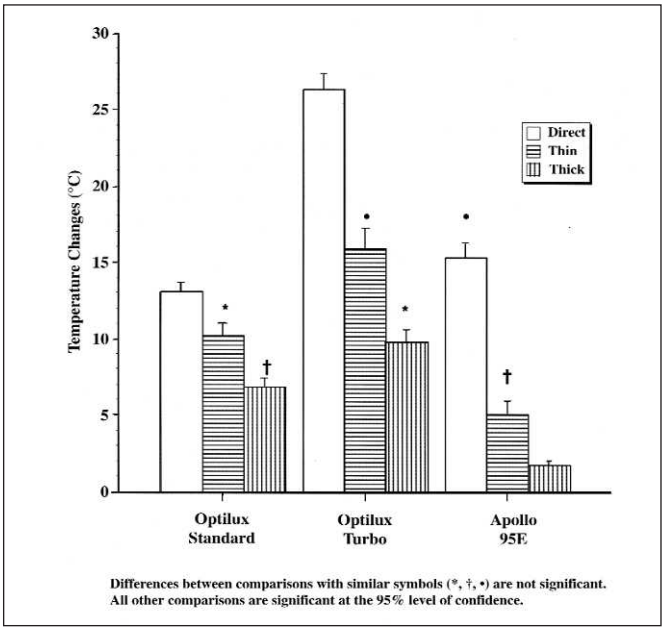

Figure 2. *Temperature changes by curing unit and sample thickness.*

Table 1: *Means and Standard Deviations (SD) of Temperature Changes by Unit/ Light Guide, and Specimen Thickness*

Curing Unit/ Lightguide and Thickness	Count	Mean (C°)	Std Dev (C°)	% of Maximum Temperature Rise Measured
Standard Direct	10	13.1	0.8	49.6
Standard Thin	10	10.2	1.1	38.6
Standard Thick	10	6.9	0.8	26.1
Turbo Direct	10	26.4	1.4	100.0
Turbo Thin	10	15.9	1.8	60.2
Turbo Thick	10	9.8	1.2	37.1
Apollo (3 sec) Direct	10	15.4	1.3	58.3
Apollo (6 sec) Direct	10	15.7	0.8	59.5
Apollo Thin (3 sec)	10	5.1	1.1	19.3
Apollo Thick (3 sec)	10	1.8	0.3	6.8

Table 3 shows the post-hoc analyses. For a given resin thickness, the differences in temperature change for all comparisons among the three curing unit/light guides were significant at the 95% level of confidence. For a given light, the differences in temperature change for all comparisons among different dentin thicknesses were significant at the 95% level of confidence. Three comparisons of light unit and dentin thickness interaction were not significant at the 95% level of confidence. For all other interaction comparisons, differences were significant at the 95% level of confidence.

DISCUSSION

The null hypothesis was rejected because of differences in temperature changes that were produced by different curing unit/light guides and specimen thicknesses. This *in vitro* study found that the Optilux light (40 seconds) with or without a concentrating light guide produced temperature changes that could be deleterious to the pulp (critical temperature of 5.5°C, (Zach & Cohen, 1965). The plasma arc unit (three seconds) was associated with temperature rises below this level. Histologic changes resulting from a 5.5°C rise in temperature may not be permanent, as previously discussed (Lloyd & others, 1986), although the critical temperature rise of 5.5°C has been shown to cause necrosis in 15% of teeth (Zach & Cohen, 1965). Zach & Cohen (1965) also found irreversible changes in 60% of teeth after an 11.1°C rise in pulpal temperature. In this study, with the combined composite and 0.58 mm thin dentin specimens, the Turbo Light Guide produced temperature increases above this level. The Optilux unit with standard light guide produced a temperature rise (Thin = 10.2°C) just below this critical temperature. Therefore, if the dentin thickness is minimal, placing light guides of this type in direct contact with resins would not seem prudent.

This research represents a worst case scenario where the light guides were touching a clear Mylar matrix in direct contact with resin composite that covered the entire surface of the dentin specimen. Pilot studies showed that even the Mylar matrix significantly reduced the light output of the Optilux unit ($p<0.004$). If there is a space between the restorative resin and the light guide, thermal conduction should be reduced. Even if the light guide is in contact with a tooth, the same temperature increases found in this study might not occur if the contact area were different (that is, if only the cusp tip contacted the light guide during curing of a Class II restoration). Temperature changes found in this study might also be artificially high because there were no oral tissues to potentially cool the thermocouple. Nonetheless, Hussey & others, 1995 have demonstrated *in vivo* temperature changes within the resin composite that were in the same range as this research.

The composite in this study was already cured in order to standardize variables such as thickness, translucency and homogeneity of the resin composite. As such, no heat from the exothermic polymerization of the resin composite contributed to the temperature rise. The heat produced by polymerization could be in the range of 1.5-3.4°C (Lloyd, 1984). This study had similar findings to those of Hannig & Bott (1999). They reported an Optilux unit produced a 7.3°C rise versus a 6.9°C rise in this research with an Optilux 401 unit, standard light guide and 40 second cure and that a different plasma arc unit produced a 5.4°C rise for a five-second cure versus 5.1°C in this study using a three-second cure. Their study used uncured resin composite, a 1 mm gap between the light and the resin during curing and a 1 mm dentin thickness.

For an individual tooth, it is almost impossible for a clinician to predict the temperature rise that may occur

Table 2: *ANOVA Table for Change in Temperature by Curing Unit and Sample Thickness*

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Curing Unit	2	2369.351	1184.675	700.02	<.0001
Sample Thickness	2	1680.31	840.155	496.444	<.0001
Curing Unit * Sample Thickness	4	243.752	60.938	36.008	<.0001
Residual	81	137.08	1.692		

Table 3: *Scheffe F-Test Comparisons of Temperature Changes*

	Mean Difference	Critical Difference	P-Value	Significant (S)
Standard Direct, Standard Thin	2.830	2.122	.0011	S
Standard Direct, Turbo Thin	-2.840	2.122	.0010	S
Standard Direct, Apollo Direct	-2.280	2.122	.0239	S
Standard Thin, Turbo Thick	.500	2.122	.9986	
Standard Thick, Turbo Thick	-2.860	2.122	.0009	S
Standard Thick, Apollo Thin	1.780	2.122	.1906	
Turbo Thin, Apollo Direct	.560	2.122	.9969	
All other comparisons significant at <.0001 (Crit Dif = 2.122)				

when curing a resin restoration. In general, the thicker the dentin and the shorter the curing time, the smaller the temperature increase. However, other variables, such as those discussed here, can significantly alter the temperature.

Considering this study's data, using the plasma arc unit for three to six seconds would be advantageous from the standpoint of minimal heat generation. However, it should be noted that use of the Apollo 95E curing unit for three seconds delivers less energy to the specimens than the other light unit/light guides. When used for 40 seconds, the Optilux standard light guide produced 26.5 J/cm^2 (663mW/cm^2 for 40 seconds), the Turbo light guide produced 39.0 J/cm^2 (973/cm^2 for 40 seconds) and the Apollo 95E produced 5.8 J/cm^2 (1930mW/cm^2 for three seconds). The difference in energy produced by these units probably accounts for the differences in the observed temperature changes. The difference in energy may also affect properties of the cured resin composite. The depth of polymerization, degree of conversion and elastic modulus have been reported to be lower when the Apollo 95E PAC light was used for three seconds compared to when a conventional quartz tungsten halogen light was used for 40 seconds (Peutzfeldt, Sahafi & Asmussen, 2000). While using a high output light for 40 seconds may improve resin properties, clinicians should be aware of the potential for increased heat transfer through dentin in delivering higher energy density. Clinicians should exercise caution when the dentin is less than 0.6 mm thick and they are curing resin for 40 seconds using a Turbo Light Guide with similar output to that tested.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Thicker dentin specimens reduced temperature changes at the recording surface ($p<0.0001$).
2. The plasma arc curing light, used for three seconds, produced lower mean temperature changes compared to the quartz tungsten halogen unit with either the standard or Turbo light guide.
3. The Turbo Light Guide tip, when used for 40 seconds, increased the temperature rise by 42% to 56% when compared to the standard light guide on the same light for the same curing time, depending on dentin thickness.

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Commentary

The Basis for Everyday, Real-Life Operative Dentistry

IA Mjör

INTRODUCTION

This "opinion paper" focuses on how clinical judgement develops, the evidence-base for general dental practice in operative dentistry, the impact of dental research and how results from practice-based research may play a significant role in identifying reoccurring problems in dental practice.

Clinical education and dental practice should be based on scientific data, and evidence-based teaching must be the goal for any clinical curriculum. However, many procedures in operative dentistry are based on experience rather than scientific evidence. Black's principles of cavity preparations for amalgam restorations, for example, were not scientifically based. They represented sound clinical judgments at the time they were developed. On the other hand, the caries-preventing measures taught and practiced in most industrialized countries today, are examples of treatments largely based on scientific evidence. However, discussions over the past decades on evidence-based operative dentistry bemoan the fact that the scientific foundation for many clinical procedures is meager, or as a renowned professor of dentistry put it, "If the teaching in restorative dentistry should be based on scientific evidence only, there would be very little teaching done." This view sums up the state-of-the-art of evidence-based teaching in restorative dentistry.

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The lack of scientific evidence in support of many well-accepted clinical procedures does not mean that the treatment rendered is inadequate or inferior. Trial and error, over decades of practice, has provided an experience base that is largely responsible for the high level of dental care furnished. Undoubtedly, the quality of care would be refined and improved, provided that a scientific basis can be established for all phases of treatment. However, the practice of operative dentistry, to a large extent, is also likely to be based on clinical experience in the future.

CLINICAL JUDGMENT

The initial clinical judgment by a newly licensed dental practitioner is based on the training received in dental school. The impact of this teaching and training is considered the foundation for future clinical judgment. This judgement will soon be affected by personal experience and continuing education. It is important that new graduates realize the value of good, evidence-based continuing dental education, which is largely the responsibility of organized dentistry at various levels. It is recognized, however, that dentists' treatment decisions vary markedly (Bader & Shugars, 1992). This recognition is important because the treatment rendered represents everyday, real-life dentistry. It is the dental care offered to the public at-large.

Dental students will soon realize that in restorative dental practice scientific evidence is virtually non-existent and many treatments are based on clinical experience. In a prevention-oriented practice, evidence-based guidelines exist, and they indicate that minimal surgical intervention may be the best treatment.

DENTAL PRACTICE AND DENTAL RESEARCH

Dental research, in its broadest sense, is conducted to provide the means to prevent dental diseases and to improve the dental care provided to the population. While dentistry has a responsibility to contribute to the general knowledge base through basic research, the ultimate goal of dental research must be to optimize treatment in general clinical practice. Originally, the traditional dental practice was disease oriented, and relief of pain was a major goal of dental treatment. This concept is still a reality in a large part of the world. In industrialized countries, preventive efforts have led to positive changes in the practice of dentistry, and the disease-oriented work in operative dentistry is being taken over by alternative treatments that focus on esthetics. These treatments are often based on subjective decisions and emotions, rather than scientific evidence, and longevity data are usually lacking.

Advances in basic and applied research have led to some major improvements in dentistry, but they are few and far between. The caries preventing effect of fluorides is the most prominent example. The only negative aspect of this fundamental research effort was that it took about 40 years after the initial basic research was done before it became a significant public preventive tool. Another largely industrial-based achievement was the development of the air-driven high-speed dental handpiece. Development of tooth-colored restorative materials, supported by public and industrial funds, has also led to major changes in the practice of dentistry. However, the development of new restorative materials, and especially of "improvements" of existing materials, is largely based on *in vitro* studies, many with dubious clinical significance.

Hundreds of millions of dollars are spent annually on dental research from public, industrial and private funds. From NIH alone, more than $1 billion is expected to be available for dental and craniofacial research and associated functions in the next three years. Based on past experience, no short-term effect on general dental practice is expected. One reason for the slow development of improvements in dental practice may be the lack of relevance of the research agenda in attacking the problems faced in general dental practice. Practice-based research may assist in alleviating such problems.

PRACTICE-BASED RESEARCH

Systematic collection of data from general dental practice is the goal of practice-based research. It cannot meet scientific criteria because treatment in general dental practice entails many uncontrollable factors. The most commonly encountered problems include variation in clinicians' treatment decisions, variation in assessment of quality and in the perception of defects that constitute a failure, frequent evaluation of one's own work, patient drop-out, misunderstood definitions and instructions provided to the clinician and unintentional provision of incorrect answers.

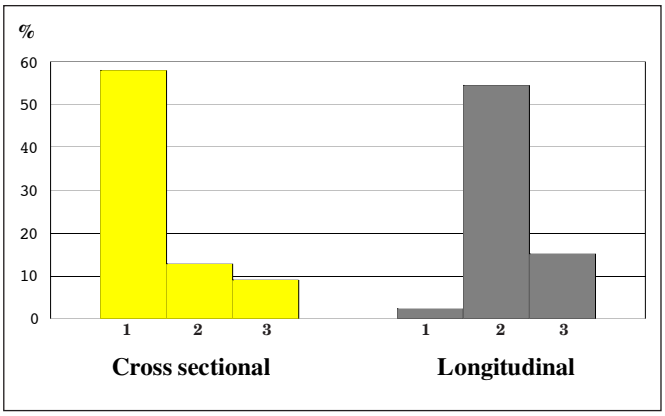

Figure 1. *Bar graphs show the marked differences in percentage of reasons for replacement of amalgam restorations in a cross sectional practice based study (Mjör, 1981) and in a controlled longitudinal investigation (Letzel & others, 1989) with respect to secondary caries (1), bulk (isthmus) fracture (2), and marginal fractures (3).*

Longitudinal practice based studies involving a number of clinicians are particularly difficult because they require the investment of much time by those involved. Cross-sectional studies allow a large number of procedures and restorations to be evaluated in a relatively short time as part of the regular treatment planning. However, circumstances prevailing at the time of treatment are unknown.

Results from cross-sectional practice-based studies, with all their inherent problems, differ markedly from those based on guidelines for controlled clinical trials. Failure of restorations based on the clinical diagnosis of secondary (recurrent) caries can be used to illustrate the difference in results obtained in the two types of studies (Figure 1). Secondary caries is, by far, the most common reason cited for replacement of restorations in general practice (Mjör, 1981 & 1997). It is rarely noted in controlled clinical trials (Letzel & others, 1989). This discrepancy is astounding. It obviously affects the longevity and cost-effectiveness of restorative treatment. The fact that meager evidence is available for making decisions related to secondary caries, including its etiology, bacteriology, progression and means of controlling the lesions (Mjör & Toffenetti, 2000) allows for subjective judgments pertaining to this clinical condition. The differential diagnosis of crevices with non-carious walls, stained margins and secondary caries is difficult and often subjective. Minimal research has been devoted to secondary caries, and certainly not in proportion to the billions of dollars spent on a worldwide basis for the replacement of restorations with this diagnosis. How can this lack of research effort be explained? A simple, but likely answer may be that secondary

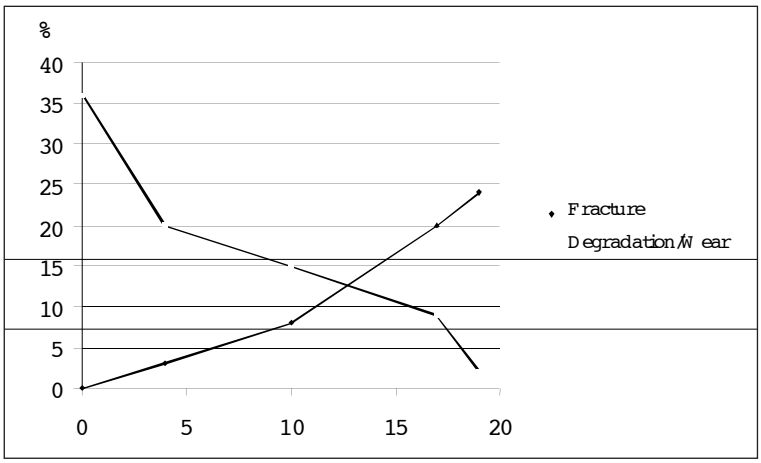

Figure 2. *Graphic presentation of fracture and degradation/wear as reasons for replacement of composite restoration over a 19-year period (1978-1997). (Data compiled from different Scandinavian practice based studies).*

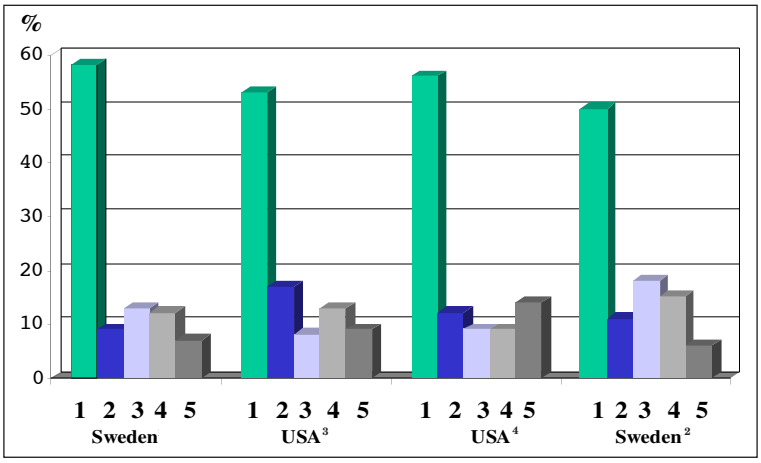

Figure 3. *Reasons for replacement of amalgam restorations in different practice based studies in Sweden (Mjör, 1981[1]; 1992[2]) and USA (Klausner, Green & Charbeneau, 1987[3]; Mjör & Moorhead, 1998[4]) using the same criteria and method. 1 - secondary (recurrent) caries; 2 - marginal fracture/degradation; 3 - bulk fracture; 4 - fracture of tooth, and 5 - other reasons.*

lesions have never been properly identified as a problem through practice-based research.

It is unlikely that practice-based research, alone, which identifies problems in general dental practice, will solve any of the problems encountered. However, without identifying the problems, it is unlikely that they will ever be solved. Identification of repeated problems may, therefore, be the most important aspect of practice-based research, however, other advantages to general practice are likely to emerge. The trends in materials selection at a given time and the reasons for restoration failures are examples of what can be studied in general dental practice (Mjör, 1997; Mjör & Moorhead, 1998). For example, practice-based studies over the last 20 years have identified major changes in the selection of materials and the reasons for replacement of resin-based composite restorations. Material degradation and wear were major reasons for replacement of such restorations in the late 1970s (Figure 2). These problems have been largely solved. Present day composite restorations are rarely replaced because of degradation and wear. However, if one property of a material is improved, it often results in the decrease of other qualities. Now, fracture of composite restorations, both through bulk and margins, has gradually become a major reason for their replacement (Figure 2). In fact, the reasons for replacement of composite restorations have, over time, become similar to those for amalgam restorations, except for discoloration, which is a reason for failure associated with tooth colored restorations. Concomitant with the increase in quality of composite restorative materials, an increase in the longevity of these restorations has been noted in practice-based studies. On the other hand, the reasons for replacing amalgam restorations in general dental practice have remained similar over the last 20 years (Figure 3) but regional differences have been noted (Qvist, Qvist & Mjör, 1990).

CONCLUDING REMARKS

Dental school teaching programs that rely on ill-defined criteria for failures, their etiology, and development, must be the starting point from which improvements in dental practice can emerge. The fact that few teaching programs in restorative dentistry are evidence-based forces teachers, students and graduates to make subjective assessments. Until relevant evidence is presented in practice-based studies, restorative dentistry will be dependent on subjective clinical, and often anecdotal, information. Swedish health authorities have acknowledged this situation, and their guidelines for acceptable standards of dental treatment are that it "should be based on science and confirmed clinical experience."

A gradual shift from confirmed clinical experience to scientific evidence is expected to occur. Practice-based research is an essential component in this transition, and it requires active participation by clinicians in general dental practice. However, it must be recognized that practice-based research has a long way to go before it meets basic scientific criteria. On the other hand, it may assist in making the dental research agenda more clinically relevant than it is today.

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Departments

Book Reviews

Fundamentals of Operative Dentistry: A Contemporary Approach

Editors: James B Summitt, DDS, MS, J William Robbins, DDS, MA and Richard S Schwartz, DDS

Published by Quintessence Publishing Company, Inc, Carol Stream, IL, 2ND ed, 2001, 588 pages, 1393 illustrations, $76.00 (US), hardcover.

The textbook is extremely well written and easy to understand. Organization and composition of the material is logical and timely. As was stated in the Preface, the textbook is, indeed, a "blend of traditional, time-proven methods and recent scientific developments."

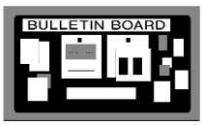
The text covers all aspects of operative dentistry, including the physiologic, anatomical, histological and etiological basis of caries initiation and progression, as well as the restorative modalities available to treat damaged teeth. Diagnosis and treatment planning are thoroughly explored as well as esthetic considerations in restorative treatment. Conservation of tooth structure is stressed throughout the text. The ultimate form of conservation of tooth structure, namely, caries prevention, discussed in Chapter 4, is further explored in a subsequent chapter on fluoride-releasing materials and serves as an underlying theme in almost every chapter. For the neophyte dental student, Chapter 6 defines nomenclature and instrumentation. Restorative techniques using traditional materials, such as cast gold and amalgam, are covered in depth. Some new applications and techniques for traditional materials are also proposed. Similarly, some of the newer techniques employing the latest adhesives, resin composites, glass ionomers, resin-modified glass ionomers, compomers and dental porcelains are described. An entire chapter is devoted to tooth bleaching, including in-office and at-home bleaching of vital teeth as well as non-vital bleaching. Another chapter admirably explains the peculiarities of the etiology, diagnosis, treatment and prevention of root caries. Restoration of the endodontically-treated tooth, as well as isolation of the operative field, are also thoroughly discussed.

Throughout the text, most statements of fact and treatment recommendations are clearly referenced and supported by recent, as well as time-honored literature. In controversial areas, the contributing authors and editors, which represent well-known experts in each of their respective fields, present references from several "camps" and allow the reader to interpret the literature. Recommendations that are made in these controversial areas are presented without the slightest hint of dogmatism and are supported by logical argument. The quality and number of illustrations and clinical photographs is exemplary. The treatment of modern restorative materials is current and supported by the literature.

In general, this is one of the more comprehensive and current texts on the modern practice of operative dentistry and represents the culmination of several years of research, experience and collaboration among experts in the field. This text would be a welcome addition to the reference library of any experienced private practitioner or dental school faculty, as well as serve as an academic text for the novice dental student.

Edward J. DeSchepper, DDS, MAEd, MSD
Professor and Section Head, Operative Dentistry
Department of Restorative Dentistry
Indiana University School of Dentistry
1121 W Michigan Street
Indianapolis, IN 46202

Announcements



Funding for Students' Research in Operative Dentistry

Students wanting to carry out research related to Operative Dentistry may apply for a Ralph Phillips Research Award, sponsored by the Founder's Fund of the Academy of Operative Dentistry.

The application should consist of a protocol (and 15 copies) outlining the background, aim/hypothesis to be tested, the methodology to be employed, a time schedule and the expected outcome of the study. The protocol should not exceed three double-spaced type-written pages and a budget page (including where the funds should be sent provided the Award is granted). The budget may not exceed $2,600.

If an abstract, based on the research and acknowledging support from the Academy of Operative Dentistry, is accepted for presentation at the IADR/AADR meeting in 2003, additional travel funds not exceeding $1,000 will be made available to the recipient.

A Faculty Advisor should be named, and he/she should co-sign the application. The application must be submitted by December 15, 2001 to:

Academy of Operative Dentistry,
Research Committee
c/o Dr Ivar A Mjör, Chairman
UFCD, Box 100415
Gainesville, FL 32610

Applications may also be submitted by e-mail to: imjor@dental.ufl.edu followed by one signed original mailed to the above address. Award recipients will be announced during the Annual Meeting of the Academy of Operative Dentistry, February 20-22, 2002.

Annual Meeting
American Academy of Gold Foil Operators

Indianapolis, Indiana
October 10-13, 2001

The annual meeting features three half-day essay sessions, plus clinical demonstrations and social activities. Emphasis will be on Direct Filling and Cast Golds.

For details and information, contact:

Dr Ronald K Harris, Secretary
17922 Tallgrass Court
Noblesville, IN 46060
Phone: 317/867-0414
Fax: 317/867-3011
e-mail: piperon@earthlink.net

2002 Meeting of the
Academy of Operative Dentistry
European Section

The 2002 meeting of the Academy of Operative Dentistry European Section will be hosted by the University of Nijmegen College of Dental Science in Nijmegen, The Netherlands. The meeting, to be entitled "Adhesive dentistry today. Transfer of research into practice" will be held December 5th-7th, 2002. Details may be obtained from:

Dr EH Verdonschot,
University of Nijmegen College of Dental Science
PO Box 9101, NL-6500 HB
Nijmegen, The Netherlands

Tel: (31) 24 3614058/6410
Fax: (31) 24 3540265
e-mail: e.verdonschot@dent.kun.nl

Classifieds:
Faculty Positions

School of Dental Medicine
University at Buffalo

The Department of Restorative Dentistry at the School of Dental Medicine, University at Buffalo, is seeking applications for two (2) full-time positions for preclinical, clinical and didactic teaching in the predoctoral program in all aspects of restorative dentistry, with primary focus on direct restoratives. Responsibilities also include administration and program development in the predoctoral or advanced level (AEGD), development of independent research program and scholarly activity. Limited teaching at advanced level (AEGD) may be required. Participation in continuing education and faculty intramural practice expected. Minimal qualifications require a DDS or equivalent and eligibility for licensure in New York State, evidence of completed advanced training in a US-accredited GPR or AEGD program and practice experience in clinical restorative dentistry. Prior teaching experience preferred. For consideration at the senior level, there must be evidence of significant teaching experience, restorative program administration and scholarly activity. The University is an Affirmative Action/Equal Opportunity Employer. Letter of interest, current CV and names/addresses of three references should be sent to: Susan Kowalewski, Assistant to the Chair, Department of Restorative Dentistry, 215 Squire Hall, 3435 Main Street, School of Dental Medicine, Buffalo, NY 14214.

University of Florida College of Dentistry

The University of Florida College of Dentistry invites applications for a full-time clinical or tenure track faculty position in the Department of Operative Dentistry at the Instructor, Assistant or Associate Professor levels. A dental degree from an ADA-accredited dental school or equivalent is required. Private practice experience and teaching experience are preferred. Salary and academic rank will be commensurate with qualifications. Duties associated with the position will include clinical and/or preclinical teaching. Participation in Faculty Practice is expected. Scholarly activity is required for tenure track appointments. Women and minorities are encouraged to apply. This selection process will be conducted under Florida's Government in the Sunshine and Public Records Law. Please submit curriculum vitae and the names of three references to Dr Paul K Blaser, Chair, Search Committee, University of Florida College of Dentistry, PO Box 100415, Gainesville, FL 32610-0415 by October 15, 2001. EEO/AA/EA employer.

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

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