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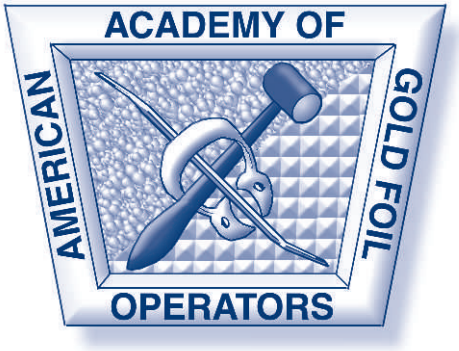

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Operative Dentistry publishes articles that advance the practice of operative dentistry. The scope of the journal includes conservation and restoration of teeth; the scientific foundation of operative dental therapy; dental materials; dental education; 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

Materials, Methods, Results and Conclusions

The four parameters of scientific inquiry are as valid for the everyday delivery of health care as they are for research. Yet, rather than keeping an open mind and exploring the myriad possibilities available for the treatment of our patients, we sometimes rely on a more dogmatic approach. This may be a result of our naiveté during our dental training, our egos or an unconscious focus on one or two of the parameters to the exclusion of the others.

I do not know if your experiences in dental school were similar to mine, but I remember having the distinct impression that the techniques and materials presented during our tenure were inviolate… the best, the most efficacious, the "only way." I do not recall that I ever heard any of my professors actually say that, but in my mind they were the ultimate authority and logically would only pass on the ultimate information. The reality of this phenomenon is borne out by the fact that the vast majority of dental graduates begin their practices using the same materials and techniques taught by their alma mater.

When I entered the Navy Dental Corps following graduation, I met colleagues from all around the country who had also been taught the "best way" during their dental education… and all of those ways were slightly different. The really interesting thing to me was that the variety of treatment techniques, variations in preparation design and selection of materials all seemed to provide very similar and successful results. My ego reared its head occasionally and whispered in my ear that the techniques I was trained to use had to be the best because they were mine! This is not particularly logical, but very human… my (insert: school, car, computer, team, significant other, child, father, etc) is (insert: more respected, more valuable, faster, more skilled, better looking, smarter, stronger, etc) than yours.

After enrolling in a graduate Operative Dentistry program, I was surprised to discover the myriad options I needed to learn, the depth of understanding of dental materials that was required and the number of factors that affected every decision-making process. However, the more I learned, the more I became convinced that the end result of treatment for any given patient was the most important consideration and that there were frequently a variety of ways to achieve a successful outcome. There were no perfect materials and the clinician could either be victimized by a product's shortcomings or rise above them with their knowledge and skill. Restorative dentistry was not black and white, but a wonderful palate of colors.

During my career in dental education, I have tried to help my students understand that there is barely enough time to teach one or two methods for the hundreds of procedures covered in their pre-doctoral training. Each school of dentistry selects techniques and materials that are teachable, match the philosophies and training of their faculty and provide suitable, long-term results for their patients. Hopefully, none put forth the idea that these techniques or materials are the only possible solutions in the vast dental armamentarium. We must also remember that the individual plays an important role and that something that works well in your hands may not yield the same results for a colleague and, as mentioned earlier, the skill and integrity of the operator can frequently minimize inherent weaknesses in a restorative material.

Yet the search for the Holy Grail continues and is reinforced subliminally (and occasionally very loudly) by dental product manufacturers and continuing edu-

cation courses. I can spend an hour lecturing about restorative materials and the factors involved in making appropriate selections only to face the first question from the audience… "Which brand is the best? What should I buy?" Colleagues engage in seemingly endless debates on the merits of materials and methods. "Pins produce too much stress! Pinless retention techniques are better!" "The only pinless retention technique should be resin-bonded amalgam! All the others remove sound tooth structure!" "Why are we even talking about retention techniques for amalgam? A metal-free practice is the only modern, healthy alternative!" Dental professionals love to argue and debate, and all feel that right is on their side and anyone who does not agree is practicing substandard health care. Many of us have begun to believe that the immediate gratification of cosmetics and convenience outweighs the advantages of longevity. Unfortunately, the focus in most forums is strictly on Materials and Methods.

Proper Materials and Methods are vitally essential but, in my opinion, results (with the modifier "long-term") are the most important to our patients and to the success of our practice of dentistry. Only by paying close attention to our clinical Results can we ever reach valid Conclusions as to the efficacy of our Materials and Methods. Practitioners with years of experience are well aware of the value of their own clinical observations. They have seen their successes and failures and most have learned from them. They may not be as quick to adopt new methods without some proof that they will produce better results. Younger colleagues will have to rely on what they are taught, accumulate their own data as they treat their patients and find out what works for them. However, the focus for all of us must be on Results and the science and techniques that make results possible—not just immediate—but long-term success. Only then will our Conclusions be based on true evidence.

Michael A Cochran
Editor

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Clinical Research

Mutans Streptococci and Lactobacilli in Saliva After the Application of Fissure Sealants

P Baca • AM Castillo • M Bravo
P Junco • AP Baca • JC Llodra

Clinical Relevance

The application of fissure sealants can contribute to reducing the levels of cariogenic bacteria in saliva.

SUMMARY

Because dental fissures may serve as reservoirs for mutans streptococci, preventive measures should be taken to control microbial concentrations at these sites. This study estimated the influence that sealing permanent first molars would have on the levels of mutans streptococci and lactobacilli in saliva of healthy seven-year-old schoolchildren. Permanent first molars were sealed in 31 children without caries (NC group) and in 32 children with caries (C group). None of the children had caries in their permanent first molars. Conventional methods were used to count mutans streptococci and lactobacilli in saliva before applying the sealant and again at 4 and 12 weeks after application. Baseline counts of lactobacilli and mutans streptococci were significantly higher in the C group. A significant reduction in mutans streptococci was observed in the NC group at 4 and 12 weeks. It was concluded that fissure sealants in permanent first molars can help reduce salivary levels of mutans streptococci in children without caries.

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INTRODUCTION

There is a clear relationship between dental caries and mutans streptococci. After dental eruption, these micro-organisms colonize different tooth surfaces. Fissures form a good reservoir, and even when they are not carious, they may harbor mutans streptococci (Theilade & others, 1982). Lactobacilli are detected less frequently in fissures (Kramer, Zelante & Simionato, 1993). Fissures of molar surfaces are more likely colonized by mutans streptococci than premolars or anterior teeth because the ecological conditions of the former are more favorable to colonization (Emilson & Lindquist, 1988).

Studies are scarce and a relationship has not been established between eliminating fissures by sealants

and the total number of caries-related micro-organisms. Two studies established an *a priori* selection of high-risk patients based on their medium or high mutans streptococci counts (Carlsson & others, 1992; Carlsson, Petersson & Twetman, 1997). Other authors studied a population with a significant number of untreated open caries (Songpaisan & others, 1994), a factor that may influence total levels of mutans streptococci. Eliminating part of the ecosystem of mutans streptococci, such as fissures, may reduce the risk of colonization and possible caries lesions on proximal surfaces. It has been shown that applying fissure sealants on permanent first molars reduces caries on both fissured and non-fissured surfaces (Bravo & others, 1997). These authors attributed the reduction to the fact that the number of caries is itself a predictive factor for the incidence of caries. Thus, reducing the number of carious fissured surfaces would reduce the risk of caries on other surfaces.

This study estimated the influence of sealing the four permanent first molars of healthy seven-year-old schoolchildren with no caries (NC) or those with at least one carious lesion (C) on the salivary levels of mutans streptococci and lactobacilli at 4 and 12 weeks.

METHODS AND MATERIALS

Subjects: Population and Study Design

The study was carried out in two elementary schools located in a low to lower-middle socioeconomic area in Granada (Andalucía, Spain). The Andalusian Public Oral Health Service provides no free restorations for caries in children and only a small number of schoolchildren are treated with fissure sealants. The level of fluoride in drinking water was 0.07 ppm.

A total of 156 seven-year-old schoolchildren participated in a preventive program to seal fissures in permanent first molars. The study was organized by the School of Dentistry, University of Granada, and inclusion criteria were children age seven who were in good health and had four permanent first molars with erupted, healthy occlusal surfaces that permitted the application of fissure sealants. Ninety-four children met these criteria and were included in the study after written informed consent had been obtained from their parents. Of these, 40 children had no caries in any deciduous or permanent teeth (group NC), whereas 54 had at least one caries lesion (Group C). Most participants did not normally use fluoride toothpaste and none had participated in a preventive program that might have affected their oral bacterial levels.

The participants were clinically examined with a mirror and an explorer to record carious lesions according to WHO criteria (WHO, 1987). Sealants were then applied on the four permanent first molars of each child. Delton (Johnson & Johnson Dental Products Co, East Windsor, NJ, USA), a light-cured resin-based material, was used. It was applied in the dental clinic at the School of Dentistry by dental students who followed the manufacturer's instructions. After applying the sealants, all parents received a leaflet that informed them of the preventive treatment that had been applied and the need for restorative treatment when caries was present. The leaflet also offered some dietary and hygienic recommendations, including using fluoride toothpaste. Over the 12-week period, 31 children were withdrawn from the study: 14 lost at least one sealant, 7 received restorative treatment, 6 received antibiotic treatment and 4 chose to abandon the study. The final sample population was 63 children, 31 without caries and 32 with at least one carious lesion. The total mean number of caries (decayed and filled deciduous teeth [dft] + decayed and missing and filled permanent teeth [DMFT]) was 3.62, with a standard deviation of 2.40.

Bacteriological Procedure

The saliva samples for counting the mutans streptococci and lactobacilli were collected on four occasions: twice before applying the sealants, with an interval of 4-to-5 weeks between the two samplings, then at 4 and 12 weeks after applying the sealants. All the samples were collected at around 10 A.M., when the children were in class and had not yet had their recess snack. A stimulated whole saliva sample was obtained while the child chewed on a piece of sterile paraffin for five minutes. The paraffin-stimulated saliva was put on ice and transported to the laboratory within 30 minutes, where it was immediately processed. Salivary samples were dispersed by sonication for five seconds and tenfold diluted in 0.05M phosphate buffer with 0.4% (w/v) KCl (pH 7.1). Aliquots of 0.1 ml were plated on MSB agar (Gold, Jordan & Van Houte, 1973) (Difco, Detroit, MI, USA) for the mutans streptococci count; and on Rogosa SL medium (Rogosa, Mitchell & Wiseman, 1951) (Difco) for lactobacilli. The total colony-forming units were counted after incubating at 37ºC for 48 hours under anaerobic conditions of 5% H_2, 10% CO_2 and 85% N_2. All the colonies on MSB agar with characteristic morphology of mutans streptococci were counted. Lactobacilli were scored based on typical colony morphology observed on Rogosa agar.

Statistical Methods

The two measurements taken before applying the sealants were compared using the Wilcoxon test for paired samples. For the analyses, bacteria counts were converted into ranks (Table 1). The baseline measures of the two groups (NC/C) were compared using the Mann-Whitney test. Within each group, the baseline measure and the 4- and 12-week measures were compared using the Friedman test. When this was statis-

tically significant ($p<0.05$), comparisons by pairs was carried out with the Wilcoxon test for paired samples.

RESULTS

Comparing the results of the two samplings prior to applying the fissure sealants revealed no significant differences in mutans streptococci or lactobacilli for either the NC or C group (results not shown). The mean of the two measurements was considered as the baseline value. Group C presented significantly higher baseline salivary levels of mutans streptococci ($p=0.032$) and lactobacilli ($p<0.001$) compared with group NC. At 4 and 12 weeks after applying the fissure sealants, the levels of lactobacilli remained statistically unchanged in both groups. A significant reduction in mutans streptococci over the study period was only observed in the NC group (Table 1): at baseline, 41.9% of these schoolchildren presented concentrations under 10^5 cfu of mutans streptococci, compared with 71% and 67.7% at 4 and 12 weeks, respectively.

DISCUSSION

The study design did not include a control group for ethical reasons because the sole treatment provided by the preventive program under study was applying fissure sealants on first permanent molars. Children who were withheld from this treatment would be denied their right to benefit from the program. As an alternative, two baseline determinations of mutans streptococci and lactobacilli were made, with an interval of 4-to-5 weeks in-between. The absence of differences between the two samplings confirms the stability of these bacterial populations in the saliva of children, as other authors have attested (Togelius & others, 1984). In contrast, Tukia-Kulmala & Tenovuo (1993) reported that levels of mutans streptococci in the saliva of young teenagers may not be identical over a nine-month period. In view of this controversy, ranges of bacterial counts were used in this study (El-Nadeef & Bratthall, 1991).

A significant number of the schoolchildren (n=31) were withdrawn from this study in order to avoid confounding factors. The large number of children who lost one or more sealants (n=14) is best explained by technique failures because they were applied by dental students as one of the first practical exercises in the students' first year of clinical training. Children were also withdrawn because they received restorative treatment which may affect the salivary levels of cariogenic bacteria (Keene, Shklair & Hoerman, 1976; Wright & others, 1992) or because they were under antibiotic treatment, to which mutans streptococci are particularly sensitive (Liébana & others, 1991).

Although results using commercial kits have been significantly correlated with those using conventional methods (Tukia-Kulmala & Tenovuo, 1993), the authors used the latter to obtain mutans streptococci and lactobacilli levels. In a previous study with the Dentocult SM Strip (Orion Diagnostica, Helsinki, Finland), it was noted that microbial colonies sometimes fell from the plastic spatula provided, leading to a possible underestimation of the results.

Salivary levels of lactobacilli were not affected by applying fissure sealants and they remained unchanged in both groups throughout the study (Table 1). This finding is consistent with previous reports that lactobacilli are not always present among fissure microbiota and, when detected, are never predominant

Table 1: *Mutans Streptococci (MS) and Lactobacilli (LB) Percent Distributions Before[a] and at 4- and 12-Weeks After Applying Fissure Sealants in Children with Caries (C) and Without Caries (NC)*

	Without Caries (NC) (n=31)			With Caries (C) (n=32)		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
MS (cfu)	$<10^5$	10^5-10^6	$>10^6$	$<10^5$	10^5-10^6	$>10^6$
LB (cfu)	$<10^3$	10^3-10^4	$>10^4$	$<10^5$	10^3-10^4	$>10^4$
MS Count						
Before[b]	41.9	35.5	22.6	21.9	31.3	46.9
4 Weeks	71.0	22.6	6.5	37.5	25.0	37.5
12 Weeks	67.7	22.6	9.7	31.3	18.8	50.0
Comparison[c]		$p=0.016$[d]			$p=0.447$	
LB count						
Before[b]	77.4	9.7	12.9	0.0	18.8	81.3
4 Weeks	64.5	22.6	12.9	18.8	15.6	65.6
12 Weeks	61.3	22.6	16.1	9.4	15.6	75.0
Comparison[c]		$p=0.657$			$p=0.168$	

a: previous measurement is the mean of two measures.
b: comparison between groups with/without caries, by using Mann-Whitney test, is significant for MS ($p=0.032$) and LB ($p<0.001$).
c: Friedman test.
d: Comparison by pairs (Wilcoxon paired test), before>4 weeks ($p=0.001$), before>12 weeks ($p<0.002$), 4 weeks=12 weeks ($p=0.180$).

(Loesche & others, 1984). A significant reduction in mutans streptococci was observed only in the NC group at 4 and 12 weeks (Table 1). Carlsson & others (1992) documented short- and long-term reductions after sealing. However, they also observed reductions in the control group, which may result from a didactic effect of the microbial tests and from a certain tendency towards a long-term decrease in mutans streptococci levels. Carlsson & others concluded that the sealants per se did not affect the salivary levels of mutans streptococci. In a later study of mutans streptococci and lactobacilli with a two-year follow-up period (Carlsson & others, 1997), only lactobacilli were reduced in the sealed group. However, both studies recruited previously selected children at high risk (with medium or high levels of salivary mutans streptococci) that may have influenced their outcomes.

Applying sealants did not affect salivary levels of mutans streptococci of the schoolchildren with caries (Table 1). In the presence of active caries, mutans streptococci levels are much higher than in subjects with inactive lesions (Nyvad & Kilian, 1990) and they decrease after restorative treatment (Wright & others, 1992). The caries lesions in this study were not restored and sealing of fissures on permanent molars did not reduce the high levels of mutans streptococci detected.

When preventing dental caries, reducing salivary levels of cariogenic bacteria may be a secondary consequence of applying sealants but is not without importance. A correlation has been established between the salivary levels of mutans streptococci and the number of colonized surfaces (Lindquist, Emilson & Wennerholm, 1989). It could be thought that even when a fissure system is eliminated, bacterial plaque can also form on the surface of the sealant. However, higher levels of streptococci mutans have been reported on occlusal surfaces with or without caries compared to forming on restored surfaces (Lindquist & Emilson, 1990), which may reflect their high level of colonization in pits and fissures. Furthermore, it is easier to eliminate plaque from the surface of a sealant than from a fissure.

CONCLUSIONS

According to current results, applying fissure sealants on the four permanent molars contributes to reducing the salivary levels of mutans streptococci in seven-year-old schoolchildren without caries lesions.

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References

Bravo M, Baca P, Llorra JC & Osorio E (1997) A 24-month study comparing sealant and fluoride varnish in caries reduction on different permanent first molar surfaces *Journal of Public Health Dentistry* **57(3)** 184-186.

Carlsson A, Jonsson Y, Svensson K, Stahl B & Twetman S (1992) Pit and fissure sealing and mutans streptococci levels in saliva *American Journal of Dentistry* **5(5)** 280-282.

Carlsson A, Petersson M & Twetman S (1997) 2-year clinical performance of a fluoride-containing fissure sealant in young schoolchildren at caries risk *American Journal of Dentistry* **10 (3)**115-119.

El-Nadeef MA & Bratthall D (1991) Intraindividual variations in counts of mutans streptococci measured by "Strep mutans" method *Scandinavian Journal of Dental Research* **99(1)** 8-12.

Emilson CG & Lindquist B (1988) Importance of infection level of mutans streptococci for recolonization of teeth after chlorhexidine treatment *Oral Microbiology and Immunology* **3(2)** 64-67.

Gold OG, Jordan HV & Van Houte J (1973) A selective medium for *Streptococcus mutans Archives of Oral Biology* **18(11)** 1357-1364.

Keene HJ, Shklair IL & Hoerman KC (1976) Partial elimination of *Streptococcus mutans* from selected tooth surfaces after restoration of carious lesions and SnF_2 prophylaxis *Journal of the American Dental Association* **93(2)** 328-333.

Kramer PF, Zelante F & Simionato MR (1993) The immediate and long-term effects of invasive and non-invasive pit and fissure sealing techniques on the microflora in occlusal fissures of human teeth *Pediatric Dentistry* **16(2)** 108-112.

Liébana J, Castillo AM, Peis J, Baca P & Piédrola G (1991) Antimicrobial susceptibility of 1042 strains of *Streptococcus Mutans* and *Streptococcus Sobrinus*: Comparison from 1985 to 1989 *Oral Microbiology and Immunology* **6(3)** 146-150.

Lindquist B, Emilson CG & Wennerholm K (1989) Relationship between mutans streptococci in saliva and their colonization of the tooth surfaces *Oral Microbiology and Immunology* **4(2)** 71-76.

Lindquist B & Emilson CG (1990) Distribution and prevalence of Mutans Streptococci in the human dentition *Journal of Dental Research* **69(5)** 1160-1166.

Loesche WJ, Eklund S, Earnest R & Burt B (1984) Longitudinal investigation of bacteriology of human fissure decay Epidemiological studies in molars shortly after eruption *Infection and Immunity* **46(3)** 765-772.

Nyvad B & Kilian M (1990) Comparison of the initial Streptococcal microflora on dental enamel in caries-active and in caries-inactive individuals *Caries Research* **24(4)** 267-272.

Rogosa M, Mitchell JA & Wiseman RF (1951) A selective medium for the isolation and enumeration of oral Lactobacilli *Journal of Dental Research* **30** 682-689.

Songpaisan Y, Serinirach R, Kuvatanasuchati J & Bratthall D (1994) Mutans streptococci in a Thai population: Relation to caries and changes in prevalence after application of fissure sealant *Caries Research* **28(3)** 161-168.

Theilade E, Fejerskov O, Karring T & Theilade J (1982) Predominant cultivable microflora of human dental fissure plaque *Infection and Immunity* **36(3)** 977-982.

Togelius J, Kristoffersson K, Anderson H & Bratthall D (1984) Streptococcus mutans in saliva: Intraindividual variations and relation to the number of colonized sites *Acta Odontologica Scandinavica* **42(3)** 157-163.

Tukia-Kulmala H & Tenovuo J (1993) Intra and Inter-individual variation in salivary flow rate, buffer effect, lactobacilli, and mutans streptococci among 11- to 12-year-old schoolchildren *Acta Odontologica Scandinavica* **51(1)** 31-37.

WHO (1987) *Oral Health Surveys: Basic Methods* 3rd ed Geneva World Health Organization 1987.

Wright JT, Cutter GR, Dasanayake AP, Stiles HM & Caufield PW (1992) Effect of conventional dental restorative treatment on bacteria in saliva *Community Dentistry and Oral Epidemiology* **20(3)** 138-143

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One-Year Clinical Performance of a Resin-Modified Glass Ionomer and a Resin Composite Restorative Material in Unprepared Class V Restorations

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BE Estrada • AA Reyes

Clinical Relevance

Although the incidence of failed restorations was higher for the resin composite, no significant difference was observed in overall clinical performance between the two materials. The appearance of the two materials was judged to be approximately equal.

SUMMARY

This study evaluated the clinical performance and appearance of a resin-modified glass ionomer and a resin composite over one year. Thirty-seven pairs of restorations of Fuji II LC and Z250/Single Bond were placed in caries-free cervical erosion/abfraction lesions without tooth preparation. Restorations were clinically evaluated at baseline and 6 and 12 months, using modified Ryge/USPHS criteria. No significant difference (p>0.05) was observed in performance of both materials, although retention of the Z250 restorations was below the minimum specified in the ADA Acceptance Program for Dentin and Enamel Adhesives. Little difference in the restorations' appearance was observed.

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INTRODUCTION

Glass-ionomer restorative materials are well-proven as adhesive restorations of non-retentive cervical cavities (Matis, Cochran & Carlson, 1996) but have been poorly accepted, primarily due to inconvenient setting characteristics. This limitation has been addressed through resin-modification of glass ionomer cement in which the set is accelerated by the presence of light-cured resins that are cross-linked to polyacids in the cement liquid. Clinical trials of resin-modified glass ionomers in non-retentive erosion/abfraction lesions have shown them to also be effective adhesive restorative materials for cervical restorations (Boghosian, Ricker & McCoy, 1999; Brackett & others, 2001).

Table 1: *Distribution of Restorative Materials to Teeth Restored; Axial Depth and Preoperative Sensitivity of Erosion/Abfraction Lesions*

Z250/Single Bond

	Incisors						Canines						Premolars						Molars					
	n	s	o	a	b	c	n	s	o	a	b	c	n	s	o	a	b	c	n	s	o	a	b	c
Maxillary	3		3		3		7	2	5	1	5	1	9	4	5		9		2		2		2	
Mandibular	1		1	1			4	1	3		4		7	1	6		5	1	4	2	2		4	

Fuji II LC

	Incisors						Canines						Premolars						Molars					
	n	s	o	a	b	c	n	s	o	a	b	c	n	s	o	a	b	c	n	s	o	a	b	c
Maxillary	3	1	2		3		1		1		1		9	3	6		9		3	2	1		3	
Mandibular	1		1		1		5		5		5		14	8	6		12	2	1		1		1	

#s = sensitive to air
o = insensitive to air

a = axial depth < 1 mm
b = axial depth 1-2 mm
c = axial depth > 2 mm

Whether resin-modified glass ionomers are adequate in appearance in Class V restorations relative to resin composites is controversial, with some clinical investigators reporting a deterioration in their appearance over time (Duke & Trevino, 1998; Gladys & others, 1999). Others report nearly ideal color match for up to five years (Boghosian & others, 1999; Brackett & others, 2001), although none of the cited investigations included both resin-modified glass ionomers and resin composites. Three studies have evaluated the appearance of both materials in Class V restorations over one-to-three years, of which one has reported resin composites as being superior (Folwaczny & others, 2000), while the other two report equal appearance (Neo & Chew, 1996; Neo & others, 1996).

Resin composites placed with recent dentin adhesives have also been shown as effective restorations for non-retentive cervical cavities. Most studies report very good appearance and clinical performance with resins when adhesives with separate primers and adhesives are used with the total-etch technique (Alhadainy & Abdalla, 1996; Van Meerbeek & others, 1996; Browning, Brackett & Gilpatrick, 2000).

Less is known about the adhesives most commonly supplied today, wherein the primer and adhesive are combined in a single bottle. Laboratory data indicate that "single-bottle" products are equivalent to multiple-component products in bond strength to dentin (Swift & Bayne, 1997; Gallo & others, 2001) and in resistance to microleakage (Brackett & Girdwood, 1999; Cardoso & others, 1999).

Clinical data are limited but indicate that single-bottle adhesives perform well in unprepared Class V resin composite restorations for up to two years (Peters & others, 2001; Ripps & others, 2001; Swift & others, 2001).

This study evaluated two representative products which have not been previously compared—a resin-modified glass ionomer and a resin composite placed with its single-bottle adhesive—in appearance and in clinical performance in non-retentive Class V restorations.

METHODS AND MATERIALS

Fuji II LC (GC America, Inc, Alsip, IL 60803, USA) was the resin-modified glass ionomer restorative material chosen for this study, while the resin composite chosen was Z250 (3M Dental Products Division, St Paul, MN 55144, USA) with the same manufacturer's single-bottle adhesive single-bottle adhesive, Single Bond. The study was conducted according to the protocol for clinical studies set forth in the 1994 American Dental Association Acceptance Program for Dentin and Enamel Adhesive Materials.

Thirty-seven pairs of equivalent-sized cervical erosion/abfraction lesions primarily in premolar and anterior teeth were identified in 24 healthy patients presenting for treatment at the student clinics of the Facultad de Estomatología, Benémerita Universidad Autónoma de Puebla. The study was conducted in accordance with all local regulations for the ethical treatment of human subjects. The median age of patients was 47 years, while the age ranged from 28 to 73 years. Each pair of cervical erosion/abfraction lesions received one restoration of each material, assigned randomly. No patient received more than two pairs of restorations. Included in the study were pairs of lesions of varied size and axial depth. The approximal size of each lesion and any sensitivity of the lesion to air from the dental unit were recorded prior to restoration (Table 1).

One investigator (MGB) placed all restorations. Isolation was achieved using cotton rolls, with gingival retraction cord placed, if necessary. All restorations were placed according to manufacturers' instructions. Other than cleaning with plain pumice and water in a rubber prophylaxis cup, no mechanical preparation or abrasion of tooth surfaces was done. Surfaces restored with Fuji II LC received a 10-second application of GC Cavity Conditioner (GC America), while surfaces

Table 2: *Modified USPHS Rating System*

Category	Score	Criteria
Retention	Alpha	No loss of restorative material
	Charlie	Any loss of restorative material
Color Match	Alpha	Matches tooth
	Bravo	Acceptable mismatch
Charlie		Unacceptable mismatch
Marginal Discoloration	Alpha	No discoloration
	Bravo	Discoloration without axial penetration
	Charlie	Discoloration with axial penetration
Secondary Caries	Alpha	No caries present
	Charlie	Caries present
Anatomic Form	Alpha	Contiguous
	Bravo	Slight discontinuity, clinically acceptable
	Charlie	Discontinuous, failure
Marginal Adaptation	Alpha	Closely adapted, no detectable margin
	Bravo	Detectable margin, clinically acceptable
	Charlie	Marginal crevice, clinical failure
Surface Smoothness	Alpha	Enamel-like surface
	Bravo	Surface rougher than enamel, clinically acceptable
	Charlie	Surface unacceptably rough

restored with Z250 were etched for 15 seconds with the supplied 35% phosphoric acid, then coated twice with Single Bond, with each coat lightly air-dried, then the two coats of adhesive were light-cured for 10 seconds.

Each restoration was placed in one increment and light cured for 40 seconds. Light output of the XL3000 curing light (3M Dental Products) exceeded 450 mW/cm^2 prior to and after the study, and was verified during placement of the restorations with the unit's built-in radiometer. For both materials, the shade considered the closest match using a Vita shade guide (Vita-Zahnfabrik, Bad Säckingen, Germany) was selected. Restorations composed of both materials were shaped with a plastic instrument prior to light curing, contoured with ET finishing diamonds (Brasseler USA, Savannah, GA 31419, USA) using air/water coolant and polished with wet Diacomp abrasive rubber points (Brasseler USA).

At baseline and at 6 and 12 months, the restorations were clinically evaluated by two other calibrated investigators using modified Ryge/USPHS criteria (Cvar & Ryge, 1971) that are listed in Table 2. The examiners were unaware of which material had been used in any restoration, and any discrepancy between examiners was resolved before the patient was dismissed. Further recalls at 18 and 24 months have been planned.

For statistical analysis purposes, the restorations receiving a score of "charlie" in any category were classified as failed restorations. The incidence of failures was analyzed as a pairwise comparison using an exact binomial test.

RESULTS

At the end of one year 31 pairs of restorations were available for evaluation—a recall rate of 84%. Five Z250 restorations were lost, four were lost prior to the six-month recall, while one Fuji II LC restoration was also lost prior to the six-month recall. The percentage of lost restorations that were the only scores of charlie assigned in the study was 16% and 3%, respectively, over one year. Fuji II LC and Z250 restorations demonstrated a good color match with tooth structure and received 90% and 100% alpha scores, respectively. The percentage of restorations receiving alpha scores for all other criteria were relatively high and nearly equal for both materials after one year except that Z250 restorations received 100% alpha scores for surface smoothness compared to 93% for Fuji II LC. This was in contrast to the scores for surface smoothness at both the baseline and six-month recalls, where the majority of the glass-ionomer restorations were scored as bravo. None of the teeth with retained restorations that exhibited sensitivity to air at the beginning of the study were sensitive at any of the recalls. No significant difference in the incidence of failed restorations was found between the materials (exact binomial test; p=0.22). Table 3 presents the complete results.

DISCUSSION

The authors acknowledge that one year is a short interval for clinical evaluation, but they believe that reporting at this interval is justified for this study due to the relatively high percentage of loss of one of the materials evaluated. Despite the lack of a statistical difference, if the results of this study are representative, Single Bond would not qualify for provisional acceptance as a dentin and enamel adhesive under the ADA acceptance program, while Fuji II LC would have qualified for provisional acceptance after the six-month recall. The effect of repeated measures on confidence level precludes running a statistical test for each criterion in a study of this size. For this reason, only the overall clinical performance in terms of failed restorations of the two materials was compared statistically.

Table 3: *Results of Cinical Evaluation for Resin-Modified Glass Ionomer and Resin Composite Restorations (%)*

Z250/Single Bond

	Retention**			Color Match			Marg. Disc.		Sec. Caries		Anat. Form		Marg. Adapt.		Surf. Smooth.	
	n*	alpha	charlie	n*	alpha	bravo	alpha	bravo	alpha	charlie	alpha	bravo	alpha	bravo	alpha	bravo
baseline	37	100	0	37	100	0	97	3	100	0	100	0	100	0	97	3
6 mos	32	88	12	28	100	0	96	4	100	0	100	0	75	25	93	7
12 mos	31	84	16	26	100	0	96	4	100	0	96	4	88	12	100	0

Fuji II LC

	Retention**			Color Match			Marg. Disc.		Sec. Caries		Anat. Form		Marg. Adapt.		Surf. Smooth.	
	n*	alpha	charlie	n*	alpha	bravo	alpha	bravo	alpha	charlie	alpha	bravo	alpha	bravo	alpha	bravo
baseline	37	100	0	37	100	0	100	0	100	0	100	0	100	0	45	55
6 mos	32	97	3	31	100	0	100	0	100	0	94	6	94	6	23	77
12 mos	31	97	3	30	90	10	100	0	100	0	93	7	87	13	93	7

** sample size larger for retention than for other criteria because lost restorations unavailable for evaluation.*
*** cumulative throughout the study.*

While approximately half of the restored areas were sensitive to air, four of the five lost resin composite restorations were lost from areas that were initially insensitive, possibly indicating dentin surfaces with occluded tubules that were resistant to etching and resin infiltration. A longer etch with this product may be indicated for dentin that is known to be sclerotic.

Although not statistically compared, the color match and surface of the two materials appear to be approximately equal up to this point in time. While using diamond-impregnated rubber points for final finishing of resin composites is a common procedure, it is less frequently reported for resin-modified glass ionomers that in previous studies have usually been finished with abrasive disks. These points appear to produce a suitable finish of both materials as long as they are used wet and with light pressure.

There is no water fluoridation in the community where the study subjects reside, which is unusual in dental school-based clinical studies. Whether the presumably high incidence of caries in this population influences the incidence of secondary caries of the restorations under recall will be of interest as this study progresses.

CONCLUSIONS

Although a larger number of resin composite restorations was lost, there was no significant difference in the clinical performance observed in non-retentive Class V restorations between the two restorative materials. Although no statistical comparison was made, no particular difference in the appearance of the two materials was evident.

Acknowledgements

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References

Alhadainy HA & Abdalla AI (1996) 2-year clinical evaluation of dentin bonding systems *American Journal of Dentistry* **9(2)** 77-79.

Boghosian A, Ricker J & McCoy R (1999) Clinical evaluation of a resin-modified glass ionomer restorative: 5 year results Abstract #1436 *Journal of Dental Research* **78(Special Issue)** (Abstract #285).

Brackett WW, Browning WD, Ross JA & Brackett MG (2001) Two-year clinical performance of a polyacid-modified resin composite and a resin-modified glass-ionomer restorative material *Operative Dentistry* **26(1)** 12-16.

Brackett WW & Girdwood BJ (1999) The effect of finishing method on the microleakage of Class V microfilled composite resin restorations *The Journal of the Tennessee Dental Associatio*n **79(2)** 24-25.

Browning WD, Brackett WW & Gilpatrick RO (2000) Two-year clinical comparison of a microfilled and a hybrid resin-based composite in non-carious Class V lesions *Operative Dentistry* **25(1)** 46-50.

Cardoso PE, Placido E, Francci CE & Perdigão J (1999) Microleakage of Class V resin-based composite restorations using five simplified adhesive systems *American Journal of Dentistry* **12(6)** 291-294.

Cvar JF & Ryge G (1971) *Criteria for the Clinical Evaluation of Dental Restorative Materials* US Public Health Service Publication #790-244 San Francisco Government Printing Office.

Duke ES & Trevino DF (1998) A resin-modified glass ionomer restorative: Three-year clinical results *Journal Indiana Dental Association* **77(3)** 13-16 25.

Folwaczny M, Loher C, Mehl A, Kunzelmann KH & Hinkel R (2000) Tooth-colored filling materials for the restoration of cervical lesions: A 24-month follow-up study *Operative Dentistry* **25(4)** 251-258.

Gallo JR, Comeaux R, Haines B, Xu X & Burgess JO (2001) Shear bond strength of four filled dentin bonding systems *Operative Dentistry* **26(1)** 44-47.

Gladys S, Van Meerbeek B, Lambrechts P & Vanherle G (1999) Evaluation of esthetic parameters of resin-modified glass-ionomer materials and a polyacid-modified resin composite in Class V cervical lesions *Quintessence International* **30(9)** 607-614.

Matis BA, Cochran M & Carlson T (1996) Longevity of glass-ionomer restorative materials: Results of a 10-year evaluation *Quintessence International* **27(6)** 373-382.

Neo J & Chew CL (1996) Direct tooth-colored materials for non-carious lesions: A 3-year clinical report *Quintessence Internationa*l **27(3)** 183-188.

Neo J, Chew CL, Yap A & Sidhu S (1996) Clinical evaluation of tooth-colored materials in cervical lesions *American Journal of Dentistry* **9(1)** 15-18.

Peters MC, Stoffers KW, Dennison JB, McLean ME & Hamilton JC (2001) Clinical evaluation of a new adhesive system; results after 18-months Abstract #230 *Journal of Dental Research* **80(Special Issue)** (Abstract #64).

Ripps A, Burgess JO, Grogona A, Rappold A & Gallo J (2001) Clinical evaluation of a self-etching primer-2-year recall, Abstract #231 *Journal of Dental Research* **80(Special Issue)** (Abstract #64).

Swift EJ Jr & Bayne SC (1997) Shear bond strength of a new one-bottle dentin adhesive *American Journal of Dentistry* **10(4)** 184-188.

Swift EJ Jr, Perdigão J, Heymann HO, Wilder AD Jr, Bayne SC, May KN Jr, Sturdevant JR & Roberson TM (2001) Eighteen-month clinical evaluation of a filled and unfilled dentin adhesive *Journal of Dentistry* **29(1)** 1-6.

Van Meerbeek B, Peumans M, Gladys S, Braem M, Lambrechts P & Vanherle G (1996) Three-year clinical effectiveness of four total-etch dentinal adhesive systems in cervical lesions *Quintessence International* **27(11)** 775-784.

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Clinical Survey

Placement and Replacement of Restorations in General Dental Practice in Iceland

IA Mjör • C Shen
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Clinical Relevance

Practice-based research allows for the monitoring of changes that occur in general practice over time. This Icelandic study shows that tooth-colored materials have become common restorative materials and the clinical diagnosis of secondary caries is still the main reason for replacement of all types of restorations.

SUMMARY

Ninety-one Icelandic practicing dentists (51% response rate) provided information related to the reasons for placement and replacement of 8,395 restorations and 741 sealants in 5,997 patients. Information included the patient's gender and age, the clinician's gender and experience in years since graduation, the defined criteria for replacement of restorations, the estimated past use of material in five-year increments and the records of 100 consecutively placed restorations. The materials used include composite (52.7%), amalgam (29.2%), glass ionomer (9.5%), resin-modified glass ionomer (7.1%) and other materials (1.4%). Although material selection was independent of the clinician's gender, female patients received more composite and fewer amalgam restorations than their male counterparts. Reasons for placing restorations comprised replacement of failed restorations (47.2%), primary caries (45.3%) and non-carious defects (7.5%). Secondary caries was the main reason for replacement for all types of restorations. Chi square analysis related to the dependence between the reasons for replacement and clinician's experience showed that more experienced clinicians recorded a lower frequency of secondary caries than less experienced ones ($p<0.0001$), while the diagnoses of discoloration and fracture of restorations increased with the clinicians' experience ($p<0.0001$).

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INTRODUCTION

Iceland has a population of 280,000 and a dentist population of just over 300, with less than 200 dentists in general practice. The country has one dental school that admits six students a year. Since 1975, the Social Security System has reimbursed the cost of restorative treatment for the age groups 0-17 years, those 67 years and older and institutionalized and disabled individuals. All treatments were carried out by general practitioners in their private offices. From 1975 to 1992 the reimbursement for schoolchildren was 100% of the cost of the treatment. Since 1992, the reimbursement was lowered to 75% for children and adolescents and became income-dependent for retired and disabled individuals.

Until three years ago, the Icelandic Dental Association and the Social Security Institute negotiated a fee schedule for restorative dental care. Subsequently, the Ministry of Health has issued a unilateral fee schedule. It includes one surface but not Class II, composite restorations. Cast restorations must be covered by the patient on a fee-for-service basis. Such regulations may have an effect on the selection of treatment and the use of restorative materials.

This investigation was initiated to study the restorative pattern in Icelandic general dental practice with regards to selecting restorative materials for initial placement of restorations and for subsequent replacement of restorations. No such information is available from Iceland except for limited unpublished data (Mjör & Eliasson, 1983), but several similar studies have been published from many countries, including other Scandinavian countries with a similar social security welfare system (Mjör, 1981, 1997, 2000; Qvist, Qvist & Mjör, 1991a,b) and from other parts of the world that have predominantly fee-for-service restorative care (Mjör & Toffenetti, 1992a,b; Mjör & Um, 1993; Pink, Minden & Simmons, 1994; Friedl, Hiller & Schmalz, 1994, 1995; Mjör & Moorhead, 1998) and in practices with a mixed system of reimbursement for restorative dental care (Wilson, Burke & Mjör, 1997; Deligeorgi & others, 2000; Burke & others, 2001; Burke & others, 2002).

METHODS AND MATERIALS

Recording forms were mailed to all 179 Icelandic dentists known to be in general practice together with a letter of invitation to participate in the study. It was an open invitation. No special incentives were provided.

Explanations were included with the letter of invitation. They related to how to do the recording and provided simple explanations for the reasons for replacements; however, no calibration of the clinicians were carried out. The clinicians were asked to use their routine methods for diagnosing primary caries and when to intervene operatively. The reasons for replacements and the explanations were the same as those used in previous studies (Mjör, 1997, 2000; Mjör & Moorhead, 1998). They included secondary (recurrent) caries, fracture of restoration (bulk and margin separately), discoloration of restoration (bulk and margin separately), fracture of tooth and "other" reasons. The use of sealants was also recorded. The clinicians were asked to record the reason for placement and replacement of 100 consecutive restorations and sealants. Information related to patient age, gender, tooth treated, restorative material used and size according to the class of restoration and clinician gender and years since graduation was also requested. The patients were divided into six groups based on age, ≤ 10 years, 11-20 years, 21-30 years, 31-40 years, 41-50 years and 50+years. The clinicians were divided into four groups based on their years of experience since graduation; they will be referred to as ≤ 10 years, 11-20 years, 21-30 years and 30+ years.

In order to obtain information on the changing pattern in the selection of restorative materials, the clinicians were also asked to estimate the use of restorative material in Class I and Class II restorations in five-year increments, current, 1-5, 6-10, 11-15 and >15 years ago.

RESULTS

Fourteen dentists returned the forms, claiming they did not have time or did not choose to participate. Two more dentists returned the forms because they placed too few restorations.

Ninety-one forms were returned from 61 male and 23 female clinicians and 7 who did not disclose their gender. Thus, the overall response rate was 60%, but only 51% provided the information requested. The mean number of years since graduation for the clinicians was 16.9 (ranging from 1– 41 years), 17.3 for male and 14.7 for female clinicians. Those who did not report their gender had a mean year-since-graduation of 19.0 (ranging from 4-35 years).

A total of 8,395 restorations and 741 sealants had been placed in 5,997 patients (52% female and 48% male). For the sealants alone, this female:male ratio was reversed. Of all permanent tooth restorations inserted, 3,029 (40.6%) were due to primary caries, 3,863 (51.7%) were replacements of failed restorations and the remaining 578 (7.7%) were for non-carious defects. Nine-hundred and twenty-five restorations (10.3%) were placed in primary teeth, 83.4% were due to primary caries, 14.5% were replacements and 2.1% were for non-carious defects. The distribution of these main reasons for placing restorations was age-dependent (Figure 1). Primary caries decreased sharply from the 11-20 year group to the 31-40 year group, while

replacements showed an opposite trend. Non-carious defects, on the other hand, showed a slight increase with the patient's age.

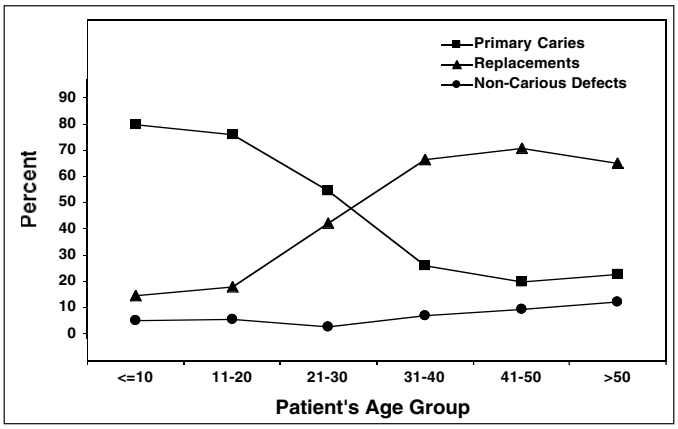
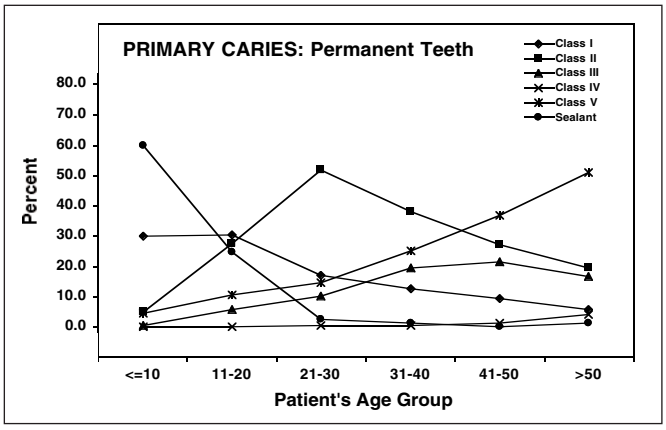


Figure 1. *Reasons for changing the placement of restorations with respect to the patient's age.*

Restorations due to primary caries and replacements by class in permanent teeth differed depending on the age of the patient (Figure 2). Ten sealants were recorded as replacements or for non-carious defects; the rest were considered as primary caries. The percent of sealant decreased from a high of 60% in the ≤ 10 year group, to 1.4% in the 21-30 years of age group and to <1% for older groups (Figure 2, left side). Class I restorations exhibited a similar age-dependent decline but still registered 6.3% for the >51-year group. Class II restorations peaked at 21-30 years and remained the dominant type of restoration for all older groups. Class III and Class IV restorations were relatively stable in frequency, although a gradual increase of Class III restorations was noted up to the 41-50 year group. On the other hand, primary Class V restorations had increased from 4.3% for the ≤ 10-year group to 50.9% for the ≥ 51-year group (Figure 2, left side). For replacement restorations, the distribution by class was similar to that for primary caries. The predominant type of replacement restoration was Class II restorations in adults. In adolescents, Class I and Class II restorations



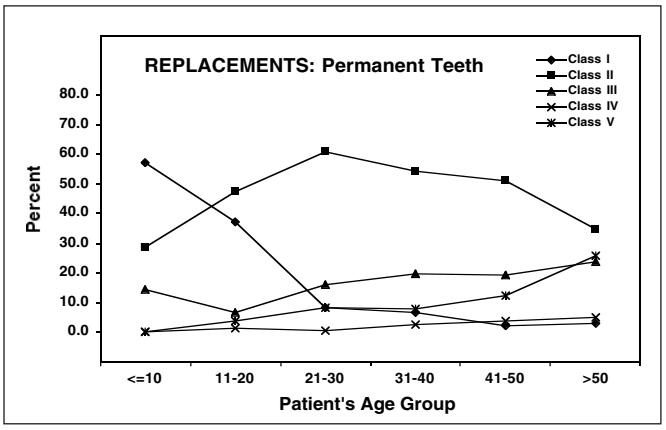
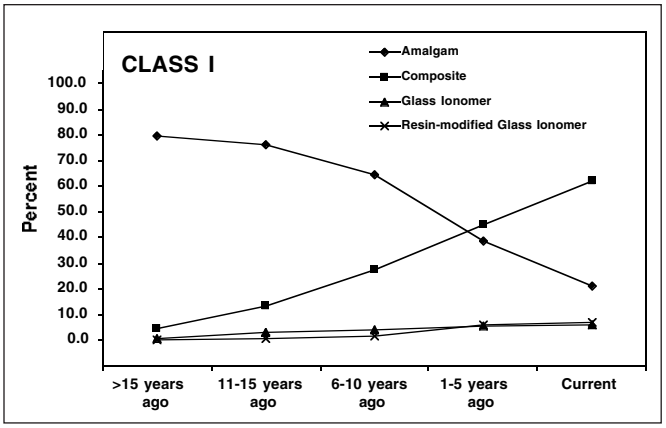


Figure 2. Distribution of types of restorations placed with respect to patient's age for placement in permanent teeth due to primary caries (left) and replacements on all permanent teeth (right).



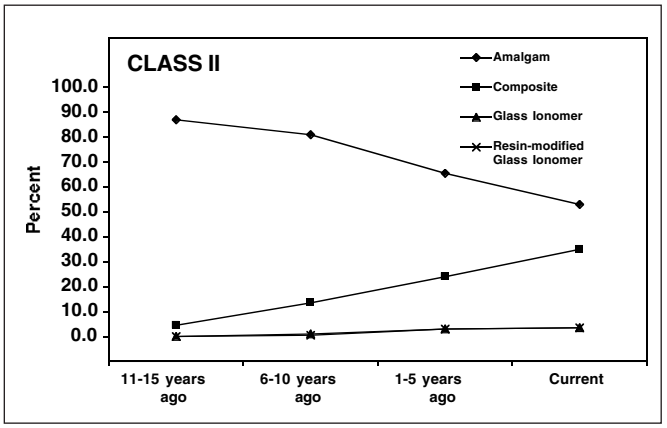


Figure 3. *Estimated use of restorative materials expressed as percent of current use and at five-year intervals up to 15 years ago and more than 15 years ago for Class I applications (left) and Class II applications (right).*

were most common and Class IV restorations were rarely replaced. Class V restorations peaked at 26% for the ≥ 50-year group.

SELECTION OF MATERIALS

The estimated past and current use of amalgam and composite materials in Class I and Class II restorations showed a gradual trend toward an increased use of resin-based materials (Figure 3). The change from amalgam was more marked for Class I than Class II restorations. Glass-ionomer materials were in minimal use >15 years ago (<1%). The use of classical glass ionomers increased gradually up to about 6.1% and leveled off approximately five years ago. The use of resin-modified glass ionomers in Class I and Class II restorations started 6-10 years ago, and their estimated present use (7.1 %) has exceeded that of the traditional type. Other materials used in stress-bearing areas, including metal castings and ceramics, comprised 2.8% of all restorations for multi-surfaced posterior restorations.

The correlation between estimated and recorded current use of amalgam and composite materials, based on the materials used and what has been recorded in this survey, showed good correlation (r^2>0.65), but with a tendency for greater underestimation of the present use of amalgam (Figure 4). The number of glass ionomer and "other" restorations were too small for detailed analyzes.

For Class I restorations, composite was the predominant material for both adults (68.1%) and adolescents (50.6%). Amalgam was most frequently used for Class II restorations, 58.6% in adults and 36.1% in adolescents. Approximately 88% of all Class III, Class IV and Class VI (mainly incisal edge) restorations were placed with composite materials. The greatest variation in the selection of materials was found for Class V restorations: composite (50.5%), glass ionomer (26.8%), resin-reinforced glass ionomer (11.9%) and amalgam (10.3%).

As far as the patients' gender was concerned, males received significantly more amalgam restorations, while females received more composite restorations (p<0.0001). On the other hand, there was no significant difference in the frequency of patients receiving amalgam or composite by gender of the clinician (p=0.2869).

Chi square analysis was used to examine whether the ratio of amalgam to composites changed with the clinician's experience. The result shows that the 21-30 year group placed more amalgam and fewer composite restorations than the other three groups, while no difference was found among these three groups.

More than half of all restorations (53.5%) in primary teeth were Class II. Amalgam was the most frequently used material in these restorations. In all other types of restorations, composites predominated as the restorative material.

SELECTION OF MATERIALS

There were 3,885 restoration replacements with known reasons: 283 in adolescents (age≤ 18) and 3,602 in adults (age>18). The clinical diagnosis of secondary caries (44.8%) was the most common reason for replacing all types of restorations in this study, followed by fracture of restoration (26.2%), discoloration of composites (11.3%), tooth fracture (9.4%) and other reasons (8.3%). Fracture of amalgam comprises 60.2% bulk and 39.8% marginal fractures. Discoloration of composite restorations comprises 69.0% bulk and 31.0% marginal discoloration. Figure 5 shows the frequency of the four major reasons of replacement. Chi square analysis shows dependence between clinical experience and the reasons. Chi square values of individual cells indicate that the diagnoses of restoration fracture and discoloration increased with clinician experience, while the diagnosis of recurrent caries decreased with experience; no trend is obvious with tooth fracture except that higher frequency was recorded for the <10 year and lower for the

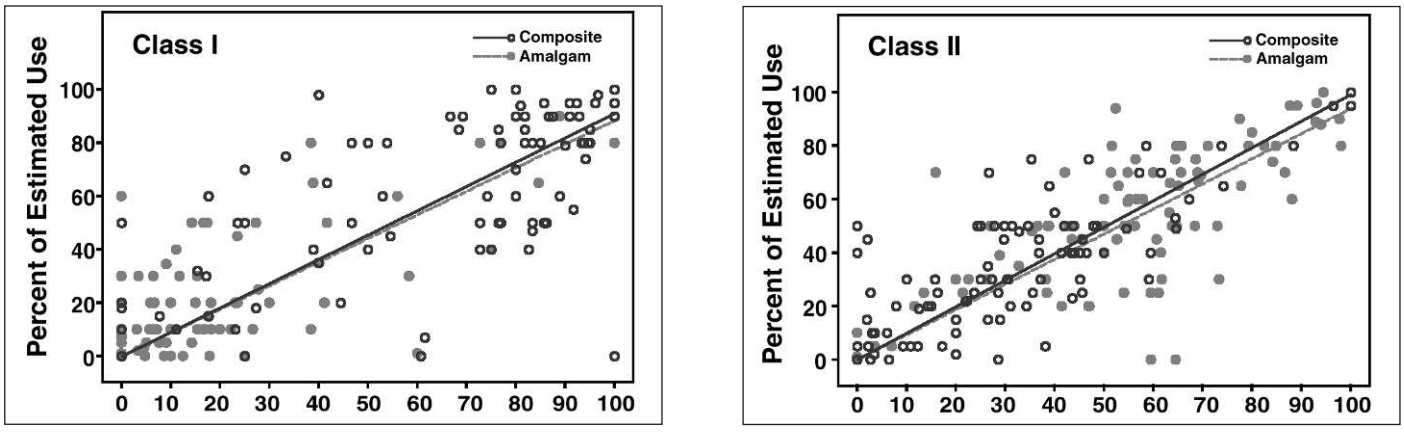


Figure 4. *The correlations between estimated and recorded current use of composite and amalgam for Class I application (left) and Class II application (right). For Class I, estimated amalgam use = 0.89 *recorded use (r^2=0.65) and estimated composite use = 0.92*recorded use (r^2=0.88). For Class II, estimated amalgam use=0.94 * recorded use (r^2=0.91) and estimated composite use=0.99*recorded use (r^2=0.85).*

11-20 year experience group. Analyses also showed significant dependence on the reasons for replacement of restorations based on patient sex but not on the clinician gender. Regardless of the clinician's gender, female patients had more tooth-colored restorations replaced than male patients. Male patients tended to have a higher frequency of fractured restorations diagnosed by male clinicians.

Secondary caries, followed by fracture of restoration, was also the primary reason for replacement of restorations in primary teeth. However, the number of replacements was so small that detailed analysis was not warranted.

DISCUSSION

The relatively high response rate (51%) is better than that in similar investigations with open invitations for practitioners to participate in practice-based studies where the response rate was in the 10%-24% range (Mjör & others, 2000). Undoubtedly, the small total dentist population in Iceland made it possible for local organizers of the data collection to encourage cooperation from their colleagues.

Since the age and gender distribution of this sample of clinicians fairly well matches that of the practicing dentist population in Iceland (Eliasson, 2000), the findings are considered representative of the restorative care provided to the population. The 52/48 female/male ratio of patients is slightly higher than the 50/50 ration for patients in Norway (Mjör, Moorhead & Dahl, 1999), but it is considered to be representative for Icelandic patients.

The selection of restorative materials, both estimated and recorded, showed the same trend towards an increased use of tooth-colored materials as in other countries (Mjör, 1997; Mjör & Moorhead, 1998; Mjör & others, 1999). Thus, restriction in the use of composite restorations set by the Ministry of Health by not refunding the cost for Class II composite restorations may not have had much of an effect on selecting restorative materials. The proportion of "other" materials, which comprises cast restorations, was remarkably low (1.4%) compared to 3% in Norway (Mjör & others, 1999) and 18% in the USA (Mjör & Moorhead, 1998).

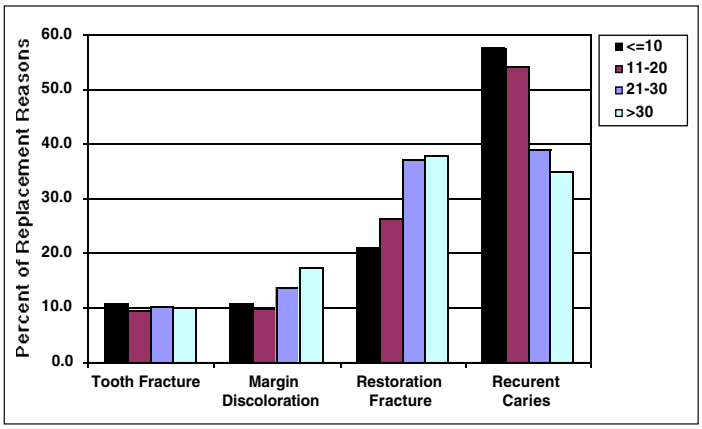


Figure 5. *Percentage distributions of the three main reasons of replacement within each year-after-graduation group; the percentages were grouped by the reasons of replacement to show changes with respect to the experience (year-after-graduation).*

The proportion of primary restorations to replacement restorations may reflect the success of the treatment provided. For example, a high proportion of replacement restorations may reflect a short life span for the restorations provided to a population that regularly receives dental treatment. In fact, during times when longevity of composite restorations was short, almost 80% in the late 1970s (Mjör, 1981) and about 60% in the late 1980s (Qvist & others, 1990b) were replacement restorations in an adult populations. The reported replacement rate for primary teeth (14.5%) was the same as that reported by other Scandinavian counties (Qvist & others 1997; Mjör, Dahl & Moorhead, 2001).

This Icelandic data, with an overall replacement rate of 40.6% in permanent teeth (37.1% for composites and 59.1% for amalgam), represents a reduction in replacements compared to the replacement rate of 47.4% (53.9% for composites and 43.9% for amalgams) in Iceland in 1983 (Mjör & Eliasson, 1983). The relatively high replacement rate for amalgam in this study may be due to a change from amalgam to composite. However, the fact that amalgam replacements in this study are high may also result from the fact that there are more amalgam than composites in patients' mouths, reflecting a change in the disease pattern. The overall replacement rate was 43% (30.6% for composites and 58.7% for amalgams) in a recent Norwegian study, but with a distinct age dependence: 68% in adults and 15% for the adolescents ≤ 18 years of age (Mjör & others, 1999). A similar patient age-dependent replacement rate has also been previously reported (Qvist & others, 1990a,b).

The reasons for replacing all types of directly placed restorations were similar to those in recent practice-based studies (Mjör, 1997, Mjör & others, 2001). Clinically-diagnosed secondary caries is still the main reason for replacing restorations, as it has been for decades (Mjör, 1981). Current observations also confirm that glass ionomer restorations are commonly replaced with this diagnosis (Mjör, 1997; Burke & others, 1999; Mjör & others, 2000). Secondary caries is most commonly diagnosed gingivally on restorations (Mjör, 1985; Mjör & Qvist, 1997).

The reasons for replacing amalgam restorations have remained much the same over time, while that for composites have changed markedly over the last 30 years (Mjör, 1993; Mjör & others, 2000). The initially-devel-

oped resin based composite materials degraded intraorally and, as a consequence, they were recorded as having poor anatomical form or wear. Present-day composite restorations fail for many of the same reasons as amalgam restorations, that is, due to secondary caries and fracture, both bulk and margin fracture. Some composite restorations are also replaced due to bulk and margin discoloration, while tooth fracture associated with replacement occurs at the 10% level for both types of restorations.

Many factors affect the replacement of restorations, for example, the age of the patients and the dentition studied (Qvist & others, 1990a,b; Mjör & others, 2000), the mode of remuneration for the dental care provided (Mjör & others, 2000; Burke & others, 2001) and a host of other factors (Burke & others, 2001). Furthermore, clinicians' gender plays a role, for example, female clinicians diagnose secondary caries more often than male clinicians and the age of restorations replaced by female clinicians is significantly lower than that replaced by male clinicians (Mjör & others, 2000). Changes in the use of restorative materials and improvements in the quality of the materials will also affect the replacement. In addition, it is likely that changes in disease pattern and in treatment philosophy will have an effect on the replacement rate.

No differences in the reasons for replacing restorations in female and male patients have been noted (Mjör & others, 2001; Burke & others, 2001) and this study confirms this finding. Previous studies have not dealt in detail with the effects of clinicians' gender on the reasons for replacing restorations. Significant differences were found with respect to some criteria for replacement, and especially the clinical diagnosis of secondary caries. The proportion of secondary caries was significantly less for the groups of clinicians who had the longest clinical experience. This finding was also noted in another study (Mjör & others, 2002). It seemed likely that this observation could be related to the differences in patient populations, that is, older clinicians had older patients, but analysis of the patients' age for the different clinician groups did not indicate any significant age differences. Since the results are presented in relative values, the most marked increase was noted in the "restoration fracture" category. It is tempting to suggest that as clinical experience increases, the ability to differentiate between "ditched" or stained margin and secondary caries improves. However, these observations need to be verified in other practice-based studies before further speculations are justified. Tooth fracture as a reason for replacement was the same for all clinicians irrespective of the experience group. This diagnosis is considered the easiest of all those leading to replacement of restorations; in fact, the patient usually makes the diagnosis.

CONCLUSIONS

Tooth-colored materials were the most frequently used restorative materials, of which 53% were composites and 17% were all types of glass ionomer materials. Amalgam was used in about 29% of all restorations, and "other" materials, which comprised cast restorations, were used in only about 1% of all restorations. Female patients received more composite and fewer amalgam restorations than males. No significant difference in the use of materials was found among most age groups of clinicians.

The clinical diagnosis secondary caries was the main reason for replacing restorations. The frequency depended on the clinicians' experience; the older group of clinicians diagnosed fewer than the younger group. Discoloration and restoration fractures as reasons for replacement increased with clinician experience, while tooth fracture was unaffected by clinician experience.

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References

Burke FJ, Cheung SW, Mjör IA & Wilson NH (1999) Restoration longevity and analysis of reasons for the placement and replacement of restorations provided by vocational dental practitioners and their trainers in the United Kingdom *Quintessence International* **30(4)** 234-242.

Burke FJT, Wilson NHF, Cheung SW & Mjör IA (2001a) Influence on methods of funding on age of failed restorations in general practice in the UK *British Dental Journal* (submitted).

Burke FJT, Wilson NHF, Cheung SW & Mjör IA (2001b) Influence of patient factors on age of restorations at failure and reasons for the placement and replacement of restorations by a group of general dental practitioners *Journal of Dentistry* (in press).

Deligeorgi V, Wilson NH, Fouzas D, Kouklaki E, Burke FJ & Mjör IA (2000) Reasons for placement and replacement of restorations in student clinics in Manchester and Athens *European Journal of Dental Education* **4(4)** 153-159.

Eliasson ST (2000) Dentistry in Iceland *EuroCondenser* **2(1)** 5-8.

Friedl K-H, Hiller K-A & Schmalz G (1994) Placement and replacement of amalgam restorations in Germany *Operative Dentistry* **19(6)** 228-232.

Friedl K-H, Hiller K-A & Schmalz G (1995) Placement and replacement of composite restorations in Germany *Operative Dentistry* **20(1)** 34-38.

Mjör IA (1981) Placement and replacement of restorations *Operative Dentistry* **6(2)** 49-54.

Mjör IA (1985) The frequency of secondary caries at various anatomical locations *Operative Dentistry* **10(3)** 88-92.

Mjör IA (1997) Selection of restorative materials in general dental practice in Sweden *Acta Odontolologica Scandinavica* **55(1)** 53-57.

Mjör IA, Moorhead JE & Dahl JE (1999) Selection of restorative materials in permanent teeth in general dental practice *Acta Odontologica Scandinavica* **57(5)** 257-262.

Mjör IA, Dahl JE & Moorhead JE (2000) Age of restorations at placement in permanent teeth in general dental practice *Acta Odontologica Scandinavica 58(3)* 97-101.

Mjör IA, Dahl JE & Moorhead JE (2001) Placement and replacement of restorations in primary teeth *Acta Odontologica Scandinavica* (submitted).

Mjör IA & Eliasson ST (1983) Unpublished observations.

Mjör IA & Moorhead J (1998) Selection of restorative materials, reasons for replacement and longevity of restorations in Florida *Journal of the American College of Dentistry* **65(3)** 27-33.

Mjör IA, Moorhead JE & Dahl JE (2000) Reasons for replacement of restorations in permanent teeth in general dental practice *International Dental Journal* **50(6)** 360-366.

Mjör IA & Qvist V (1997) Marginal failures of amalgam and composite restorations *Journal of Dentistry* **7(1)** 25-30.

Mjör IA & Toffenetti F (1992a) Placement and replacement of amalgam restorations in Italy *Operative Dentistry* **17(2)** 70-73.

Mjör IA & Toffenetti F (1992b) Placement and replacement of resin based composite restorations in Italy *Operative Dentistry* **17(3)** 82-85.

Mjör IA & Um CM (1993) Survey of amalgam and composite restorations in Korea *International Dental Journal* **43(4)** 311-316.

Pink FE, Minden NJ & Simmons S (1994) Decisions of practitioners regarding placement of amalgam and composite restorations in general practice settings *Operative Dentistry* **19(4)** 127-132.

Qvist J, Qvist V & Mjör IA (1990a) Placement and longevity of amalgam restorations in Denmark *Acta Odontologica Scandinavica* **48(5)** 297-303.

Qvist V, Qvist J & Mjör IA (1990b) Placement and longevity of tooth-colored restorations in Denmark *Acta Odontologica Scandinavica* **48(5)** 305-311.

Wilson NHF, Burke FJ & Mjör IA (1997) Reasons for placement and replacement of restorations of direct restorative materials by a selected group of practitioners in the UK *Quintessence International* **28(4)** 245-248.

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Laboratory Research

Penetrability of Dentinal Tubules in Adhesive-Lined Cavity Walls

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Clinical Relevance

Dentin adhesives do not completely seal dentinal tubules in cavity walls. As a result, they do not prevent bacterial penetration.

SUMMARY

This study investigated the penetrability of dentinal tubules in cavity walls lined with different dentin bonding systems. Occlusal Class I cavities were prepared in 93 premolars. The cavities in the control group had an intact smear layer without a lining, while those in the experimental group were lined with Gluma CPS, Scotchbond Multi-Purpose Plus or One-Step. The penetrability of the dentinal tubules was tested with a dye (basic fuchsin) or bacteria (S faecalis) **immediately after adhesive lining and after one-month storage in water at 37°C. Some of the lined samples were sectioned and examined under the SEM.**

In some samples in the experimental group, the dye penetrated to the pulp and bacteria up to 125 µm into the dentinal tubules immediately after lining. The Kruskal Wallis ANOVA and Tukey test showed the depth of dye and bacterial penetration to be significantly less in teeth with bonding systems than those in the control group ($p<0.05$). **However, there was no statistically significant difference between the control and experimental groups after storage in water** ($p>0.05$). **SEM examination showed that the hybrid layer and resin tags were present in the cavity walls immediately after lining but absent after storage in water. Therefore, adhesive linings under the experimental conditions were ineffective in preventing dye or bacterial penetration of the dentinal tubules.**

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INTRODUCTION

Dentin adhesives have been used to promote bonding of restorations to cavity walls, thereby minimizing microleakage, post-operative sensitivity and cuspal flexion. Applying most of these adhesive systems involves removing or modifying the smear layer and demineralizing the dentin surface; thus allowing penetration of the bonding system and formation of the hybrid layer (Nakabayashi, Kojimak & Masuhara, 1982). The adhesive also forms tags that are hybridized to the peritubular dentin to plug the dentinal tubules, thus preventing ingress of micro-organisms.

There is controversy regarding whether the bonding systems completely seal the dentinal tubules and eliminate microleakage. Moodley & others (2000) compared microleakage at the restoration-dentin interface when two different bonding systems were used with compomers. In the group that used a non-rinse/ Primer & Bond NT bonding system, there was microleakage in most samples. However, microleakage was not observed in the group that utilized Scotchbond Multi-Purpose Plus. Also, Gwinnett & Kanca (1992) reported the absence of gap formation in composite resin restorations when the cavities were lined with bonding systems.

In contrast, Fukushima & others (1991) demonstrated microleakage in cavities lined with various brands of adhesive systems. Browning, Johnson & Gregory (1997) compared post-operative pain following lining amalgam cavities with dentinal adhesive or copal varnish and conventional base. They found that both groups experienced post-operative sensitivity to cold one week following treatment and concluded that using an adhesive liner under amalgam restorations did not eliminate post-operative sensitivity to cold. Akpata & Sadiq (2001) reported a higher prevalence of post-operative sensitivity in adhesive-lined compared to glass ionomer-lined posterior composites, suggesting incomplete sealing of dentinal tubules in the cavity walls. The authors therefore hypothesized that hydration that occurs in the oral environment may weaken the bond between the hybrid layer and the underlying dentin, allowing hydrodynamic dentinal fluid shift or penetration of the tubules by micro-organisms and their toxins.

This work therefore studied the ability of bacteria and dyes to penetrate dentinal tubules in Class I cavity floors lined by different dentin bonding systems.

METHODS AND MATERIALS

Cleaning of Teeth and Cavity Preparation

A total of 93 extracted teeth free of restorations, caries or attrition were used for the study. The teeth were scaled and polished with a rubber cup and flour of pumice before the operative procedures.

Using an ultra-high speed handpiece, occlusal Class I cavities measuring about 2 mm deep, 5 mm mesiodistally and 2-3 mm buccolingually were prepared with a #37 tungsten carbide inverted cone bur cooled with copious water spray. The cavities were then thoroughly washed with water to remove loosely attached debris.

Grouping of Teeth

The teeth were divided into two main groups: the control and experimental group. Only the experimental group received an application of the adhesive systems (Figure 1).

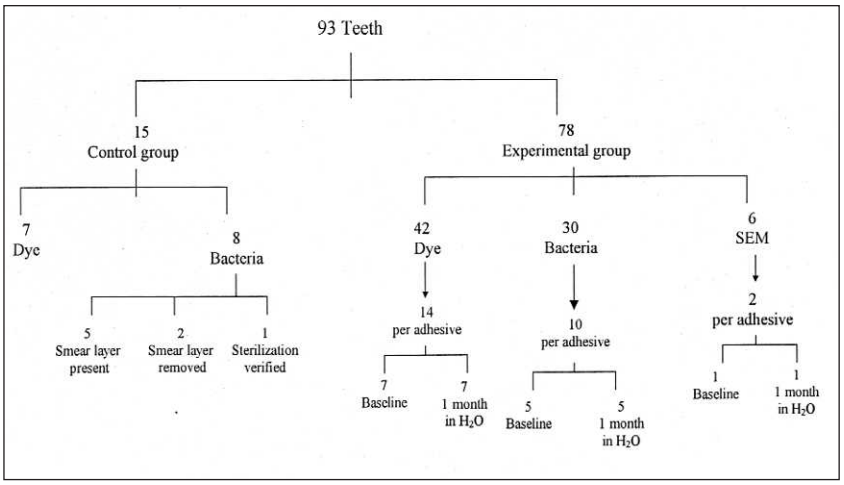

Figure 1. *Grouping of teeth.*

Of the 15 teeth in the control group, seven were used for investigating dye penetration and eight for bacterial invasion. There were 78 teeth in the experimental group, which were divided into three subgroups: 42 in the first subgroup were used for studying dye penetration, 30 in the second subgroup for bacterial invasion and six in the third subgroup for SEM evaluation of the adhesive resins (Figure 1).

Of the teeth identified for studying bacterial penetration in the control group, five had the smear layer left intact, two had it removed through acid etching and the remaining tooth was used to check the effectiveness of ethylene oxide gas sterilization.

Cutting Off Roots and Sterilization of Teeth

Half of the teeth had the roots cut off to facilitate mounting later. The prepared teeth were stored in physiological saline at 4°C in a refrigerator until used. The teeth inoculated with bacteria were sterilized by ethylene oxide gas at 50°-60°C for four hours. After sterilization, they were aerated for 16 hours to remove residual ethylene oxide. Prior to use, the teeth were stored in physiological saline to re-hydrate and further dilute or remove any residual ethylene oxide.

Application of Bonding Systems

The prepared cavities in teeth in the experimental subgroup were lined with bonding systems (Gluma CPS [Heraeus Kulzer GmbH & Co, KG, Dormagen, Germany], Scotchbond Multi-Purpose Plus [3M Dental Products, St Paul, MN 55144, USA] and One-Step [BISCO Inc, Schaumburg, IL 60193, USA]) following manufacturers' instructions.

The cavities lined with Gluma CPS were etched with 20% phosphoric acid for 30 seconds, washed with water for 10 seconds and dried with a gentle stream of

air, leaving the cavity surface visibly moist. The primer was applied to cavity surfaces with a brush and left undisturbed for 30 seconds before being air-dried.

Finally, a thin layer of the sealer (adhesive resin) was applied to the cavity surfaces and uniformly spread with a gentle stream of air. The sealer was activated for 20 seconds with visible light using an Elipar Highlight curing unit (ESPE, Germany Dental-Medizin GmbH & Co, D-8222 Seefeld, KG). The curing unit was checked periodically to ensure that the power output was not less than 300 mW/cm^2.

In the case of Scotchbond Multi-Purpose Plus (Scotchbond MP Plus), the cavities were etched with 35% phosphoric acid gel for 15 seconds, washed with water for 10 seconds and gently dried for five seconds to remove excess water, leaving the cavity surfaces moist. Primer was then applied with a brush. The surfaces were gently dried for five seconds, leaving them shiny. Finally, adhesive resin was applied to the cavity surfaces with a brush and light cured for 10 seconds.

The teeth in the remaining third of the experimental subgroup were lined with One-Step. The prepared cavities were etched with 35% phosphoric acid gel for 15 seconds, Unitech (BISCO), then washed with a gentle stream of water. Excess water was removed with a brief stream of air, leaving cavity surfaces moist. Two consecutive coats of One-Step adhesive were then applied to cavity surfaces. The coated cavity walls were air dried for 10 seconds to remove excess solvent and water. The adhesive was then light cured for 10 seconds.

Mounting of Teeth in Tissue Culture Plate

After applying the bonding systems, the teeth were arranged in a tissue culture plate (24-well #662160). The roots were stabilized with molten wax used to fill half the depth of the tissue culture wells. When the wax was semi-solid, the teeth were vertically implanted with the occlusal cavities facing up, ready to receive the bacteria or dye.

BACTERIAL PENETRATION

Inoculation of Bacteria into Cavities and Determining Their Total Viable Count

The cavities in the teeth being studied for bacterial penetration were inoculated with 0.1 ml aliquots of 24-hour culture of *Streptococcus faecalis* (ATCC 29212) that had been maintained in a brain-heart infusion agar slope. The inoculated teeth were incubated at 37°C for three weeks. To maintain 100% humidity, water was placed in the space between the wells of the culture plates. Also, a container full of sterile distilled water was placed inside the incubator. After the first 24 hours of incubation, 0.1 ml of nutrient broth was pipetted into each of the prepared cavities. This was repeated every 24 hours throughout the entire incubation period. After three weeks, the tooth specimens were stored in 10% buffered formalin prior to histobacterial examination.

Blood agar plates were inoculated with aliquots of the serial dilutions obtained from the bacterial suspension using the spread plate method. The plates were incubated at 37°C for 24 hours to determine the viability and count of the bacteria.

Control Groups

The smear layer was removed from two teeth by etching the cavities with 37% phosphoric acid for 30 seconds. The samples were kept in water for 24 hours to remove any residual acid. The cavities were then inoculated with *S faecalis* and the teeth incubated at 37°C for three weeks. In five other samples, the smear layer was left intact and the balance of procedure repeated.

To assess the efficacy of the ethylene oxide gas sterilization, one sample with smear layer intact was inoculated with sterile nutrient broth at each experimental session. The teeth were incubated at 37°C for three weeks. The tooth samples were evaluated for bacterial penetration of the dentinal tubules.

Histobacterial Studies

Half the teeth inoculated with the bacteria were sectioned for evaluation after three weeks of incubation at 37°C (baseline). The remaining half were stored in sterile distilled water at 37°C for one month prior to sectioning and evaluation.

Before preparing the inoculated tooth samples for histobacterial studies, a platinum loop was used to pick up a sample from the inoculated cavity. The sample was spread on a glass slide, Gram stained and examined with a microscope for bacterial morphology.

The tooth specimens were decalcified in 11% hydrochloric acid containing 0.2% EDTA for 10-14 days, dehydrated with alcohol, cleared with chloroform and impregnated with formalin followed by alcohol. The impregnated specimens were embedded in paraffin, and six mesiodistal sections, each 5 µm thick, were made from each specimen using a Jung 1600 Saw Microtome (Leica Instrument GmbH, Heidelberger St, 17-19 Germany). The mounted sections were then stained with Brown & Brenn stain (Brown & Brenn, 1931).

Assessment of Bacterial Penetration

An optical microscope measured the depth of bacterial penetration to the nearest 5.0 µm on each slide. The measurement was made in the tubule with the deepest bacterial penetration.

Measuring the depth of bacterial penetration was repeated in 10% of the samples for the microbiological study to assess intra-examiner reproducibility. The measurement was repeated by another dentist to assess inter-examiner reproducibility.

DYE PENETRATION

Preparation of Teeth and Dye Placement

The surfaces of the 42 teeth used for the dye penetration experiment were covered with nail varnish 1 mm from the prepared cavity margins. The teeth were then vertically implanted in tissue culture plates.

Using a dropper, the prepared cavities were filled with 0.5% basic fuchsin solution, which soaked into the teeth for 10 minutes. The cavities were then re-filled with the dye and the teeth were incubated at 37°C for 24 hours in 100% humidity.

Mounting of Teeth

Each tooth was mounted in a cork stopper (Fisher Company, UK) and the spaces between the cork and tooth were filled with paraffin wax. The mounted teeth were sectioned mesiodistally into two halves using the Isomet 2000 precision saw (Buehler Ltd, Lake Bluff, IL, USA), after which the samples were examined and photographs taken.

Assessment of Dye Penetration

Two aspects of dye penetration were scored:

1. Mesiodistal extent of penetration, that is, the proportion of the mesiodistal width of the cavity floor penetrated by the dye (Table 1).
2. Depth of penetration, that is, the proportion of the distance between the cavity floor and the underlying roof of the pulp chamber penetrated by the dye (Table 2).

To assess the intra-examiner reproducibility of the assessment, all samples used for dye penetration were scored by an investigator a second time for the extent and depth of penetration two weeks after the first scoring. In addition, the scoring was repeated by another dentist to determine inter-examiner reproducibility.

SCANNING ELECTRON MICROSCOPIC EXAMINATION

Each adhesive was used to line two tooth samples, one of which was stored in sterile distilled water for one month, and the other sectioned after storage in water for 24 hours at 37°C. The teeth were then sectioned into two halves to obtain specimens that were fixed in 3% gluteraldehyde before being sputtered with a thin layer of gold and examined under the SEM at 15 kv (JEOL SMT 330, JEOL Ltd, Tokyo, Japan).

Statistical Analysis

Data obtained from assessment of the dye and bacterial penetration was subjected to Kruskal Wallis one-way analysis of variance (ANOVA) at 5% confidence level and Tukey test for non-parametric multiple comparisons.

Table 1: *Criteria for Scoring the Mesiodistal Extent of Dye Penetration*

Score	Description
0	No evidence of dye penetration at the tooth/liner interface of the cavity floor
1	Dye penetration along the cavity floor up to 1/3 the mesiodistal width of the cavity floor
2	Dye penetration along the cavity floor up to 2/3 the mesiodistal width of the cavity floor
3	Dye penetration of the entire mesiodistal width of the cavity floor

Table 2: *Criteria for Scoring Depth of Dye Penetration*

Score	Description
0	No evidence of dye penetration at the tooth liner interface
1	Dye penetration at the interface up to 1/3 the distance between the cavity floor and the underlying roof of the pulp chamber
2	Dye penetration of 2/3 the distance between the cavity floor and the underlying roof of the pulp chamber
3	Dye penetration of the entire distance between the cavity floor and the underlying roof of the pulp chamber.

RESULTS

REPRODUCIBILITY TESTS

Intra- and inter-examiner agreement were high, Cohen's percentage agreement ranging between 89.3% and 100% when assessment of the extent and depth of dye penetration was repeated.

When measurement of bacterial penetration of the dentinal tubules was repeated, Pearson's intra-examiner and inter-examiner correlation coefficients were 0.88 and 0.90, respectively.

BACTERIAL PENETRATION

Viability and Enumeration of the Test Bacteria

Bacterial colonies could be seen in the blood agar inoculated with the 24-hour culture of Strep faecalis used for inoculation of the lined cavities. Furthermore, the total viable count of bacteria in the suspension was in the order of 108 cfu/ml.

Control Groups

Bacteria penetrated the dentinal tubules up to the pulp chamber in samples with the smear layer removed. In samples with the smear layer intact, bacterial invasion of the dentinal tubules was for distances varying between 200 and 245 µm but did not extend up to the pulp chamber at baseline (Figure 2). Nevertheless, the bacteria penetrated the tubules up to the pulp chamber after storing the specimens in water for one month. No bacteria were seen in sections of the sterilized sample inoculated with sterile nutrient broth.

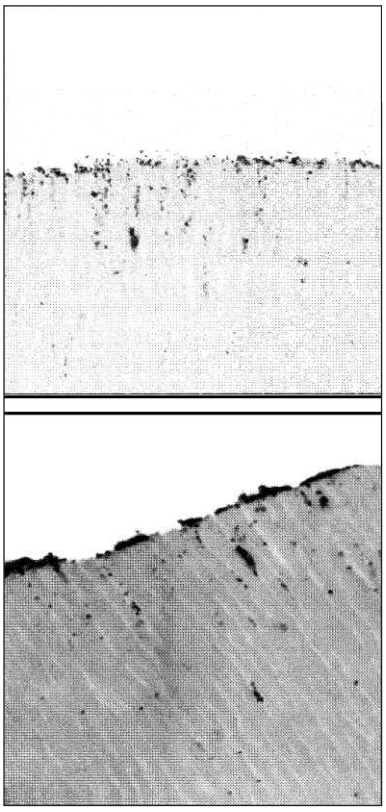

Figure 2. *Top: Bacterial penetration of dentinal tubules for short distances when the smear layer was left intact (original magnification x1000). Bottom: Bacterial invasion of dentinal tubules for long distances when the smear layer was removed (original magnification x400).*

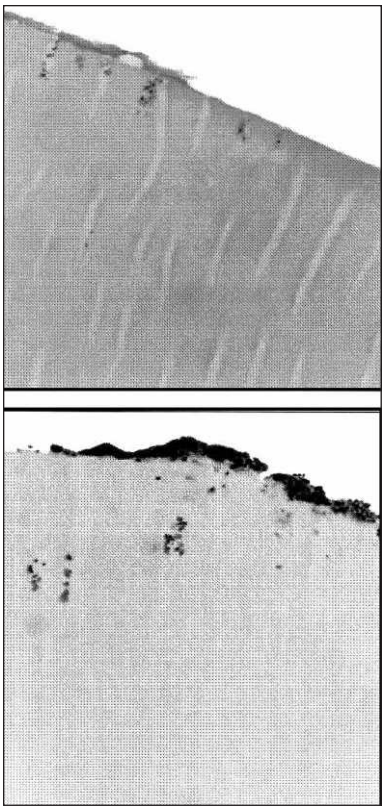

Figure 3. *Top: Superficial bacterial penetration of dentinal tubules (at baseline) in cavity walls lined with Scotchbond Multi-Purpose Plus (original magnification x1000). Bottom: Bacterial invasion of adhesive lining with Scotchbond Multi-Purpose Plus (after one-month storage in water) and penetration of dentinal tubules for longer distances (original magnification x1000).*

Experimental Groups

At baseline, histological sections of some of the samples showed bacteria on the surface of the cavity floor, while in others the bacteria were seen in the adhesive linings, sometimes penetrating the dentinal tubules for varying distances (Figure 3). The distribution of these distances was not normal and Kruskal-Wallis ANOVA showed that there was a statistically significant difference between the depth of bacterial penetration in the control groups and those lined with Gluma CPS, Scotchbond MP Plus or One-Step ($p<0.05$). However, non-parametric multiple comparison Tukey test showed that there was no statistically significant difference between the depth of bacterial penetration among the different bonding systems.

After one-month storage in water, all the samples showed bacterial penetration deeper than without storage in water: the depth of penetration varied between 35 and 225 μm (Figure 4). Kruskal-Wallis ANOVA showed no statistically significant difference between the depth of bacterial penetration in the experimental and control groups.

DYE PENETRATION

Control Groups

All the samples in this group showed dye penetration through the dentinal tubules from the cavity floor to the roof of the pulp canal (Figure 5) both at baseline and after storage in water at 37°C for one month. A longitudinal section of the teeth showed staining of the tubules to be triangular, with the base of the triangle at the cavity floor and the apex at the pulp chamber (Figure 5).

Experimental Groups

In some of the lined cavities, the dye was seen only at the top of the resin lining with no dye penetration of the pulpal floor or dentinal tubules at the baseline. In other cavities, the dye penetrated the dentinal tubules for variable distances but less than those in the control group.

After immersion in water at 37°C for one month, however, all the samples showed dye penetration from the cavity floor to the roof of the pulp chamber except One-Step, where the dye failed to penetrate to the pulpal floor in one sample only (Figure 5).

Kruskall-Wallis ANOVA showed that there was a statistically significant difference in the means of extent of dye penetration between the control group (with intact smear layer) and the experimental groups in which the cavities were lined with Gluma CPS, Scotchbond Multi-Purpose Plus or One-Step ($p<0.05$). When the data were subjected to non-parametric multiple comparison (Tukey) test, however, only the depth and mesiodistal extent of dye penetration in the teeth with Gluma CPS lining were significantly different from those in the control group ($p<0.05$).

Scanning Electron Microscopic Study

The tooth samples with adhesive lining showed the hybrid layer and resin tag formation in the dentinal tubules (Figure 6). After storage of the tooth specimens in water for one month, however, the samples showed no sign of the hybrid layer or resin tags (Figure 6).

DISCUSSION

Penetrability of dentinal tubules in adhesive-lined cavity walls after restoration depends on the ability of the adhesive to seal the tubules and adaptation/bonding of the restorative material to the lining. In order to focus on the sealing ability of the adhesive lining alone,

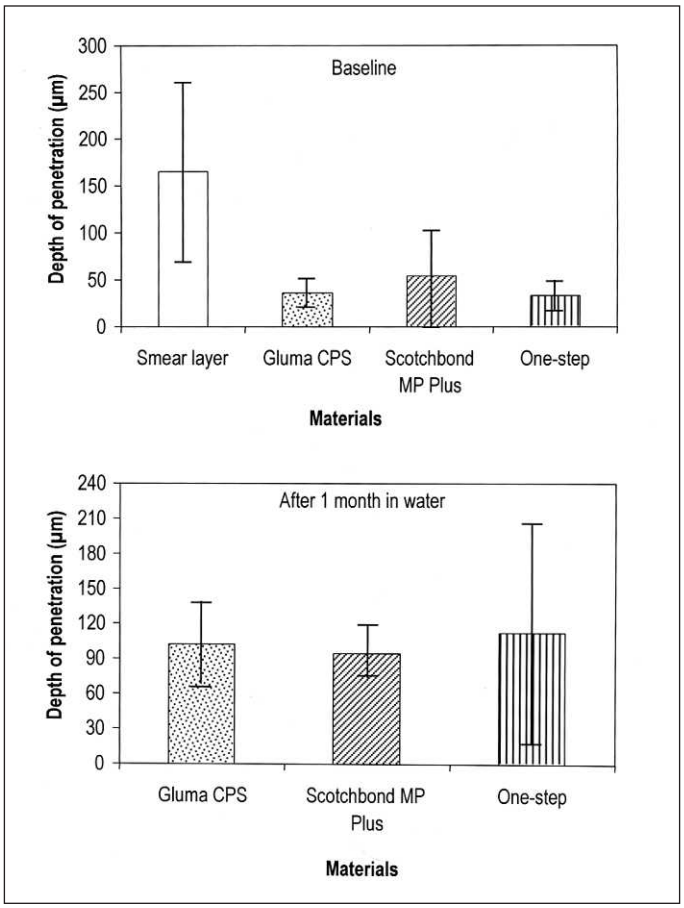

Figure 4. *Histograms showing depth of bacterial penetration of dentinal tubules in cavity walls lined with different adhesives, at baseline and after one-month storage in water. (Bar for smear layer (control) after one-month storage in water was omitted because it would be too long and those for bonding systems diminutive on the same scale.)*

no restorations were placed in the cavities utilized in this study.

To evaluate the ability of three different cement bases to prevent bacterial penetration along the base-dentin interface, Heys & Fitzgerald (1991) used Class V composites lined with each base. Under the circumstances, variable and indeterminate bacterial load seeped into the restoration-dentin interface in the various samples. In this study, known bacterial load (in the order of 10^8 cfu/ml) was introduced into the prepared Class I cavities.

Ethylene oxide gas sterilization was used in this study to avoid denaturation of the organic content of dentin. As this tended to make the teeth somewhat dry, they were stored in sterile physiological saline prior to use.

Adhesion of bonding systems to cavity walls has been shown to be influenced by cavity depth and smear layer treatment (Tagami, Tao & Pashley, 1990). All the prepared cavities in this study were of uniform depth and the smear layer was treated uniformly. In spite of these precautionary measures, variation in the thickness of smear layer in the prepared cavities cannot be entirely ruled out.

Bonding of the fourth and fifth generation adhesive systems is mainly micro-mechanical via the hybrid layer to etched dentin surface; chemical bonding is minimal and varies with different adhesive systems. The choice of bonding systems in this study represented the different bonding mechanisms: Gluma CPS bonds chemically to the organic component of etched dentin, while the chemical bond of Scotchbond MP Plus and One-Step is to the inorganic phase of dentin (Asmussen & Hansen, 1993).

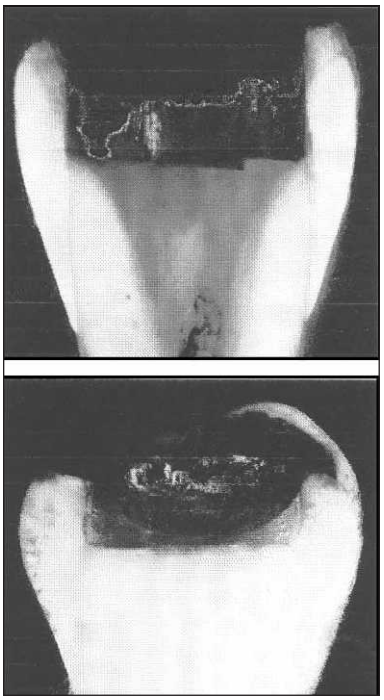

Figure 5. *Top: Dye penetration of dentinal tubules (at baseline) extending from the cavity floor to the roof of the pulp chamber in the control group (original magnification x8). Bottom: Dye confined to the cavity floor, following adhesive lining with Gluma CPS (original magnification x8).*

Penetrability of dentinal tubules in this study was assessed using *S faecalis*, a facultative gram positive anaerobe and 0.5% basic fuchsin, a dye of low molecular weight to simulate bacterial toxin. *S faecalis* was selected because of its fast rate of growth and frequent occurrence in the oral cavity (McCracken & Cawson, 1983) and root canal infection (Bystrom & Sundqvist 1981). A three-week incubation period was used because Akpata & Blechman (1982) demonstrated that bacterial invasion of dentinal tubules was time-dependent and *S faecalis* inoculated into the root canal invaded pulpal dentin wall in large numbers, penetrating to the dentin-enamel junction in three weeks.

The control group's bacterial invasion deep into the dentinal tubules after removing the smear layer confirms the reported widening of the ends of dentinal tubules when dentin is etched with phosphoric acid (Brännström, Vojinovic & Nordenvall, 1979). The bacterial penetration of dentinal tubules in the control group with smear layer intact is at variance with results from the experiments by Bergenholtz & others (1982), Daculsi & others (1987) and Love, Chandler & Jenkinson (1996). These investigators reported the inability of *S mutans* to penetrate the tubules in dentin discs in the presence of the smear layer. However, the

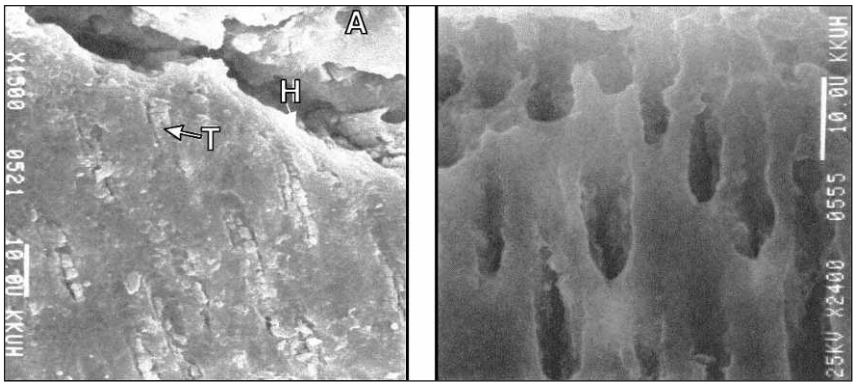

Figure 6. *Left: Scanning electron micrograph of adhesive-lined cavity wall (at baseline), showing adhesive lining (A), hybrid layer (H) and resin tag (T). (Original magnification x1500). Right: Scanning electron micrograph of resin-lined cavity wall (after one-month storage in water) with no sign of adhesive, hybrid layer or resin tags. (Original magnification x2400).*

results of this study agree with those of Tronstad & Langeland (1971) and Olgart, Brännström & Johnson (1974), who observed bacterial penetration *in vivo* when smeared dentin was left exposed to the oral environment. A possible explanation for the bacterial penetration of dentinal tubules with intact smear layer is that over the three-week incubation period the micro-organisms generated enough metabolic acids to dissolve the smear layer. To explain a similar finding from their experiment, Meryon & Brook (1990) suggested that bacteria digested and penetrated the smear layer to invade the dentinal tubules.

The dye penetration of dentinal tubules in all samples in the control group (with smear layer intact) agrees with the findings of Bergenholtz & others (1982), who reported that the smear layer acts as filter paper that permits the passage of materials of low molecular weight. Thus, the smear layer may be incapable of preventing irritants of relatively low molecular size, such as bacterial toxins, from penetrating the dentinal tubules to irritate the pulp.

Immediately after applying adhesive linings in the experimental group, Gluma CPS was the only bonding system with significant ability to seal the dentinal tubules and prevent dye penetration. This finding may be explained by the fact that this adhesive system bonds chemically to the organic phase of the etched dentin surface, unlike Scotchbond MP-Plus and One-Step, which bond to the inorganic phase (Asmussen & Hansen, 1993). As etching with phosphoric acid depletes the inorganic phase of the dentin cavity wall, adhesive systems that depend on bonding to hydroxyapatite are unable to seal the dentinal tubules effectively. There is therefore a need to develop adhesive systems that bond chemically to both organic and inorganic components of dentin.

Although the three adhesive linings significantly reduced bacterial penetration of the dentinal tubules at baseline, after storing the specimens in water at 37°C for one month, the bacteria invaded the dentinal tubules. This may be due to the fact that the bonding system may not fully penetrate the etched dentin surface (Sano & others, 1994, Spencer & others, 2000). The non-infiltrated collagen peptides may then undergo hydrolysis, providing a pathway for bacterial invasion of the dentinal tubules. In addition, hydration may lead to separation of the hybrid layer together with the resin tags from the lined dentin surface. This was clearly evident from the SEM appearance of the samples: at baseline the hybrid layer and resin tags were evident but could not be seen after water storage at 37°C for one month. Besides, the absence of any trace of adhesives in the sectioned samples after one-month storage in water could result from degradation of the resin liner and, if this were to occur in vital teeth, would have far reaching clinical implications.

Restoration of the cavities in this study might have mitigated separation of the adhesive linings from the cavity walls. Furthermore, no attempt was made to simulate intra-pulpal pressure, a factor that might have influenced adhesion (Prati, Pashley & Montanari, 1991) and bacterial invasion of the dentinal tubules. The effect that these factors may have on dye and bacterial penetration of dentinal tubules in adhesive-lined cavity walls need to be elucidated by future research.

CONCLUSIONS

Under the conditions of this study, resin liners did not completely seal the dentinal tubules to prevent dye and bacterial penetration. When the teeth with adhesive-lined cavities were stored in water for one month, the linings were lost, allowing dye and bacterial penetration deeply into the dentinal tubules.

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References

Akpata ES & Blechman H (1982) Bacterial invasion of pulpal dentin wall *in vitro Journal of Dental Research* **61(2)** 435-438.

Akpata ES & Sadiq W (2001) Post-operative sensitivity in glass-ionomer vs adhesive resin-lined composites *American Journal of Dentistry* (in press).

Asmussen E & Hansen EK (1993) Dentine bonding systems in *State of the art on direct posterior filling materials and dentine-bonding* Vanherle G, Degrange M & Willems G (eds) Proceedings of the International Symposium Euro-Disney Paris March 24-25 33-47.

Bergenholtz G, Cox CF, Loechse WJ & Syed SA (1982) Bacterial leakage around restorations: Its effect on conditioners and cleaning agents on prepared dentin surfaces: A scanning microscopic investigation *Journal of Prosthetic Dentistry* **31** 422-430.

Brännström M, Vojinovic O & Nordenvall KJ (1979) Bacteria and pulpal reactions under silicate cement restorations *Journal of Prosthetic Dentistry* **41(3)** 90-295.

Browning WD, Johnson WW & Gregory PN (1997) Post-operative pain following bonded amalgam restorations *Operative Dentistry* **22(2)** 66-71.

Brown JH & Brenn L (1931) A method for the differential staining of Gram-positive and Gram-negative bacteria in tissue sections *Bulletin of John Hopkins Hospital* **48** 69-73.

Bystrom A & Sundqvist G (1981) Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy *Scandinavian Journal of Dental Research* **89(4)** 321-328.

Daculsi G, LeGeros RZ, Jean A & Kerebel B (1987) Possible physico-chemical processes in human dental caries *Journal of Dental Research* **66(8)** 1356-1359.

Fukushima M, Nakamata T, Okabe T, Yamaga M, Sunada S & Iwaku M (1991) Microleakage of various dentin adhesive systems on root surface caries *Adhesive Dentistry* **9** 9-23.

Gwinnett AJ & Kanca J (1992) Micromorphological relationship between resin and dentin *in vivo* and *in vitro American Journal of Dentistry* **5(1)** 19-23.

Heys RJ & Fitzgerald M (1991) Microleakage of three cement bases *Journal of Dental Research* **70(1)** 55-58.

Love RM, Chandler NP & Jenkinson HF (1996) Penetration of smeared or non-smeared dentin by *Streptococcus gordonii International Endodontic Journal* **29(1)** 2-12.

McCracken AW & Cawson RA (1983) *Clinical and Oral Microbiology* Hemisphere Publishing Corporation Washington 454.

Meryon, SD & Brook AM (1990) Penetration of dentine by the oral bacteria *in vitro* and their associated cytotoxicity *International Endodontic Journal* **23(4)** 196-202.

Moodley D, Grobler SR, Rossouw RJ, Oberholzer TG & Patel N (2000) *In vitro* evaluation of two adhesive systems used with compomer filling materials *International Dental Journal* **50(6)** 400-406.

Nakabayashi N, Kojimak MA & Masuhara E (1982) The promotion of adhesion by the infiltration of monomers into tooth substrates *Journal of Biomedical Material Research* **16(3)** 265-273.

Olgart L, Brännström M & Johnson G (1974) Invasion of bacteria into dentinal tubules Experiments *in vivo* and *in vitro Acta Odontologica Scandinavica* **32(1)** 61-70.

Prati C, Pashley DH & Montanari G (1991) Hydrostatic intrapulpal pressure and bond strength of bonding systems *Dental Materials* **7(1)** 54-58.

Sano H, Shono T, Takatsu T & Hosoda H (1994) Microporous dentin zone beneath resin impregnated layer *Operative Dentistry* **19(2)** 59-64.

Spencer P, Wang Y, Walker MP, Wieliczka DM & Swafford JR (2000) Interfacial chemistry of the dentin/adhesive bond *Journal of Dental Research* **79(7)** 1458-1463.

Tagami J, Tao L & Pashley DH (1990) Correlation among dentin depth, permeability and bond strength of adhesive resins *Dental Materials* **6(1)** 45-50.

Tronstad L & Langeland K (1971) Effect of attrition on subjacent dentin and pulp *Journal of Dental Research* **50(1)** 1-30.

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Marginal Adaptation of Ceramic Inserts After Cementation

M Özcan • P Pfeiffer • I Nergiz

Clinical Relevance

Proximal ceramic inserts placed in cavities prepared with ultrasonic tips provide clinically acceptable marginal gap values and high marginal quality.

SUMMARY

The advantage of using ceramic inserts is to prevent major drawbacks of composite resins such as polymerization shrinkage, wear and microleakage. This in vitro **study evaluated the marginal adaptation of two approximal ceramic insert systems after cementation to the cavities opened with ultrasonic tips. Proximal cavities with margins in enamel were prepared in 20 intact molars using ultrasonic tips (SONICSYS approx tips [microtorpedo size #2 and #3]; Siplus Instrument approximal [U-shaped]). Inserts of similar sizes (n=10) from two systems corresponding to the ultrasonic tips were placed in the cavities (SONICSYS Inlay; SDS-Inlay system), one on the mesial side and the other on the distal side of the same molar. Following cementation and thermocycling (5000 cycles, between 5-55ºC), cement thickness was measured at the buccal, lingual walls and pulpal floors of the proximal boxes under light microscope (x150). The mean cement thickness values recorded for SONICSYS inserts #2 (25 µm) was not significantly different** ($p>0.05$) **from that of SDS inserts of similar size (26 µm). There was a significant difference** ($p<0.05$) **in cement thickness values between SONICSYS #3 inserts (34 µm) and SDS inserts of similar size (23 µm). Comparison of mean values between the ceramic insert systems examined revealed that marginal adaptation was better at the buccal and lingual proximal walls than those at the pulpal floor in the SDS system, however, there was no difference for SONICSYS at both sizes. Ceramic inserts placed in cavities prepared with ultrasonic tips provide clinically acceptable marginal quality.**

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INTRODUCTION

Progress has been made in the field of inlays through the introduction of minimal invasive techniques using ultrasonic tips and ceramic inserts whereby composite-resin filling polymerization shrinkage, wear and microleakage problems are avoided (Bowen, Eichmiller

& Marjenhoff, 1991). Shrinkage forces during polymerization are major problems that affect the marginal integrity of composite-resin fillings. If the amount of polymerizing material in composite restorations could be reduced, polymerization shrinkage would also decrease. Incorporating glass-ceramic inserts into composite restorations permits the inserts to serve as large megafiller particles within the restoration. These inserts can displace between 50-75% of the composite material in some restorations, thus reducing microleakage and postoperative sensitivity (Bowen, 1987; Donly & others, 1989).

Various inlay systems have been developed which offer improved marginal quality in the critical proximal areas using ultrasonic or oscillating movements (Federlin, Thonemann & Schmalz, 2000). Oscillating systems claim advantages such as the instruments being coated with diamond inlay burs on one side. This helps to guide the instrument along the adjacent tooth and prevent the risk of accidentally damaging the adjacent tooth, which is often the case with rotary instruments. Moreover, the coated side has a defined shape, that is, it is possible to prepare reproducible standard cavities.

This *in vitro* investigation evaluated the marginal adaptation of two approximal ceramic insert systems after cementation to the cavities opened with their corresponding ultrasonic tips.

METHODS AND MATERIALS

Proximal Class II slots with margins in enamel were prepared in 20 newly extracted intact molars stored in 0.01% Chloramine T prior to the experiment, using ultrasonic tips (SONICSYS approx tips, microtorpedo #2 and #3, [KaVo, Biberach, Germany]; Siplus Instrument approximal, U-shaped [Gebr Brasseler, Lemgo, Germany] and SDS-Inlay system [Schumacher Dental Systems, Rendsburg, Germany and SONICSYS Inlay System, Kavo, Biberach, Germany]) (Table 1). The primary cavities were opened in the traditional manner using fine diamond inlay burs (Intensiv, Grancia, Switzerland) with a high-speed hand piece utilizing water spray. After every eighth preparation, a new bur was used. The oscillating tips were then used to access and extend the proximal cavity form to the desired size and to bevel the margins.

The cavities were cleaned with water spray and dried with an air syringe. Thirty-seven percent phosphoric acid (Email Preparator GS, Ivoclar Vivadent, Schaan, Liechtenstein) was applied on enamel and dentin for 15 seconds. The cavities were then thoroughly rinsed with water for 15 seconds and gently air-dried. All cavity surfaces were first covered with Syntac Single Component (Ivoclar Vivadent) and left for 20 seconds. After excess was blown away, they were light cured for 20 seconds.

The inlay holders from both systems were used to remove the inserts from their dispensers. Each insert was fitted with an adapter. In the SDS system, a transparent silicone stamp with matching support was applied from the top after placing the insert that helped to minimize the voids and porosities in the luting composite resin. In order to reduce the possibility of contamination, so-called try-in inserts or measuring devices were used before final application.

Tetric Flow (Ivoclar Vivadent) was applied to the gingival and axial walls, covering two-thirds of the proximal box. Custom-fit inserts of similar sizes (n=10) from two systems corresponding to the ultrasonic tips were placed in the cavities, one on the mesial side and the other on the distal side of the same molar from the occlusal direction. Excess cement was removed from the margins, then light cured for 40 seconds from each direction. The occlusal cavity was restored with Tetric Ceram (Ivoclar Vivadent). It was light cured from three different directions with an Optilux 401 light-curing unit (Kerr Demetron, Orange, CA 92867, USA). The light output of the curing unit was tested to be 630 mW/cm^2 with a Cure Rite (Model 8000, EFOS Inc, ON LFN 6H7, Canada). The irradiation distance between the exit window and the resin surface was kept to a maximum of 10 mm in order to obtain adequate polymerization (Asmussen & Peutzfeldt, 1990; Loza-Herrero & others, 1998).

All the restorations were finished wet. Fine diamond burs were used to remove the excess cement. Proximal and occlusal surfaces were further finished with coarse, medium, fine and ultra-fine finishing disks (3M Dental Products, St Paul, MN 55144, USA).

Following cementation, each specimen was subjected to thermocycling (5000 cycles, between 5-55ºC, 30 seconds). Marginal adaptation was evaluated at the buccal, lingual walls and pulpal floor of the proximal boxes under light microscope (x150). The measurements were achieved using video digitizing (Camera TK-1070E, JVC, Tokyo, Japan) with a stereo microscope (Stemi SV11, Zeiss, Oberkochen, Germany) connected to a computer (Power Macintosh 8500, Apple Computer, Cupertino, CA 95014, USA).

The data obtained were statistically analyzed using analysis of variance, ANOVA, alpha=0.05. Significant differences were calculated utilizing the post hoc test of Bonferroni/Dunn (StatView 5.0, SAS Institute Inc, Cary, NC 27513, USA).

Table 1: *Cavity Preparation Systems and the Matching Ceramic Inserts*

Cavity Preparation Systems	Ceramic Inserts
SONICSYS approx tips (microtorpedo) (#2 and #3)	SONICSYS Inlay system (#2 and #3)
Siplus Instrument approximal (U-shaped)	SDS-Inlay system (#2 and #3)

RESULTS

The mean cement thickness value recorded for SONICSYS inserts #2 (25±16 µm) was not significantly different ($p>0.05$) from that of SDS inserts of similar size (26±17 µm). There was a significant difference ($p<0.05$) in overall cement thickness values between SONICSYS #3 proximal inserts (34±19 µm) and SDS inserts of similar size (23±14 µm).

In the SDS system, marginal gaps were significantly higher ($p<0.0001$) at pulpal floors for size #2 (34 µm) than those at the buccal (25 µm) and lingual walls (16 µm). Figures 1 and 2 show the cement thickness measurements of both systems and sizes.

After 20 specimens were cemented and thermocycled, most showed perfect margins, while only five showed marginal discrepancies and small irregularities (less than 50 µm) for SONICSYS inserts size #2 and one for SDS size #2 inserts. In cavities prepared for SDS inserts, one marginal microcrack for size #3 and four for SONICSYS size #3 were observed at different locations of the cavity walls (Figure 3).

DISCUSSION

Despite the improved characteristics of posterior composite resins, they still show relatively high polymerization shrinkage of 2.6 to 7.1%, low resistance to clinical wear and a high coefficient of thermal expansion (Feilzer, de Gee & Davidson, 1988; Burgoyne, Nicholls & Brudvik, 1991).

Numerous *in vitro* studies have demonstrated that disadvantages of composite restorations may be compensated for by using modern insert technology, however, this technique has received little attention (Yip & Samaranayake, 1998). Insert systems that use matching instruments for cavity preparation increase the custom-fit of inserts, and the composite volume can thus be further reduced, resulting in a better marginal adaptation (George, Richards & Eichmiller, 1995), which has been shown to be comparable with the marginal adaptation of direct ceramic inlays (Bowen & others, 1993). Principally, these prefabricated inlays are recommended for use in combination with highly viscous composites. This study measured the cement thickness between the inserts and the cavity walls at buccal, lingual and pulpal floor areas.

The marginal interface is said to be filled by a dual-cured composite resin-luting agent. However, in the long-term, this could be a serious drawback that promotes failure of the restoration due to dissolution, leakage, discoloration and excessive wear of the luting agent. Although an ideal range for the marginal gap of luting composite cements has not yet been reported, some authors (Leinderfeld, Isenberg & Essig, 1989; Van Meerbeek & others, 1992; Schmalz, Federlin & Reich, 1995) suggested that the maximum gap should not exceed 100 µm.

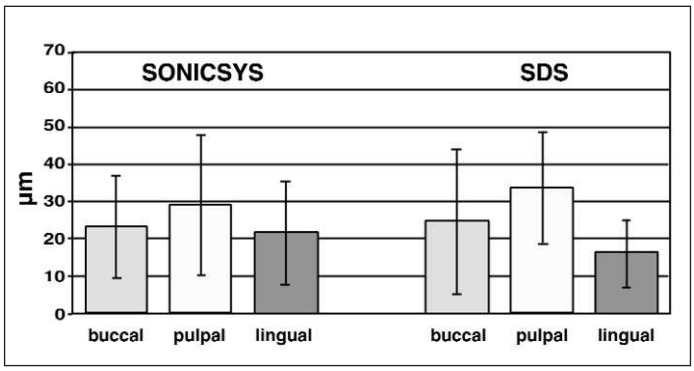

Figure 1. *Cement thickness measurements for SONICSYS approx tips/SONICSYS and Siplus tip/SDS (#2) insert combinations at buccal, lingual walls and pulpal floors.*

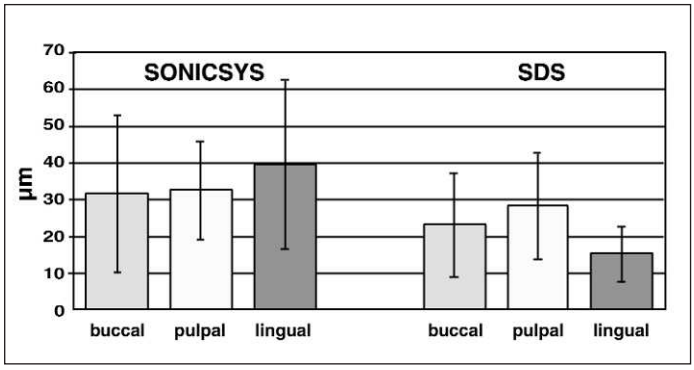

Figure 2. *Cement thickness measurements for SONICSYS approx tips/SONICSYS and Siplus tip/SDS (#3) insert combinations at buccal, lingual walls and pulpal floors.*

The overall mean marginal gap values obtained in this study did not exceed 40 µm for both insert systems and sizes. This study's findings were similar to those reported earlier (Hugo & others, 1996; Hahn & others, 1998) where comparable marginal adaptation with ceramic inserts and ceramic inlays was found when a highly viscous luting composite, a low-viscous luting composite or a polyacid-modified composite were used. The results obtained from this study demonstrate that almost identical cavities could be opened using oscillating systems. One conceivable explanation could be the beveling of the enamel with the ultrasonic tips.

The low number of preparation defects observed at the cavity margins was in accordance with those who reported 1-7% fractures of marginal tooth structure that occur with the oscillating preparation techniques compared to traditional rotating systems (Hugo & others, 1996; Krejci, Lutz & Krejci, 1995).

An interesting finding was that greater cement thickness was observed almost exclusively in the cervicoproximal or pulpal floor of restorations compared to those at the buccal and lingual cavity margins. It could be interpreted that the inserts did not completely fit the depth of the cavity. Although the ceramic inserts

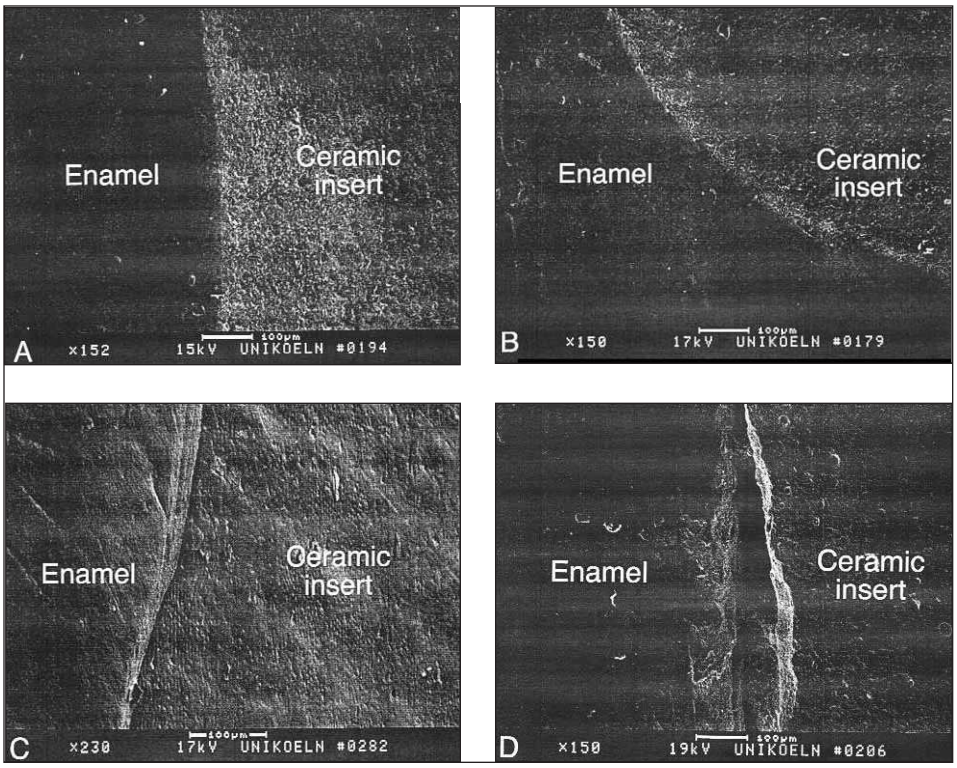

Figure 3. *Marginal quality at the ceramic insert-cavity interface after thermocycling (A=Perfect margin, B=Irregularities, C=Hairline gap, D=Gap, bottom visible).*

were prepared according to CAD/CAM technique, this needs to be improved since the pulpal floor is the critical area for microleakage (Bott & Hannig, 1995).

While ceramic inserts also facilitate good physiological contact area, higher gap values were mostly obtained in the regions where enamel was cracked. The individual mechanisms that produce these cracks occur during the use of conventional inlay burs, ultrasonic tips or they can result from polymerization shrinkage stress of the luting resin, which needs to be clarified.

In a three-year-follow up study (Sjögren & others, 2000), clinical performance of ceramic inserts was found to be inferior to ceramic or resin composite restorations. In other studies, the clinical performance of ceramic inserts was found to be promising (Odman, Nilsson & Pietruszka, 1998; Eberhard, Dörfer & Staehle, 1996) and are advised as an alternative to other tooth-colored materials. Once the insert has been placed, the remaining occlusal cavity is restored with a high-viscosity composite resin (Donly & others, 1989; Hugo & others, 1996). Normally, the major part of the cavity still contains composite resin with all its restrictions and disadvantages.

This study was carried out on sound teeth but it was anticipated that possible caries underneath the cervical region could not be removed by oscillating systems. The surfaces of the inserts were etched and silanized by the manufacturer but contamination with a finger led to dramatically reduced bond strengths and it was advised that the silane coating should be repeated at chairside (Frankenberger & others, 1998). For this reason, during experimental process, care was exercised not to touch the inner surfaces of the inserts.

The permanence of excellent marginal adaptation under the diverse masticatory, thermal and chemical influences is important. The oral environment determines the quality of the restoration and its clinical success. That is why the restorations included in this study were exposed to thermalcycling.

The use of these and other ultrasonic techniques in restorative treatment warrants extensive clinical trials, and their clinical limitations and longevity are yet to be determined prior to general use.

CONCLUSIONS

1. Comparison of the mean cement thickness values between the ceramic insert systems examined revealed that marginal adaptation was better at the buccal and lingual proximal walls than at the pulpal floor in SDS system in size #2, however, there was no difference for SONICSYS at both sizes.
2. Ceramic proximal inserts placed in the cavities prepared with ultrasonic tips provided clinically acceptable marginal quality.

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References

Asmussen E & Peutzfeldt A (1990) Mechanical properties of heat-treated restorative resins for use in the inlay/onlay technique *Scandinavian Journal of Dental Research* **98(6)** 564-567.

Bott B & Hannig M (1995) Optimizing Class II composite resin esthetic restorations by the use of ceramic inserts *Journal of Esthetic Dentistry* **7(3)** 110-117.

Bowen RL (1987) Reduction of microleakage around composite restorations *Journal of Dental Research* **66** 246 (Abstract #1117).

Bowen RL, Eichmiller FC & Marjenhoff WA (1991) Glass-ceramic inserts anticipated for "megafilled" composite restorations. Research moves into the office *Journal of the American Dental Association* **122(3)** 71-75.

Bowen RL, George LA, Eichmiller FC & Misra DN (1993) An esthetic glass-ceramic for use in composite restoration inserts *Dental Materials* **9(5)** 290-294.

Burgoyne AR, Nicholls IJ & Brudvik JS (1991) *In vitro* two-body wear of inlay-onlay composite resin restoratives *Journal of Prosthetic Dentistry* **65(2)** 206-214.

Donly KJ, Wild TW, Bowen RL & Jensen ME (1989) An *in vitro* investigation of the effects of glass inserts on the effective composite resin polymerization shrinkage *Journal of Dental Research* **68(8)** 1234-1237.

Eberhard J, Dörfer C & Staehle HJ (1996) Einfluss der Insert-Technik auf approximale Kontaktstärken bei Kompositrestaurationen *in vitro Deutsche Zahnärztliche Zeitschrift* **51** 184-187.

Federlin M, Thonemann B & Schmalz G (2000) Inserts-megafillers in composite restorations: A literature review *Clinical Oral Investigations* **4(1)** 1-8.

Feilzer AJ, de Gee AJ & Davidson CL (1988) Curing contraction of composites and glass ionomer cements *Journal of Prosthetic Dentistry* **59(3)** 297-300.

Frankenberger R, Sindel J, Krämer N & Pelka M (1998) Zur Komposithaftung von Glaskeramikinserts *Deutsche Zahnärztliche Zeitschrift* **53** 139-142.

George LA, Richards ND & Eichmiller FC (1995) Reduction of marginal gaps in composite restorations by use of glass-ceramic inserts *Operative Dentistry* **20(4)** 151-154.

Hahn P, Schaller HG, Mullner U & Hellwig E (1998) Marginal leakage in Class II-restorations after use of ceramic-inserts luted with different materials *Journal of Oral Rehabilitation* **25(8)** 567-574.

Hugo B, Stassinakis A, Hotz P & Klaiber B (1996) Die Entwicklung einer neuen Präparationsmethode zur defektbezogenen Erstversorgung approximaler kariöser Defekte *Deutsche Zahnärztliche Zeitschrift* **51** 518-523.

Krejci I, Lutz F & Krejci D (1995) Schall/Ultraschallbetriebene diamantierte Instrumente zur Kavitätenpräparation, zum Konturieren und zum Finieren *Zahnärztliche Welt* **104** 781-786.

Leinderfeld KF, Isenberg BP & Essig ME (1989) A new method for generating ceramic restorations: CAD-CAM system *Journal of the American Dental Association* **118(6)** 703-707.

Loza-Herrero MA, Rueggeberg FA, Caughman WF, Schuster GS, Lefebvre CA & Gardner FM (1998) Effect of heating delay on conversion and strength of a post-cured resin composite *Journal of Dental Research* **77(2)** 426-431.

Odman P, Nilsson E & Pietruszka K (1998) Cerena—a new method for the restoration of teeth with prefabricated ceramic inlays *Journal of Oral Rehabilitation* **25(5)** 340-347.

Schmalz G, Federlin M & Reich E (1995) Effect of dimension of luting space and luting composite on marginal adaptation of a Class II ceramic inlay *Journal of Prosthetic Dentistry* **73(4)** 392-399.

Sjögren G, Hedlund SO, Jonsson C & Sandstrom A (2000) A 3-year follow-up study of preformed beta-quartz glass-ceramic insert restorations *Quintessence International* **31(1)** 25-31.

Van Meerbeek B, Inokoshi S, Willems G, Noack MJ, Braem M, Lambrechts P, Roulet JF & Van Herle G (1992) Marginal adaptation of four tooth colored-inlay systems *in vivo* *Journal of Dentistry* **20(1)** 18-26.

Yip HK & Samaranayake LP (1998) Caries removal techniques and instrumentation: A review *Clinical Oral Investigations* **2(4)** 148-154.

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Effects of In-Office Tooth Whiteners on Hardness of Tooth-Colored Restoratives

AUJ Yap • P Wattanapayungkul

Clinical Relevance

The hardness of resin-modified glass ionomer cements, hybrid, polyacid-modified and PRG (pre-reacted glass ionomer) composites is not significantly affected by the use of in-office tooth whiteners employing the use of strong oxidizing agents.

SUMMARY

This study investigated the effects of in-office tooth whiteners on the hardness of hybrid (Spectrum TPH), polyacid-modified (Dyract AP), PRG (Reactmer) composites and a resin-modified glass ionomer cement (Fuji II LC). Twenty-seven specimens of each material were fabricated, randomly divided into three groups of nine and treated as follows—Group 1: stored in distilled water at 37°C for three weeks (control); Group 2: treated with 35% carbamide peroxide (Opalescence Quick) for 30 minutes/week for three weeks; Group 3: treated with 35% hydrogen peroxide power bleach (Opalescence Xtra) for 30 minutes/week for three weeks. For Groups 2 and 3, specimens were stored in distilled water at 37°C during the hiatus periods. The treated specimens were subsequently subjected to microhardness testing (load = 500gf; dwell time = 15 seconds). Results were analyzed using ANOVA/Scheffe's test ($p<0.05$). For all treatment groups, Spectrum was significantly harder than the other materials and Reactmer was significantly harder than Dyract and Fuji II LC. The effects of in-office tooth whiteners on microhardness were material-dependent. No significant difference in hardness was observed between treatment groups for Dyract and Reactmer. For Spectrum and Fuji II LC, specimens treated with Opalescence Quick were significantly harder than those treated with Opalescence Xtra. No significant difference in hardness was observed between the control and bleached groups for all materials. The hardness of resin-modified glass-ionomer cements, hybrid, polyacid-modified and PRG composites is therefore not significantly affected by the use of 35% carbamide peroxide and 35% hydrogen peroxide in-office tooth whiteners.

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INTRODUCTION

Bleaching was first used to whiten teeth in the late 1870s (Fasanaro, 1992). Bleaching techniques may be classified by whether they involve vital or non-vital teeth and by whether the procedure is performed in the office or has an at-home component. The use of bleaching for improving the aesthetics of natural dentition has widened only after the introduction of home bleaching systems in the 1990s (Haywood & Heymann, 1989). The latter created a resurgence of bleaching, primarily because of its relative ease of application, the lower cost, its general availability to all socio-economic classes of patients, the safety of the materials used and the high percentage of successful treatment (Haywood, 1992). With the home or mouthguard bleaching technique, patients apply bleaching solutions, most of which contain 10% carbamide peroxide, to their teeth in custom-fitted plastic stents for a few hours each day. Over the past few years, in-office tooth-whitening systems employing the use of strong oxidizing agents have been re-introduced. Advantages are that it is totally under the dentist's control, the soft-tissue is generally protected from the process and it has the potential for bleaching quickly in situations in which it is effective.

There may be Class III, IV and V tooth-colored restorations on the teeth to be bleached. Although there are several reports on the effects of home bleaching systems on hybrid composites (Cooley & Burger, 1991; Bailey & Swift, 1992; Cullen, Nelson & Sandrik, 1993; Nathoo, Chmielewski & Kirkup, 1994), little is known about the effects of in-office bleaching systems on resin-modified glass-ionomer cements, polyacid-modified composites and PRG composites. PRG composites or giomers are a new class of hybrid restorative materials that employ the use of pre-reacted glass ionomer (PRG) technology. Polyacid-modified composite resins or compomers are defined as materials that contain either or both of the essential components of a glass-ionomer cement but at levels insufficient to promote acid-base cure reaction in the dark (McLean, Nicholson & Wilson, 1994). Although PRG composites contain both of the essential components of glass ionomer cements, they cannot be classified as polyacid-modified composites as the fluoroalumino silicate glass is reacted with polyacrylic acid (that is, acid-base reaction has taken place) prior to inclusion into the urethane resin. Like hybrid and polyacid-modified composites, PRG composites are light polymerized and require the use of bonding systems for adhesion to enamel and dentin. The manufacturer's claims include fluoride release, fluoride recharge, biocompatibility, smooth surface finish, excellent aesthetics and clinical stability.

This study determined whether in-office tooth whiteners employing the use of strong oxidizing agents cause chemical softening of direct tooth colored-restoratives. The surface hardness of the different materials after treatment was also compared.

METHODS AND MATERIALS

The tooth-colored restoratives selected for this study included a hybrid composite (Spectrum TPH, Dentsply-De Trey, Konstanz, Germany), a polyacid-modified composite (Dyract AP, Dentsply-De Trey, Konstanz, Germany), a PRG composite (Reactmer, Shofu Inc, Kyoto, Japan) and a resin-modified glass-ionomer cement (Fuji II LC, Tokyo, Japan). All materials were of the A2 shade with the exception of Reactmer, where the lightest shade available (A3) was selected. The restorative materials were placed in the rectangular recesses (4 mm long x 3 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over this and pressure applied to extrude excess material. The restoratives were light polymerized according to manufacturers' cure times (Spectrum—20 seconds; Dyract—40 seconds; Reactmer—30 seconds; and Fuji II LC—20 seconds) through the glass slide with a PolyLUX II light-cure unit (KaVo Dental, Warthausen, Germany). The mean intensity of the light source (588±4 mW/cm^2) was determined with a radiometer (CureRite, EFOS Inc, Ontario Canada) prior to starting the experiment. Twenty-seven specimens of each material were fabricated and randomly divided into three groups of nine. Specimens in Group 1 were stored in distilled water at 37°C for three weeks (control). Group 2 specimens were treated with 35% carbamide peroxide (Opalescence Quick) for 30 minutes/week for three weeks and Group 3 specimens were treated with 35% hydrogen peroxide power bleach (Opalescence Xtra) for 30 minutes/week for three weeks. For Groups 2 and 3, the first bleaching treatment was conducted after seven days storage in distilled water at 37°C. Each 30 minute treatment session with Opalescence Xtra consisted of two 15 minute cycles of gel application with 20-second light exposure to enhance the action of peroxide. The bleaching gels were removed using a water jet and a standardized rinsing time of one minute. Storage medium was distilled water at 37°C during the hiatus periods.

The treated specimens were subjected to hardness testing using a digital microhardness tester (FM7, Future-Tech Corp, Tokyo, Japan). Specimens were placed centrally beneath the indenter and a 500g load was applied through the indenter for a dwell time of 15 seconds. The Knoop Hardness Number (KHN) corresponding to each indentation was computed by measuring the dimensions of the indentations and using the formula KHN = 1.451 x (F/d^2), where F is the test load in Newtons and d is the longer diagonal length of an indentation in millimeters. The advantage of hardness testing with the Knoop indenter compared to the Vickers indenter is the need for only one measurement

to derive the hardness number. All statistical analysis was conducted at a significance level of $p<0.05$. Two-way analysis of variance (ANOVA) was performed on hardness data with restorative materials and bleaching products as main effects. One-way ANOVA and Scheffe's post-hoc tests were also performed with materials and treatment groups as independent variables to determine the effects of the in-office bleaching systems and compare the hardness of the different materials, respectively.

RESULTS

Table 1 and Figure 1 show the mean KHN of the materials after various treatments. Results of statistical analysis are reflected in Table 2.

Two-way ANOVA of hardness data showed significant interaction between materials and treatments. The effect of in-office tooth whiteners on hardness were therefore material dependent. No significant difference in hardness was observed between treatment groups for Dyract and Reactmer. For Spectrum and Fuji II LC, specimens treated with Opalescence Quick were significantly harder than those treated with Opalescence Xtra. No significant difference in hardness was observed between the control and bleached groups for all materials. Ranking of hardness by materials was similar for all treatment groups and was as follows: Spectrum > Reactmer > Dyract > Fuji II LC. Spectrum was significantly harder than the other materials and Reactmer was significantly harder than Dyract and Fuji II LC.

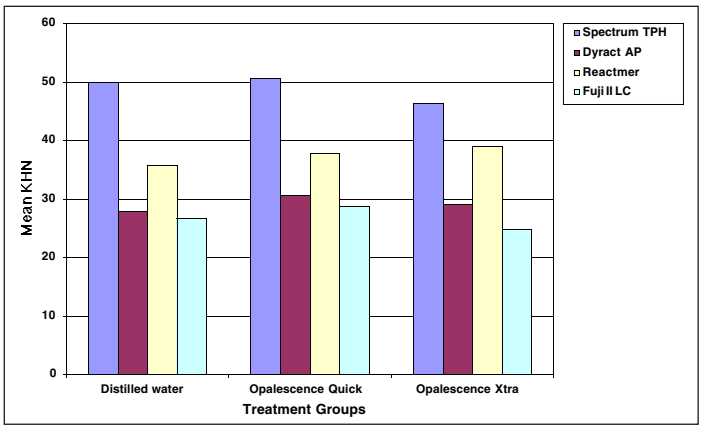

Figure 1. *Treatment groups.*

DISCUSSION

Hardness is defined as the resistance of a material to indentation or penetration (O'Brien, 1997). As hardness is related to a material's strength, proportional limit and its ability to abrade or to be abraded by opposing dental structures/materials (Anusavice, 1996), any chemical softening resulting from bleaching has implications on the clinical durability of restorations. The materials were exposed to bleaching agents after seven days to allow for post-irradiation hardening of the composites and maturation of the resin-modified glass-ionomer cement (Leung, Adishian & Johnston, 1985; Yap, 1997; Wan, Yap & Hastings, 1999). Clinically relevant bleaching regimens that followed manufacturer's recommendations were adopted for the current research. This was in contrast to several other bleaching studies in which materials were exposed continuously to bleaching products for several days to simulate cumulative effects over a time period (Monaghan, Lim & Lautenschlager, 1992; Cullen & others, 1993).

Opalescence Xtra is a premixed, syringe delivered 35% hydrogen peroxide power bleach containing carotene. The latter is a natural orange pigment found in carrots and other fruits and vegetables that can convert natural blue wavelength light of standard curing light to heat energy. Opalescence Quick is a highly viscous 35% carbamide peroxide "waiting room" whitener. It is applied to teeth using a custom-fitted, thin, scalloped tray. Carbamide peroxide degrades into approximately one-third hydrogen peroxide and two-thirds urea (Fasanaro, 1992), and hydrogen peroxide can be considered its active ingredient (Haywood, 1990). The hydrogen peroxide content in Opalescence Quick is therefore much lower than that in Opalescence Xtra. Hydrogen per-

Table 1: *Mean KHN of the Different Materials After Treatment*

Materials	Distilled Water	Opalescence Quick	Opalescence Xtra
Spectrum TPH	49.84 (1.26)	50.58 (2.63)	46.38 (4.86)
Dyract AP	27.79 (2.85)	30.66 (3.40)	29.13 (2.47)
Reactmer	35.69 (2.20)	37.74 (4.34)	38.98 (3.11)
Fuji II LC	26.61 (2.65)	28.80 (2.08)	24.83 (1.74)

Standard deviation in parenthesis.

Table 2: *Results of Statistical Analysis*

Variables		Significance Spectrum TPH
Materials	Spectrum TPH	Opalescence Quick > Opalescence Xtra
	Dyract AP	NS
	Reactmer	NS
	Fuji II LC	Opalescence Quick > Opalescence Xtra
Treatment Groups	Distilled water	Spectrum TPH > All other materials Reactmer > Dyract AP & Fuji II LC
	Opalescence Quick	Spectrum TPH > All other materials Reactmer > Dyract AP & Fuji II LC
	Opalescence Xtra	Spectrum TPH > All other materials Reactmer > Dyract AP & Fuji II LC

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

oxide can form several different active oxygen species depending on temperature, pH, light, co-catalysts, presence of transitional metals and other conditions (Feinman, Madray & Yarborough, 1991). For brief periods perhydroxyl free radicals are formed: $H_2O_2 \rightarrow HO_2$- + H+. The perhyroxyl free radical HO_2- is extremely reactive and has great oxidative power. It may break up large macromolecular stains into smaller stain molecules and by diffusion expel them to the surface. It is also thought to attach to the molecular stain in the inorganic structure as well as protein matrix (Fasanaro, 1992). The free radicals eventually combine to form molecular oxygen and water. Some aspect of this chemical process might accelerate the hydrolytic degradation of composites described by Söderholm & others (1984). Chemical softening of the restorative materials might also occur if the bleaching products have solubility parameters similar to that of the resin matrix. The Bisphenol A-glycidyl methacrylate (BisGMA) and urethane dimethacrylate (UDMA) resin polymers used in composites can be softened by chemicals with solubility parameters in the range of 1.82 x 10^4 to 2.97 x 10^4 $(J/m^3)^{1/2}$ (Wu & McKinney, 1982). As the bleaching agents and many of their components are not listed in the solvent tables of the *Polymer Handbook* (Brandup & Immergut, 1989), it is unclear whether they have solubility parameters similar to that of resins used in the various materials.

The hardness of composite resins exposed to home-use carbamide peroxide gels has been reported to increase (Cooley & Burger, 1991), decrease (Bailey & Swift, 1992) or be unchanged (Nathoo & others, 1994). Such wide variations in data suggest that some tooth-colored restorative materials may be more susceptible to alterations and some bleaching agents are more likely to cause those alterations (Swift & Perdigão, 1998). The latter may be attributed to the differences in pH between bleaching agents (Price, Sedarous & Hiltz, 2000). In this study, the effects of bleaching products on hardness were found to be material dependent. Although no significant difference in hardness was observed between treatment groups for Dyract and Reactmer, Spectrum and Fuji II LC specimens treated with Opalescence Quick were significantly harder than those treated with Opalescence Xtra. This was caused by a slight increase in hardness after treatment with Opalescence Quick and a slight softening of the materials after treatment with Opalescence Xtra. As the active ingredient for both bleaching gels is the same, it is likely that the aforementioned observation is caused by differences in gel formulation of which the presence of carotene in Opalescence Xtra is the most obvious. The exact mechanism is, however, not known and warrants further investigation.

No significant difference in hardness was observed between the control and bleached groups for all materials. Therefore, the use of in-office whiteners employing strong oxidizing agents does not cause significant chemical softening of direct tooth-colored restoratives. Both in-office and home-use bleaching products should, however, not be used indiscriminately when tooth-colored restorations are present. Bleaching agents can create visually perceptible color changes (Monaghan, Trowbridge & Lautenschlager, 1992), increase surface roughness (Cooley & Burger, 1991; Bailey & Swift, 1992) and affect adherence of certain cariogenic microorganisms to the outer surface (Mor & others, 1998) of tooth-colored restorative materials. In addition, they have been shown to reduce enamel shear bond strength (McGockin, Thurmond & Osovitz, 1992; Sung & others, 1999) and increase microleakage at gingival margins of Class V composite restorations (Crim, 1992). Patients should be informed that bleaching may accelerate the natural "aging" process of tooth-colored restoratives and must also realize that restorations might need to be replaced to ensure proper shade matching if bleaching is successful. For all treatment groups, the composite resin was significantly harder than the other hybrid materials. This was in agreement with other studies comparing the physico-mechanical properties of tooth-colored materials (Gladys & others, 1997; Berg 1998). The PRG composite was significantly harder than the polyacid-modified composite and resin-modified glass-ionomer cement.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The effects of in-office tooth whiteners on hardness were material dependent.
2. For Dyract AP and Reactmer, no significant difference in hardness was observed among all groups.
3. For Spectrum TPH and Fuji II LC, specimens treated with Opalescence Quick were significantly harder than those treated with Opalescence Xtra.
4. No significant difference in hardness was observed between the control and bleached groups for all materials.
5. For all groups, Spectrum TPH was significant harder than the other materials and Reactmer was significantly harder than Dyract AP and Fuji II LC.

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References

Anusavice KL (1996) Mechanical properties of dental materials in *Phillip's Science of Dental Materials* 10th edition Philadelphia WB Saunders Co p 69.

Bailey SJ & Swift EJ (1992) Effects of home bleaching products on composite resin *Quintessence International* **23(7)** 489-494.

Berg JH (1998) The continuum of restorative materials in pediatric dentistry—a review for the clinician *Pediatric Dentistry* **20(2)** 93-100

Brandup J & Immergut EH (1989) *Polymer Handbook* 3rd edition New York John Wiley & Sons pp 519-559.

Cooley RL & Burger KM (1991) Effect of carbamide peroxide on composite resins *Quintessence International* **22(10)** 817-821.

Crim GA (1992) Post-operative bleaching: Effect on microleakage *American Journal of Dentistry* **5(2)** 109-112.

Cullen DR, Nelson JA & Sandrik JL (1993) Peroxide bleaching effect on tensile strength of composite resins *Journal of Prosthetic Dentistry* **69(3)** 247-249.

Fasanaro TS (1992) Bleaching teeth: History, chemicals and methods used for common tooth discolorations *Journal of Esthetic Dentistry* **4(3)** 71-78.

Feinman RA, Madray G & Yarborough D (1991) Chemical, optical and physiologic mechanisms of bleaching products: A review *Practical Periodontics and Aesthetic Dentistry* **3(2)** 32-37.

Gladys S, Van Meerbeek B, Braem M, Lambrechts P & Vanherle G (1997) Comparative physico-mechanical characterization of new hybrid restorative materials with conventional glass-ionomer and resin composite restorative materials *Journal of Dental Research* **76(4)** 883-894.

Haywood VB (1990) Nightguard vital bleaching: Current information and research *Esthetic Dentistry Update* **1(2)** 7-12.

Haywood VB (1992) History, safety and effectiveness of current bleaching techniques and applications of the nightguard vital bleaching technique *Quintessence International* **23(7)** 471-488.

Haywood VB & Heymann HO (1989) Nightguard vital bleaching *Quintessence International* **20(3)** 173-176.

Leung RL, Adishian SR & Johnston WM (1985) Post-irradation hardening of visible light activated composite resin *Journal of Prosthetic Dentistry* **54(5)** 645-9.

McGockin RS, Thurmond BA & Osovitz S (1992) Enamel shear bond strengths after vital bleaching *American Journal of Dentistry* **5(4)** 216-222.

McLean JW, Nicholson JW & Wilson AD (1994) Proposed nomenclature for glass ionomer cements and related materials *Quintessence International* **25(9)** 587-589.

Monaghan P, Lim E & Lautenschlager E (1992) Effects of home bleaching preparations on composite resin color *Journal of Prosthetic Dentistry* **68(4)** 575-578.

Monaghan P, Trowbridge T & Lautenschlager E (1992) Composite resin color change after vital tooth bleaching *Journal of Prosthetic Dentistry* **67(6)** 778-781.

Mor C, Steinberg D, Dogan H & Rotstein I (1998) Bacterial adherence to bleached surfaces of composite resin *in vitro Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **86(5)** 582-586.

Nathoo SA, Chmielewski MB & Kirkup RE (1994) Effects of Colgate platinum professional tooth whitening system on microhardness of enamel, dentin and composite resins *Compendium of Continuing Dental Education* **Supplement 17** S627-630.

O'Brien WJ (1997) Physical properties in *Dental Materials and Their Selection* 2nd edition Illinois Quintessence Publishing Co p18.

Price RBT, Sedarous M & Hiltz GS (2000) The pH of tooth-whitening products *Journal of the Canadian Dental Association* **66(8)** 421-426.

Söderholm KJ, Zigan M, Ragan M, Fischlschweiger W & Bergman M (1984) Hydrolytic degradation of dental composites *Journal of Dental Research* **63(10)** 1248-1254.

Sung EC, Chan SM, Mito R & Caputo AA (1999) Effect of carbamide peroxide bleaching on the shear bond strength of composite to dental bonding agent enhanced enamel *Journal of Prosthetic Dentistry* **82(5)** 595-599.

Swift JE & Perdigão J (1998) Effects of bleaching on teeth and restorations *Compendium* **19(8)** 815-820.

Wan ACA, Yap AUJ & Hastings GW (1999) Acid-base complex reactions in resin-modified and hybridglass ionomer cements *Journal of Biomedical Materials Research* (*Applied Biomaterials*) **48(5)** 700-704.

Wu W & McKinney JE (1982) Influence of chemicals on wear of dental composites *Journal of Dental Research* **61(10)** 1180-1183.

Yap AUJ (1997) Post-irradation hardness of resin-modified glass ionomer cements and a polyacid-modified composite *Journal of Materials Science Materials in Medicine* **8** 413-416.

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Influence of ZOE Temporary Restorations on Microleakage in Composite Restorations

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Clinical Relevance

The influence of ZOE temporary restorations on microleakage in composite restorations is dependent on the powder:liquid ratio of the cement.

SUMMARY

This study investigated the influence of zinc-oxide eugenol (ZOE) temporary restorations on microleakage in composite restorations. Class V cavities were prepared on the buccal surfaces of 32 freshly extracted, non-carious human premolars. The teeth were randomly divided into four groups of eight teeth. Specimens in Group 1 (control) received no temporary restoration. Group 2 and 3 specimens were covered with IRM (Type III ZOE cement) mixed at powder:liquid (P:L) ratio of 10g: 1g and 10g: 2g, respectively. Specimens in Group 4 were covered with polycarboxylate cement (eugenol-free) mixed at a P:L ratio of 2.85g:1g. The temporary restorations were removed mechanically with an ultrasonic scaler after one week storage in distilled water at 37ºC. The preparations were washed and restored with Scotchbond Multi-Purpose Plus and Z100 according to manufacturers' instructions. The restorations were finished, thermally stressed for 400 cycles and subjected to dye penetration testing. Results were analyzed using Kruskal-Wallis and Mann-Whitney tests at a significance level of 0.05. At both enamel and dentin margins, the microleakage associated with Group 3 was significantly greater than for Groups 1, 2 and 4. For Groups 1 and 4, leakage at the dentin margins was significantly greater than in enamel margins. For the groups pre-treated with IRM, no significant difference in dye penetration scores was observed between enamel and dentin. Pre-treatment with IRM mixed at a P:L ratio of 10g: 2g significantly increased microleakage and is not recommended clinically.

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INTRODUCTION

The various formulations of zinc oxide eugenol (ZOE) cement are reflected in ADA specification No 30. Type I cement is used for temporary cementation. Type II is intended for permanent cementation of restorations or

appliances fabricated outside the mouth. Type III cement is used for temporary restorations or thermal insulating bases, while Type IV cement is used as a cavity liner. ZOE cements also serve as root canal sealers, surgical dressings and impression materials. They have a sedative effect on teeth, are inexpensive, easily removed and can provide an excellent seal against leakage (Anusavice, 1996).

Studies have shown that the physical properties of composite resins are adversely affected by eugenol (Reisbick & Brodsky 1971; Civjan, Huget & Simon, 1973). Eugenol increases the surface roughness and discoloration of composites, and inhibits composite polymerization (Grajower, Hirschfeld & Zalkind, 1974; Lingard, Davies & von Fraunhofer, 1981; Taira & others, 1992). Eugenol released from ZOE mixtures has been shown to penetrate dentin (Hume, 1984; Meryon, Johnson & Smith, 1988; Kielbassa, Attin & Hellwig, 1997). Although the bond strength of composites to enamel is not affected by eugenol (Jung, Ganss & Senger, 1998), contradictory findings exist with regard to bond strength to dentin. While earlier research has found that pre-treatment with ZOE cements reduced bond strength of composites to dentin (Xie, Powers & McGuckin, 1993; Terata & others, 1994), later research has found otherwise (Ganss & Jung, 1998; Kelsey, Latta & Blankenau, 1998). It has been hypothesized that current dentin-bonding systems are effective in removing any residual cement (Terata, 1993) and eugenol-contaminated dentin, and are consequently insensitive to pre-treatment with ZOE cements.

Although the bond strength of composites to enamel/dentin may not be significantly affected, ZOE cements may change other clinically important characteristics, such as microleakage. Woody & Davis (1992) compared the microleakage among groups of resin-luted inlays when the cavity preparations were pre-treated with Type I ZOE cement, a eugenol-free cement or no temporary cement. No significant difference in leakage was demonstrated between groups treated with eugenol-containing and eugenol-free temporary cements. Studies related to the influence of Type III ZOE cements (ZOE temporary restorations) on microleakage in composite restorations are limited. ZOE temporary restorations may be required due to the lapse of clinical time, intermediate restoration of multiple carious teeth and use of indirect pulp capping procedures. As clinical usage of composite resins for the restoration of posterior teeth has increased substantially, it is important to determine the influence of ZOE temporary restorations on microleakage in composite restorations.

This investigation compared microleakage in Class V composite restorations following pre-treatment with ZOE temporary restorations of different powder: liquid ratios and a eugenol-free temporary restoration. Specimens that received no temporary restoration were used as control. For each treatment group, the difference between enamel and dentin microleakage was also compared.

METHODS AND MATERIALS

Table 1 lists the materials used and their manufacturers. Thirty-two freshly extracted, non-carious human premolars were selected for the study. Class V cavities (mesiodistal width of 3 mm, occlusogingival height of 2 mm and a depth of 2 mm) were prepared on the buccal surface of each tooth using a high-speed diamond bur (HS1411; Shofu, Tokyo, Japan) with water coolant. The occlusal margins of the preparations were in enamel and the gingival margins were in dentin. The enamel margins were bevelled with a carbide bur (HS7901; Shofu, Tokyo, Japan). The teeth were washed and randomly divided into four groups of eight teeth. The specimens in Group 1 (control) received no temporary restoration. Group 2 specimens were covered with IRM (Type III ZOE cement) mixed at manufacturer's recommended powder: liquid (P:L) ratio of 10g: 1g (one scoop of powder: one drop of liquid). Specimens in Group 3 were also covered with IRM but at a lower P:L ratio of 10g: 2g (one scoop of powder: two drops of liquid). Group 4 specimens were covered with zinc polycarboxylate cement (eugenol-free) mixed at a P:L of 2.85g: 1g (one scoop of powder: two drops of liquid). All temporarily restored specimens were then stored in distilled water at 37ºC for one week.

After the one-week incubation time, the temporary materials were mechanically removed with an ultrasonic scaler until the preparations were macroscopically free of material. The preparations were then washed and treated with the Scotchbond Multi-Purpose Plus System (SBMP) (3M Dental Products, St Paul, MN 55144, USA). The preparations were etched with 37% phosphoric acid gel for 15 seconds, rinsed for 15 seconds and blotted dry. SBMP primer was placed for five seconds and dried. A thin layer of SBMP adhesive was placed and light-cured for 10 seconds using a PolyLux II light-curing unit (KaVo Dental, Warthausen, Germany). A

Table 1: *Materials Used and Their Manufacturers*

Material	Manufacturer	Batch #
Intermediate Restorative Material (IRM)	Dentsply-Caulk, Milford, DE 19963	000614
Hy-Bond Polycarboxylate Cement	Shofu Inc, Kyoto, Japan	9903
Scotchbond Multi-Purpose Plus	3M Dental Products, St Paul, MN 55144	19980121
Z100 (A2 shade)	3M Dental Products, St Paul, MN 55144	19980106

mini-filled composite resin (Z100; 3M Dental Products) was placed in one increment, bulk-polymerized and immediately finished with a diamond finishing bur (Two Striper 285MF3; Premier Dental Products, Norristown, PA 19404, USA) and a series of Sof-Lex discs (3M Dental Products). Ten strokes of each series of disc (coarse, medium, fine and super-fine) were used. Finishing was done in only one direction with a low-speed handpiece at 25,000 rpm without water spray.

The restorations were subsequently thermally stressed for 400 cycles with an exposure time of two seconds at 5ºC and 65°C and a dwell time of 10 seconds in a resting bath of 34°C. In preparation for dye penetration testing, the teeth were sealed with utility wax at the apex of the roots and two coats of varnish, leaving the restorations and 1 mm beyond the margins exposed to dye. The restorations were then placed in 0.5% aqueous basic fuchsin dye for 24 hours at 37ºC. After removal from the dye solution, the teeth were cleaned and sectioned longitudinally through the restorations in a bucco-palatal/lingual plane with a diamond-sectioning instrument (Microslice II: Cambridge Instruments Ltd, Cambridge, UK).

The sectioned restorations were examined for microleakage using VM stereomicroscope (Olympus, Tokyo, Japan) at X40 magnification. Microleakage at the enamel/dentin and restoration interfaces was scored using an ordinal scale where 0 = no evidence of dye penetration; 1 = dye penetration to less than half the cavity depth; 2 = dye penetration to the full cavity depth and 3 = dye penetration to the axial wall and beyond. As each tooth was sectioned into two, the section with the greater dye penetration was scored. Two evaluators independently scored the specimens and any discrepancies were discussed. If an agreement could not be reached, a third-party opinion was sought. Microleakage data was subjected to statistical analysis using Kruskal-Wallis and Mann-Whitney tests at a significance level of 0.05.

RESULTS

The distribution of dye penetration scores at the enamel-restoration and dentin-restoration interfaces is shown in Table 2. Results of statistical analysis are shown in

Table 2: *Frequency Distribution of Dye Penetration Scores*

Treatment	Enamel Margin				Dentin Margin			
	0	1	2	3	0	1	2	3
Group 1 (Control)	4	4	0	0	0	4	0	4
Group 2 (IRM 10g: 1g)	1	5	0	2	0	3	1	4
Group 3 (IRM 10g: 2g)	0	1	1	6	0	0	0	8
Group 4 (Polycarboxylate 2.85g :1g)	1	7	0	0	0	5	0	3

Table 3: *Results of Statistical Analysis*

Comparison Between Treatment Groups	
Enamel margins	Group 3 > Groups 1, 2 and 4
Dentin margins	Group 3 > Groups 1, 2 and 4
Comparison Between Dentin and Enamel Microleakage	
Group 1	Dentin > enamel
Group 2	NS
Group 3	NS
Group 4	Dentin > enamel

> indicates statistically significant difference in leakage scores (results of Kruskal-Wallis and/or Mann-Whitney test at significance level 0.05). NS indicates no statistically significant differences.

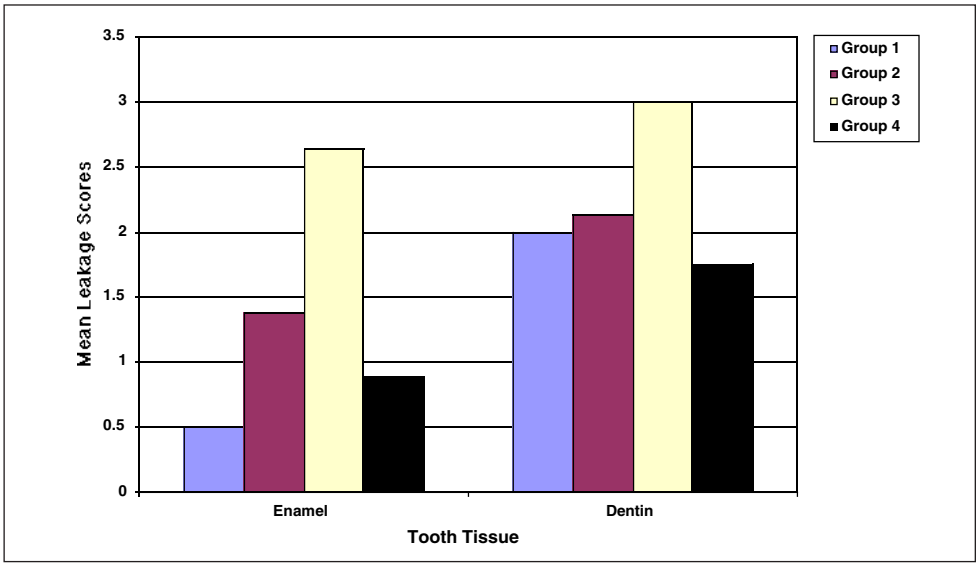

Figure 1. *Mean leakage scores for the various treatment groups.*

Table 3. The mean leakage scores for the various treatment groups are reflected in Figure 1. Ranking of mean leakage scores at the enamel margins was Group 1 < Group 4 < Group 2 < Group 3. Ranking of mean leakage scores at the dentin margin was Group 4 < Group 1 < Group 2 < Group 3. At both enamel and dentin margins, the microleakage associated with Group 3 was significantly greater than for Groups 1, 2 and 4. For the control group (Group 1) and Group 4, leakage at the dentin margins was significantly greater than in enamel margins. For the groups pre-treated with ZOE temporary restorations, no significant difference in dye penetration scores was observed between enamel and dentin.

DISCUSSION

Microleakage is the term used for the penetration of oral fluids, bacteria, toxins, soluble ions and molecules into the interface between the prepared cavity wall and the restoration. The effects of bacterial leakage upon the dental pulp have been well documented (Brännström, 1987). In addition, bacteria by-products may demineralize the enamel and dentin walls of the cavity adjacent to the restoration and lead to secondary caries (Kidd, 1981). Microleakage also results in marginal discoloration leading to an unaesthetic restoration. Prevention of microleakage along the margins of restorations is therefore a high priority.

The polymerization reaction of composite resins and resin bonding systems takes place by free-radical addition polymerization. As with other phenolic compounds, eugenol is a free-radical scavenger that inhibits the polymerization of resin materials (Taira & others, 1992). Eugenol release and diffusion through dentin has been observed from all ZOE mixtures (Kielbassa & others, 1997). Hume (1988) found a concentration of eugenol in the aqueous phase in the order of 10^{-2} M just beneath the ZOE cement and 10^{-4} M adjacent to the pulp. The diffusion rate of eugenol was highest at one day and decreased rapidly after one week (Hume, 1988). A one-week pre-treatment time with temporary restorations was thus selected. The composite resins were placed in one increment to minimize variables associated with the incremental technique. The bulk-pack technique also results in higher shrinkage during setting, creating wider marginal gaps with greater microleakage (Jörgensen & Hisamitsu, 1984), giving a worst-case scenario. The thermal-cycling regimen used was that recommended by Longman & Pearson (1987) based on a clinical study on the variations in tooth surface temperature in the oral cavity during fluid intake. This thermal-cycling regimen provides greater thermal stresses than does one with a longer dwell time at temperature extremes. At temperature extremes, there will be differential thermal expansion at the different sites within the restorations, depending on the thermal diffusivity of the material. This variation in expansion is likely to stress the material and increase microleakage (Yap, Lim & Neo, 1995).

Peutzfeldt & Asmussen (1999) found that temporary filling of dentin cavities with IRM did not influence wall-to-wall composite contraction. Their findings were in contrast to that of Hansen & Asmussen (1987), who found markedly increased contractions gaps in dentin pre-treated with ZOE filling materials. The difference in findings may be attributed to the "total-etch" technique employed by the newer types of dentin-bonding systems. EDTA used in older bonding systems can only demineralize dentin to a depth of approximately 5 µm, while the total-etch systems used today will demineralize 10-15 µm (Erickson, 1989; Uno & Finger, 1996). The results of the current study are in agreement with that of Peutzfeldt & Asmussen (1999). IRM mixed at manufacturer's recommended P:L ratio of 10g: 1g did not influence microleakage at both enamel and dentin margins as there was no significant difference in leakage scores between this and the control group. Acid etching with 37% phosphoric acid employed by SBMP was therefore effective in removing any residual cement and eugenol-contaminated dentin. There was also no significant difference in enamel and dentin leakage scores between specimens treated with IRM mixed at 10g: 1g and polycarboxylate cement. It is, however, difficult to manipulate and place IRM mixed at a P:L ratio of 10g: 1g. A lower P:L ratio is more commonly employed clinically. Pre-treatment with IRM mixed at a P:L ratio of 10g: 2g resulted in significantly more enamel and dentin leakage than the other treatment groups. Wetter ZOE mixtures have been shown to have significantly higher eugenol diffusion rates (Kielbassa & others, 1997). The greater amount and possible deeper penetration of eugenol associated with the aforementioned group (Group 3) may inhibit polymerization of the bonding system resulting in bond failure and microleakage. The central issue is thus not the use of ZOE temporary cements but the P:L ratio of ZOE cement used.

For the control group and the group pre-treated with polycarboxylate cement, leakage at the dentin margins was significantly greater than in the enamel margins. There was little or no observable microleakage at the enamel margins of these groups, proving the effectiveness of the acid-etch technique. A secure seal to dentin was not achieved with certainty as was found in previous microleakage studies (Yap & others, 1995; Yap, Stokes & Pearson, 1996). No significant difference in leakage was, however, observed between enamel and dentin for both IRM pre-treated groups. The effectiveness of the acid-etch technique in sealing enamel margins was therefore compromised by pre-treatment with IRM temporary restorations especially when mixed in P:L ratio of 10g: 2g. Although the results obtained from

this study may not be directly extrapolated to the clinical situation, they provide some information with regard to the performance of composite resins where there is prior placement of ZOE temporary restorations.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

1. Temporary restorations made with IRM mixed at a P:L ratio of 10g: 1g or polycarboxylate cement did not affect the microleakage of composite restorations.
2. Temporary restorations made with IRM mixed at a P:L ratio of 10g: 2g significantly increased microleakage and is not recommended clinically.
3. For the control group and the group pre-treated with polycarboxylate cement, microleakage at the dentin margins was significantly greater than in enamel margins.
4. For the groups pre-treated with IRM, no significant difference in microleakage was observed between enamel and dentin.

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References

Anusavice KJ (1996) Dental cement for restorations and pulp protection in *Phillips' Science of Dental Materials* 10th edition Philadelphia WB Saunders pp 543-545.

Brännström M (1987) Infection beneath composite resin restorations: Can it be avoided? *Operative Dentistry* **12(4)** 158-163.

Civjan S, Huget EF & Simon LB (1973) Compatibility of resin composites with varnishes, liners and bases *Journal of Dental Research* **52** 65 (Abstract #27).

Erickson RL (1989) Mechanism and clinical implications of bond formation for two dentin-bonding agents *American Journal of Dentistry* **2** 117-123.

Ganss C & Jung M (1998) Effect of eugenol-containing temporary cements on bond strength of composite to dentin *Operative Dentistry* **23(2)** 55-62.

Grajower R, Hirschfeld Z & Zalkind M (1974) Compatibility of a composite resin with pulp insulating materials. A scanning electron microscope study *Journal of Prosthetic Dentistry* **32(1)** 70-77.

Hansen EK & Asmussen E (1987) Influence of temporary filling materials on effect of dentin-bonding agents *Scandinavian Journal of Dental Research* **95(6)** 516-520.

Hume WR (1984) An analysis of the release and the diffusion through dentin of eugenol from zinc oxide-eugenol mixtures *Journal of Dental Research* **63(6)** 881-884.

Hume WR (1988) *In vitro* studies on the local pharmacodynamics, pharmacology and toxicology of eugenol and zinc oxide-eugenol *International Endodontic Journal* **21(2)** 130-134.

Jörgensen KD & Hisamitsu H (1984) Class II composite restorations: Prevention *in vitro* of contraction gaps *Journal of Dental Research* **63(2)** 141-145.

Jung M, Ganss C & Senger S (1998) Effect of eugenol-containing temporary cements on bond strength of composite to enamel *Operative Dentistry* **23(2)** 63-68.

Kelsey WP, Latta MA & Blankenau RJ (1998) Effect of provision restorations on dentin bond strengths of resin cements *American Journal of Dentistry* **11** 67-70.

Kidd EA (1981) Secondary caries *Dental Update* **8(4)** 253-260.

Kielbassa AM, Attin T & Hellwig E (1997) Diffusion behavior of eugenol from zinc oxide-eugenol mixtures through human and bovine dentin *in vitro Operative Dentistry* **22(1)** 15-20.

Lingard GL, Davies EH & von Fraunhofer JA (1981) The interaction between lining materials and composite resin restorative materials *Journal of Oral Rehabilitation* **8(2)** 121-129.

Longman CM & Pearson GJ (1987) Variations in tooth surface temperature in the oral cavity during fluid intake *Biomaterials* **8(5)** 411-414.

Meryon SD, Johnson SG & Smith AJ (1988) Eugenol release and the cytotoxity of different zinc oxide-eugenol combinations *Journal of Dentistry* **16(2)** 66-70.

Peutzfeldt A & Asmussen E (1999) Influence of eugenol-containing temporary cement on efficacy of dentin-bonding systems *European Journal of Oral Science* **107(1)** 65-69.

Reisbick MH & Brodsky JF (1971) Strength parameters of composite resins *Journal of Prosthetic Dentistry* **26(2)** 178-185.

Taira J, Ikemoto T, Yoneya T, Hagi A, Murakami A & Makino K (1992) Essential oil phenyl propanoids. Useful as OH scavengers? *Free Radical Research Community* **16(3)** 197-204.

Terata R (1993) Characterization of enamel and dentin surfaces after removal of temporary cement—Study on removal of temporary cement *Dental Materials* **12(1)** 18-28.

Terata R, Nakashima K, Obara M & Kubota M (1994) Characterization of enamel and dentin surfaces after removal of temporary cement – effect of temporary cement on tensile bond strength of resin luting cement *Dental Materials Journal* **13(2)** 148-154.

Uno S & Finger WJ (1996) Effects of acidic conditioners on dentin demineralization and dimension of hybrid layers *Journal of Dentistry* **24(3)** 211-216.

Woody TL & Davis RD (1992) The effect of eugenol-containing and eugenol-free temporary cements on microleakage in resin bonded restorations *Operative Dentistry* **17(5)** 175-180.

Xie J, Powers JM & McGuckin RS (1993) *In vitro* bond strength of two adhesives to enamel and dentin under normal and contaminated conditions *Dental Materials* **9(5)** 295-299.

Yap AUJ, Lim CC & Neo JCL (1995) Marginal sealing ability of three cervical restorative systems *Quintessence International* **26(11)** 817-820.

Yap AUJ, Stokes AN & Pearson GJ (1996) An *in vitro* microleakage study of a new multi-purpose dental adhesive system *Journal of Oral Rehabilitation* **23(5)** 302-308.

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Effects of Cyclic Temperature Changes on Water Sorption and Solubility of Composite Restoratives

AUJ Yap • KEC Wee

Clinical Relevance

Cyclic temperature changes increase the water sorption of some composites but do not influence composite solubility. Although water sorption allows for some degree of relaxation of polymerization stresses, it may result in staining, breakage in margin contours and decreased mechanical properties. Cyclic temperature changes may therefore compromise the longevity of some composite restorations.

SUMMARY

This study investigated the effects of cyclic temperature changes on the water sorption and solubility of four commercial composite resins (Silux Plus, Z100, Ariston pHc and Surefil). The methodology was based upon ISO 4049 procedures with modifications for specimen dimension and thermal-cycling. Eighteen disc specimens (10 ± 1 mm diameter and 1 ± 0.1 mm thick) were made for each composite and randomly divided into three groups. The specimens were stored in a desiccator maintained at 35 ± 1°C until a constant mass was achieved and treated as follows: Group 1—stored in distilled water at 35ºC for 178 hrs; Group 2—stored in distilled water at 35ºC for 173 hours and subjected to five hours of thermal-cycling with an upper temperature of 45ºC; and Group 3—stored in distilled water at 35ºC for 173 hours and subjected to five hours of thermal-cycling with an upper temperature of 60ºC. Mass after treatment was measured and specimens were re-conditioned to constant mass. The volume of the specimens was obtained and water sorption/solubility calculated. Data was analyzed using factorial ANOVA/Scheffe's post-hoc test at significance level 0.05. The effects of thermal-cycling on water sorption was material dependent. Thermal-cycling at an upper temperature of 60ºC significantly increased water sorption of Silux Plus. A significant increase in water sorption was also observed when Z100 was thermal-cycled at an upper temperature of 45ºC. The water sorption of Ariston pHc and Surefil was not affected by thermal-cycling. Thermal-cycling did not affect the solubility of all composites. For all treatment groups, Surefil had significantly lower water sorption than the other composites evaluated. The water sorption of Z100 and Surefil was significantly lower than Silux Plus and Ariston pHc.

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INTRODUCTION

Composites may be defined as three-dimensional combinations of at least two chemically different materials with a distinct interface (Phillips, 1981). Dental composites are essentially comprised of a resin matrix (organic phase), inorganic filler particles (dispersed phase), filler-matrix coupling agent (interface) and minor additions including polymerization initiators, stabilizers and coloring pigments. An inherent disadvantage of composites, including polyacid-modified composites, is that they undergo shrinkage during polymerization (Yap & others, 2000; Sakaguchi, Douglas & Peters, 1992). The initial rapid polymerization results in significant stresses that may be sufficient to disrupt the seal between the material and the structures to which it is bonded (Feilzer, de Gee & Davidson, 1987; Bausch & others, 1982). The clinical effects of shrinkage can be minimized by incremental placement, multiple site light activation, application of liners and slow, low intensity light activation (Davidson & Feilzer, 1997; Kemp-Scholte & Davidson, 1990; Krejci, Sperr & Lutz, 1987; Hansen, 1986).

Composite restoratives are not stable after polymerization and constantly interact with their environment. The principle interaction occurs with water which diffuses into the matrix causing two opposing phenomena. In some composites, water will leach out free, unreacted monomers and ions (Ferracane, 1994). Elution of leachable components contributes to further shrinkage and loss in weight of the material. Conversely, hygroscopic absorption of water leads to a swelling of the material and an increase in weight. This phenomenon may allow for some degree of relaxation of polymerization stresses and reduce marginal gaps (Thonemann & others, 1997; Carvalho & others, 1996). It may also result in staining, breakage in margin contours and decreased mechanical properties (Yap, Low & Ong, 2000; Indrani & others, 1995; Øysæd & Ruyter, 1986a). Although the effects of thermal-cycling on tracer penetration, marginal gap and bond strength tests of composites has been widely investigated, studies on its effects on water sorption and solubility are limited. After assessing the reports describing temperature changes of teeth *in vivo* and an analysis of 130 *in vitro* studies involving thermal-cycling of teeth, a clinically relevant thermal-cycling regimen was suggested by Gale & Darvell (1999). The purpose of this study was to investigate the effects of cyclic temperature changes (thermal-cycling) on the water sorption and solubility of four commercial composite restoratives based on the regimen advocated by Gale & Darvell (1999). The water sorption and solubility of the different composites was also compared.

METHODS AND MATERIALS

The technical profiles of the composites evaluated are shown in Table 1. They included a microfilled (Silux Plus), two minifilled (Z100 and Surefil) and a midifilled (Ariston pHc) composite. The methodology was based upon ISO 4049 procedures (International Standards Organization, 1992) with modifications for specimen dimensions and thermal testing. The composites were placed in circular recesses of customized delrin molds (10 ± 1 mm diameter and 1.0 ± 0.1 mm thick) and cov-

Table 1. *Technical Profiles of the Composites Evaluated*

Material	Manufacturer	Type Cure Time	Polymer	Fillers	Filler Size (μm)	Filler Content (% by volume)
Silux Plus (Lot #19980106)	3M Dental Products, St Paul, MN, USA	Microfill 40 seconds	BisGMA TEGDMA	Silica	0.04 (mean)	40
Z100 (Lot #19980203)	3M Dental Products, St Paul, MN, USA	Minifill 40 seconds	BisGMA TEGDMA	Zirconia Silica	0.5 – 0.7 (mean)	66
Ariston pHc (Lot #A06719)	Vivadent Schaan, Liechtenstein	Midifill 40 seconds	BisGMA UDMA TEGDMA	Ba-Al-Fluorosilicate glass Alkaline glass Silica Ytterbium Trifluoride	1.3 (mean)	59
Surefil (Lot #980709)	Dentsply-Caulk, Milford, DE, USA	Minifill 40 seconds	Urethane-modified BisGMA	Ba-Boron-Fluoro-silicate glass Silica	0.8 (mean)	65

BisGMA = Bisphenol-A-dimethacrylate
TEDGMA = Triethylene glycol dimethacrylate
UMDA = Urethane dimethacrylate

ered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was placed over the acetate strip and pressure was applied to extrude excess material. The composites were then light cured for 40 seconds through the glass slide/acetate strip using a Spectrum curing light (Dentsply Inc, Milford, DE 19963, USA) with a 13 mm diameter light tip. The mean output intensity of the light source, as assessed with a commercial radiometer (CureRite, EFOS Inc, Ontario, Canada), was 445 ± 6 mW/cm^2.

A total of 18 specimens were made for each composite. The composite specimens were randomly divided into three treatment groups of six specimens each. After removal from the molds, the specimens were transferred to a desiccator containing silica gel maintained at 35 ± 1°C and stored for 24 hours. After 24 hours they were removed and stored in a desiccator maintained at 23 ± 1°C for one hour, then weighed to a precision of ± 0.2 mg using an analytical balance (GR-200, A&D Company, Tokyo, Japan). This cycle was repeated until a constant mass, m_1, was obtained. The specimens were then treated as follows:

Group 1 (Control). Stored in distilled water at 35ºC for 178 hours.

Group 2 (Cycled 45ºC). Stored in distilled water at 35ºC for 173 hours and subjected to five hours (300 cycles) of thermal-cycling with an upper temperature of 45ºC.

Group 3 (Cycled 60ºC). Stored in distilled water at 35ºC for 173 hours and subjected to five hours (300 cycles) of thermal-cycling with an upper temperature of 60ºC.

One thermal-cycle consisted of the cycle ABAC. The temperature of the water in containers A and B were fixed at 35ºC and 15ºC, respectively. The temperature of the water in container C was either 45ºC or 60ºC, depending on the treatment group. Dwell (immersion) time in container A was 28 seconds, while dwell time in containers B and C was two seconds. The total time for each thermal-cycle was therefore one minute and the total number of dwell cycles for each specimen was 600.

After the above-mentioned treatment (Group 1-3), the specimens were removed and the surface water was blotted away until it was free from visible moisture. The specimens were then waved in the air for about 15 seconds and weighed one minute after being removed from the water. This mass was recorded as m_2. After this weighing, the specimens were reconditioned to constant mass in the desiccators using the cycle described above. This mass was recorded as m_3. The volume V of the specimens was calculated after measuring the diameter at four equally spaced points on the circumference and the thickness at the center of the specimens in cubic millimeters with a digimatic calipers (CD6BS, Mitutoyo, Kanagawa, Japan).

The values for water sorption ω_{sp} in μg/mm^3 were calculated using the following formula:

$$\omega_{sp} = \frac{m_2 - m_3}{V}$$

where

m_2 is the mass of the specimen, in μg, after treatment (Groups 1-3)

m_3 is the reconditioned mass of the specimen in μg

V is the volume of the specimen in mm$_3$

Values for solubility ω_{sl} in μg/mm^3 were obtained using the following formula:

$$\omega_{sl} = \frac{m_1 - m_3}{V}$$

where

m_1 is the conditioned mass, in μg, prior to treatment (Groups 1-3)

m_3 is the reconditioned mass of the specimen in μg

V is the volume of the specimen in mm^3

For all statistical analyses, a significance level of 0.05 was used. An ANOVA model for factorial design was constructed to determine the interaction between materials and treatment with water sorption and solubility as main effects. For each material, one-way ANOVA and Scheffe's post-hoc test were performed, with treatment as independent variables and water sorption and solubility data as dependent variables. The aforementioned tests were also used for inter-material comparison for each treatment group.

RESULTS

The mean water sorption and solubility are shown in Table 2 and Figures 1 and 2. Results of the statistical analysis are reflected in Table 3. Multi-factorial analysis showed significant interaction between materials and treatment groups only for water sorption. The effects of thermal-cycling on water sorption was therefore material dependent. For most materials, an increase in water sorption was observed after thermal-cycling. A significant increase was only observed for Silux Plus and Z100 when thermal-cycled at upper temperatures of 60ºC and 45ºC, respectively. The water sorption of Ariston pHc and Surefil was not significantly affected by thermal-cycling. Thermal-cycling did not affect the solubility of any composite evaluated.

For all treatment groups, the water sorption of Surefil was significantly lower than the other composites evaluated. In addition, the water sorption of Ariston pHc was significantly greater than Silux Plus and that of Z100 was significantly greater than Silux Plus and Ariston pHc for Groups 1 and 2,

respectively. For all treatment groups, the solubility of Z100 and Surefil was significantly lower than Silux Plus and Ariston pHc. When thermal-cycled at an upper temperature of 45ºC, the solubility of Z100 was significantly greater than Surefil.

Table 2: *Mean Water Sorption (µg/mm3) the Different Materials and Treatment Group*

Materials	Group 1 (Control)	Group 2 (Cycled 45ºC)	Group 3 (Cycled 60ºC)
Mean water sorption (µg/mm³)			
Silux	26.18 (2.67)	29.86 (1.35)	32.02 (2.91)
Z100	29.67 (2.10)	35.40 (4.16)	32.47 (2.93)
Ariston pHc	31.73 (2.94)	29.45 (2.56)	33.20 (2.19)
Surefil	9.64 (1.79)	11.40 (3.39)	11.30 (3.28)
Mean solubility (µg/mm³)			
Silux	19.57 (2.04)	23.10 (3.07)	23.21 (2.23)
Z100	7.00 (3.36)	9.67 (3.76)	8.95 (4.76)
Ariston pHc	22.83 (5.83)	23.98 (2.43)	22.64 (2.59)
Surefil	6.25 (1.51)	3.34 (2.01)	4.18 (1.85)

Table 3: *Comparison Between Groups*

Material	Dependent Variable	Differences
Silux Plus	Water sorption	Group 3 (Cycled 60ºC) > Group 1 (Control)
	Solubility	NS
Z100	Water sorption	Group 2 (Cycled 45ºC) > Group 1 (Control)
	Solubility	NS
Ariston pHc	Water sorption	NS
	Solubility	NS
Surefil	Water sorption	NS
	Solubility	NS
Comparison Between Materials		
Treatment Group	**Dependent Variable**	**Differences**
Group 1 (Control)	Water sorption	Silux Plus, Z100 and Ariston pHc > Surefil Ariston pHc > Silux Plus
	Solubility	Silux Plus and Ariston pHc > Z100 and Surefil
Group 2 (Cycled 45ºC)	Water sorption	Silux Plus, Z100 and Ariston pHc > Surefil Z100 > Silux Plus and Ariston pHc
	Solubility	Silux Plus and Ariston pHc > Z100 and Surefil Z100 > Surefil
Group 3 Surefil	Water sorption **(Cycled 60ºC)**	Silux Plus, Z100 and Ariston pHc > Solubility Silux Plus and Ariston pHc > Z100

(Results of one-way ANOVA and Scheffe's post-hoc test at significance level 0.05.
NS indicates no significant difference and > indicates statistical significance.

DISCUSSION

Routine eating, drinking and breathing can produce changes in intra-oral temperatures (Palmer, Braco & Billy, 1992; Boehm, 1972). Thermal stresses can be pathogenic in two ways. First, mechanical stresses generated by differences in coefficient of thermal expansion can result in bond failure at the tooth-restorative interface (Crim & García-Godoy, 1987). Second, changing gap dimensions are associated with gap volume changes that pump pathogenic oral fluids in and out of the gaps (Torstenson & Brännström, 1988). Mechanical properties such as fracture toughness and wear may also be affected by thermal stress (Mair, 1991; Lloyd, 1982). No known studies, however, have reported the effects of thermal-cycling on water sorption and solubility of composite restoratives. The thermal-cycling regimen advocated by Gale & Darvell (1999) (that is, 35ºC [28 seconds], 15ºC [two seconds], 35ºC [28 seconds], 45ºC [two seconds]) was derived from *in vivo* information and it was suggested as the benchmark standard for all laboratory testing of dental restorations. The extremes in temperature were fixed at 15ºC and 45ºC as they were the lowest/highest comfortable temperatures reported from *in vivo* studies (Gale & Darvell, 1999). As an upper temperature limit of 60ºC had been shown to increase surface degradation and wear of composites (Mair, 1991; Montes & Draughn, 1986), it was also included in this current study. The sample size of six selected for this study was two more than the minimum stipulated in ISO 4049.

The amount of water absorbed and the rate of absorption by composites has been shown to be diffusion controlled (Swartz & others, 1982; Braden, Causton & Clarke, 1976). There are a number of factors that will determine the diffusion coefficient for any particular polymer-based material. These include the nature of the resin, the resin volume and filler type, the accessibility of water to the resin, the concentration of catalyst and/or initiating systems, the presence of air-filled voids within the matrix and the environmental temperature. Environmental temperature has an effect on the density of the bathing medium, which in turn may affect the rate of absorption and diffusion of fluids into the polymer (Martin & Jedynakiewicz, 1998). The effects of cyclic temperature changes on water sorption was material dependent. Although thermal-cycling generally increased water

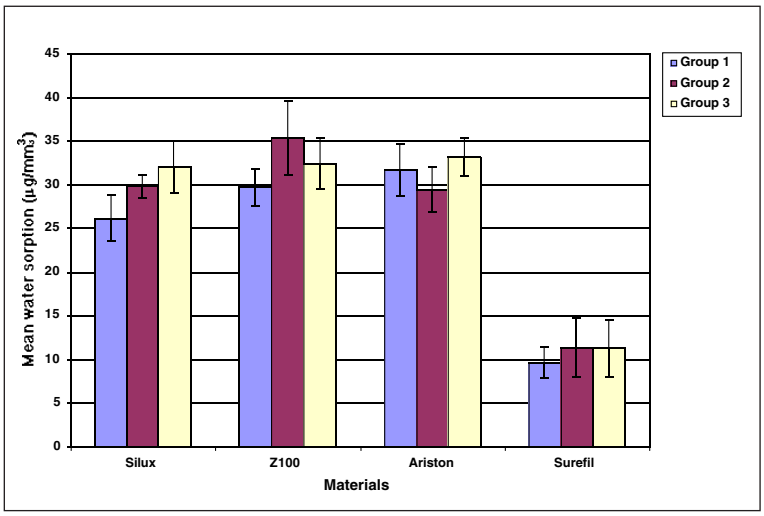

Figure 1. *Mean water sorption (micrograms/mm³) for the different treatment groups.*

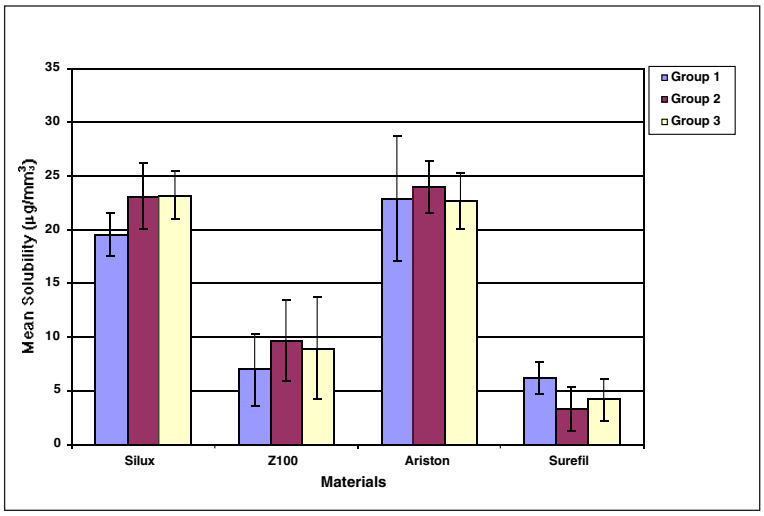

Figure 2. *Mean solubility (micrograms/mm³) for the different treatment groups.*

sorption, the increase was only significant for Silux Plus and Z100. As the bulk of sorption is in the resin phase (Braden & Clarke, 1984), the finding may be explained by the type of resins employed. Pearson & Longman (1989) found that under normal curing conditions, urethane diamethacrylate materials absorbed less water than those based on BisGMA. Water sorption, if exacerbated by thermal-cycling, is thus expected to be greater with BisGMA materials than with UDMA or urethane-modified materials. Both Silux Plus and Z100 are based on BisGMA with TEDGMA as diluent. Ariston pHc uses UDMA in addition to the aforementioned resins, while Surefil utilizes a urethane-modified BisGMA. The upper temperature appears to influence the degree of water sorption of Silux Plus and Z100. While water sorption of Silux Plus was affected by an upper temperature of 60ºC, Z100 was affected by a lower upper temperature of 45ºC. This finding may be attributed to resin content and filler size, type and content, as the resins used were identical. The precise mechanism is not known and cannot be determined from this study.

The use of urethane-modified BisGMA explains the significantly lower water sorption of Surefil compared to the other materials for all treatment groups. A previous study examining the degree of hygroscopic expansion in resin-based composites has shown an inverse relationship between filler-loading and water sorption (Øysæd & Ruyter, 1986b). As the volume of filler increases, the amount of water absorbed into the matrix is reduced. This was contradictory to the findings of this study. Although Silux Plus had the lowest filler volume (40%), it had significantly lower water sorption than Ariston pHc and Z100 for Groups 1 and 2, respectively. Kalachandra (1989) characterized the water sorption of dental composites in terms of water uptake, diffusion coefficients and polymer content to study how these parameters are influenced by fillers. When water sorption of filled composites was compared to predictions of ideal systems based solely on polymer content, filled specimens were found to absorb twice as much water as the unfilled materials. It was hypothesized that the filler-matrix interface, if uncoupled, provides paths of facile diffusion similar to grain boundary diffusion. A higher filler content may therefore lead to increased accommodation of water at the interface between the fillers and matrix resulting in increased water sorption. The aforementioned may explain the generally higher water sorption of Z100 and Ariston pHc compared to Silux Plus in all treatment groups. Ariston pHc is the first "smart" dental composite to be developed and marketed. It uses a low oral pH to increase fluoride release. This episodic release prolongs the therapeutic usefulness of the composite and optimizes fluoride release (Combe & Douglas, 1998). For more effective fluoride and ionic release, the composite structure needs to be more open. The latter may also contribute to the higher water sorption values observed.

Solubility or the leaching of components from dental composites has a potential impact on both the structural stability and the biocompatibility of the material. Components may be eluted into salivary fluids and brought into contact with mucosal tissues. In addition, components may be extracted into dentin where they may diffuse toward the pulp (Ferracane, 1994). One major problem with composites is their incomplete polymerization. A degree of conversion in the range of 60 to 75% has been shown (Øilo, 1992). Light-initiated polymerization has increased the possibilities for incomplete conversions during clinical work as new

sources for failures are introduced. Incomplete conversion may leave unreacted monomers that might dissolve in a wet environment. Another possibility is that reactive sites (that is, double bonds) are susceptible to hydrolysis or oxidation and, thereby, degradation of the material. Dissolution of elements present in fillers has also been reported (Söderholm 1990; Söderholm 1983). Tests have shown that approximately 50% of the leachable species are eluted within three hours and elution of nearly all leachable components was complete within 24 hours in water (Ferracane & Condon, 1990). The total water contact time was 178 hours for the three treatment groups and all leachable components were expected to be eluted. Solubility of all composites was not affected by thermal-cycling. Significant differences in solubility were, however, observed between materials. For all treatment groups, Z100 and Surefil had significantly lower solubility than Silux Plus and Ariston pHc. Tanaka & others (1991), using gas-liquid chromatography and mass spectroscopy, showed that most of the unreacted monomers present in a BisGMA/TEGDMA composites were TEGDMA diluent molecules. The higher resin content, and hence presence of TEGDMA in Silux Plus and Ariston pHc, may account for their significantly higher solubility. The high solubility of Ariston pHc may also be attributed to the release of high levels of methacrylic acid (Yap, Lee & Sabapathy, 2000). The cumulative methacrylic acid release over seven days was 519.04 ppm for Ariston pHc. Values obtained for Silux Plus, Z100 and Surefil were significantly lower and ranged from 5.66 to 20.21 ppm.

CONCLUSIONS

The effects of cyclic temperature changes on the water sorption and solubility of four commercial composite resins (Silux Plus, Z100, Ariston pHc and Surefil) were investigated. The methodology was based upon ISO 4049 procedures with modifications for specimen dimension and thermal-cycling. Thermal-cycling did not affect the solubility of any of the composites evaluated. The effects of cyclic temperature changes on water sorption was found to be material dependent. A significant increase in water sorption was observed for Silux Plus and Z100 when these restoratives were thermal-cycled at upper temperatures of 60°C and 45°C, respectively. The water sorption of Ariston pHc and Surefil was not significantly affected by cyclic temperature changes.

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References

Bausch JR, de Lange K, Davidson CL, Peters A & de Gee AJ (1982) Clinical significance of polymerization shrinkage of composite resins *Journal of Prosthetic Dentistry* **48(1)** 59-67.

Boehm RF (1972) Thermal environment of teeth during open mouth respiration *Journal of Dental Research* **51(1)** 75-78.

Braden M, Causton BE & Clarke RL (1976) Diffusion of water in composite filling materials *Journal of Dental Research* **55(5)** 730-732.

Braden M & Clarke RL (1984) Water sorption characteristics of dental microfine composite filling materials *Biomaterials* **5(6)** 369-376.

Carvalho RM, Pereira JC, Yoshiyama M & Pashley DH (1996) A review of polymerization contraction: The influence of stress development versus stress relief *Operative Dentistry* **21(1)** 17-24.

Combe EC & Douglas WH (1998) The future of dental materials *Dental Update* **25(9)** 411-417.

Crim GA & Garcia-Godoy F (1987) Microleakage: The effect of storage and cycling duration *Journal of Prosthetic Dentistry* **57(5)** 574-576.

Davidson CL & Feilzer AJ (1997) Polymerization shrinkage and polymerization shrinkage stress in polymer-based restorative *Journal of Dentistry* **25(6)** 435-440.

Feilzer AJ, de Gee AJ & Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636-1639.

Ferracane JL (1994) Elution of leachable components from composites *Journal of Oral Rehabilitation* **21(4)** 441-452.

Ferracane JL & Condon JR (1990) Rate of elution of leachable components from composites *Dental Materials* **6(4)** 282-287.

Gale MS & Darvell BW (1999). Thermal-cycling procedures for laboratory testing of dental restorations *Journal of Dentistry* **27(2)** 89-99.

Hansen EK (1986) Effect of cavity depth and application technique on marginal adaptation of resins in dentin cavities *Journal of Dental Research* **65(11)** 1319-1321.

Indrani DJ, Cook WD, Televantos F, Tyas MJ & Harcourt JK (1995) Fracture toughness of water-aged resin composite restorative materials *Dental Materials* **11(3)** 201-207.

International Standards Organization (1992) ISO 4049: 1988/Cor1 1992(E) Dentistry—Resin-based filling materials Geneva: International Standards Organization pp 8-9.

Kalachandra S (1989) Influence of fillers on water sorption of composites *Dental Materials* **5(4)** 283-288.

Kemp-Scholte CM & Davidson CL (1990) Complete marginal seal of Class V resin composite restorations effected by increased flexibility *Journal of Dental Research* **69(6) 1**240-1243.

Krejci I, Sperr D & Lutz F (1987) A three-sited light curing technique for conventional Class II composite restorations *Quintessence International* **18** 125-131.

Lloyd CH (1982) The fracture toughness of dental composites II: The environmental and temperature dependence of the stress intensification factor *Journal of Oral Rehabilitation* **9(1)** 133-138.

Mair LH (1991) Effect of surface conditioning on the abrasion rate of dental composites *Journal of Dentistry* **19(2)** 100-106.

Martin N & Jedynakiewicz N (1998) Measurement of water sorption in dental composites *Biomaterials* **19(1-3)** 77-83.

Montes GGM & Draughn RA (1986) *In-vitro* surface degradation of composites by water and thermal-cycling *Dental Materials* **2 (5)**193-197.

Øilo G (1992) Biodegradation of dental composites/glass ionomer cements *Advanced Dental Research* **6** 50-54.

Øysæd H & Ruyter IE (1986a) Composites for use in posterior teeth: Mechanical properties tested under dry and wet conditions *Journal of Biomedical Materials Research* **20(2)** 261-271.

Øysæd H & Ruyter IE (1986b) Water sorption and filler characteristics of composites for use in posterior teeth *Journal of Dental Research* **65(11)** 1315-1318.

Palmer DS, Braco MT & Billy EJ (1992) Temperature extremes produced orally by hot and cold liquids *Journal of Prosthetic Dentistry* **67(3)** 325-327.

Pearson GJ & Longman CM (1989) Water sorption and solubility of resin-based materials following inadequate polymerization by a visible-light curing system *Journal of Oral Rehabilitation* **16(1)** 57-61.

Phillips RW (1981) Past, present and future composite systems *Dental Clinics of North America* **25** 209-219.

Sakaguchi RL, Douglas WH & Peters MCRB (1992) Curing light performance and polymerization of composite restorative materials *Journal of Dentistry* **20(3)** 183-188.

Söderholm KJM (1983) Leaking of fillers in dental composites *Journal of Dental Research* **62(2)** 126-130.

Söderholm KJM (1990) Filler leachability during water storage of six composite materials *Scandinavian Journal of Dental Research* **98(1)** 82-88.

Swartz ML, Moore BK, Philips RW & Rhodes BF (1982) Direct restorative resins: A comparative study *Journal of Prosthetic Dentistry* **47(2)** 163-170.

Tanaka K, Taira M, Shintani H, Wakasa K & Yamaki M (1991) Residual monomers (TEGDMA and BisGMA) of a set visible-light-cured dental composite resin when immersed in water *Journal of Oral Rehabilitation* **18(4)** 353-362.

Thonemann BM, Federlin M, Schmalz G & Hiller KA (1997) SEM analysis of marginal expansion and gap formation in Class II composite restorations *Dental Materials* **13(3)** 192-197.

Torstenson B & Brännström M (1988) Contraction gap under composite resin restorations: Effects of hygroscopic expansion and thermal stress *Operative Dentistry* **13(1)** 24-31.

Yap AUJ, Lee KH & Sabapathy R (2000) Release of methacrylic acid from dental composites *Dental Materials* **16(3)** 172-179.

Yap AUJ, Low JS & Ong LFKL (2000) Effect of food-simulating liquids on surface characteristics of composite and polyacid-modified composite restoratives *Operative Dentistry* **25(2)** 170-176.

Yap AUJ, Wang HB, Siow KS & Gan LM (2000) Polymerization shrinkage of visible-light-cured composites *Operative Dentistry* **25(1)** 98-103.

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The Influence of a Dentin Desensitizer on the Microtensile Bond Strength of Two Bonding Systems

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Clinical Relevance

D/Sense 2 application on dentin prior to bonding procedures resulted in dramatically lower bond strengths.

SUMMARY

A laboratory study evaluated the influence of a dentin desensitizer (D/Sense 2) on the microtensile bond strength of two adhesive systems: a self-etching primer (Bistite II SC) and a one-bottle adhesive (Prime & Bond 2.1). Sixteen crown dentin discs were obtained from extracted sound human third molars. Dentin surfaces were ground with 600 grit silicon carbide (SiC) abrasive papers to produce a standardized smear layer. Teeth were randomly divided into four groups (n=4). G1-D/Sense 2 + Prime & Bond 2.1; G2-D/Sense 2 + Bistite II SC; G3- and G4-dentin surfaces were bonded with Prime & Bond 2.1 and Bistite II SC, respectively, with no previous treatment with D/Sense 2. Eight mm high resin composite crowns (TPH Spectrum) were incrementally built-up on the treated surfaces. One sample from each group was prepared for evaluation of the hybrid layer on SEM. The specimens for the microtensile test were serially sectioned perpendicular to the adhesive layer to obtain 1 mm² bounded sticks. Then, each stick was submitted to the microtensile test performed at a 0.5 mm/min crosshead speed. One-way ANOVA and Tukey test showed statistically significant differences among the groups ($p<0.05$). Values in MPa were: G1-17.85; G2-9.88; G3-35.16; G4-15.57. Based on the results of this study, it can be concluded that the D/Sense 2 desensitizer decreased the bond strength of Prime & Bond 2.1 and Bistite II SC bonding systems.

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INTRODUCTION

Dentin sensitivity is a common problem that affects one out of seven adult patients (Graf & Galasse, 1977). One of the most common non-carious etiology for dentin sensitivity is abrasion in the cervical region that can result from the abrasiveness of toothpaste, the frequency and pressure of brushing and the quality of the toothbrush (Peres & others, 1999). For this reason, it is normal to

face patients who complain about pain caused by temperature changes, chemical, tactile or osmotic stimuli (Peres & others, 1999).

Various theories have explained the mechanism of dentin sensitivity. Currently, the hydrodynamic theory is widely accepted. It is a displacement of tubular contents such as fluids that might produce a deformation of the nerve fibers in the pulp despite the absence of nerve fibers in the dentin tubule (Brännström & Aström, 1964). Thus, products that occlude dentin tubules to any extend can significantly reduce fluid filtration across dentin and cause dentin sensitivity (Jain & others, 1997).

Among dentist-applied treatments, topical methods are largely used because they are convenient and have an immediate effect. Applying desensitizer solutions and dentifrices containing ferric, aluminum and potassium oxalates are the first treatments of choice (Villa, Cardoso & Lascala, 1995), but their effect is not permanent. The durability of these topical treatments is influenced by several factors. The most common problem is the dissolution of the desensitizer material by saliva and oral fluids (Jain & others, 1997; Ciucchi & others, 1995). In 1991, Kerns, Scheidt & Pashley treated dentin samples with potassium oxalate, showing few remaining crystals after seven days in the patient's mouth.

To obtain a long-lasting effect, adhesive restorative procedures can be used after a desensitizer treatment has failed (Mausner, Goldstein & Georgescu, 1996). In 1992, Pashley demonstrated that sealing dentinal tubules with polymeric resins reduced sensitivity. However, there is concern regarding the effect of pre-treatment with a desensitizer on the bond strength between dentin and resin composite.

This study evaluated the influence of a pre-treatment with a dentin desensitizer on the microtensile bond strength of two dentin-bonding systems. Electron microscopy also examined the effect of these treatments on dentin surfaces.

METHODS AND MATERIALS

Tooth Preparation

For this study 16 non-carious human third molars were used within two months after extraction. The teeth were stored in 10% formalin until the gross debris was accomplished.

The occlusal enamel was removed by sectioning the crown perpendicular to the long axis of the tooth with a low-speed diamond saw (KG Sorensen, Barueri, SP, Brazil) under running water mounted in a handpiece. The roots were removed by a second dentin section made as close as possible to the pulp floor, approximately 0.5 mm below the cemento-enamel junction.

Dentin surfaces were ground with 320 and 400/grit SiC (silicon carbide abrasive papers—Carborundum Abrasives, Recife, PE, Brazil) and hand finished using 20 strokes each with a wet 600/grit SiC paper for 20 seconds to create a standardized smear layer. The remaining dentin thickness between the flat occlusal plane and the pulp horns was kept in the range of 2.5-3 mm measured by means of a precision micrometer positioned on the pulp chamber. Dentin discs were then stored in distilled water for seven days before beginning bonding procedures.

Bonding Procedures

Teeth were randomly assigned to one of four test groups (n=4):

Group 1: D/Sense 2 + acid etch + Prime & Bond 2.1 + TPH

Group 2: D/Sense 2 + Bistite II SC + TPH

Group 3: Acid etch + Prime & Bond 2.1 + TPH

Group 4: Bistite II SC+ TPH

Group 1: Dentin surfaces were dried with a cotton pellet (Johnson & Johnson, São José dos Campos, SP, Brazil). Three coats of step 1 liquid of D/Sense 2 (Centrix Incorporated, Neugasse 2C, D-65719 Hofheim, Germany) desensitizer was rubbed on dentin surfaces for 10 seconds with a brush. Then, three coats of step 2 liquid of D/Sense 2 desensitizer was applied on dentin surfaces using the same method. The combination of the two liquids resulted in a visible reaction, sealing the dentin tubules deeply with inorganic microcrystals. The dentin surfaces were washed and air-dried before conditioning with 37% phosphoric acid (Caulk Tooth Conditioner Gel, Dentsply/Caulk, Milford, DE 19963, USA) for 15 seconds, washed with water spray, dried with cotton pellets (Pereira & Paulillo, 2000) and left visibly moist. Prime & Bond 2.1 (Dentsply/Caulk) was applied to the dentin surface and left undisturbed for 30 seconds, air dried for five seconds, light cured for 10 seconds (XL 3000–3M Dental Products, St Paul, MN 55144, USA) and this process was repeated.

Group 2: Dentin surfaces were dried with a cotton pellet and D/Sense 2 desensitizer was applied as described above. The surfaces were washed and air dried before applying Bistite II SC (Tokuyama Corp, 3-1, Shibuya-ku, Tokyo, Japan). Primers 1A and 1B were mixed and applied to the dentin surfaces. The mixture was left undisturbed for 30 seconds, then air dried for three seconds. Primer 2 was applied and light cured for 10 seconds.

Group 3: Dentin surfaces were etched with 37% phosphoric acid for 15 seconds, washed with water spray, dried slightly with cotton pellets and left visibly moist for applying Prime & Bond 2.1 as in Group 1.

Group 4: Bistite II SC, a self-etching primer system was used in this group. Primers 1A and 1B were mixed and applied on dentin surfaces. The mixture was left undisturbed for 30 seconds, then air dried for three seconds. Primer 2 was applied and light cured for 10 seconds. All products were used according to the manufacturers' directions.

Table 1: *One-Way ANOVA for Microtensile Bond Strengths*

Source	DF	Sum of Squares	Mean Squares	F Value	PR>F
Model	3	5338.1898	1779.3966	166.48	0.05
Error	56	598.5467	10.6883		
Total	59	5936.7365			
C.V	16.67				

Table 2: *Tukey Test for Microtensile Bond Strengths (MPa) of the Groups*

Group	Microtensile Bond Strength	Tukey
G3- P&B	35.1600	a*
G1- P&B+D/Sense	17.8467	b
G4- Bistite	15.5733	b
G2-Bistite+D/Sense	9.8800	c
Tukey	$\alpha = 0.05$	

*Different letters- significantly different mean values ($p<0.05$).

After the bonding procedures, a flat composite crown was built-up on each dentin disc to a height of 8 mm using TPH Spectrum (Prisma TPH Spectrum, Dentsply/Caulk). Each of the four 2 mm increments of resin composite was light cured (XL 3000—3M Dental Products) for 40 seconds. The teeth were then stored in distilled water at 37°C for one week. The pulp chamber of each tooth was then dried with air, conditioned with phosphoric acid for 15 seconds and primed with Prime & Bond 2.1 to be filled with TPH resin composite. This procedure reinforced the dentin structure near the pulp horns, where dentin was thinner.

The samples were fixed by their root portions in acrylic plaques by a cyanoacrylate cement (Super Bonder, Loctite, Brasil Ltd, Itapevi, SP, Brazil) and positioned in a low-speed cutting machine (Isomet—Buehler Ltd, Lake Bluff, IL 60044, USA) equipped with a diamond-impregnated copper disc (Extec, Enfield, CT, USA). Each tooth was then vertically sectioned under copious water irrigation in a mesio-distal direction through the composite buildups and dentin to produce a series of 1 mm thick slabs. Each slab was then serially sectioned again in a buccal-lingual direction to produce approximately 1x1x8 mm sticks.

The sticks were individually tested for bond strength (Figure 6). Special flat stainless steel grips were made to fit a Bencor Multi-T device (Bencor Multi-T, Danville Engineering Co, San Ramon, CA 94583, USA) which was held in an Instron Universal testing machine (Instron 4411, Canton, MA, USA). A small drop of a cyanoacrylate cement was placed at the extreme ends of each specimen stick. Each stick was then carefully placed on the grips with a slight pressure. An accelerator (Zapit, DVA, 217 Lewis Ct, Corona, CA 91720, USA) was spread on either grip to

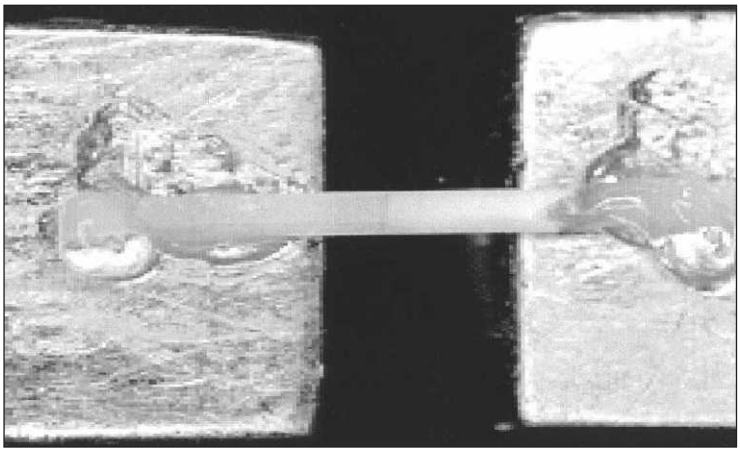

Figure 6. *Dentin/resin stick placed on the stainless steel grips made to fit a Bencor Multi-T device.*

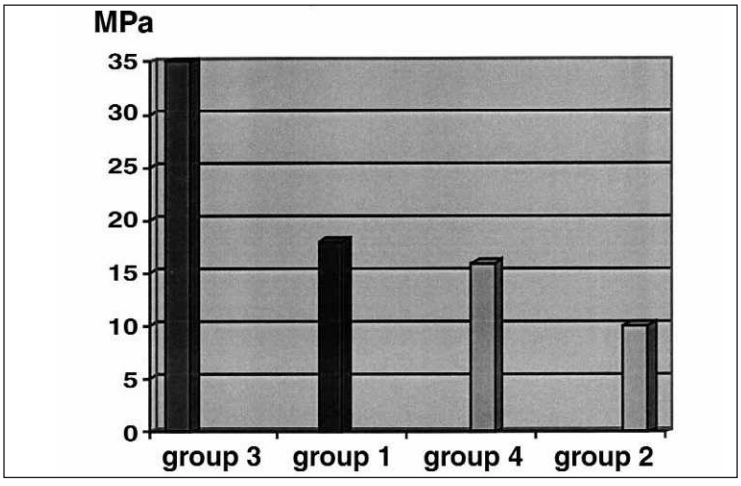

Figure 6. *A schematic representation of bond strengths values distribution. Y-axis represents micro-tensile bond strengths in MPa and X axis represents the groups evaluated. Group 1- D/Sense 2 + Prime & Bond 2.1, Group 2- D/Sense 2 + Bistite II SC, Group 3- Prime & Bond 2.1 and Group 4- Bistite II SC.*

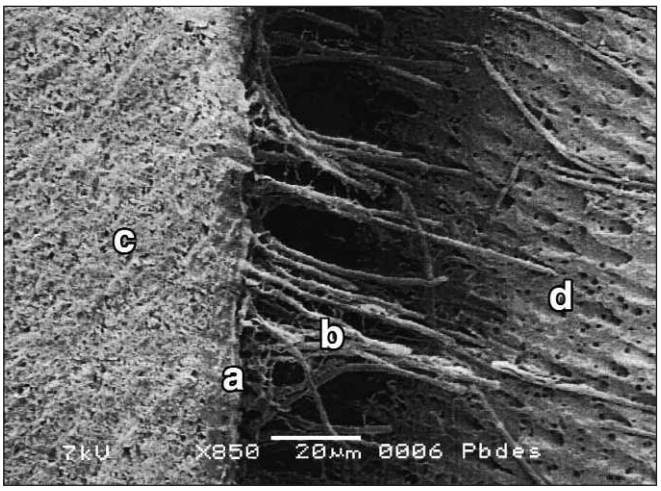

Figure 1. *Scanning electron microscopic (SEM) image of dentin treated with D/Sense 2 and Prime & Bond 2.1 showing a non-uniform hybrid layer (a) and the presence of a few number of tags (b). Resin composite (c) and dentin (d). x850 magnification.*

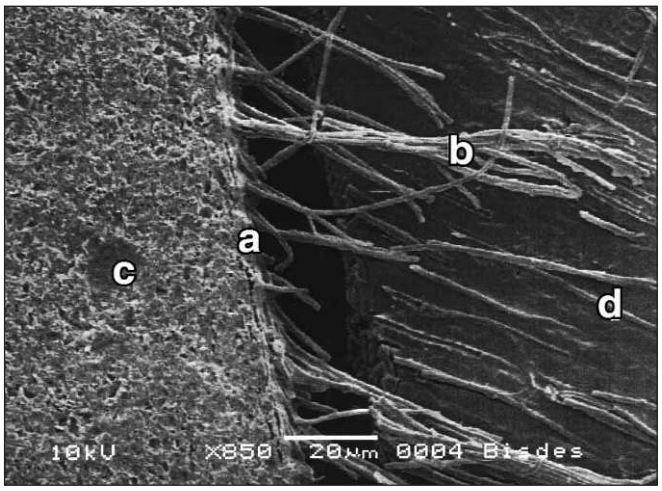

Figure 2. *An inconsistent and thinner hybrid layer (a) and a decreased number of tags (b) were formed when Bistite II SC and D/Sense 2 were applied on dentin surface. Resin composite (c) and dentin (d). x850 magnification.*

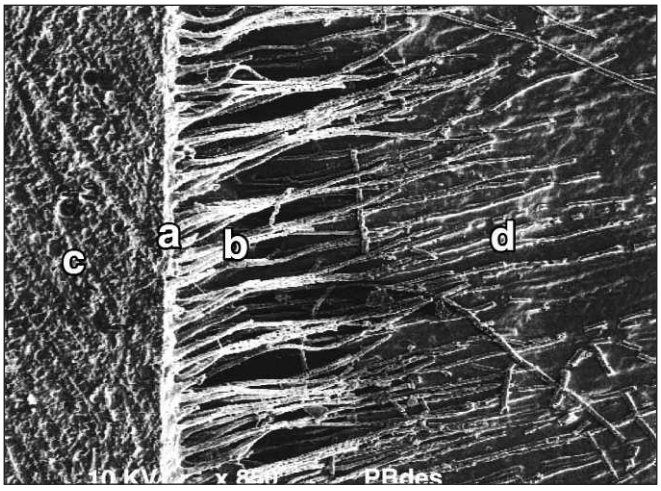

Figure 3. *Dentin surface treated with the adhesive system Prime & Bond 2.1 as the manufacturer's instructions. Note the uniform hybrid layer (a) formed between the dentin (d) and the resin composite (c). Observe the presence of a great number of resin tags (b). x850 magnification.*

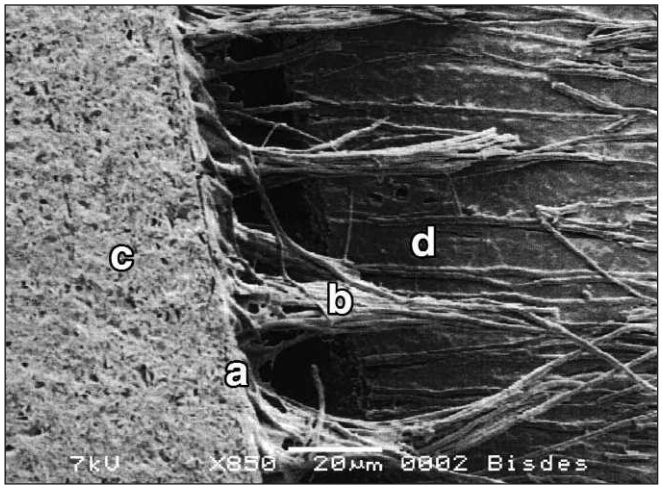

Figure 4. *Dentin surface treated with a self-etching primer Bistite II SC- even without the desensitizer, this adhesive system showed a thin hybrid layer, although a higher number of tags. x850 magnification.*

initiate polymerization of the cyanoacrylate. Once base and catalyst were mixed, the setting reaction was instantaneous and prevented flow of the cyanoacrylate material. It avoided contamination of the bonded interface with this cement. The beam was subject to tensile force at a crosshead speed of 0.5 mm/min.

After failure, each specimen was measured using a digital caliper. The load at failure (KgF) divided by the area of the specimen yielded the apparent ultimate stress in MPa of the resin-dentin bonds.

One-way analysis of variance (ANOVA) detected any significant differences ($p<0.05$) in bond strength among the groups (Table 1), and Tukey test was used as the analytic method for post-comparison of the groups (Table 2, Figure 5).

Scanning Electron Microscopy (SEM) Examination of Bonded Specimens

SEM examination was conducted in order to evaluate the effect of D/Sense 2 desensitizer on the hybrid layer formation of Prime & Bond 2.1 and Bistite II SC bonding systems.

One bonded specimen of each group was cross-sectioned with a diamond impregnated saw under water coolant to create two halves, which were hand-polished with 400, 600, 1000 and 1200 grit silicon (SiC) abrasive papers. After polishing with each silicon abrasive paper, the specimens were cleaned with an ultrasonic machine

(T-14 Thornton Impetch Eletrônica Ltda, Saõ Paulo-Brazil) for 10 minutes. The freshly prepared surfaces were decalcified by immersion in 6 mol/L HCl for 45 seconds to demineralize any mineral component of the dentin surfaces not protected by resin. This procedure enhances the contrast between the resin-infiltrated and non-infiltrated dentin. The samples were then immersed in 10% sodium hypochlorite (NaOCl) for 10 minutes, rinsed with water and air dried. This second treatment removed the exposed collagen fibrils.

The specimens were mounted on SEM stubs, sputter-coated with gold-palladium (MED 010, Balzers, Lichtenstein) and examined in a SEM (DSM 940- A-Zeiss, Oberkochen, Germany). Photographs of the most expressive regions were taken at x850 magnification.

RESULTS

One-way analysis of variance (ANOVA) was used to detect any significant differences in bond strength among the groups. One-way ANOVA revealed a statistically significant F value at p=0.05 for the group factor, within a 16.67% coefficient of variation (Table 1). Tukey test, α=0.05, was used to compare the statistical difference among the experimental groups, and Table 2 and Figure 5 show the results.

Analyzing Table 2, the Tukey test presents the following results: Group 3 presented the highest bond strength means that was statistically different from the others groups. Group 1 and Group 4 presented statistically similar values. Group 2 presented the lowest means.

SEM Observations

The scanning electron microscopic images showed a non-uniform and thinner hybrid layer when both adhesive systems were applied after treatment with D/Sense 2 (Figures 1 and 2).

On the other hand, when D/Sense 2 was not applied, better dentin hybridization was observed. However, the hybrid layer formed by Bistite II SC (Figure 4) was thinner than that formed by Prime & Bond 2.1 (Figure 3).

DISCUSSION

Dentin hypersensitivity is a very common clinical problem characterized by pain arising from exposed dentin ranging from brief, mild discomfort to sharp, severe pain of short duration in response to various stimuli (Brännström & Aström, 1964).

In-office treatment for dentinal hypersensitivity is primarily based upon a non-invasive and basically reversible technique based upon certain desensitizing materials occluding to dentinal tubules, reducing the rapid movement of fluids across dentin and consequently reducing pain (Jain & others, 1997; Schüpbach, Lutz & Finger, 1997).

The desensitizing agents currently used are quite diverse. D/Sense 2 has recently been introduced into the market and is comprised of two liquids. Step 1 liquid contains potassium phosphate, potassium carbonate, sodium methylparaben and deionized water. Step 2 liquid contains calcium chloride, strontium chloride, sodium benzoate and deionized water. D/Sense 2 desensitizes dentin by occluding dentin tubules with a natural, inorganic microcrystalline complex. This complex is produced through the successive application and reaction of the two liquids directly applied to the tooth surface. This reaction produces four calcium and strontium salts plus a desensitizing potassium salt. According to the manufacturer, these salts completely block the tubule orifice and decrease its patency and permeability. However, it may not be a long-lasting treatment as the crystals can be partially dissolved by saliva and other oral fluids.

If pain remains, adhesive restorative procedures can be used after a desensitizer treatment has failed (Mausner & others, 1996). Restorative treatment would benefit greatly if dentin tubules could be effectively occluded by resin monomers. Dentin biopsies examined six months after treatment with an adhesive system showed the presence of resin-like material in a majority of the tubules in dentin where hypersensitivity was no longer perceived (Jain & others, 1997).

D/Sense 2 is also indicated by its manufacturer for use under restorative materials prior to applying etchants, primers and bonding agents. While it is desirable to reduce sensitivity, it is also important to evaluate the possible adverse effects of these desensitizing agents on the diffusion and adhesion of composite to dentin.

The principle of dentin bonding relies on the formation of a resin-infiltrated layer in the intertubular and peritubular conditioned dentin. Following polymerization, these monomers may form a micro-mechanical bond with the primed dentin forming the hybrid layer, the principle mechanism of bonding (Perdigão, Swift Jr & Choe, 1993; Santini & Mitchell, 1998). However, to obtain a reliable dentin adhesion, the open tubules and exposed collagen-rich meshwork must be completely and homogeneously infiltrated by resin monomers. Otherwise, a weak layer formed by non-encapsulated collagen remains at the bottom of the hybrid layer, which propagates fracture, reducing the bond strength and the durability of adhesion (Santini & Mitchell, 1998; Titley, 1994; Gwinnett, 1993).

Many factors contribute to the incomplete resin infiltration, reducing dentin bond strength. Among them, dentin permeability is one of the most important (Tagami, Tao & Pashley, 1990; Hamid, Sutton & Hume, 1996). It was observed in several studies that desensi-

tizing agents effectively reduced dentin permeability between 60-80% (Jain & others, 1997, Camps & others, 1998).

These observations confirm the results obtained in this study. When D/Sense 2 desensitizer was applied before Prime & Bond 2.1 bond system, the microtensile bond strength (Group 1=17.8 MPa) was significantly reduced compared to the results obtained for the same adhesive system with no previous treatment (Group 3= 35.2 MPa). It probably occurred because of the substantial decrease in dentin permeability caused by blocking the tubules and intertubular diffusion channels. The reduction noted might result from precipitation of crystals during the application of D/Sense 2. These crystals are acid-resistant and may chemically and physically prevented complete penetration of the resin components of the bonding system through the outermost demineralized, collagen-rich zone into the partially-demineralized zone bellow (Haveman & Charlton, 1994), thus decreasing the bond strength values (Titley, 1994).

The results of this study are supported by a study by Mausner & others, 1996 in which the results showed a significant reduction in cast retention when All Bond desensitizing agent was used with a polycarboxylate cement. Haveman & Charlton, 1994, realized an *in vitro* study wherein they observed that a monohydrogen-monopotassium oxalate solution adversely affected the shear bond strength of Fuji II LC and Variglass VLC. In 1993, Pashley, Tao & Pashley reported that a dentin desensitizer significantly decreased the bond strength of three dentin bonding agents. The authors concluded that regardless of the restorative material utilized and its specific bonding mechanism, clinicians need to be aware that previous dentin treatment with a desensitizing agent may adversely affect the bonding strength of certain materials.

When self-etching primer Bistite II SC was applied, the results were even lower. Effective bonding requires acid etching, rinsing and drying the dentin before applying the primer. Self-etching primers succeeded in eliminating the dentin-conditioning steps before priming. Normally, self-etching primers are very effective in creating diffusion channels while simultaneously promoting monomer impregnation at the same depth (Nakabayashi & Saimi, 1996; Barkmeier, Los & Triolo, 1995). However, this did not occur when Bistite II SC was used, probably because its acidity was not low enough to completely diffuse through a retained smear layer and infiltrate the underlying dentin surface, resulting in low bond strength values (Group 4=15.6 MPa). These results decreased when D/Sense 2 was previously applied, recording the lowest bond strength values (Group 2=9.88 MPa), presumably because this adhesive did not decalcify the mineral crystals present on the dentin surface. Pumicing dentin after treatment with a desensitizer solution has been found to effectively remove the crystals, neutralizing their negative effects on bond strength (Pashley & Galloway, 1985).

CONCLUSIONS

According to the results of this study, it can be concluded that the D/Sense 2 desensitizer decreased the microtensile bond strength of Prime & Bond 2.1 and Bistite II SC bonding systems. The decreased bond strengths may be the result of crystals deposition blocking the dentin tubule orifices and intertubular diffusion channels, thereby, reducing dentin permeability and mechanical retention between the resin monomers and dentin. It was evident from SEM evaluation of the desensitizer-treated dentin surfaces that subsequent application of an acid conditioner did not remove these crystals.

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References

Barkmeier WW, Los SA & Triolo JR PT (1995) Bond strengths and SEM evaluation of Clearfil Liner Bond 2 *American Journal of Dentistry* **8(6)** 289-293.

Brännström M & Aström A (1964) A study on the mechanism of pain elicited from the dentin *Journal of Dental Research* **43(4)** 219-227.

Camps J, Pizant S, Dejou J & Franquin JC (1998). Effects of desensitizing agents on human dentin permeability *American Journal of Dentistry* **11(6)** 286-290.

Ciucchi B, Bouillaguet S, Holz J & Pashley D (1995) Dentinal fluid dynamics in human teeth, *in vivo Journal of Endodontics* **21(4)** 191-194.

Graf H & Galasse R (1977) Morbidity, prevalence and intraoral distribution of hypersensitive teeth *Journal of Dental Research* **56(479)**.

Gwinnett AJ (1993) Quantitative contribution of resin infiltration/hybridization to dentin bonding *American Journal of Dentistry* **6(1)** 7-9.

Hamid A, Sutton W & Hume WR (1996) Variation in phosphoric acid concentration and treatment time and HEMA diffusion through dentin *American Journal of Dentistry* **9(5)** 211-214.

Haveman CW & Charlton DG (1994) Dentin treatment with an oxalate solution and glass ionomer bond strength *American Journal of Dentistry* **7(5)** 247-251.

Jain P, Vargas MA, Denehy GE & Boyer DB (1997) Dentin desensitizing agents: SEM and X-ray microanalysis assessment *American Journal of Dentistry* **10(1)** 21-26.

Kerns DG, Scheidt MJ & Pashley DH (1991) Dentinal tubule occlusion and root hypersensitivity *Journal of Periodontology* **62(7)** 421-428.

Mausner IK, Goldstein, GR & Georgescu, M (1996) Effect of two dentinal desensitizing agents on retention of complete cast coping using four cements *The Journal of Prosthetic Dentistry* **75(2)** 129-134.

Nakabayashi N & Saimi Y (1996) Bonding to intact dentin *Journal of Dental Research* **75(9)** 1706-1715.

Pashley DH & Galloway SE (1985) The effects of oxalate treatment on the smear layer of ground surfaces of human dentin *Archives of Oral Biology* **30(10)** 731-737.

Pashley EL (1992) Dentin permeability: Sealing the dentin in crown preparations *Operative Dentistry* **17(1)** 13-20.

Pashley EL, Tao L & Pashley D (1993) Effects of oxalate on dentin bonding *American Journal of Dentistry* **6(3)** 116-118.

Perdigão J, Swift EJ Jr & Choe BC (1993) Effects of etchants, surface moisture and resin composite on dentin bond strength *American Journal of Dentistry* **6(2)** 61-64.

Pereira GDS & Paulillo LAMS (2000) Influence of dentin moisture on adhesive system's shear bond strength *Journal of Dental Research* **79(2392)** 442.

Peres CR, Salgado LPS, Sérgio PP & Júnior RH (1999) Hiperestesia dentinária: Etiologia, diagnóstico e forma de tratamento *Revista Brasileira de Odontologia* **56(5)** 204-207.

Santini A & Mitchell S (1998) Effect of wet and dry bonding techniques on marginal leakage *American Journal of Dentistry* **11(5)** 219-224.

Schüpbach P, Lutz F & Finger WJ (1997) Closing of dental tubules by Gluma desensitizer *European Journal of Oral Science* **105(5 P & 1)** 414-421.

Tagami J, Tao L & Pashley DH (1990) Correlation among dentin depth, permeability and bond strength of adhesive resins *Dental Materials* **6(1)** 45-50.

Titley K (1994) Penetration of a dentin bonding agent into dentin *American Journal of Dentistry* **7(4)** 190-194.

Villa LAC, Cardoso RH & Lascala NT (1995) Estudo clínico do tratamento de retrações gengivais localizadas *Revista da Associação Paulista de Cirurgiões-Dentistas* **19(2)** 137-141.

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Surface Finish of a New Hybrid Aesthetic Restorative Material

AUJ Yap • BYY Mok

Clinical Relevance

Giomers may have better surface finish than conventional/resin-modified glass ionomer cements and comparable surface finish to composites and compomers.

SUMMARY

This study compared the surface finish of a new hybrid aesthetic restorative material (Reactmer) over time to four different types of existing materials. The latter included a composite (Spectrum TPH), a compomer (Dyract AP) and conventional (Fuji II) and resin-modified glass ionomer cements (Fuji II LC). Six specimens of each material were fabricated and stored in distilled water at 37ºC for one week. The materials were subsequently finished with a series of Sof-Lex contouring and polishing disks. The average surface roughness (Ra, µm) of each specimen was measured at three days and three months by a surface profilometer. Storage medium was distilled water at 37ºC during the hiatus periods. Data was analyzed by ANOVA/Scheffe's and independent samples t-tests at significance level 0.05. At both time periods, Fuji II and Fuji II LC were significantly rougher than Spectrum, Dyract and Reactmer. For all materials, surface roughness at three days was not significantly different from that at three months. The surface finish of the giomer (Reactmer) was significantly better than conventional/resin-modified glass ionomer cements and comparable to the composite and compomer evaluated. The quality of surface finish for all materials was not significantly affected by long-term storage in water.

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INTRODUCTION

Glass ionomer cements were first introduced to the dental profession in the early 1970s (Wilson & Kent, 1972). Their favorable adhesive and fluoride-releasing properties have led to their widespread use as luting, lining and restorative materials (Sidhu & Watson, 1995). Disadvantages of these cements, however, include sensitivity to moisture, low initial mechanical

properties and inferior translucency compared to resin composites. Hybrid materials combining the technologies of glass ionomers and resin composite were subsequently developed to help overcome the problems of conventional glass ionomer cements and at the same time maintain their clinical advantages. Examples of these hybrid materials include resin-modified glass ionomer cements and compomers (polyacid-modified resin composites). Recently, a new category of hybrid aesthetic restorative material was presented to the dental profession. Known as giomers, they employ the use of pre-reacted glass ionomer (PRG) technology to form a stable phase of glass ionomer in the restorative. The fluoroalumino silicate glass in these materials is reacted with polyalkenoic acid in water prior to inclusion into the silica-filled urethane resin. This technology differs from compomers, in which a variable amount of dehydrated polyalkenoic acid is incorporated into the resin matrix. The acid does not react with the glass until water uptake into the restoration occurs. Like compomers, giomers are light polymerized and require bonding systems (Reactmer Bond) for adhesion to tooth structure. Giomers come in a one-paste form and manufacturers' claims include fluoride release and recharge, biocompatibility, clinical stability, excellent aesthetics and smooth surface finish. Independent studies on fluoride release and recharge of giomers are currently not available. The indications for giomers include the restoration of root caries, non-carious cervical lesions, Class V cavities and deciduous tooth caries.

The aesthetics and life span of tooth-colored restorative materials is heavily dependent on the quality of surface finish as the presence of irregularities on the surface of materials may influence appearance, plaque retention, surface discoloration and gingival irritation (Shintani & others, 1985; Dunkin & Chambers, 1983; Chan, Fuller & Hormati, 1980; Weitman & Eames, 1975; Larato, 1972). In addition, smoother restorations have been shown to be more easily maintained (Strassler & Bauman, 1993; Weitman & Eames, 1975). Although the surface finish of composites, compomers and resin-modified glass ionomer cements have been widely investigated both *in vitro* (Hoelscher & others, 1998; Yap, Lye & Sau, 1997; Hondrum & Fernandez, 1997; Tate & Powers, 1996; St Germain & Meiers, 1996) and *in vivo* (Folwaczny & others, 2001; Gladys & others, 1999; Duke & Trevino, 1998), the quality of surface finish of giomers has not been reported. This study compared the surface finish of a giomer to a composite, a compomer and conventional and resin-modified glass ionomer cements. As the surface roughness and texture of other hybrid materials has been shown to deteriorate clinically over time (Folwaczny & others, 2001; Gladys & others, 1999; Duke & Trevino, 1998), the stability of surface finish with long-term storage in water was also investigated for the different materials.

METHODS AND MATERIALS

Table 1 lists the aesthetic restorative materials evaluated in this study. Both glass ionomer cements were in capsulated form and were activated/mixed according to manufacturers' directions. The restorative materials were injected or placed in the rectangular recesses (4 mm long x 3 mm wide x 2 mm deep) of customized acrylic molds and covered with matrix strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over this and pressure applied to extrude excess material. The light-cured restoratives were light-polymerized according to manufacturers' cure times through the glass slide with a Spectrum curing light (Dentsply Inc, Milford, DE 19963, USA) while the conventional glass ionomer cement was allowed to set for 10 minutes. The intensity of the light sources was checked with a radiometer (CureRite, EFOS Inc, Ontario Canada) before starting the experiment. The mean output was 515 ± 2 mW/cm^2 and output was not affected by illumination through the glass slide and matrix strip. Immediately after light polymerization/setting, the matrix strips were discarded and the materials stored in distilled water at 37ºC for one week. Six specimens were made for each material.

After one-week storage, the restorative materials were finished/polished with a series of Sof-Lex contouring and polishing disks (3M Dental Products, St Paul, MN 55144, USA) by one evaluator. Finishing/polishing was carried out dry at 10,000 rpm for coarse and medium discs and 30,000 rpm for fine and superfine discs according to manufacturer instructions. Ten strokes of each disc grade were used and contact dura-

Table 1: *Aesthetic Restorative Materials Evaluated in the Study*

Material	Category	Manufacturer	Batch #	Shade Cure Time
Reactmer	Giomer	Shofu Inc, Kyoto, Japan	0400	A3 30 seconds
Spectrum TPH	Composite (Minifill)	Dentsply-De Trey, Konstanz, Germany	0006000747	A2 20 seconds
Dyract AP	Compomer	Dentsply-De Trey, Konstanz, Germany	0003001083	A2 40 seconds
Fuji II (Capsulated)	Conventional glass ionomer cement	GC Corporation, Tokyo, Japan	9905255	22 (Not applicable)
Fuji II LC (Capsulated)	Resin-modified glass ionomer cement	GC Corporation, Tokyo, Japan	9912202	A2 20 seconds

tion of each stroke was 10 seconds. After finishing/polishing, the specimens were washed and stored in distilled water at 37ºC. The average surface roughness (Ra, µm) of each specimen was measured at three days and three months by a surface profilometer (Surftest SV-400, Mitutoyo, Kanagawa, Japan). Readings were taken at the center of the specimens. Four sampling lengths of 0.25 mm were used, giving a total evaluation length of 1 mm. The profilometer was accurate to 0.01 µm. Profile tracings of

Table 2: *Mean Ra Values (µm)and Standard Deviations for the Different Materials at the Two Time Intervals*

Material	3 Days	3 Months
Reactmer	0.15 (0.03)	0.15 (0.03)
Spectrum TPH	0.12 (0.02)	0.12 (0.03)
Dyract AP	0.19 (0.07)	0.19 (0.05)
Fuji II (Capsulated)	0.29 (0.02)	0.32 (0.05)
Fuji II LC (Capsulated)	0.35 (0.03)	0.36 (0.03)

Standard deviations in parenthesis.

Table 3: *Results of Statistical Analysis*

	Comparison Between Materials
3 days	Fuji II & Fuji II LC > Reactmer, Spectrum and Dyract
3 months	Fuji II & Fuji II LC > Reactmer, Spectrum and Dyract
	Comparison Between Time Intervals
Reactmer	NS
Spectrum TPH	NS
Dyract AP	NS
Fuji II	NS
Fuji II LC	NS

> indicates statistically significant difference in Ra values (results on one-way ANOVA/Scheffe's post-hoc test or independent samples *t*-test). NS indicates no statistically significant difference.

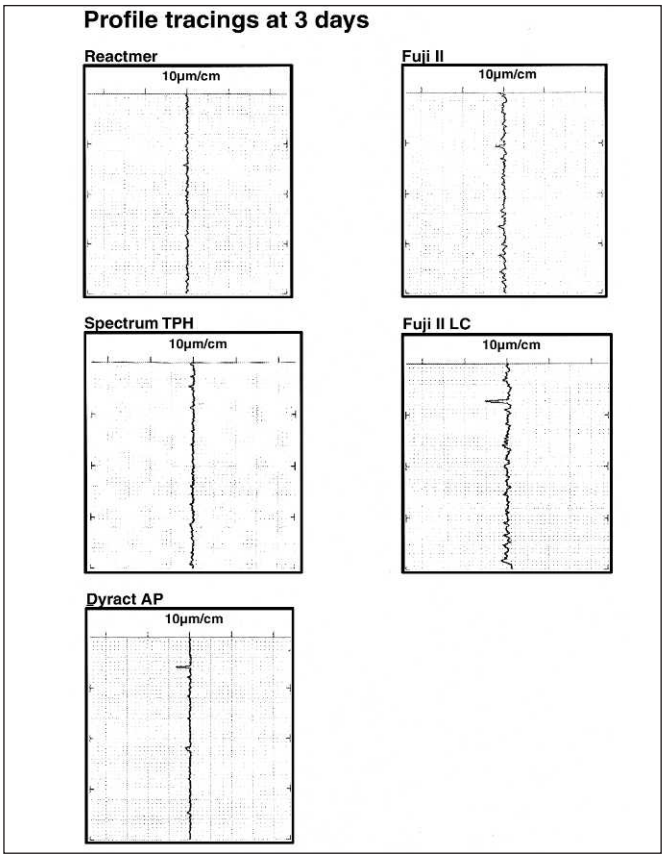

Figure 1. *Profile tracings at three days.*

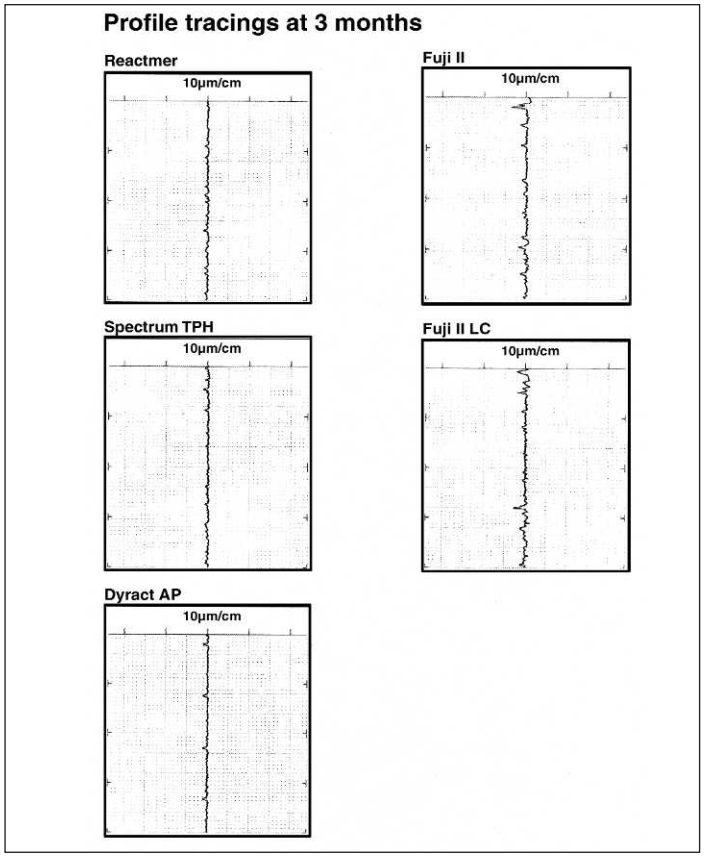

Figure 2. *Profile tracings at three months.*

representative specimens were obtained at x1000 vertical and x50 horizontal magnification. Storage medium during the hiatus period was distilled water at 37ºC. All statistical analysis was carried out at significance level 0.05. One-way ANOVA and Scheffe's post-hoc tests were used to compare the surface finish of the materials, while independent samples *t*-tests was employed to evaluate the effects of time on surface finish.

RESULTS

The mean Ra values for the different materials at the two time intervals are shown in Table 2. Results of statistical analysis are reflected in Table 3. Figures 1 and 2 show the profile tracings of representative specimens at three days and three months, respectively.

The ranking of mean Ra values by materials were identical at both time periods and were as follows: Fuji II LC > Fuji II > Dyract > Reactmer > Spectrum. At three days and three months, Fuji II LC and Fuji II were significantly rougher than the other materials. Mean Ra values ranged from 0.12 to 0.35 µm at three days and 0.12 to 0.36 µm at three months. No significant difference in surface roughness was observed between the two time intervals for all materials evaluated.

Profile tracings were consistent with mean Ra values obtained. At three days and three months, Reactmer and Spectrum showed relatively flat profiles with peak and valley heights of less than 1 µm. The Dyract profile was also moderately flat at both time periods. Valleys of 1-to-3 µm were, however, observed. The profile tracings of the glass ionomer cements were more irregular. Valleys of 1-to-5 µm were observed for both conventional and resin-modified glass ionomer cements at both time periods.

DISCUSSION

The materials evaluated in this study represent the entire continuum of direct aesthetic restorative materials currently available to the dental practitioner. Although Reactmer has been called a light-cure, one pack glass-ionomer restorative by the manufacturer, it should be considered a composite as it does not have a significant acid-base reaction as part of its curing process and cannot set in the dark (Tay, 1995). Compomers or polyacid-modified composites are defined as materials that contain either or both of the essential components of a glass ionomer cement but at levels insufficient to promote the acid-base cure reaction in the dark (McLean, Nicholson & Wilson, 1994). Although giomers contain both essential components of glass ionomer cements, they cannot be classified as compomers as the acid-base reaction has already occurred. The term PRG (pre-reacted glass ionomer) composite is suggested to describe giomers. For composites, compomers, conventional and resin-modified glass ionomer cements, the smoothest surfaces were produced when the materials were allowed to cure against a matrix (Yap & others, 1997; Hondrum & Fernandez, 1997; Stoddard & Johnson, 1991). Despite careful placement of matrixes, removing excess material and re-contouring restorations is often clinically necessary. This will require some degree of finishing and polishing, which will violate the smoothness obtained with a matrix (Lui & Low, 1982). An abrasive disc system was selected for finishing/polishing, as it provided the smoothest finished surfaces for most of the materials evaluated (Hoelscher & others, 1998; Yap & others, 1997; Hondrum & Fernandez, 1997; St Germain & Meiers, 1996). Strict adherence to manufacturers' instructions on finishing/polishing procedures was observed as improper application of the discs could lead to decreased effectiveness. Every effort was also made to standardize the finishing/polishing procedure, including controlling the number of strokes and the contact duration of each stroke, using only one evaluator for finishing/polishing procedures. Finishing/polishing was delayed for one week to allow for post-irradiation hardening of composites and maturation of the glass ionomer cements (Wan, Yap & Hastings, 1999; Yap, 1997; Leung, Adishian & Johnston, 1985).

Ra is the arithmetic mean of the absolute values of the distances from the mean line to the profile. The various phases of the materials evaluated differ in hardness and do not abrade uniformly. Valleys on the profile tracings may indicate the areas removed by the coated abrasives or the dislodgement of filler or glass particles. Ra measurements at three days showed significant differences in surface roughness between materials. The conventional and resin-modified glass ionomer cements were significantly rougher than the giomer, composite and compomer. No significant differences in surface roughness were observed among the latter three materials. Results may be explained in part by the microstructure and the mean particle size of the restorative materials. The materials evaluated can be considered biphasic, with one phase embedded in the other. Glass ionomers consist of glass particles in a hydrogel matrix, and composites consist of glass fillers embedded in a polymer resin. During finishing/polishing, there is preferential removal of the softer resin or hydrogel matrix between the harder glass particle/fillers. Eventually, the glass particles/fillers are left unsupported and are displaced. Materials with large glass particle/filler sizes are therefore expected to be rougher after finishing. The mean particle size of the giomer (not inclusive of the PRG particles), composite and compomer are all below 1 µm according to manufacturers' data. The mean particle size of the glass ionomers evaluated is approximately four times greater. Fuji II has a mean particle size of 4.4 µm while Fuji II LC has a particle size of 4.8 µm. Profile tracings

support the above-mentioned propositions. Valley depths generally corresponded well to the size of the glass particles and/or fillers utilized in the various materials. Valleys of up to 3 μm in Dyract AP can be accounted for by the use of strontium fluorosilicate glass particles (2.5 μm in size) for fluoride release. The size and volume fraction of PRG particles in Reactmer is not known.

The surface finish of the different restorative materials may be affected by long-term exposure to water. The resin-matrix of composites and resin-modified glass ionomer cements has been shown to absorb a small percentage of water (Martin & Jedynakiewicz, 1998; Iwami & others, 1998; Kanchanavasita, Anstice & Pearson, 1997; Yap, 1996). Silicate glass particles and fillers have irregularly distributed Si-O-Si bonds. On exposure to water, the resin matrix swells due to water sorption and introduces radial tensile stresses at the glass-matrix interfaces. The high energy levels resulting from strained Si-O-Si bonds make the glass particles/fillers more susceptible to stress corrosion attack (Söderholm, 1983). Complete or partial debonding of the fillers may occur due to stress corrosion at the surface layers, resulting in increased surface roughness. Results of statistical analysis at three months were identical to that at three days. The glass ionomer cements were found to be significantly rougher than other materials evaluated. No significant difference in Ra values was observed between the two time periods for all materials. Although the quality of surface finish for all materials was not significantly affected by long-term storage in water, more investigations are required before conclusions can be made regarding the clinical durability of the surface finish. Patients' diet (chemical environment), topical fluoride treatments and cyclic temperature changes may affect the surface roughness of the restorative evaluated (Yip, Peng & Smales, 2001; Yap, Low & Ong, 2000). Clinical data has showed that hybrid materials, especially resin-modified glass ionomer cements, appear rough/dull or lose their surface texture after one-and-a-half to three years (Folwaczny & others, 2001; Gladys & others, 1999; Duke & Trevino, 1998).

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The surface finish of the giomer was significantly better than the conventional and resin-modified glass ionomer cements evaluated.
2. The surface finish of the giomer was comparable to that of the composite and compomer evaluated.
3. The quality of surface finish for all materials was not significantly affected by long-term storage in water.

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References

Chan KC, Fuller JL & Hormati AA (1980) The ability of foods to stain two composite resins *Journal of Prosthetic Dentistry* **43(5)** 542-545.

Duke ES & Trevino DF (1998) A resin-modified glass ionomer restorative: Three-year clinical results *Journal Indiana Dental Association* **77(3)** 13-16.

Dunkin RT & Chambers DW (1983) Gingival response to Class V composite resins restoration *Journal of the American Dental Association* **106(4)** 482-484.

Folwaczny M, Loher C, Mehl A, Kunzelmann KH & Hickel R (2001) Class V lesions restored with four different tooth-colored materials 3-year results *Clinical Oral Investigations* **5(1)** 31-39.

Gladys S, Van Meerbeek B, Lambrechts P & Vanherle G (1999) Evaluation of esthetic parameters of resin-modified glass ionomer materials and a polyacid-modified resin composite in Class V cervical lesions *Quintessence International* **30(9)** 607-614.

Hoelscher DC, Neme AML, Pink FE & Hughes PJ (1998) The effect of three finishing systems on four aesthetic restorative materials *Operative Dentistry* **23(1)** 36-42.

Hondrum SO & Fernandez R (1997) Contouring, finishing and polishing Class V restorative materials *Operative Dentistry* **22(1)** 30-36.

Iwami Y, Yamamoto H, Sato W, Kawai K, Torii M & Ebisu S (1998) Weight change of various light-cured restorative materials after water immersion *Operative Dentistry* **23(3)** 132-137.

Kanchanavasita W, Anstice HM & Pearson GJ (1997) Water sorption characteristics of resin-modified glass-ionomer cements *Biomaterials* **18(4)** 343-349.

Larato DC (1972) Influence of a composite resin restoration on the gingiva *Journal of Prosthetic Dentistry* **28(4)** 402-404.

Leung RL, Adishian SR & Johnston WM (1985) Post-irradiation comparison of photo-activated composite resins *Journal of Prosthetic Dentistry* **54(5)** 645-649.

Lui JL & Low T (1982) The surface finish of the new microfill restorative materials. A scanning electron microscope study *Journal of Oral Rehabilitation* **9(1)** 67-82.

Martin N & Jedynakiewicz N (1998) Measurement of water sorption in dental composites *Biomaterials* **19(3)** 77-83.

McLean JW, Nicholson JW & Wilson AD (1994) Proposed nomenclature for glass ionomer dental cements and related materials *Quintessence International* **25(9)** 587-589.

Shintani H, Satiy J, Satou N, Hayashihara H & Inoue T (1985) Effects of various finishing methods on staining and accumulation of Streptococcus mutans HS-6 on composite resins *Dental Materials* **1(6)** 225-227.

Sidhu SK & Watson TF (1995) Resin-modified glass ionomer materials. A status report for the American Journal of Dentistry *American Journal of Dentistry* **8(1)** 59-67.

Söderholm KJM (1983) Leaking of fillers in dental composites *Journal of Dental Research* **62(2)** 126-130.

St Germain HA & Meiers JC (1996) Surface roughness of light-activated glass ionomer cement restorative materials after finishing *Operative Dentistry* **21(3)** 103-109.

Stoddard JW & Johnson GH (1991) An evaluation of polishing agents for composite resins *Journal of Prosthetic Dentistry* **65(4)** 491-495.

Strassler HE & Bauman G (1993) Current concepts in polishing composite resins *Practical Periodontics and Aesthetic Dentistry* **5(3 Supplement 1)** 12-17.

Tate WH & Powers JM (1996) Surface roughness of composites and hybrid ionomers *Operative Dentistry* **21(1)** 53-58.

Tay WM (1995) An update on glass ionomer cements *Dental Update* **22(7)** 283-286.

Wan ACA, Yap AUJ & Hastings GW (1999) Acid-base complex reactions in resin-modified and conventional glass ionomer cements *Journal of Biomedical Materials Research* (*Applied Biomaterials*) **48(5)** 700-704.

Weitman RT & Eames WB (1975) Plaque accumulation on composite surface after various finishing procedures *Journal of the American Dental Association* **91(1)** 101-106.

Wilson AD & Kent BE (1972) A new translucent cement for dentistry. The glass ionomer cement *British Dental Journal* **132(4)** 133-135.

Yap AUJ (1996) Resin-modified glass ionomer cements: A comparison of water sorption characteristics *Biomaterials* **17(19)** 1897-1900.

Yap AUJ (1997) Post-irradation hardness of resin-modified glass ionomer cements and a polyacid-modified composite *Journal of Materials Science: Materials in Medicine* **8** 413-416.

Yap AUJ, Low JS & Ong LFKL (2000) Effect of food-simulating liquids on surface characteristics of composite and polyacid-modified composite restoratives *Operative Dentistry* **25(3)** 170-176.

Yap AUJ, Lye KW & Sau CW (1997) Surface characteristics of tooth-colored restorative polished utilizing different polishing systems *Operative Dentistry* **22(3)** 260-265.

Yip KHK, Peng D & Smales RJ (2001) Effects of APF gel on the physical structure of compomers and glass ionomer cements *Operative Dentistry* **26(3)** 231-238.

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The Influence of Dental Alloys on Three-Body Wear of Human Enamel and Dentin in an Inlay-Like Situation

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Clinical Relevance

When considering three-body abrasion, a soft gold alloy for inlays can be recommended since the wear rate of the gold alloy corresponds to that of human enamel.

SUMMARY

This in vitro **study evaluated the effect of metal alloys on three-body wear resistance of enamel and dentin, and vice versa. Three-body wear of human enamel, dentin, a soft gold alloy (BiOcclus Inlay), a CoCr alloy (Remanium 2000), a resin cement (Variolink II) and a zinc oxide phosphate cement (Harvard) was investigated using the ACTA-machine. Sample chambers of eight sample wheels were prepared with pure materials or combinations of human tooth substance, alloys and cement, simulating an inlay-like situation. After 100,000 and 200,000 cycles in a millet suspension with a spring force of 20 N, the amount of abraded material was profilometrically measured and evaluated by 3D surface data analysis. After 200,000 cycles, the materials demonstrated a mean loss of 0.41 µm for CoCr, 51 µm for gold, 57 µm for enamel, 164 µm for dentin, 79 µm for Variolink and 369 µm for Harvard. Using ANOVA and the Games-Howell-test, resin cement, enamel and gold were a subset not shown to differ, as was zinc phosphate cement and dentin. CoCr demonstrated the least wear and differed significantly from all materials. Enamel wear was significantly reduced in mixed chambers with CoCr and gold after 200,000 cycles compared to enamel in pure chambers. In summary, a soft gold alloy can be recommended for inlays when considering three-body abrasion since the wear rate of the "soft" gold alloy corresponded to that of human enamel.**

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INTRODUCTION

Wear of human tooth structure is a natural process that is frequently caused by the abrasive action of certain foods and antagonistic tooth contacts. Often, abrasion is also accelerated by pathological procedures such as bruxism and acids (Hickel, 1989). Sometimes, artificial denture materials also change the natural wear pattern of teeth. Differences in the wear characteristics of natural teeth and restorative materials may cause abrasion. Discrepancies between the tooth surface and the

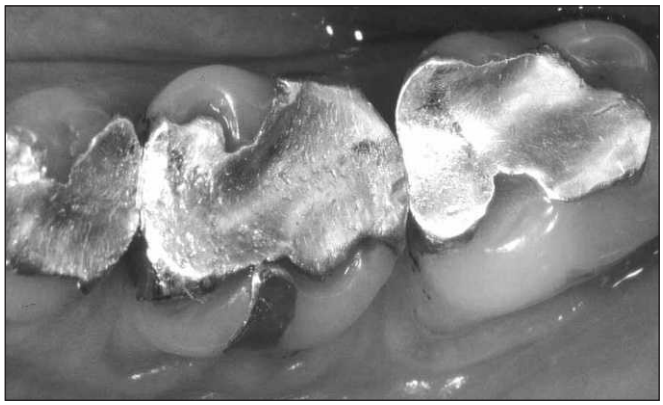

Figure 1. *Clinical wear of a 15-year-old gold inlay ("soft gold alloy").*

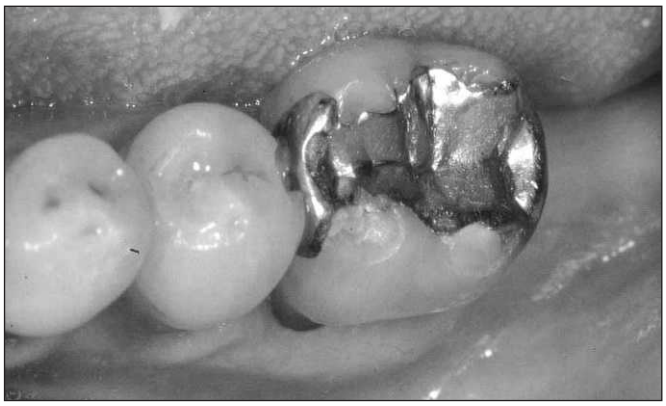

Figure 2. *Fracture of enamel adjacent to an inlay made from a "hard"gold alloy.*

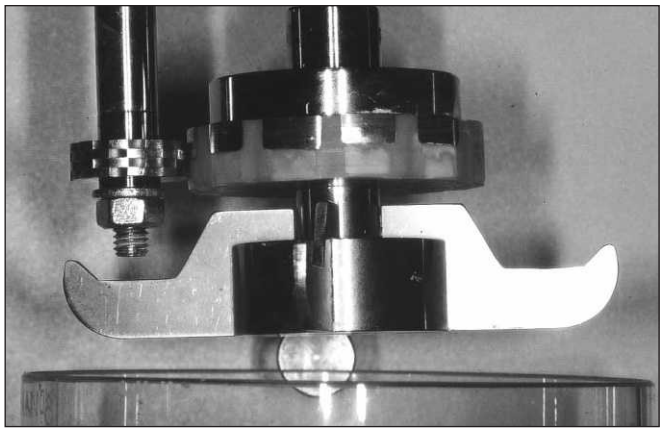

Figure 3. *Sample wheel with mixed chambers and antagonist wheel.*

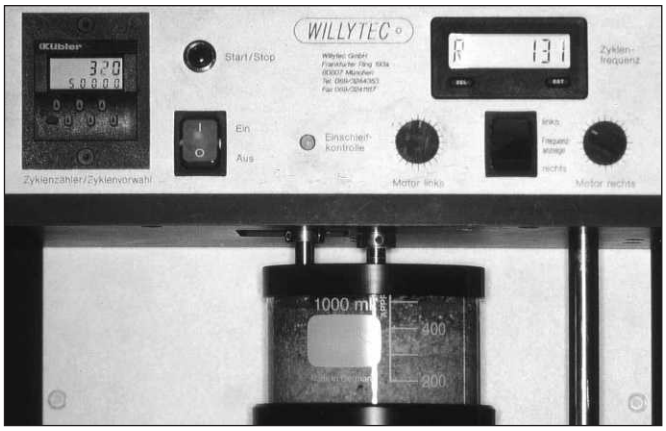

Figure 4. *ACTA-machine with the sample wheel in a millet seed suspension.*

restoration can also lead to accelerated wear, and less wear resistance of restorative materials can result in a loss of occlusal contact, with the sequellae of supraeruption of the antagonist and the emergence of occlusal interferences.

When a metallic inlay restoration is seated and cemented, there is a cement gap of varying sizes between the restoration and the adjacent enamel finish line. With occlusal function, problems with inlays can occur with the fracture of enamel adjacent to the casting margin or from a discrepancy in the restoration-enamel height (Figures 1 and 2).

Wear resistance is an important parameter for the long-term durability of inlay restorations. *In vitro* wear research on restorative materials has advanced considerably in the past decade, especially following failure of early resin composite generations and with applying glass ionomer in occlusal, stress-bearing areas of posterior teeth (Johnson & others, 1992; Roulet, 1997; Bauer, Kunzelmann & Hickel, 1995; Bauer, Kunzelmann & Hickel, 1996). Often, materials were recommended and placed with little clinical evidence regarding their efficacy. To better predict the abrasion behavior of these materials, a variety of chewing simulators and other *in vitro* test instruments were developed. These wear machines have been designed to simulate two-body abrasion (for example, "pin-on-disc"-simulators, Rice & others, 1982; Soltez & others, 1979) or three-body abrasion, such as toothbrushing machines (Krejci & Lutz, 1990) and the ACTA-machine (de Gee, Pallav & Davidson, 1986).

The ACTA-machine, developed by de Gee and others (de Gee & others, 1986; de Gee & Pallav, 1994), consists of two motor-driven, individually-controlled wheels that rotate against each other. During the abrasion experiment the two wheels rotate in a bowl containing an abrasion medium, usually a millet seed suspension (Krämer & others, 1997). The antagonist wheel consists of stainless steel with honeycomb-like transportation fields to entrap the abrasion medium. In order to simulate the sliding action of opposing teeth, the rotational surface speeds differ by 20%.

Extensive three-body wear data exists for composite filling materials, but little data is available for the wear of human teeth. The published *in vivo* wear of enamel ranges from 15 µm to 94 µm per year (Christensen, Smith & Aina, 2000; Ishizaki & others, 2000;

Lambrechts & others, 1989; Willems & others, 1993). For human dentin and casting alloys, there are no comparable *in vivo* or *in vitro* wear values in the literature. It is also devoid of information regarding the reciprocal effects of restorative materials and hard tooth structure.

This *in vitro* study investigated the effect of metal alloys and luting agents on three-body wear resistance of human enamel and dentin and vice versa.

METHODS AND MATERIALS

The ACTA-machine developed by de Gee and others (Bauer & others, 1996; de Gee & others, 1986) was used for simulation of the three-body abrasion (Figures 3 and 4). The wear of six materials was assessed, individually, then as restorative systems. The test materials were 1) human enamel, 2) human dentin, 3) a soft gold alloy (BiOcclus Inlay, Degussa, Hanau), 4) the hard CoCr alloy (Remanium 2000, Dentaurum, Ispringen), 5) the luting cement (Variolink II, Vivadent, Ellwangen) and 6) a zinc phosphate cement (Harvard, Richter, Berlin). BiOcclus Inlay is a soft Type 2 alloy with HV 5 and a dense of 17.4 g/cm^3. Eight 12-chamber sample wheels were prepared as solo materials or in combination with human enamel and dentin, two different luting agents and two alloys. Table 1 shows the experimental groups. The rectangular chambers of the sample wheel were filled in two steps with composite filling material. To create a round base wheel, the surface of the sample wheel was coated with a microglass composite (Charisma F, Heraeus Kulzer, Wehrheim) using a curved-jig, then it was light-cured. Rectangular-shaped segments were harvested from the buccal or lingual areas of extracted molars that were trimmed and placed into the recesses of chambers containing the Charisma F composite. The enamel was then bonded using an acid etching technique and mounted at the surface. To obtain a round sample wheel, the surface was ground in the ACTA machine. The antagonist wheel of the ACTA machine was replaced with wheels suitable for grinding. CoCr and gold inlays were made using the lost wax technique and then secured adjacent to the hard tooth structure on the sample wheel. To create a standardized cement gap, a cement space was created using a 250 µm thick foil between the inlay and the hard tooth structure. Thereafter, the gap was filled with zinc phosphate or resin composite cement. For resin cement, the enamel was etched in one case for 30-60 seconds using 39% phosphoric acid. In the other case, no enamel etching was employed. For this reason there were three types of cement gaps. The sample wheels were stored in a 0.1% thymol solution until wear testing commenced.

After the restorative material and cement were placed, the wheels were again ground in the ACTA-machine. Since hardness of the different materials varied, it was not possible to obtain a perfectly round surface. Therefore, baseline data was taken for each sample using the DMA-MESS profilometric system (Fa Willytec, Munich) before beginning the abrasion experiment. The distance between measuring points was 100 µm, the number of measuring points per line was 90, the number of the series of measurements per sample was 40, which resulted in 3,600 measuring points for each sample. Thereafter, the samples were subjected to 200,000 cycles of wear using a spring force of 20 N. A millet suspension was used to simulate food or the third body. The suspension was always renewed after 50,000 cycles to avoid a waxy layer on the surface of the wheel (Pallav & others, 1993). In addition, the pH of the solution was regularly monitored and controlled.

Profilometric measurements were again made for each specimen after 100,000 and 200,000 cycles. The wear data were matched with that of the first profilometric measurement using the Match3D software (Mehl & others, 1979). Using on-screen projections of the surfaces, areas of interest on a sample could be marked and evaluated separately. The mean abrasion values of the individual samples were obtained from a data matrix and analyzed with the statistical program SPSS/PC.

A two-factor analysis of variance was first conducted with material and cycles as the factors. Since there were significant cross-product interactions between the material and cycles, one-factor analysis of variance was employed for 100,000 and separately for 200,000 cycles of wear. Since Levene's test of homogeneity of variance was significant, the Games-Howell test (SPSS, 1999) for unequal variances was employed to

Table 1: *Distribution of the Experimental Groups*

Experimental Material	Adjacent Material	Cement	Conditioning
Enamel	gold	ZP	no
	gold	Resin	no
	gold	Resin	acid etched
	CoCr	ZP	no
	CoCr	Resin	no
	CoCr	Resin	acid etched
Gold	enamel	ZP	no
	enamel	Resin	no
	enamel	Resin	acid etched
CoCr	enamel	ZP	no
	enamel	Resin	no
	enamel	Resin	acid etched

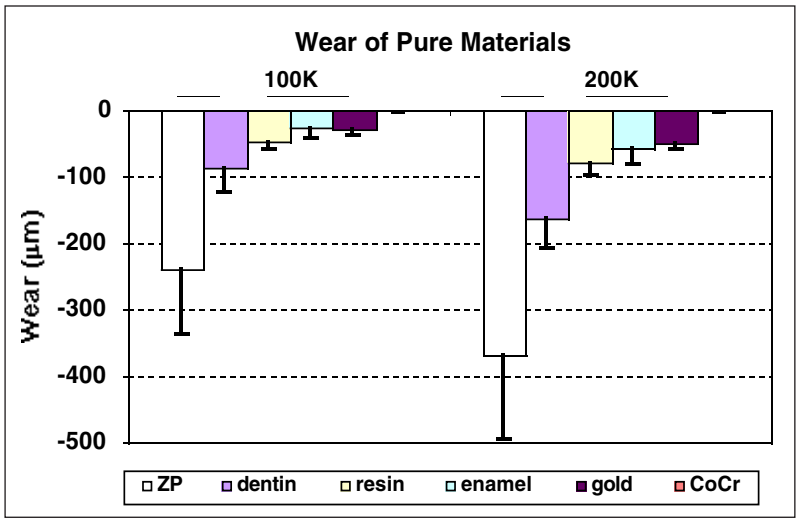

Figure 5. *Wear of pure materials after 100,000 and 200,000 cyles in the ACTA-machine (the vertical loss of material is marked with negative values).*

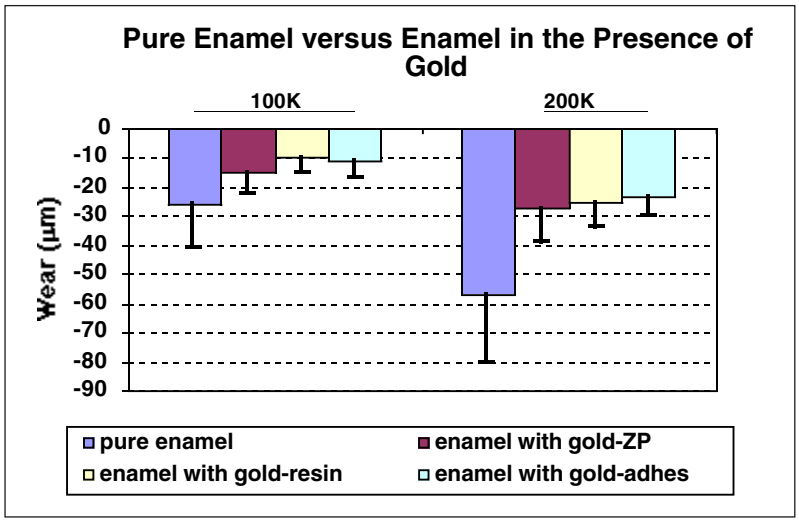

Figure 6. *Pure enamel versus enamel in the presence of gold after 100,000 and 200,000 cycles (the vertical loss of material is indicated by negative values).*

locate differences among materials. All hypothesis testing was conducted at α=0.05. The Chi square test of association was used for the visual, qualitative evaluation of the destruction of the cement lines.

After 200,0000 cycles of abrasion, scanning electron microscopic (SEM) photomicrographs were made of selected samples. Each gap was evaluated with the Match3D software according to worst-case principle. When measuring the depth of the gap, the additional wear of the cement relative to the adjacent surfaces (that is, enamel, metal, etc) was measured in three places from which a mean value was recorded. In addition, the gaps were examined with a light-microscope at a magnification of x20, whereby the continuity of the cement line was qualitatively evaluated. A scale with five different variations was used: completely intact cement gap (with or without little traces of abrasion), cement gap not less than 90% intact (pieces of the gap broke out), 50-90% of the gap intact, less than 50% intact gap and completely destroyed gap.

RESULTS

Figure 5 shows distinct differences for abrasive wear among pure materials, and there were identical statistical groupings for 100,000 and 200,000 cycles. After 100,000 cycles of abrasion, CoCr demonstrated virtually no wear, whereas zinc phosphate cement showed a mean loss of 217 µm, dentin was 86 µm, resin cement was 47 µm and enamel was 26 µm. Using ANOVA and the Games-Howell-test (SPSS, 1999) for mean comparisons, resin cement, enamel and gold were a subset not shown to differ, as was zinc phosphate cement and dentin. CoCr demonstrated the least wear and differed significantly from all materials. A significant difference could not be demonstrated between zinc phosphate cement and dentin, even though the means were quite different since the standard deviation associated with zinc phosphate was high relative to other materials.

After 200,000 abrasion cycles, CoCr showed a minimal abrasion of 0.41 µm. The other materials exhibited a loss of material approximately double that shown for 100,000 cycles. The statistical grouping for 200,000 cycles was the same as that for 100,000 cycles.

The wear values for the pure materials were also compared with wear observed in the mixed chambers. Figure 6 shows the wear for pure enamel compared to enamel in the presence of a cemented gold casting and Figure 7 shows wear in the presence of a cemented CoCr casting. After 100,000 cycles, pure enamel versus enamel in the presence of gold demonstrated no differences for all three cement variations (Figure 6). After 200,000 cycles, the mean abrasion of pure enamel (57 µm) was significantly greater than enamel wear for the three cement combinations of enamel in the presence of a gold casting (23-27 µm). Pure enamel demonstrated greater wear than enamel in the presence of CoCr for both 100,000 and 200,000 cycles (Figure 7). For 200,000 cycles, the wear values were approximately double that of 100,000 cycles. In both cases, there were no differences in enamel wear by cements. No differences were shown for pure gold and gold in the presence enamel and luting materials at either 100,000 or 200,000 cycles (Figure 8). The mean values were quite similar and increased only modestly with an increase in cycles. Figure 9 shows the wear of pure CoCr and CoCr in the presence of enamel and luting systems. The magnitude

of wear is very low in all cases, and the magnitudes are similar for both 100,000 and 200,000 cycles. No statistical differences were detected.

On the SEM photomicrograph of a complete mixed chamber (Figure 10), the inlay-like structure of the mixed chambers with metal casting, the cement gap and the tooth hard substance (enamel, dentin) can be seen. Evaluation of the SEM photomicrographs for gold clearly showed visible grooves after 200,000 cycles of abrasion in the ACTA machine. One can recognize cutting traces and "chips" and note a clear difference between abraded and non-abraded material (Figure 11). The hard CoCr alloy showed clear traces after 200,000 cycles, but they were artifactual since they arose from longitudinal grinding during sample preparation. Very few surface changes were found that could be attributed to the abrasion process (Figures 12 and 13). The SEM photomicrograph (Figure 14) shows zinc phosphate cement as very coarse grained and inhomogeneous, and the continuity between enamel and cement was interrupted. Enamel, after 200,000 cycles of abrasion, showed a relatively smooth surface with small fractures (Figure 15).

The width of the joint was standardized using a foil that had a thickness of 250 µm. With sample preparation, the width of the gaps was actually somewhat larger. The mean width was 353 µm for zinc phosphate cement, 367 µm for resin without adhesive and 345 µm for adhesive resin cement. Since the distance between points measured with this technique was 100 µm, maximally, 3 x 3 data points were possible for measuring the depth. Thus, few values were measured with evaluation of the cement line compared to other evaluation schemes. The statistic evaluation was not significant for width ($p>0.05$) or depth ($p>0.05$) among cement line types.

Table 2 shows the results of the qualitative evaluation of the cement gap. For the cement line of zinc phosphate, all (100%) spaces evaluated were completely destroyed after 200,000 cycles of the abrasion test and it was not possible to evaluate two of the cement lines, the reason was that a section of the specimen was lost. For bonded resin cement, most cement lines were classified as completely or 90% intact (70%). In contrast, only four (36%) of the resin cement lines without bonding were placed in these two categories. The χ^2 comparison for the joint quality of the two resin cement lines was not significant ($p=0.246$), but there was a significant difference between two resin cement lines and zinc phosphate cement (χ^2, $p=0.001$).

Match3D software measured wear in the cement lines according to the worst-case principle where, for each line, the three places with the greatest

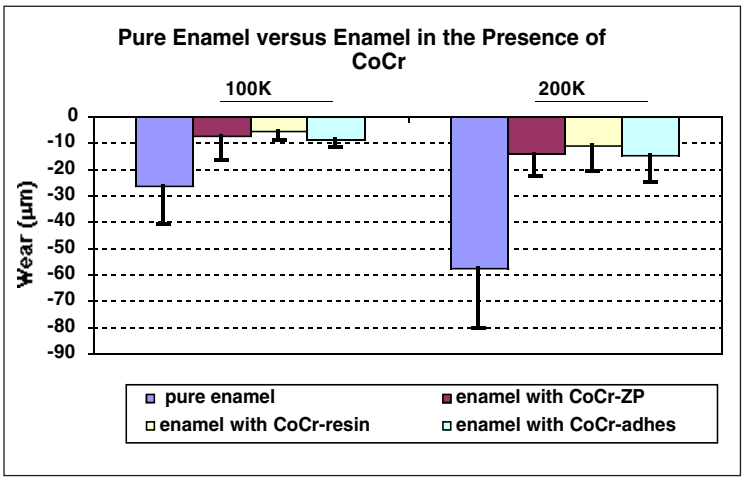

Figure 7. *Pure Enamel versus Enamel in the Presence CoCr after 100,000 and 200,000 cycles (the vertical loss of material is indicated by negative values).*

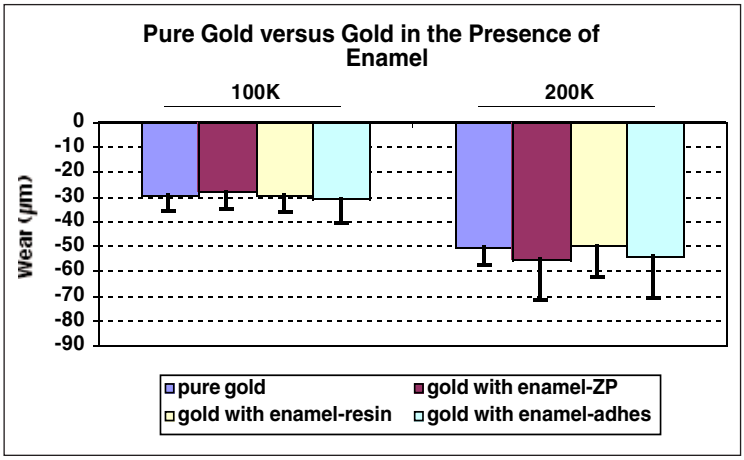

Figure 8. *Pure Gold versus Gold in the presence of Enamel after 100,000 and 200,000 cyles (the vertical loss of material is indicated by negative values).*

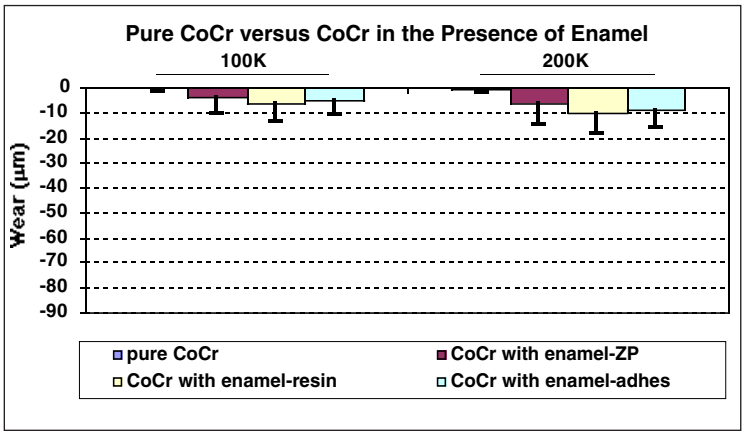

Figure 9. *Pure CoCr versus CoCr in the presence of Enamel after 100,000 and 200,000 cyles (the vertical loss of material is indicated by negative values).*

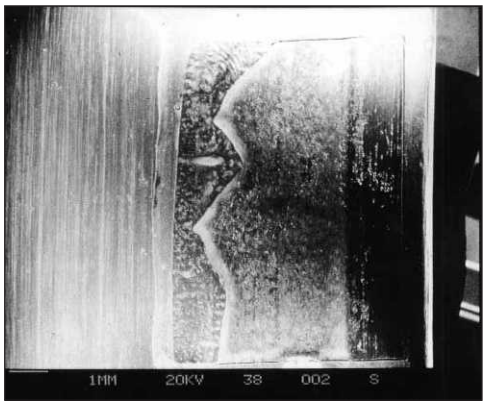

Figure 10. *SEM micrograph of an abraded mixed chamber.*

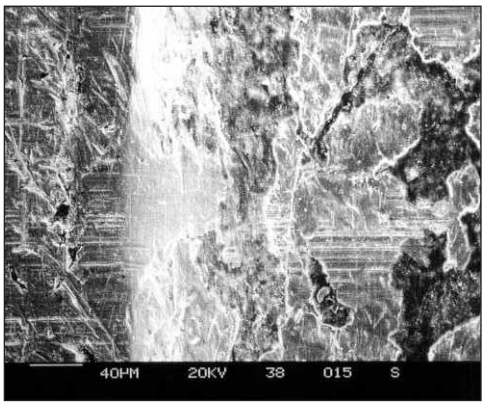

Figure 11. *Gold sample after 200,000 cycles, not abraded margin, abraded region with cutting traces and "chips."*

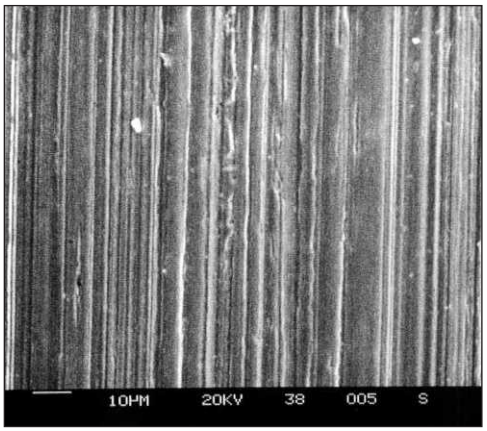

Figure 12. *CoCr sample before abrasion with traces from the grinding process.*

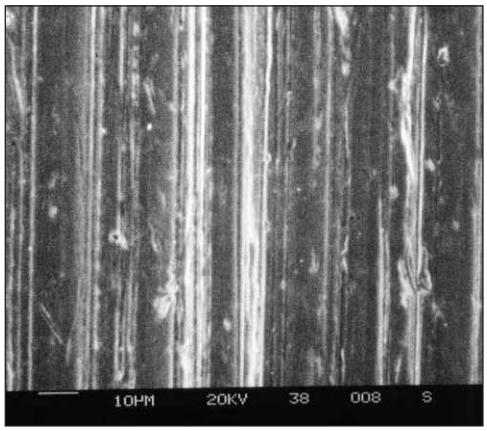

Figure 13. *CoCr after 200,000 cycles demonstrating minimal surface changes.*

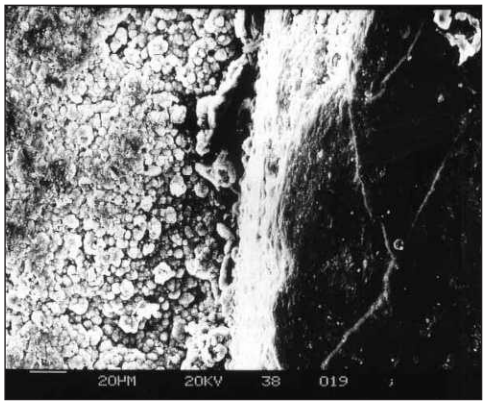

Figure 14. *Zinc-phospate cement after 200,000 cycles very coarse-grained and inhomogeneous.*

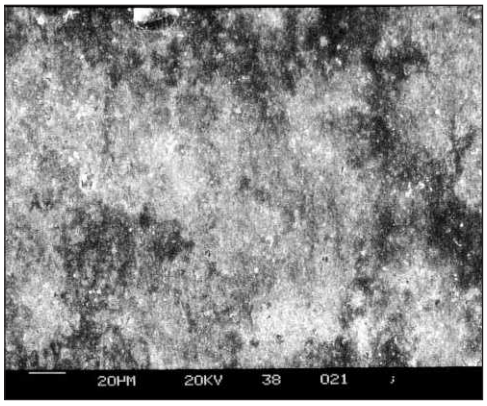

Figure 15. *Smooth surface of enamel after 200,000 cycles of abrasion.*

destruction were evaluated. This principle was used since the greatest area of destruction of a cement line is clinically most relevant. The maximum depth after 200,000 cycles, regardless of the type of joint, was around 27 µm. This value reflects the additional wear of the cement line material compared with the adjacent limiting materials.

DISCUSSION

The three-body-wear test of de Gee and others (de Gee & others, 1986; de Gee & Pallav, 1994) is considered to be an international standard for the simulation of food abrasion. The main abrasion mechanisms of the ACTA machine are material fatigue, abrasion by phytolithes (Gügel, 1998) and pH-dependent solution procedures. Millet seeds contain phytolithes (plant opals) that are similar to inorganic silica and are found in different morphologic types and contain very sharp edges. The abrasion is most likely caused by the effects of phytolithes, fatigue and pH changes in the solution (Kunzelmann, 1998). Decomposition of bacteria in the millet solution can lead to the dissolution of enamel due to a decrease in pH. In this experimental setup, the pH of the solution was controlled by replacing the millet suspension after every 50,000 cycles of wear. Only a minor decrease in pH, from 6.5 to 6.0, was noted after 50,000 cycles.

For pure materials after 200,000 cycles, CoCr was shown to be the most abrasion-resistant material. Under the conditions of three-body-wear, the abrasion behavior of gold, enamel and resin cement were quite similar. Dentin and zinc-phosphate cement demonstrated more wear than these three. Since mainly composite, amalgam and glass ionomer cement have been evaluated with the ACTA-machine to date (Bauer, & others, 1995; Bauer & others, 1996; de Gee & others, 1986; Pallav & others, 1989), few reference values could be extracted from the literature for the materials tested in this study. Comparable results are noted with work by Pelka & others, 1998, using comparable

Table 2. *Qualitative Evaluation of the Degree of Destruction of the Cement Line After 200,000 Cycles of Wear*

Cement Gap	100% Intact	90% Intact	50-90% Intact	< 50% Intact	Completely Destroyed	Total Evaluated	Incapable of Evaluation
Resin cement–bonded	1 (8%)	8 (62%)	3 (23%)	1 (8%)	0 (0%)	13	3
Resin cement–not bonded	0 (0%)	4 (36%)	7 (64%)	0 (0%)	0 (0%)	11	5
Zinc phosphate	0 (0%)	0 (0%)	0 (0%)	0 (0%)	14 (100%)	14	2

The first number in each cell reflects frequency observed and the number in parentheses is the relative percent observed for a particular cement line.

methodology. They found the lowest abrasion rates for ceramic (Empress), followed by gold and the highest for composite (Charisma). Enamel was shown to have the highest abrasion rates, but this result was artifactual since the reported wear included dentinal wear and enamel. Through interactive computation of wear values in this study using the Match3D software, only areas of intact enamel were taken into consideration for wear assessment.

In another *in vitro* study (Gügel, 1998), wear of human enamel ranged from 34 µm to 49 µm after 200,000 cycles. The contact pressure was 15 N compared to 20 N in this study, and the differential velocity of the two sample wheels was 5% less than that employed in this study. The higher values for enamel wear in the current study (61 µm) may be caused by these differences.

A clinically interesting aspect of this study was to investigate the influence of adjacent casting and luting cement on enamel wear and vice versa. When enamel was abraded in the presence of a gold or CoCr casting, there was a self-protection effect provided by the casting since pure enamel demonstrated significantly more wear compared to enamel adjacent to a casting. Regarding enamel abrasion, the presence or absence of bonding and the type of cement had little effect on wear.

Enamel combined with CoCr was shown to be clearly less abraded for all cement types than enamel combined with gold. After 200,000 cycles, the wear of enamel in the presence of a CoCr casting was about half (15 µm) that of enamel in the presence of gold (27 µm). The strong protective effect of CoCr on the adjacent enamel was independent of the type of cement line.

Clinically, these results tend to support a conservative approach to inlay preparation form. In areas where there is strong masticatory function, it may not be necessary for the finish line to be extended to cover the complete area of occlusal function (that is, wear facets) since the casting provides a protective effect for the enamel. Another clinical region of interest is the marginal ridge. If a natural tooth is approximal to a metal casting, the metal may provide a protective effect to the marginal ridge of the tooth and vice versa. On the other hand, the abrasion of gold and enamel were found to be similar and no steps or discrepancies between casting and enamel should occur with occlusal function. However, there is still no answer for two-body-wear effects.

There were some limitations to this study. For quantitative measurement of the depth of the cement line, the profilometer supplied only few values within this area, which is statistically unfavorable. Second, it is possible that the tip of the profilometer did not always engage the complete depth of the cement line, leading to values that were too small compared to the actual depth. In a previous study aimed at assessing abrasion of cement lines (Frankenberger & others, 1996), the samples were also profilometrically measured. That author mentioned this problem with measuring, but no solution was offered. The qualitative evaluation in the current study showed a clear difference among the three types of cement lines. After 200,000 cycles, the condition of the resin adhesive cement gap was best. The adhesive cementing mode appeared to protect the cement line best against influences of the three-body abrasion. The unetched resin cement lines showed more traces of abrasion. For zinc phosphate cement, all cement lines were completely destroyed after 200,000 cycles. This shows that three-body abrasion caused significantly greater destruction to the zinc phosphate cement line compared to resin luting cement. Several investigations for cement line wear have been conducted with the ACTA-machine (Frankenberger & others, 1996; Noack & de Gee, 1992; Shinkai & others, 1995), however, not one investigated the differences in cementing procedures.

CONCLUSIONS

In summary, a soft gold alloy for inlays can be recommended when considering three-body abrasion since the wear rate of gold corresponded to that of human enamel. Due to the greater wear of zinc phosphate cement, using resin cement is preferred when mastication may have a strong influence on the cement line. For final clinical recommendations, however, the influence of two-body abrasion should also be examined and

clinical data for the effects of both abrasion mechanisms must be ascertained.

Acknowledgements

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References

Bauer CM, Kunzelmann KH & Hickel R (1995) Simulated wear of composite materials and ormoceres (in German) *Deutsche Zahnärztliche Zeitung* **50** 635-638.

Bauer CM, Kunzelmann KH & Hickel R (1996) Silico-phosphate-cements and glass ionomer cements—a substitute for amalgam? (in German) *Deutsche Zahnärztliche Zeitung* **51** 339-341.

Christensen R, Smith SL & Aina TC (2000) Quantifying Wear in Human Adult Teeth, *in vivo*—2-Year Report *Journal of Dental Research* **79** 543 (Abstract #3196).

de Gee AJ, Pallav P & Davidson CL (1986) Effect of abrasion medium on wear of stress-bearing composites and amalgam *in vitro Journal of Dental Research* **65(5)** 654-658.

de Gee AJ & Pallav P (1994) Occlusal wear simulation with the ACTA wear machine *Journal of Dentistry* **22(Supplement 1)** 21-27.

Frankenberger R, Krämer N, Hahn C, Sindel J & Pelka M (1996) *In vivo* analysis of luting film abrasion of adhesive inlays *Deutsche Zahnärztliche Zeitung* **51** 591-594.

Güegel IR (1998) *Simulationsversuch von Microwear mit Merkmalsvergleichen an Frühmittelalterlichen* Molaren Diplomarbeit Mikrobiologie Munich, Germany.

Hickel R (1989) Forschungsbericht Zahnabrasion: Zahnabrasion und beruflich bedingte Einflüsse bei Steinbrucharbeitern, *Schriftenreihe des Hauptverbandes der gewerblichen Berufsgenossenschaften*.

Ishizaki H, Fukushima M, Makino H & Iwaku M (2000) Relationship between occlusal force and enamel wear in caries-free dentition *Journal of Dental Research* **79 (**Abstract #3195).

Johnson GH, Bales DJ, Gordon GE & Powell EV (1992) Clinical performance of posterior composite resin restorations *Quintessence International* **23(10)** 705-711.

Krämer N, Pelka M, Kautetzky P, Sindel J & Petschelt A (1997) Wear resistance of compomers and condensable glass ionomer cements (GIC) (in German) *Deutsche Zahnärztliche Zeitung* **52** 186-189.

Krejci I & Lutz F (1990) *In-vitro* test for evaluation of dental restorative systems. 2. toothbrush/toothpaste abrasion and chemical disintegration *Schweizer Monatsschrift für Zahnmedizin* **100** 164-1168.

Kunzelmann KH (1998) Wear analysis and—quantifying of filling materials *in vivo* and *in vitro* Shaker Verlag Aachen, Germany.

Lambrechts P, Bream M, Vuylsteke-Wausters M & Vanherle G (1989) Quantitative *in vivo* wear of human enamel *Journal of Dental Research* **68(12)** 1752-1754.

Mehl A, Gloger W, Kunzelmann KH & Hickel R (1997) A new optical 3-D device for the detection of wear *Journal of Dental Research* **76(11)** 1799-1807.

Noack MJ, de Gee AJ, Roulet JF & Davidson CL (1992) Interfacial wear of luting composites *Journal of Dental Research* **77 (**Abstract #58).

Pallav P, de Gee AJ, Davidson CL, Erickson RL & Glasspoole EA (1989) The influence of admixing microfiller to small-particle composite resin on wear, tensile strength, hardness, and surface roughness *in-vitro Journal of Dental Research* **68(3)** 489-490.

Pallav P, de Gee AJ, Werner A & Davidson CL (1993) Influence of shearing action of food on contact stress and subsequent wear of stress-bearing composites *Journal of Dental Research* **72(1)** 56-61.

Rice S, Baily WF, Pacelli P & Blanck WR (1982) Influence of enamel stylus stiffness on the sliding-wear behavior of a composite restorative *Journal of Dental Research* **61** 493-496.

Shinkai K, Suzuki S, Leinfelder KF & Katoh Y (1995) Effect of gap dimension on wear resistance of luting agents *American Journal of Dentistry* **8(3)** 149-151.

Soltez U, Klaiber B, Pergande CH & Richter H (1979) Vergleichende Untersuchungen über das Abrasionsverhalten von Composit-Füllungsmaterialien *Deutsche Zahnärztliche Zeitung* **34** 406-412.

SPSS Base 9.0 User's Guide (1999) SPSS Inc, 257.

Willems G, Lambrechts P, Braem M & Vanherle G (1993) Three-year follow-up of five posterior composites: *In vivo* wear *Journal of Dentistry* **21(2)** 74-78.

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Finishing and Polishing of a Hybrid Composite and a Heat-Pressed Glass Ceramic

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Clinical Relevance

Rotating instruments for finishing should be selected with respect to the abrasive potential of the following polishing method. After finishing in two steps, composite surfaces were efficiently polished using a diamond impregnated felt wheel and diamond gel, whereas on ceramic surfaces, a diamond impregnated rubber polisher and diamond gel yielded the best polishing results.

SUMMARY

This study assessed the finishing and polishing of a hybrid composite and a glass-ceramic. Ninety Tetric specimens were divided into three groups of 30 specimens and finished with three different finishing procedures. The 30 specimens were subsequently subdivided into six groups of five and polished using the following polishing systems: Sof-Lex disks, the Ceramiste kit, a diamond polisher, Diafix-oral, the MPS gel and the Politip system. Seventy-five IPS-Empress specimens were divided into groups of 25 and finished with three different procedures. The 25 specimens were then subdivided into five groups of five and polished with the same systems, except for the Politip technique. The polished surfaces were evaluated quantitatively by laser stylus profilometry with respect to R_a and profile-length-ratio (LR). Qualitative assessment was carried out by SEM. Quantitative results were examined statistically by one- and two-way Anova and LSD test with significance level of 0.05. The lowest roughness on composite specimens was achieved by the MPS gel and Diafix after finishing according to FM 3 and FM 2. With respect to all methods used, there were no significant differences among the five methods with the lowest Ra-values.The ceramic specimens were able to be polished to lower roughness values ($p<0.001$ for LR). The best results on ceramic surfaces were achieved with the MPS system after finishing according to FM 3 and FM 2. There were no significant differences among the three methods with the lowest Ra-values and the glazed surface.

SEM evaluation largely confirmed the quantitative results. Composite specimens exhibited signs of selective resin matrix removal when the Ceramiste system or the Politip system were used.

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INTRODUCTION

Direct composite fillings or inlays made of composites or ceramics are widely used for restoring posterior teeth where tooth-colored material is deemed appropriate.

Following placement, tooth-colored restorations require further finishing and polishing. Finishing is needed to remove excess composite material and to adjust the occlusion. Finishing also comprises the preliminary smoothening of the roughened surfaces. Final polishing reduces the remaining roughness to the lowest possible extent, using extremely fine abrasives. Polishing is of special importance because rough surfaces accumulate more plaque (Rimondini & others, 1997), show greater wear and are more abrasive towards antagonistic tooth surfaces when occluding (Jagger & Harrison, 1994). Efficient polishing prevents discoloration of rough areas and enhances the gloss and natural appearance of tooth-colored restorations. With respect to ceramics, remaining grooves after rotary instrumentation may initiate crack propagation, which can cause an early fracture of the restoration (Pospiech & others, 1998).

Flexible discs have been efficient for finishing and polishing (Hoelscher & others, 1998). Unfortunately, their use is confined to convex surfaces, thus necessitating the use of alternative techniques for anatomically structured surfaces such as the occlusal surface of posterior teeth or the lingual aspect of anterior teeth. Rigid rotary instruments such as diamonds and tungsten carbide burs have been recommended for finishing (Northeast & van Noort, 1988), using either a single rotary instrument or a sequence of burs. Rubber polishers, felt wheels and different pastes are used for polishing structured surfaces. The abrasiveness of polishing techniques varies widely and influences the degree of finishing that is necessary prior to polishing. More recently, polishing techniques have become available using diamond particles in different application forms as abrasives.

Several microfilled and hybrid composites and ceramics have been the subject of surface evaluation. Currently, there is little information about the surface characteristics of a hybrid composite containing ytterbiumtrifluoride (YbF_3) as a filler particle and a leucite-reinforced glass ceramic.

This study evaluated the effect of three finishing methods followed by six different polishing techniques on the surface of a small particle hybrid composite and of a heat-pressed glass ceramic.

METHODS AND MATERIALS

Composite Specimens

Ninety specimens were prepared from the fine particle hybrid composite Tetric (Vivadent, FL-9494 Schaan, Liechtenstein). The specimens were 6x6 mm in size with a thickness of 4 mm (Table 1). The specimens (batch #709533 and #709534) were light cured in a glass mold from both sides for 60 seconds each using the polymerization unit Optilux 400 (VCL 401; Demetron/Kerr, Danbury, CT 06810, USA). The light intensity was checked with a curing radiometer (Model 100, P/N 10503, Demetron) and was >600 mW/cm^2. After curing, the composite surfaces were ground flat under running water with abrasive paper discs of 400 and 600 grit (Leco Corporation, St Joseph, Michigan 49085, USA) for 30 seconds each. Composite specimens were stored at 100% humidity.

The specimens were divided into three groups of 30 specimens and finished with three different finishing methods (FM):

FM 1: a single 30 µm diamond

FM 2: a 30 µm diamond followed by a 20 µm diamond

FM 3: a 30 µm diamond followed by a 16-fluted tungsten carbide bur

After initial finishing, the 30 specimens were subsequently subdivided into six groups of five and polished

Table 1: *Composition of the Hybrid Composite Tetric and the Glass Ceramic IPS Empress*

Component	Portion (% by weight)
Tetric	
Bisphenol-A-Glycidyl-dimethacrylate (Bis-GMA)	7.3
Urethandimethacrylate (UDMA)	6.3
Triethylenglycoldimethacrylate (TEGDMA)	3.7
Decamethylendimethacrylate (D_3MA)	<0.1
Catalyst, stabilizers	0.2
Pigments	<0.1
Sphärosil (silane treated)	16.5
Siliconoxide (SiO_2, silane treated)	3.8
Barium glass (silane treated)	46.8
Ytterbiumtrifluoride (YbF_3)	15.4
IPS Empress	
Siliconoxide (Si_2)	59-63
Aluminiumoxide (AL_3O_3)	19-23.5
Potassiumoxide (K_2O)	10-14
Sodiumoxide (N_2O)	3.5-6.5
Boronoxide (B_2O_3)	0-1
Ceriumoxide (CeO_2)	0-1
Calciumoxide (CaO)	0.5-3
Bariumoxide (BaO)	0-1.5
Titaniumoxide (Ti_2)	0-0.5

according to the following polishing techniques. Aluminumoxide coated Sof-Lex discs (1) served as a polishing standard (control). Ceramiste silicon points (2) pointed diamond impregnated rubber polishers (3) and Diafix-oral felt wheels impregnated with diamond particles (4) were used. The Two Striper MPS kit (5) was based on two diamond gels being applied with a rotating brush. Politip polishing points (6) were silicon carbide rubber polishers. Table 2 presents the details of the rotary instruments.

Thus, three finishing techniques followed by six polishing techniques resulted in 18 methods of rotary instrumentation on the composite specimens.

Ceramic Specimens

Seventy-five specimens (6x6 mm in size, 4 mm thick) were fabricated using the glass-ceramic IPS Empress (Ivoclar, D-73471 Ellwangen, Germany). The ceramic specimens were produced according to the manufacturer's instructions using the Empress staining technique utilizing IPS Empress blanks (batch #702768) pressed at 5 bar at a temperature of 1075°C in an EP 500 furnace (Ivoclar). The final glazing of the ceramic surfaces was done at 880°C using Empress glazing paste (batch #712374) and staining liquid (batch #706890).

The ceramic specimens were divided into three groups of 25 specimens and finished with three different finishing procedures (FM 1-3, as specified above). The 25 specimens were then subdivided into five groups of five and polished with (1) Sof-Lex discs, (2) Ceramiste silicon points, (3) diamond impregnated rubber polishers, (4) Diafix-oral felt wheels and (5) the Two Striper MPS kit.

Thus, three finishing techniques followed by five polishing techniques resulted in 15 methods of rotary instrumentation on the ceramic specimens.

Table 2: *Details of the Rotary Instruments for Finishing and Polishing*

System	Steps/Grain Size	Shape	Order-#	Abrasive	Application	Manufacturer
Finishing						
diamond bur	24-40 µm	point	806314166514014 514014	diamond	40,000 RPM/ water-cooling	Brasseler, Savannah, GA 31419, USA
diamond bur	15-30 µm	point	806314166504014	diamond	40,000 RPM/ water-cooling	Brasseler
tungsten-carbide bur	16-fluted	point	500314166 041014	tungsten-carbide	40,000 RPM/ water-cooling	Brasseler
Polishing						
Sof-Lex	coarse (100 µm) medium (29 µm) fine (14 µm) superfine (5 µm)	disc	1982 C 1982 M 1982 F 1982 SF	Al_2O_3	4,000 RPM/ water-cooling	3M ESPE Dental Products, St Paul MN 55144, USA
Ceramiste	standard (48 µm) ultra (28 µm) ultra II (6.3 µm)	point	253 A 256 A 259 A	silicon-carbide	10,500 RPM/ water-cooling	Shofu Inc, Kyoto 605-0983, Japan
Diamond-polisher	1 step (< 10 µm)	point	9547 204 030	diamond	5,000 RPM/ no cooling	Brasseler
Diafix-oral oral	1 step (3-5 µm)	wheel	80099	diamond	3,200 RPM/ no cooling	Mueller Dental, D-51789 Lindlar, Germany
Two Striper MPS	gel 1 (4-6 µm) gel 2 (<1 µm)	brush	14101	diamond	6,000 RPM/ no cooling	Premier Dental Products, Norristown, PA 19404, USA
Politip	Politip-F (52 µm) Politip-P (30 µm)	point	43573 47264	silicon-carbide	5,000 RPM/ water-cooling	Vivadent, FL-9494 Schaan, Liechtenstein

Rotary Instrumentation

The finishing burs were mounted in an unused red-ring handpiece 24 LN Intra Matic Lux 2 (KaVo, D-88400 Biberach, Germany) with a friction grip mechanism. Finishing was limited to 30 seconds for each surface and carried out manually at 40,000 RPM under three-way water cooling. A new bur was used after five specimens had been finished.

Polishing was performed with a blue-ring handpiece 20 LN/68 LDN (KaVo). Conditions of the polishing procedure, including cooling and revolutions per minute (RPM), were set according to the manufacturer's recommendations (Table 2). A new polishing instrument was used for each specimen. Polishing was limited to 30 seconds for each rotary instrument.

Surface Evaluation

After polishing, the specimens were evaluated quantitatively by laser stylus profilometry and qualitatively by SEM. For quantitative evaluation, a laser pick-up Focodyn (Rodenstock, D-80469 Munich, Germany) was used with a focus diameter of 1 µm. Each surface was scanned automatically by nine parallel tracings under the following conditions:

- transverse length L_T = 1.75 mm - sampling length L_M = 1.25 mm
- distance between scans L_Y = 0.219 mm - evaluated area: 1.75 x 1.25 mm
- profile filter cut-off λ_c = 0.25 mm (Gauss-filter)

The control of the measurement conditions was performed using the S8P (Mahr, D-37073 Göttingen, Germany). Surfaces were characterized with respect to average roughness (R_a) and profile-length-ratio (LR). R_a is defined as the arithmetic mean of the absolute ordinate values within the sampling length (ISO 4287 [ISO-Standards, 1997]). LR represents the ratio between the true profile length, that is the length of the profile drawn out in a straight line, and the sampling length (DIN 4762 [DIN-Normen, 1996]). LR is therefore a dimensionless parameter; an ideally smooth surface would yield an LR=1.

Statistical analysis of the quantitative results was carried out using SPSS for Windows (version 7.5.2G). The R_a and LR data were distributed normally and differences between the methods were analyzed with one- and two-way Anova and LSD post-hoc tests at a significance level $p<0.05$. The relation between the R_a and LR data was described using the Spearman correlation coefficient.

Scanning electron microscopy (PSEM 500, Philips Electronics, 5600 MD Eindhoven, Netherlands) was used for qualitative evaluation, with working tension set at 25 kV. Each finishing and polishing method was represented by two composite and two ceramic specimens, randomly selected for the SEM study. After gold-coating (sputtering device SCD 040, Bal-Tec, FL-9496 Balzers, Liechtenstein), one photomicrograph of the polished surfaces was taken (magnification x80). Photoprints sized 16x12 cm were divided into 48 squares. Each square was assessed with respect to the following grading:

grade 1 - smooth, homogeneous surface

grade 2 - minor roughness

grade 3 - severe roughness

grade 4 - surface damage or selective polishing

RESULTS

Quantitative Evaluation

The average roughness (r_a) produced by the various finishing and polishing techniques is shown in Figure 1 and the profile length radios (LR) in Figure 2. The finishing and polishing methods tested had different effects on composite and ceramic surfaces ($p<0.001$). The lowest R_a and LR values on composite surfaces were found after using the MPS gel regardless of the previous finishing technique (R_a=0.47-0.52 µm; LR=1.22-1.26) and after using the Diafix felt wheels when initial finishing had been carried out either with two diamonds (R_a=0.54 µm, LR=1.22) or with a diamond followed by a carbide bur (R_a=0.5, LR=1.21). There were no significant differences among the five methods with the lowest Ra-values. Compared to these results, composite specimens after applying Sof-Lex discs were significantly rougher (R_a=0.69-0.71 µm, LR=1.38 - 1.41). When the Diafix wheels were used after finishing with a single 30 µm diamond, R_a reached the highest values found on composite surfaces (R_a=1.11 µm). The application of the Ceramiste kit (after FM 2) and the diamond polishing tip (after FM 2 and 3) caused the highest LR values on composite surfaces.

On ceramic specimens, R_a and LR values extended over a wider range (R_a=0.21 - 2.18 µm, LR=1.03 - 1.65; Figures 1 and 2) compared to the results on composite surfaces. The glazed Empress specimens yielded an R_a=0.37 µm. The best polishing results on the ceramic surfaces were achieved with the MPS gel after previous finishing with a diamond followed by a tungsten carbide bur (R_a=0.21 µm, LR=1.03) or a sequence of two diamonds (R_a=0.32 µm, LR=1.05). These two methods and the diamond polishing tip after finishing with a diamond and a tungsten carbide bur (R_a=0.34) yielded lower R_a values than the glazed surface. With respect to R_a, there were no significant differences among these three methods and the glazed specimens.

R_a and LR values were reduced to lower levels on ceramic specimens compared to composite surfaces. Overall, LR values for ceramic specimens were significantly lower

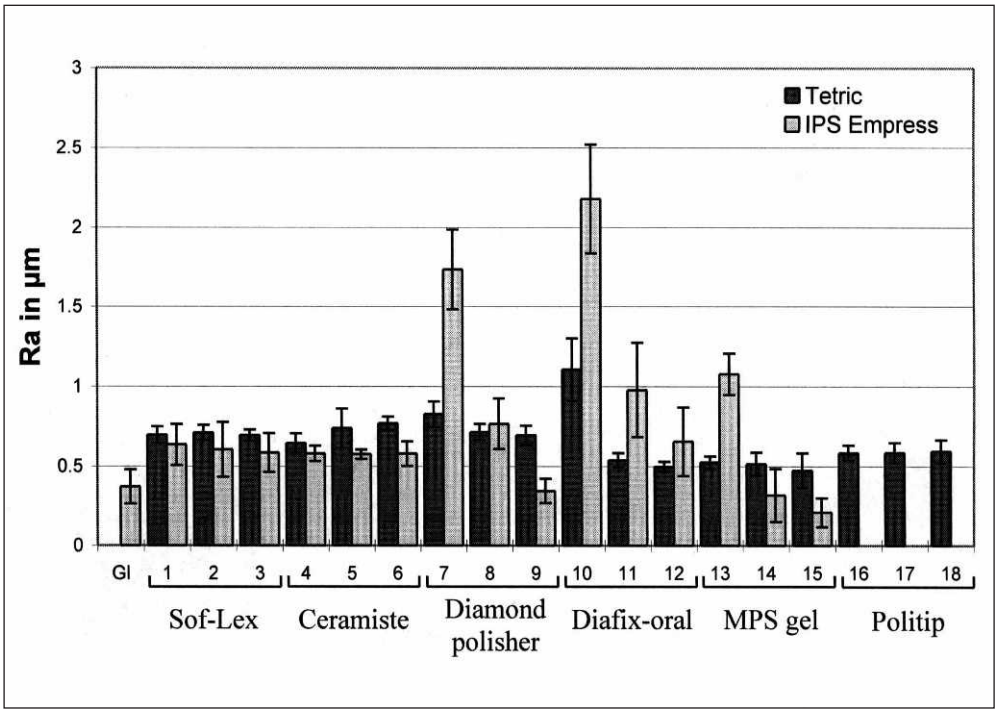

Figure 1. *Average roughness R_a ($\bar{x}$, SD) of composite and ceramic specimens; the x-axis depicts the finishing and polishing methods in consecutive numbers; each polishing technique is specified by three pairs of bars; the left pair represents initial finishing with a single 30 µm diamond, the middle pair represents previous finishing with two diamonds (30 and 20 µm) and the right pair represents initial finishing with a 30 µm diamond and a tungsten carbide bur.*

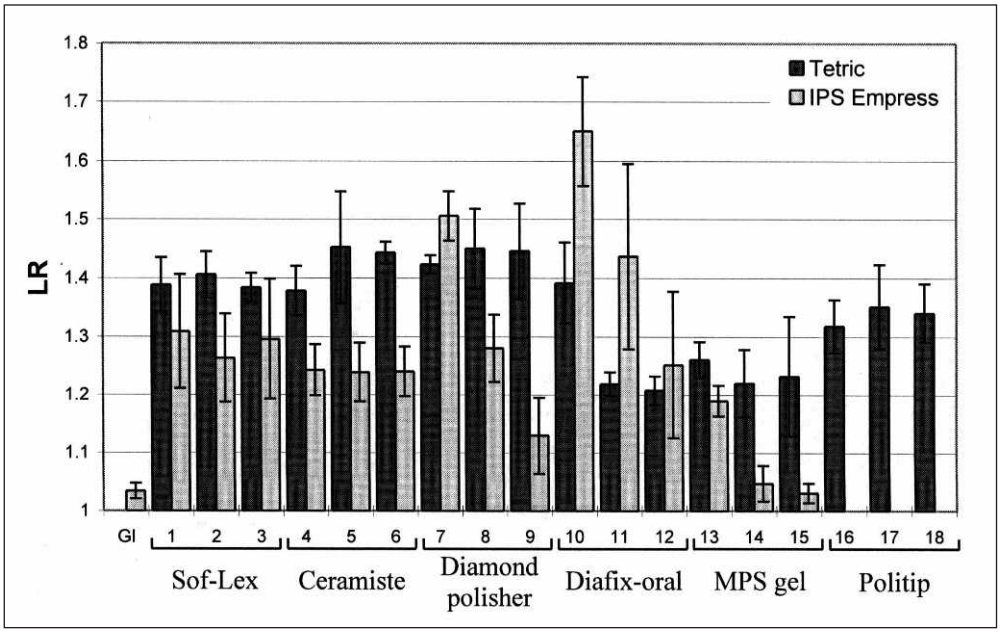

Figure 2. *Profile-length-ratio LR (x, SD) of composite and ceramic specimens; the x-axis depicts the finishing and polishing methods in consecutive numbers; each polishing technique is specified by three pairs of bars; the left pair represents initial finishing with a single 30 µm diamond, the middle pair represents previous finishing with two diamonds (30 and 20 µm) and the right pair represents initial finishing with a 30 µm diamond and a tungsten carbide bur.*

than for composite specimens ($p<0.001$).

The Spearman correlation coefficient for R_a and LR was 0.881 with respect to results on composite surfaces and 0.845 with respect to ceramics. Thus, 71 to 78% of the variance of R_a was determined by LR ($p<0.001$).

Qualitative Evaluation

Figures 3A to 3D show photomicrographs of polished composite and ceramic surfaces representing the four gradings. The results of the profilometric measurements were largely confirmed by SEM. The highest percentage of smooth area on composite surfaces was produced by using the Diafix wheels after finishing with a sequence of diamond and tungsten carbide instruments (Figure 4). There were signs of selective organic matrix removal around the filler particles on several composite surfaces (Figure 3D). Application of the Ceramiste (4.2 to 11.5%) and the Politip system (6 to 9%) caused the highest percentage of this phenomenon.

On ceramic surfaces, the MPS gel, after finishing with a sequence of a diamond and a carbide bur (81.3%) and two diamonds (53.1%), achieved the highest percentage of smooth and homogeneous areas (Figure 5). Only two ceramic specimens polished with the diamond tip (method 8) and the Diafix wheels (method 10) showed rare signs of surface damage.

DISCUSSION

A considerable number of polishing techniques are available for composites and ceramics. In order to cover several regimes, selection of the six polishing techniques assesssed in this study was carried out with

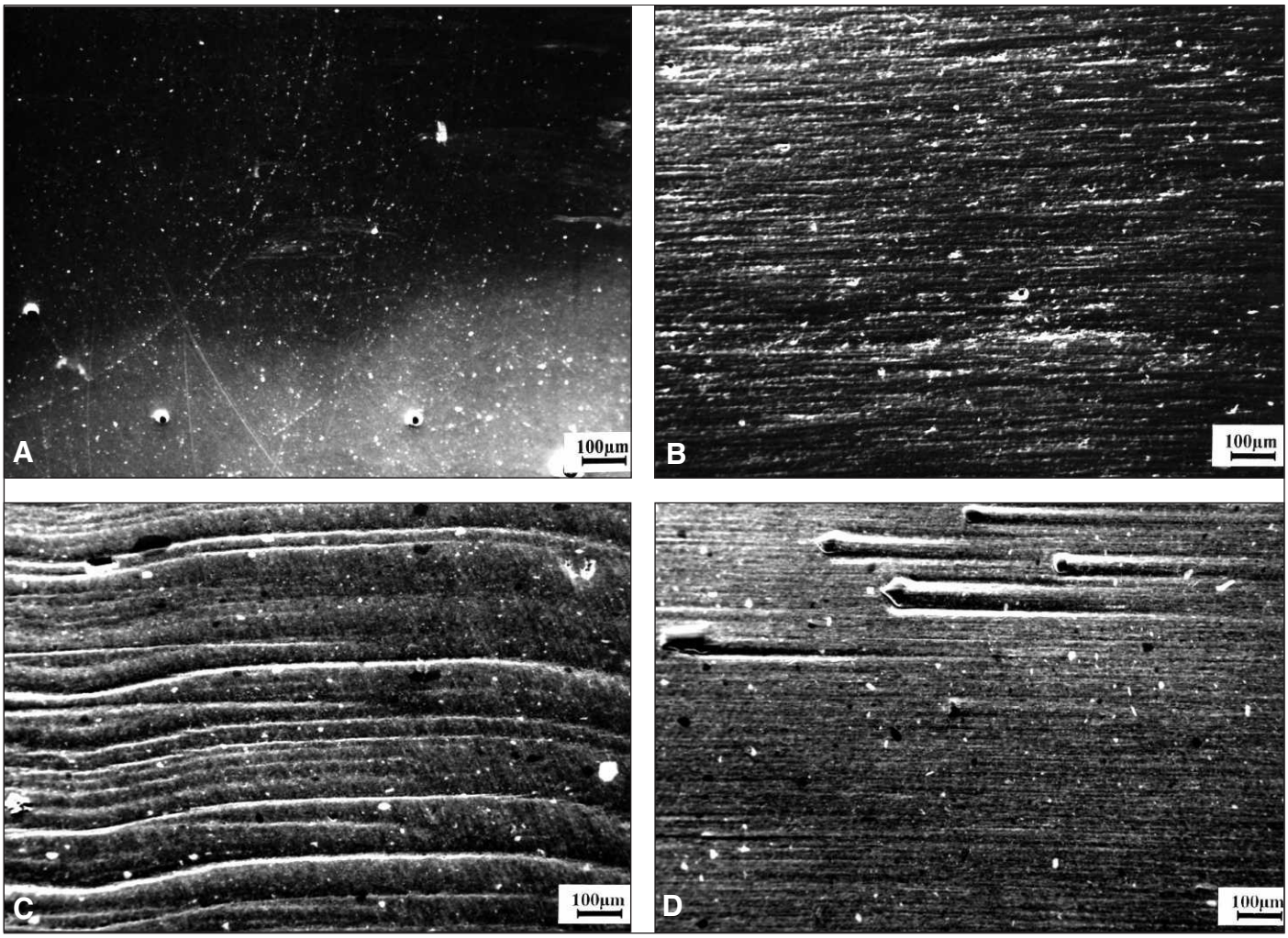

Figure 3. *Photomicrographs of finished and polished composite and ceramic surfaces;*
A. Smooth and homogenous ceramic surface (grade 1) after the use of MPS gel and finishing according to FM 3.
B. Minor roughness on a ceramic surface (grade 2) after application of the Ceramiste system and finishing according to FM 2.
C. Severe roughness on a composite surface (grade 3) after the use of a Diafix wheel and finishing according to FM 1.
D. Selective matrix reduction on a composite surface (grade 4) after application of the Politip system and finishing according to FM 3.

respect to variations in the number of polishing steps, the type of abrasive particles and the application method.

As ceramic inlays are luted adhesively with dual curing composites, the polishing of these restorations will affect both the ceramic surface and the composite luting gap. For this reason, the polishing techniques that are primarily designed for ceramic materials (for example the Ceramiste system and the diamond polishing tip) will, in the clinical situation, also be applied to composite surfaces.

Profilometry is widely used for quantative evaluation of surface characteristics. The use of mechanical pick-up systems with a stylus tip diameter varying from 4-20 µm is problematic for polished surfaces because of the crude dimensions of the stylus tip. The Focodyn laser pick-up with a focus diameter of 1 µm provides more sensitivity for measuring small and narrow surface irregularities.

Two different roughness parameters were chosen for evaluation of the polished surfaces. R_a represents only the vertical dimension of roughness, whereas LR includes both the vertical (height of profile elements) and the horizontal (number of surface irregularities) dimension of roughness. The differences between the two parameters became obvious, particularly when comparing R_a and LR data following use of the Diafix wheel and previous finishing with a single 30 µm diamond. SEM indicated that the corresponding surface was characterized by a small number of deep grooves that remained after polishing because they could not be removed effectively by the felt wheels. These surface features correlated with the greatest R_a values found on composite specimens. The corresponding increase in LR

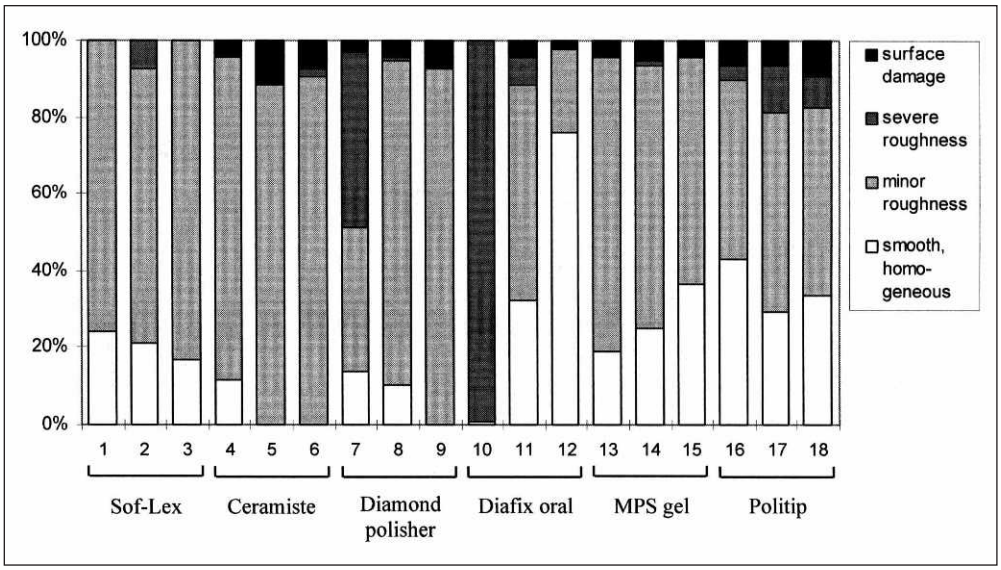

Figure 4. *The portion of surface chararcteristics on composite specimens in SEM.*

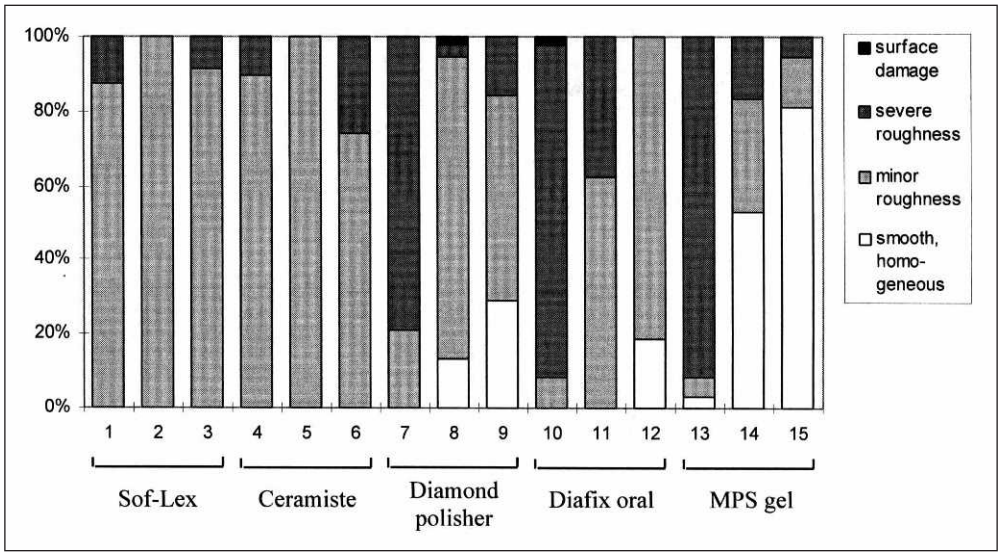

Figure 5. *The portion of surface chararcteristics on ceramic specimens in SEM.*

value was only moderate, due to the small number of profile peaks.

Differences in results between R_a and LR were the reason for calculating the correlation between the two parameters. The Spearman correlation coefficient for R_a and LR demonstrated that the two parameters were correlated stochastically, but not by a direct chain of causality.

The finishing technique had a strong effect on the subsequent surface texture following polishing if the polishing method included only one or two steps. Initial finishing with a single 30 µm diamond caused severe surface roughness, which was not efficiently polished by the diamond polishing tip, the felt wheel or the MPS gel. In combination with these polishing techniques, initial finishing with a sequence of a 30 µm diamond and a tungsten carbide bur led to lower R_a and LR values after polishing than finishing with two diamonds. This can be explained by a stronger smoothening effect of the tungsten carbide finishing bur compared to a 20 µm diamond, which has been described for composite surfaces (Jung, 1997). When polishing was performed in three or four steps, the results were similar regardless of the previous finishing procedure.

Compared to using flexible discs, better polishing results on composites were achieved by the MPS gel and felt wheels. Both techniques included diamond abrasive particles that permitted efficient polishing. The large grain size of the particles contained in the diamond polishing tip (10 µm) might explain the greater surface roughness on composite specimens caused by this technique. In contrast, the Politip instruments contained silicon carbide as an abrasive. Despite lower roughness values compared to flexible discs, this technique cannot be recommended for the hybrid composite due to the phenomenon of selective matrix removal. This phenomenon causes protruding filler particles that may crack when subjected to mechanical stress, leaving the surface in a rough condition. These findings demonstrate the importance of additional qualitative evaluation of surface characteristics.

With respect to ceramics, the glazed surface is accepted as a clinical standard. This study showed that MPS gel and the diamond polishing tip, after appropriate finishing, achieved even lower average roughness. Again, diamond abrasive particles produced an efficient polishing result. Perhaps the size of the diamond particles included in the felt wheel were too small to permit sufficient polishing on ceramic surfaces.

When analyzing the differences in surface roughness between the finishing and polishing methods, only selected comparisons turned out to be significant. This

can be attributed to the many methods that led to numerous pairwise contrasts. The wide range of roughness data, particularly with respect to ceramic surfaces, also contributed to this effect.

Ceramic specimens were polishable to lower roughness values than the composite specimens. This is considered to be due to the homogeneous nature of the ceramic itself, consisting of leucite crystals tightly integrated in a glass matrix. Composites are more heterogeneous. They contain hard filler particles embedded in a soft resin matrix, making polishing more difficult.

Small particle hybrid composites are generally regarded as the material of choice for the direct tooth-colored restoration of posterior teeth (Lambrechts, Braem & Vanherle, 1987). The composite Tetric, selected for this investigation, represents this type of material. Presently, there is a paucity of information in the published literature with respect to surface characteristics of this material. Studies by Kaplan & others (1996) and Hondrum & Fernandez (1997) confirmed the superior polishing efficiency of the MPS gel on different hybrid composites compared to flexible discs and two other techniques. The effect of diamond impregnated felt wheels on a hybrid composite was superior to flexible discs with respect to surface roughness, a result supported by another study (Jung, Baumstieger & Klimek, 1997). Northeast & van Noort (1988) observed selective removal of resin matrix after applying rubber polishers on various composites. Yap, Lye & Sau (1997) reported the same phenomenon on hybrid composites after polishing with discs and gels.

IPS Empress, the glass-ceramic selected for this study, is suited for the inlay technique because of its mechanical properties (reduced microhardness and wear, improved fracture toughness) and translucency (Krejci & others, 1993, Lüthy, 1996, Van Meerbeek & others, 1992). Only a few studies address the surface characteristics of this material. Karapetian & others (1996) evaluated the effect of the Ceramiste kit, the MPS gel and flexible discs on IPS Empress surfaces. The average roughness values reported were very small compared to the current results, ranging from 0.038–0.122 µm. This could be the result of using a mechanical pick-up with a stylus tip width of 10 µm for profilometry. In accordance with this study, the MPS gel was more efficient than the Ceramiste system. After polishing IPS Empress with flexible discs with the Ceramiste system and a gel containing diamond particles, the roughness data as reported by Stoll & others (1996) were comparable to the current results.

The beneficial effect of using a tungsten carbide bur for finishing with respect to subsequent polishing quality is confirmed by Ward, Tate & Powers (1995) and Haywood, Heymann & Scurria (1989).

Further studies must demonstrate whether the surface quality achieved under *in vitro* conditions can be transferred to the clinical situation. Furthermore, the question as to which degree a surface must be finished cannot be answered sufficiently at the moment. Achieving the roughness of occluding enamel surfaces (Willems & others, 1991) or achieving profile irregularities smaller than the average size of bacteria (Shintani & others, 1985) are discussed as possible thresholds. Surfaces appear optically smooth when their roughness is smaller than 1 µm (Chung, 1994). Currently, there is little information about the optimum surface roughness with respect to mechanical properties of the corresponding materials. As long as there is some uncertainty regarding this question, the best possible finish should be created.

CONCLUSIONS

Composite and ceramic surfaces were polished effectively by the diamond gel after finishing with two diamonds or a sequence of a diamond and a tungsten carbide bur. The other polishing techniques investigated had different effects on composite and ceramic specimens.

Ceramic surfaces proved to be polishable to lower R_a- and LR values than composite surfaces.

Selective composite matrix removal was observed especially when the Ceramiste and the Politip system were used.

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References

Chung K (1994) Effects of finishing and polishing procedures on the surface texture of resin composites *Dental Materials* **10(5)** 325-330.

DIN-Normen (1996) DIN 4762 Oberflächenrauhheit Begriffe Oberfläche und ihre Kenngrößen Identisch mit ISO 4287/1:1984 DIN Taschenbuch 106. Verzahnungsterminologie Normen (Antriebstechnik 1) Berlin, Wien, Zürich: Beuth Verlag GmbH 4 Auflage 334-349.

Haywood VB, Heymann HO & Scurria MS (1989) Effects of water, speed, and experimental instrumentation on finishing and polishing porcelain intra-orally *Dental Materials* **5(3)** 185-188.

Hoelscher DC, Neme AML, Pink FE & Hughes PJ (1998) The effect of three finishing systems on four esthetic restorative materials *Operative Dentistry* **23(1)** 36-42.

Hondrum SO & Fernandez R Jr (1997) Contouring, finishing, and polishing Class V restorative materials *Operative Dentistry* **22(1)** 30-36.

ISO-Standards (1997) ISO 4287 Geometrical Product Specifications (GPS)—Surface texture: Profile method—

Terms, definitions and surface texture parameters International Standard ISO 4287 Geneve: International Organization for Standardization 1 edition 1-25.

Jagger DC & Harrison A (1994) An *in vitro* investigation into the wear effects of unglazed, glazed, and polished porcelain on human enamel *Journal of Prosthetic Dentistry* **72(3)** 320-323.

Jung M (1997) Surface roughness and cutting efficiency of composite finishing instruments *Operative Dentistry* **22(2)** 98-104.

Jung M, Baumstieger M & Klimek J (1997) Effectiveness of diamond-impregnated felt wheels for polishing a hybrid composite *Clinical Oral Investigations* **1(2)** 71-76.

Kaplan BA, Goldstein GR, Vijayaraghavan TV & Nelson IK (1996) The effect of three polishing systems on the surface roughness of four hybrid composites: A profilometric and scanning electron microscopy study *Journal of Prosthetic Dentistry* **76(1)** 34-38.

Karapetian VE, Sorg T, Jöckel V & Baumann MA (1996) Comparison of different polishing systems for dental inlay ceramics in *CAD/CAM in Aesthetic Dentistry. Cerec 10 Year Anniversary Symposium* ed Mörmann WH pp 554-559 Chicago, Berlin: Quintessenz Publishing Co Inc.

Krejci I, Lutz F, Reimer M & Heinzmann JL (1993) Wear of ceramic inlays, their enamel antagonists, and luting cements *Journal of Prosthetic Dentistry* **69(4)** 425-430.

Lambrechts P, Braem M & Vanherle G (1987) Evaluation of clinical performance for posterior composite resins and dentin adhesives *Operative Dentistry* **12(2)** 53-78.

Lüthy H (1996) Strength and toughness of dental ceramics in *CAD/CAM in Aesthetic Dentistry Cerec 10 Year Anniversary* ed Mörmann WH pp 229-239 Chicago, Berlin: Quintessenz Publishing Co Inc.

Northeast SE & van Noort R (1988) Surface characteristics of finished posterior composite resins *Dental Materials* **4(5)** 278-288.

Pospiech P, Vangerow R, Rammelsberg P & Gernet W (1998) The influence of surface treatment on the flexural strength of veneer porcelains *Journal of Dental Research* **77** 912 (Abstract #2246).

Rimondini L, Farè S, Brambilla E, Felloni A, Consonni C, Brossa F & Carrassi A (1997) The effect of surface roughness on early *in vivo* plaque colonization on titanium *Journal of Periodontology* **68(6)** 556-562.

Shintani H, Satou J, Satou N & Hayashihara TI (1985) Effects of various finishing methods on staining and accumulation of Streptococcus mutans HS-6 on composite resins *Dental Materials* **1(6)** 225-227.

Stoll R, Seitner T, Schulte A & Stachniss V (1996) The use of polishing systems on the surface of different ceramic materials in *CAD/CAM in Aesthetic Dentistry, Cerec 10 Year Anniversary Symposium* ed Mörmann WH pp 589-597 Chicago, Berlin: Quintessenz Publishing Co Inc.

Van Meerbeek B, Inokoshi S, Willems G, Noack MJ, Braem M, Lambrechts P, Roulet J-F & Vanherle G (1992) Marginal adaptation of four tooth-colored inlay systems *in vivo Journal of Dentistry* **20(1)** 18-26.

Ward MT, Tate WH & Powers JM (1995) Surface roughness of opalescent porcelains after polishing *Operative Dentistry* **20(3)** 106-110.

Willems G, Lambrechts P, Braem M, Vuylsteke-Wauters M & Vanherle G (1991) The surface roughness of enamel-to-enamel contact areas compared with the intrinsic roughness of dental resin composites *Journal of Dental Research* **70(9)** 1299-1305.

Yap AUJ, Lye KW & Sau CW (1997) Surface characteristics of tooth-colored restoratives polished utilizing different polishing systems *Operative Dentistry* **22(6)** 260-265.

©*Operative Dentistry, 2002,* **27**, 184-191

Influence of Bonding Agent Composition on Flexural Properties of an Ultra-High Molecular Weight Polyethylene Fiber-Reinforced Composite

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Clinical Relevance

Bonding agent pre-treatment before composite application significantly affects ($p<0.05$) the flexural strength of Ultra-High Molecular Weight Polyethylene fiber reinforced composite. Bonding agent chemistry has an important role. The findings of this study will help the practitioner decide on an appropriate bonding agent pre-treatment (resination) for the clinical application of this type of fiber reinforcement.

SUMMARY

This study evaluated the influence of seven commercially available bonding agents on the flexural properties of an Ultra High Molecular Weight Polyethylene (UHMWPE) Fiber-Reinforced Composite (FRC). Nine groups (n=10 per group) of flexural strength specimens were prepared from an indirect composite reinforced with UHMWPE fiber and cured according to manufacturers' instructions (Groups A to I). Group I was a fiber-reinforced negative control without any bonding agent resination. A tenth group (Group J) was a positive control group prepared using indirect composite alone. The fiber reinforcement material for Groups A to H was resinated with one of the seven different bonding agents. Group H used the same bonding agent as for Group G specimens. However, the fiber was silanized before bonding agent application for Group G specimens. Specimens were stored wet for 24 hours at 37°C before measuring flexural strength and modulus in three-point bend at a crosshead speed of 1 mm/minute. Scanning Electron Microscopy (SEM) was employed to assess the fiber-resin interface of representative samples. The mean (SD) flexural strength of the test groups impregnated by the bonding agents ranged from 169 (37) to 266 (39) MPa. Statistical analysis of the flexural strength

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data using one-way ANOVA revealed significant ($p<0.05$) differences between the test groups. There was catastrophic fiber/composite failure in the positive control group that had a mean flexural strength of 75 (8) MPa. Silane pre-treatment of UHMWPE fiber before impregnation with the bonding agent significantly reduced the flexural strength ($p<0.05$).

INTRODUCTION

Fiber reinforcement is becoming increasingly popular for dental applications. Currently, there are two main fiber systems available for reinforcing dental composite either as non pre-impregnated (Connect fiber, Kerr, Orange, CA 92867, USA) or pre-impregnated (Stick tech fiber, Turku, Fin-20521, Finland) systems. Non pre-impregnated systems are preferred for direct applications such as splinting or direct adhesive bridges (Freilich & others, 1999).

Non pre-impregnated systems require resination by the dentist or the dental technician using a dental adhesive resin to create optimal bonding to the overlying dental composite matrix and ensure a void-free fiber-matrix interface.

The structure and properties of the fiber-matrix interface play a major role in determining the mechanical and physical properties of composite materials. In particular, the difference between the elastic properties of the matrix and the fibers influence the transfer of stresses through the interface. In other words, the stresses acting on the matrix are transmitted to the fibers across the interface. Some appreciation of the properties of the interface is therefore essential for an understanding of the factors influencing composite material properties (Ashby & Jones, 1993). Composite materials with weak interfaces are flexible and have low strength but high fracture toughness. By comparison, materials with well-bonded interfaces have high strength and stiffness but are very brittle. The effect is related to the ease of debonding and the pullout of fibers from the matrix during crack propagation (Hull, 1981).

Adequate adhesion of the fibers to the polymer matrix is one of the most important variables for optimizing the strength of the FRC. The chemical bond between the polymer and fibers should ideally be of a covalent nature. Proper adhesion makes it possible to transfer the stresses from the matrix to the fibers, maximizing the reinforcing effect of the fibers. Silane coupling agents have been used successfully to improve adhesion between polymers and glass fibers. The function of any silane-coupling agent is based on two types of chemical bond. One bond is a siloxane-bridge formed by a condensation reaction of silanol groups to the silica surface of the glass fiber. Simultaneously, with the condensation reaction, the silanol molecule forms hydrogen bonds. Using silanes to improve the adhesion between fibers other than glass fibers and polymer is based on the surface wettability theory (Rosen, 1978). The silanes on the surface of the fibers improve the physical adsorption of polymer to the micro-irregularities of the surface. Another important factor affecting the strength of the fiber composite is impregnating the fibers with resin. Effective impregnation allows the resin matrix to come in contact with the surface of every fiber (Peltonen & Järvelä, 1982).

The tensile strength (~4 GPa) and tensile modulus (~120 GPa) of the ultra-high-molecular weight polyethylene (UHMWPE fibers) selected for this study match or even surpass that of materials commonly regarded as posing high stiffness and strength, such as Kevlar fibers (Barham & Keller, 1985). The specific gravity of UHMWPE fibers is 1.0 g/cm^3. These properties make it possible to produce composites that combine good mechanical properties with a low specific mass. However, the nature of the material makes it difficult to achieve a satisfactory bond with resin-based polymers. First, linear polyethylene is chemically inert. Second, isotropic polyethylene is known to have a low surface energy $\cong$ 33 mJm^{-2} (Ladizesky, Ward & Phillips, 1982). Surface treatment of these fibers was found to be essential to allow proper bonding with the overlying composite matrix.

Gao & Zeng (1993a) reported that adhesion between UHMWPE fiber and epoxy increases by at least a factor of four after plasma pre-treatment. The best results were obtained when the plasma parameters were as follows: treatment times 90-300 seconds, power 70-100 W and gas pressure 0.1-0.2 Torr. This process introduces various kinds of oxygen-containing groups onto the fiber surface resulting in an increase in the polar component of the surface energy (Gao & Zeng, 1993b). The surface of plasma-pretreated UHMWPE fiber is insensitive to aging. After a slight decrease within the first two to three days following treatment, the surface energy reaches its plateau value (Gao & Zeng, 1993b). However, Vallittu (1997) has reported difficulties in obtaining satisfactory bonding between UHMWPE fibers (Ribbond Fibers/Ribbond Inc, Seattle, WA 98101, USA) and polymer matrices.

UHMWPE fibers are commercially available from a number of dental manufacturers. Manufacturers recommend that fibers be resinated with a dental adhesive resin as the combination of plasma etch pre-treatment and chemical bonding may improve fiber-resin interface stability.

This study investigated the influence of resination of UHMWPE fiber on the flexural properties of UHMWPE fiber-reinforced composite using a range of commercial bonding agents (n=7) of varied product chemistry. The surface morphology of UHMWPE fiber was also assessed by scanning electron microscopy (SEM)

after prolonged immersion in some common dental bonding agent constituents (acetone, ethanol and hydroxy-ethylmethacrylate [HEMA]).

METHODS AND MATERIALS

Details of the bonding agents used in this investigation are given in Table 1. Nine groups (n=10 per group) of test specimens coded A to I were prepared for three-point bend testing (Table 2). A split Polytetrafluloroethylene (PTFE) mold, (2 mm x 2 mm x 25 mm) was used for specimen preparation. The composite specimens were prepared from Solidex (Shade T, Translucent, Batch #069653/Shofu, Kyoto 605, Japan) particulate composite reinforced with Connect (Batch #2002/04, braid weave architecture, 2 mm in width, Kerr), Ultra High Molecular Weight Polyethylene (UHMWPE) fiber. According to manufacturers' product information, the Solidex laboratory composite material selected for this investigation is composed of 53% inorganic ceramic microfillers, 25% copolymer with multifunctional resin and 22% conventional resins/photo-initiators by weight.

For Groups A to H, equal lengths of fiber reinforcement material were resinated with one of the seven different bonding agents (Table 1) and placed in the base (tensile side) of the mold. The overlying veneering composite was applied taking care not to displace the pre-impregnated fiber from the base of the mold. Group H was similar to Group B except that fiber was silanated (Silane primer, Batch #23448, Kerr) before Kolor Plus

Table 1: *Description of Bonding Agents' Composition Used in This Study*

Brand Name	Composition	Batch #	Company
Kolor Plus	Bis-GMA, TEGDMA, EBADM, ODMAB, 53% by weight barium aluminosilicate	23401	Kerr, MFG Co, 1717 West Collins Orange, CA 92867, USA
XR Bond	Bis-GMA, UDMA, TEGDMA, HEMA	510045	Kerr
Optibond Solo	BIS-GMA, HEMA, GPDM , ethanol, fumed silica, barium glass, sodium hexafluorosilicate 25% filled by weight	803712	Kerr
Prime & Bond 2.1	PENTA, Di-tri methacrylate resins cetylamine hydrofluoride, acetone	9712000172	Dentsply, De-Trey-Straße 1, 78467 Konstanz, Germany
Prime & Bond NT	As Prime & Bond 2.1 + nanofillers*	9806000001	Dentsply
One Step	Bis-GMA, BPDM, HEMA and acetone	9800000996	BISCO Inc, 1100 W Irving Park Rd, Schaumburg, IL 60193, USA
D/E Bonding Resin	Bis-GMA, UDMA and HEMA	9900001550	BISCO

Bis-GMA Bis-phenol glycidyl methacrylate
TEGDMA Triethyleneglycol dimethacrylate
EBADM Ethoxylated bisphenol A dimethacrylate
ODMAB 2-(ethylhexyl)4-(dimethylamino)benzoate
UDMA Urethane dimethacrylate
HEMA Hydroxy-ethyl methacrylate
GPDM Glycerophosphate dimethacrylate
PENTA (dipentaerythritol penta acrylate monophosphate)
BPDM Biphenyl dimethacrylate
*Amorphous silicon dioxide

Table 2: *Mean Flexural Strength MPa (SD) and Flexural Modulus GPa (SD) of Solidex Dental Composite Reinforced by UHMWPE Fibers (Connect) Using Different Bonding Agents After Storage in Distilled Water at 37°C for 24 Hours*

Group Code	Bonding Agent	Flexural Strength MPa (SD)	Flexural Modulus GPa (SD)
A	Prime Bond NT	203 (30)[b]	4.7 (0.4)[a]
B	Prime Bond 2.1	195 (32)[b]	4.6 (0.5)[a]
C	One Step	206 (26)[b]	4.9 (0.5)[a]
D	D/E Bonding Resin	266 (67)[a]	5.1 (0.4)[a]
E	XR Bond	204 (23)[b]	4.5 (0.4)[a]
F	Optibond Solo	208 (28)[b]	4.7 (0.5)[a]
G	Kolor Plus	265 (40)[a]	5.3 (0.6)[a]
H	Silane+Kolor Plus	169 (37)[b]	5.1 (0.7)[a]
I*	Negative control	75 (8)[c]	3.0 (0.1)[b]
J**	Positive control	66 (8)[c]	4.9 (0.6)[a]

Groups with the same superscript under the same mechanical property are not significantly different ($p>0.05$) according to post-hoc Tukey test comparisons.
* Group I was a negative control group with fiber addition to composite but without any bonding agent pre-treatment of the fiber.
** Group J was a positive control group (composite without any fiber reinforcement).

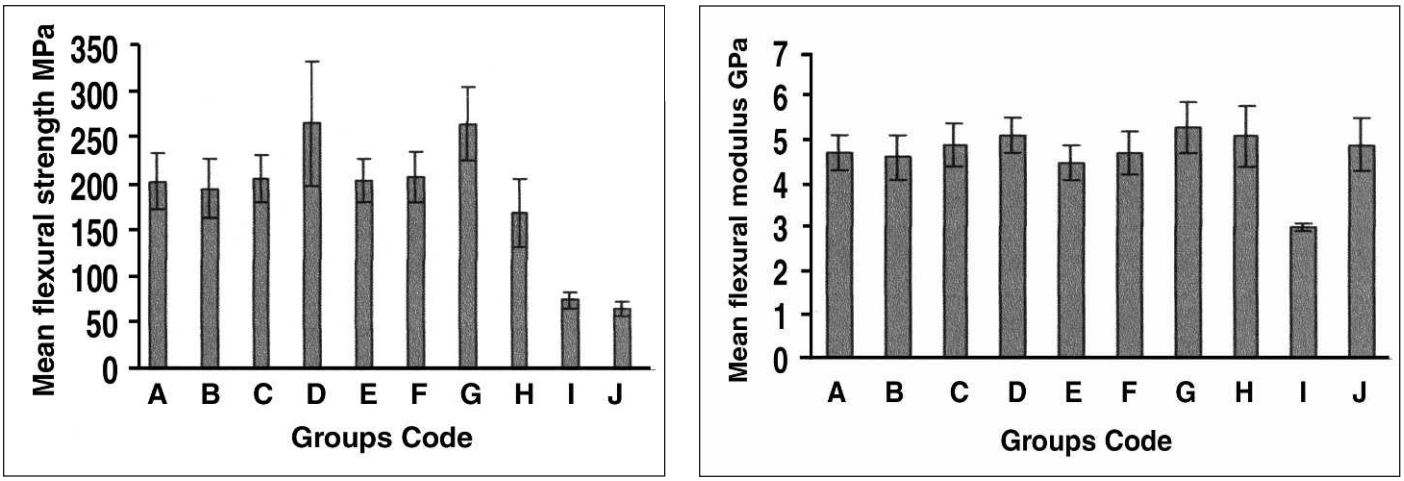

Figure 1A - B. *Mean flexural strength Mpa (Figure 1A) and Modulus GPa (Figure 1B) values of the different experimental groups of UHMWPE fiber reinforced indirect dental composite. One standard deviation (±) indicated by error bar in each case.*

bonding agent impregnation. The appropriate length of fiber was placed on a glass slab, Silane primer was applied and air dried for 15 seconds before bonding agent application. Group I was a fiber-reinforced negative control without any bonding agent resination of the fiber. The tenth group, a positive control, was prepared from composite alone (Group J).

All the test samples were cured for 10 minutes according to the manufacturer's instructions in a Solidilite EX curing oven (Serial #98129538, Shofu).

After curing, specimens were removed from the mold and flash was removed. Specimens were stored in distilled water at 37°C for 24 hours before testing. The specimens were tested dry at room temperature ± 23°C by applying load at a rate of 1 mm/minute using a universal testing machine (Instron, Model TM 5565, Canton, MA, USA) one hour after removal from the incubator. A specially designed jig supplied by the manufacturer of the universal testing machine was used to support the samples during testing.

The means and standard deviations of each group were calculated and compared. One way analyses of variance (ANOVA) followed by post-hoc Tukey pair group comparison tests ($p<0.05$) were used for flexural strength and modulus data analysis. After testing, all samples were examined using a stereomicroscope (M3C Wild Heerbrugg, Switzerland) at X40 and selected specimens (n=5 per group) were further examined by SEM (JSM 5300 LV/JOEL Ltd, Akishima, Tokyo, Japan) using back-scattered electron mode imaging (BEI) to examine the fiber-matrix interface. Specimens were examined at magnifications ranging from x150 to x5000.

A separate assessment was performed to investigate the possible influence of prolonged immersion of UHMWPE fiber in two solvents (acetone and ethanol) and one wetting agent (hydroxyethyl methacrylate, HEMA), which are common constituents of many dentin-bonding agents (Van Meerbeek & others, 1996). Samples of fiber (2 mm in length and width) were immersed in acetone (Batch #9893237338, Fisher Scientific, Loughborough, LE11 5RG, UK), ethanol (Batch #9925015279, Fisher Scientific) or/and HEMA (Batch #109H 3504, Sigma Chemical Co, St Louis, Missouri, MO 63178, USA) solution for 24 hours, respectively. The fibers were then removed from the solvents/wetting agents and allowed to air dry before SEM inspection. The fiber external surfaces were then examined by SEM for possible change in morphology in comparison to untreated control UHMWPE fiber samples.

Determination of Flexural Results

The flexural strength (σ) and modulus of elasticity were calculated using the following equations:

$$\text{Flexural strength } (\sigma)\ \text{MPa} = \frac{3WI}{2bd^2}$$

$$\text{Flexural modulus (E) MPa} = \frac{SI^3}{4bd^2}$$

Where:

W is the maximum load (N) exerted on the specimen.

I is the distance between the supports (mm).

b is the width of the specimen (mm) measured immediately prior to testing.

d is the height of the specimen (mm) measured immediately prior to testing.

S is the slope of the initial straight-line portion of the load-extension curve.

RESULTS

After fracture the fragments of all the fiber-reinforced specimens remained attached to each other, while the positive control group specimens failed catastrophi-

Table 3: *Results of ANOVA Tests for Flexural Properties*

		SS	df	MS	F -Value	p-Value
Flexural strength (MPa)	Between Groups	405103.8	9	45011.5	40.4	0.001
	Within Groups Total	97034.6 502138.4	87 96	1115.3		
Flexural modulus (GPa)	Between Groups	36.9	9	4.1	16.8	0.001
	Within Groups Total	21.3 58.1	87 96	0.2		

SS = Sum of Squares, df=Degrees of freedom, MS=Mean Square

cally. Results for flexural strength and modulus of elasticity are presented in Table 2/Figure 1A-B. Findings of the one-way Analysis of Variance on the mean flexural strengths and moduli are given in Table 3, with post-hoc Tukey test comparisons presented in Table 2. Analysis of the flexural strength data showed that the FRC groups (A to H) were significantly stronger ($p<0.05$) than both the negative and positive control groups (Groups I and J). Groups G and D were significantly stronger than Groups H to C ($p<0.05$). Group D was significantly stronger than Group E ($p<0.05$).

Silanization of the fiber before impregnation with Kolor Plus bonding agent (Group H versus Group G) led to a significant reduction ($p<0.05$) in mean flexural strength of 64%. The mean flexural modulus of Group I (the negative control) was significantly lower ($p<0.05$) than the values recorded for all other groups.

Groups A to H, in which the fibers were resinated with bonding agents, showed complete apposition between the fiber and the composite when examined by SEM (Figure 2A). SEM micrographs of the interface between the composite and the fiber without bonding agent (Group I) are shown in Figure 2B. Examination of the negative control (Group I) samples by SEM showed areas of separation between the composite and the UHMWPE fibers.

When the Connect fibers were immersed in acetone for 24 hours, the fiber was completely dissolved. Immersion of Connect fiber in ethanol solution for 24 hours resulted in craze lines on its surface (Figures 4A & 4B) compared to the untreated control fiber samples (control/Figure 3). Placement of Connect fiber in HEMA solution for 24 hours had no obvious effect on the external surface of the fiber (Figure 5). The surface was covered by residual HEMA particles.

DISCUSSION

Enamel and dentin bonding agents have been proposed for wetting UHMWPE fibers before reinforcement of direct and indirect composite restoration materials. The compatibility between dental bonding agents of varied composition and UHMWPE fibers is an important issue that has not yet been investigated.

An indirect resin composite material (Solidex) was chosen for this investigation as the manufacturer's recommended curing regime facilitated standardized polymerization of the 25 mm long test specimens. Use of a direct composite would have required overlapping applications of the light guide from a conventional light-curing unit.

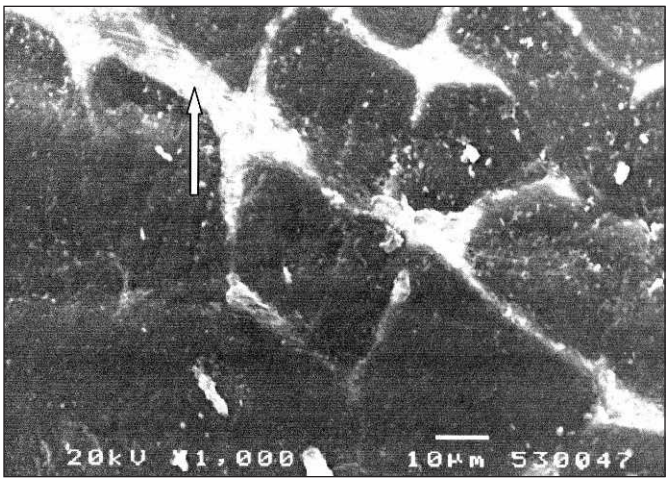

Figure 2A. *Scanning electron micrograph showing the lateral view of the interface between plasma treated UHMWPE fiber wetted by Kolor Plus and the gap-free union between the fiber and the bonding agent (Group G).*

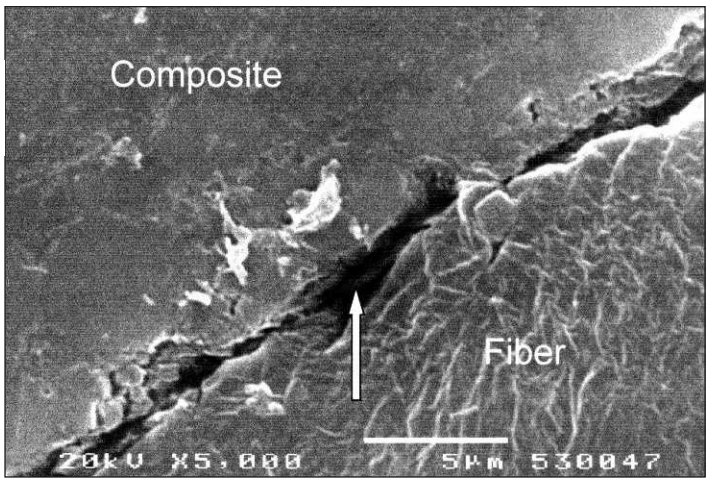

Figure 2B. *Scanning electron micrograph showing complete separation (arrow) between plasma treated UHMWPE fiber and the overlying composite (Group I).*

The bonding agents selected for this study differ in composition according to the solvent and wetting agent combinations (acetone, ethanol and/or HEMA) used, filler loading (range from 0% to 53% by weight) and filler type (micro- or nanofillers). In order to find the most appropriate bonding agent pre-treatment for UHMWPE fibers, both the veneering composite and the particular fiber reinforcement system used must be standardized. Using fiber reinforcement without any bonding agent (Group I) depends on plasma surface treatment only for property enhancement. This resulted in significantly ($p<0.05$) less flexural strength and modulus of the tested composite compared to all test groups (A to H) where bonding agent pre-treatment was employed. Gap formation between the tested composite and the interface with fiber was noted in this test group (Figure 2B). This means that significant tensile stresses will tend to be carried by the composite, not the fiber. While fiber reinforcement without resination (Group I) significantly reduced the flexural modulus ($p<0.05$) compared to the positive control (Group J), there was no significant difference ($p>0.05$) between the mean flexural strength of these two test groups.

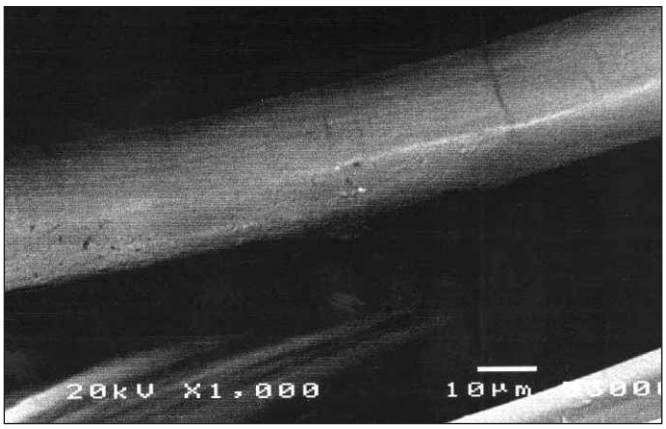

Figure 3. *Scanning electron micrographs showing the external surface of Connect fiber before immersion in ethanol, acetone and HEMA.*

A threefold increase in flexural strength of Group G (wetted by Kolor Plus) (Table 2) compared to the flexural strength of the negative control group (Group I) demonstrates the importance of bonding agent chemistry.

One possible explanation for the higher mean flexural strength of the fiber test specimens impregnated with 53% filled bonding agent (Group G) was proposed by Latta & Barkmeier (1998), who suggested that the use of fillers in adhesive bonding resin creates a system that exhibits less polymerization shrinkage in the bonding layer. It is hypothesized that generating less residual shrinkage stress in the adhesive reduces bond failures and may explain the significant difference in the mean flexural strength ($p<0.05$) between Group G and Groups A, B, E and F. The results of this study are consistent with the above mentioned hypothesis.

There is no information regarding the need for silanization of UHMWPE fibers before bonding agent impregnation (resination). The assumption is that adhesion will be improved akin to the improved bonding resulting from silanization of glass fibers. There is a consensus that silanization of glass fibers will improve their bond to the composite matrix (Rosen, 1978). This contradicts the findings of the current investigation, which showed that silanization of UHMWPE fibers had the opposite effect on flexural strength (Groups H and G). The reduction in flexural strength may be attributed to a negative influence of the silane on plasma surface treatment of the fiber, leading to a reduction in subsequent fiber wettability by the bonding agent.

According to the manufacturer of Prime & Bond NT (Dentsply De-Trey-Straße 1,78467 Konstanz, Germany), the nanofiller is small enough and chemically modified

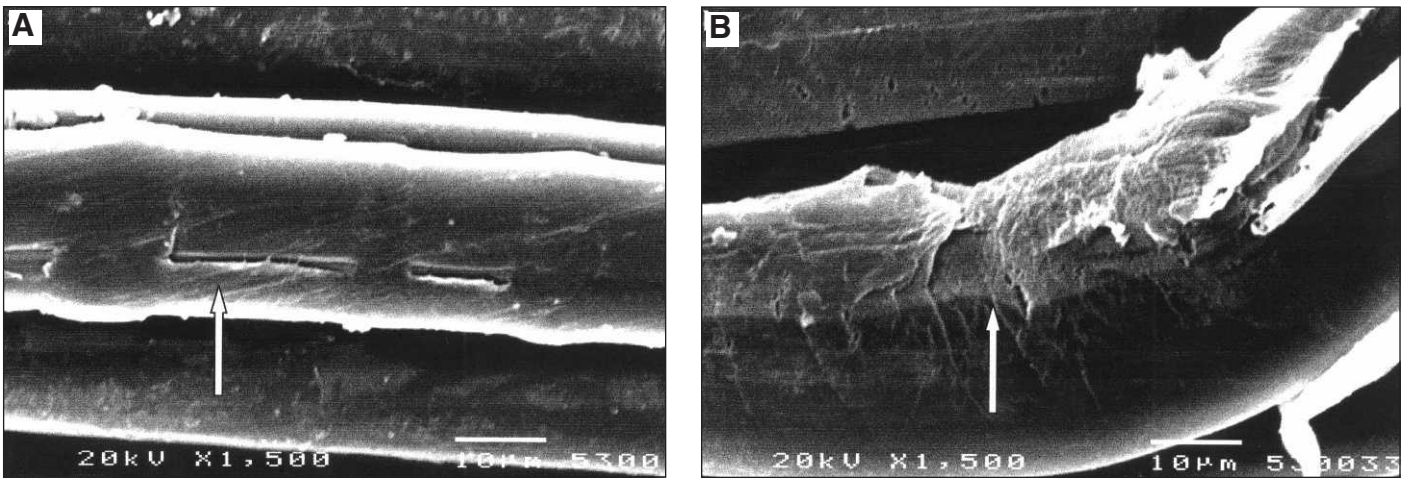

Figure 4A and B. *Scanning electron micrographs showing craze lines (arrow) through the external surface of Connect fiber after immersion in ethanol solution for 24 hours.*

at its surface to form a stable sol with the liquid components of Prime & Bond NT due to its optimal degree of dispersion (that is, the nanofiller does not settle). Also, according to the manufacturer's data, the nanofiller does not change the viscosity of the adhesive liquid. Because the nanofiller is so small, in theory, it will wet microscopic gaps and its unfilled predecessor. The nanofiller serves as an additional cross-linking agent and therefore strengthens the adhesive layer (Eick & others, 1997).

A strengthened, filled adhesive displays better micromechanical retention than an unfilled one. The huge surface area of the nanofiller and its extremely small particle size guarantee optimum interaction between the organic molecules of the adhesive and the nanofiller. The nanofiller size is extremely well-suited for bonding to etched enamel and dentin surfaces. Collagen microfibrils have a diameter of about 5-10 nm (Eick & others, 1997). After conditioning, the channels between the collagen fibrils of the demineralized dentin matrix are about 20 nm wide (Van Meerbeek & others, 1993; Watanabe, Nakabayashi & Pashley, 1994). With a primary particle size of about 7 nm, the nanofiller has a sufficiently small size to penetrate into these channels, providing nano-retention, not microretention. Bonding of fiber to composite presents a different challenge compared to bonding to dentin.

Bonding of fibers to composite requires specific types of bonding agents, and it is essential that the constituents of the bonding agent do not have an adverse effect on the fiber itself. Adhesives containing acetone or ethanol (Table 1) might theoretically affect the fiber itself or influence the polymer properties. Manson & Sperling (1976) have shown that liquid acetone may change the state of a polymer and interact with the fiber, leading to stress cracking in the presence of mechanical stress.

Bonds may also degrade as a consequence of chemical reactions that lead to formation of weak bonds. The results of this study showed that prolonged immersion of fibers in acetone completely dissolved the fibers, and immersion in ethanol solution resulted in cracks appearing in the external surface of the fibers (Figures 4A & 4B) compared to control fiber (Figure 3). According to the findings of this investigation, it seems prudent to assume that unless proven otherwise a deleterious chemical effect may exist when wetting UHMWPE fibers with acetone and/or ethanol-based bonding agents. This may account, in part, for the higher mean flexural strengths found between Groups D and G versus Groups A to C and Group F (Table 2). The results of this study also demonstrate that wetting by D/E Bonding Resin (Group D) improved the results compared to wetting with a conventional bis-GMA based enamel-bonding agent (Group E). This may be attributed to this bonding agent possessing a higher

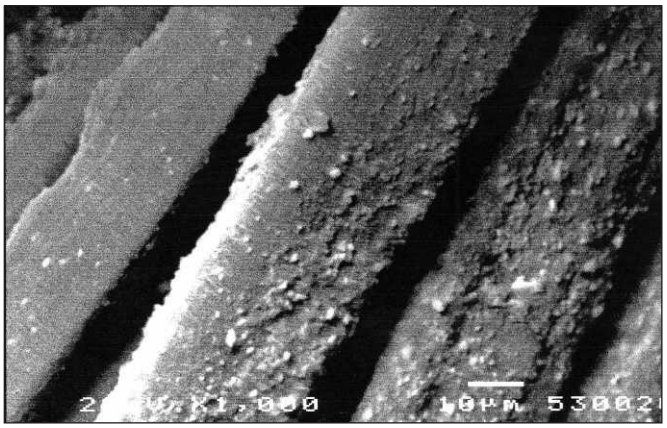

Figure 5. *Scanning electron micrograph showing HEMA particles covering (arrow) the external surface of Connect fiber. No apparent crazing of the fiber surface is evident.*

flexural modulus (E stated to be 3 GPa for D/E Bonding Resin; personal communication with the manufacturer) resin compared to XR Bond. The results of this study revealed no adverse effect after prolonged immersion in HEMA on the fiber (the wetting agent used in D/E Bonding Resin) as shown in Figure 5.

It should be noted that while the results show a significant improvement in flexural strength, there was a less distinct improvement in flexural modulus after fiber reinforcement and impregnation with different bonding agents. The flexural modulus of fiber-reinforced composite depends on the position and quantity of fibers in relation to the applied stresses. When the fiber is placed parallel to the applied stress so that increasing the fiber volume fraction (amount of fiber in the sample in relation to the amount of composite) will increase the flexural modulus significantly (Obraztsov & Vail'ev, 1989). Placement of the fiber perpendicular to the applied stresses, as shown in this study, will minimally improve the modulus (Obraztsov & Vail'ev, 1989).

The difference between the results of this investigation and the previous study by Vallittu (1997) may possibly be attributed to differences in experimental protocol. In the study by Vallittu (1997), the UHMWPE fiber was dusted with polymer powder before composite was added. This may have resulted in a deleterious effect on the surface treatment of the fiber used and hence poor bonding. Further investigation is required to test this hypothesis. The difference in bonding to UHMWPE fibers reported by Vallittu (1997), compared to the findings of the current investigation, may also be related to differences in fiber architecture, wetting monomers used and the nature of the overlying polymer.

Further research is needed to evaluate the influence of water storage for longer periods of time on the flexural properties of UHMWPE fiber-reinforced composite wetted by the different bonding agents investigated. The findings of this investigation are only applicable to

UHMWPE fiber reinforced composites and further work with other fiber types and a wider range of bonding agents is indicated. Within the limitations of this study (short storage period), the results demonstrate the important role of bonding agent compatibility with the fiber used.

CONCLUSIONS

The following conclusions can be drawn from the results obtained:

1. Bonding agents generally improve the flexural strength of fiber-reinforced dental composites, although the degree of enhancement may vary depending on bonding agent formulation.
2. Silanization of UHMWPE fibers before impregnation with a filled bonding agent significantly decreases the flexural strength of the test samples ($p<0.05$) and is therefore not recommended.
3. Of the bonding agents investigated, a filled bonding agent (Kolor Plus) recommended by the manufacturer for use with Connect fiber, generated the maximum improvement of flexural strength of the final fiber-reinforced composite (FRC).
4. Using D/E Bonding Resin also enhanced the flexural strength of the final FRC compared to the other bonding agents investigated.
5. Dental adhesives containing solvents such as ethanol or acetone may adversely affect the fiber matrix interface.

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References

Ashby MF & Jones DR (1993) An introduction to their properties and applications *Engineering Materials* **1** 129-134.

Barham PJ & Keller A (1985) High-strength polyethylene fibers from solution and gel spinning *Journal of Material Science* **20** 2281-2289.

Eick JD, Gwinnett AJ, Pashley DH & Robinson SJ (1997) Current concepts on adhesion to dentin *Critical Reviews in Oral Biology & Medicine* **8(3)** 306-335.

Freilich MA, Meiers JC, Duncan JP & Goldberg AJ (1999) Composition, architecture, and mechanical properties of fiber-reinforced composites in Freilich MA, Meiers JC, Duncan JP & Goldberg AJ *Fiber-Reinforced Composites in Clinical Dentistry* Chapter 2 Chicago Quintessence Publishing Co, Inc 30-45.

Gao S & Zeng Y (1993a) Surface modification of Ultrahigh Molecular Weight polyethylene fibers by plasma treatment I Improve surface adhesion *Journal of Applied Polymer Science* **47** 2065-2071.

Gao S & Zeng Y (1993b) Surface modification of Ultrahigh Molecular Weight polyethylene fibers by plasma treatment II Mechanism of surface modification *Journal of Applied Polymer Science* 4**7** 2093-2101.

Hull D (1981) An introduction to composite materials British Library Cambridge Great Britain 244.

Ladizesky NH, Ward IM & Phillips LN (1982) Proceeding of *ICCCM* IV 203.

Latta MA & Barkmeier WW (1998) Dental adhesives in contemporary restorative dentistry *Dental Clinics of North America* **42(4)** 567-577.

Manson JA & Sperling LH (1976) *Polymer Blends and Composites* Plenum Press New York 171.

Obraztsov IF & Vail'ev VV (1989) Optimal design of composite structures in *Handbook of Composites* Vol 2, Structures and Design Elsevier Publishing Co, New York.

Peltonen P & Järvelä P (1982) Methodology for determining the degree of impregnation from continuous glass fiber *Polymer Testing* **11** 215-224.

Rosen MR (1978) From treating solution to filler surface and beyond. The life history of a silane coupling agent *Journal of Coating Technology* **50** 70-82.

Vallittu PK (1997) Ultra-high-modulus polyethylene ribbon as reinforcement for denture polymethyl methacrylate: A short communication *Dental Materials* **13** 381-282.

Van Meerbeek B, Dhem A, Goret-Nicaise M, Braem M, Lambrechts P & Vanherle G (1993) Comparative SEM and TEM examination of the ultrastructure of the resin-dentin interdiffusion zone *Journal of Dental Research* **72(2)** 495-501.

Van Meerbeek B, Perdigão J, Gladys S, Lambrechts P & Vanherle G (1996) Enamel and dentin adhesion in Schwartz R, Summitt J & Robbins J *Fundamentals of Operative Dentistry A Contemporary Approach* Chapter 6 Chicago Quintessence Publishing Co, Inc 141-175.

Watanabe I, Nakabayashi N & Pashley DH (1994) Bonding to ground dentin by a phenyl-P self-etching primer *Journal of Dental Research* **73(6)** 1212-1220.

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Effect of the Photo-Activation Method On Polymerization Shrinkage of Restorative Composites

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Clinical Relevance

Reducing polymerization shrinkage produces a better marginal integrity of composite restorations and can be achieved by programmed use of photo-activation methods.

SUMMARY

This study measured the gap that resulted from polymerization shrinkage of seven restorative resin composites after curing by three different methods. Contraction behavior, according to the specimen region, was also characterized. The materials used for this study were Alert (Jeneric/Pentron, Wallingford, CT 06492, USA), Surefil (Dentsply Caulk, Milford, DE 19963, USA), P60 (3M Dental Products, St Paul, MN 55144, USA), Z250 (3M), Z100 (3M), Definite (Degussa-Hüls, Hanau, Germany) and Flow-it (Jeneric/Pentron). The composite was placed in a circular brass mold 7 mm in diameter and 2 mm in height. Photo-activation was performed by a) continuous light (500 mW/cm²) for 40 seconds; b) stepped light with low intensity (150 mW/cm²) for 10 seconds and high intensity (500 mW/cm²) for 30 seconds and c) intermittent light (450 mW/cm²) for 60 seconds. The top and bottom surfaces were then polished and after 24 ± 1 hours, the contraction gap was measured by SEM at variable pressure (LEO 435 VP, Cambridge, England). Results were analyzed by ANOVA and the means compared by Tukey's test (5%). The results demonstrated 1) the continuous light method presented the greatest gap values (15.88 µm), while the other methods demonstrated lower polymerization shrinkage values (stepped light, 13.26 µm; intermittent light, 12.79 µm); 2) restorative composites shrunk more at the bottom surface (15.84 µm) than at the top surface (12.11 µm) and (3) the composites Alert (12.02 µm), Surefil (11.86 µm), Z250 (10.81 µm) and P60 (10.17 µm) presented the least contraction gaps, followed by Z100 (15.84 µm) and Definite (14.06 µm) and finally Flow-it (23.09 µm) low viscosity composite, which had the greatest mean value.

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INTRODUCTION

Since restorative resin composites were introduced into dentistry in the mid-1960s, these materials have developed significantly, allowing their application on both anterior and posterior areas. However, problems such as marginal leakage and recurrent caries can occur after their use (Ferracane, 1992). This partially results from polymerization shrinkage that is inherent with these materials (Peutzfeldt, 1997).

Composite shrinkage occurs during the polymerization process as a result of short-range covalent bonds forming between the monomer units, which result in shortening of the final network polymer (Rees & Jacobsen, 1989). Walls, McCabe & Murray (1988) related four variables that influence polymerization shrinkage of the composites: a) size of the monomer molecules, where the larger molecules present lower shrinkage; b) the volume fraction of filler that within limited parameters provides reduced shrinkage; c) the degree of polymerization, which is directly proportional to increased shrinkage and d) the nature of the resin and consequently the mechanism of polymerization.

Polymerization shrinkage may result in gap formation around the margins of the restoration due to stress produced in these areas, which disrupts the bond of the composite to dental tissues. This shrinkage may cause marginal leakage and lead to further irritation or pulp necrosis (Bowen, 1963; Uno & Shimokobe, 1994). For these reasons, polymerization shrinkage is one of the main factors that determines the longevity of composite restorations (Rees & Jacobsen, 1989; Ferracane, 1992; Peutzfeldt, 1997).

A number of ways of increasing the marginal integrity of these restorations have been suggested, including using lining materials with elastic properties that absorb the stress (Tolidis, Nobecourt & Randall, 1998); using adhesive systems that bond adequately to dental structures (Asmussen, 1975; Versluis, Tantbirojn & Douglas, 1998; Unterbrink & Liebenberg, 1999); incremental placement techniques (Lutz, Krejci & Oldenburg, 1986) and controlling the flow of the composite during polymerization (Uno & Shimokobe, 1994; Feilzer & others, 1995; Unterbrink & Muessner, 1995; Venhoven, de Gee & Davidson, 1996) since the polymerization process seems more dependent upon the presence of energy than light intensity (Miyazaki & others, 1996; Sakaguchi & Berge, 1998).

Controlled polymerization may result in a high degree of conversion and decreased polymerization shrinkage. In this context, methods of stepped light (Uno & Asmussen, 1991; Feilzer & others, 1995; Unterbrink & Muessner, 1995; Koran & Kürschner, 1998) or intermittent light (Tarle & others, 1998) can be used.

This study (1) verified shrinkage behavior depending on the region of the specimens, and (2) measured the resultant gap of polymerization shrinkage using composites with different compositions and viscosities when three photo-activation techniques were utilized.

METHODS AND MATERIALS

For this study seven restorative resin composites with different viscosities were used: high viscosity: Alert (Jeneric/Pentron), Surefil (Dentsply/Caulk) and P60 (3M); medium viscosity: Z100 (3M), Z250 (3M)

Table 1: *Composition of the Restorative Resin Composites*

	Composition		
Composite	**Organic/Inorganic Matrix**	**Inorganic Filler**	**% in Volume (Filler)**
Alert	Polycarbonate dimethacrylate (PCDMA)	Boro-silicate-barium glass, silica and glass	70*
	Dimethacrylate diphenol-A ethoxylated Diethylamino ethyl methacrylate	fiber	
Surefil	Modified Bis-GMA urethane resin fluoride, silanized barium and silica	Boro-silicate-alunimium	66*
P60	Bisphenol-glycidyl methacrylate (Bis-GMA), urethanethyl dimethacrylate (UEDMA) and Bisphenol-polyethylene glycol dimethacrylate (Bis-EMA)	Zirconia /Silica	61**
Z100	Bisphenol-glycidyl methacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA)	Zirconia/Silica	66**
Z250	Bisphenol-glycidyl methacrylate (Bis-GMA), urethanethyl dimethacrylate (UEDMA) and Bisphenol-polyethylene glycol dimethacrylate (Bis-EMA)	Zirconia/Silica	60**
Definite	Organically modified ceramic-matrix (ORMOCER)	Barium glass and silica	88**
Flow-it	Ethoxylated Bis-GMA and triethylene glycol dimethacrylate (TEGDMA)	Barium glass, silica and TiO_2	55**

* Source: *Dental Advisor*, **6(10)** 4, Nov 1999.
** Manufacturer's information
PS: The filler content of Definite composite includes the inorganic portion of ORMOCER, according to the manufacturer's personal communication.

and Definite (Degussa-Hüls) and low viscosity: Flow-it (Jeneric/Pentron). The composition of these materials is presented in Table 1.

The restorative composites were placed in a circular brass mold 7 mm in inner diameter and 2 mm in height. The composites were then covered with a Mylar strip and pressed with a glass slab. Eight specimens were prepared for each material. The composites were cured as follows: a) continuous light, b) stepped light and c) intermittent light.

For the continuous light technique, the curing tip was positioned closed to the brass mold/restorative composite. The photo-activation was performed for 40 seconds with a high intensity of 500 mW/cm^2, using a XL 1500 curing unit (3M). The light intensity was measured with a radiometer (Curing Radiometer, model 100, Demetron/Kerr, Danbury, CT 06810, USA).

Curing for the stepped light method was performed using the same curing unit, however, the specimens were subjected to an initial 10-second exposure to the activating light with an intensity of approximately 150 mW/cm^2, maintaining a distance of nearly 1.5 cm from the curing tip. The curing tip was then positioned close to the brass mold/restorative composite, resulting in an increased light intensity of 500 mW/cm^2, which was maintained for an additional 30 seconds, with a total exposure time of 40 seconds.

Finally, for the intermittent light method, a curing unit developed in the Dental Materials Department, School Dental of Piracicaba, UNICAMP, was used, which provided a half-second of light with an intensity of 450 mW/cm^2 and a half-second without light. The total exposure time was 60 seconds. The top and the bottom surfaces of the specimens were then polished with sandpaper of decrescent grit 320, 400, 600 and 1200.

After 24 ± 1 hours, the specimens were mounted in stubs and the gap formed between the brass mold/restorative composite interface was measured by Scanning Electronic Microscopy at low vacuum ("black scattered" SEM - LEO 435 VP, Cambridge, England) using the microscope software and a magnification of x1500.

The measurements, achieved in micrometers, were obtained in four points located in positions corresponding to 3, 6, 9 and 12 hours of a clock face. The readings were performed on both top and bottom surfaces. The arithmetic means was calculated for each region of the specimen.

The data were submitted to analysis of variance (ANOVA) and the means were compared by Tukey's test (5% of significance level).

RESULTS

The bottom surface of the specimens showed greater polymerization shrinkage values (Table 2), which were statistically different when compared to the top surface ($p<0.05$) according to Tukey's test.

The continuous light method presented the largest contraction gap (Table 3) and was statistically different from the stepped light and intermittent light methods. No significant difference was observed between the stepped light and intermittent light ($p<0.05$) methods.

Independent of the photo-activation method or the region examined, the Flow-it composite (Jeneric/Pentron) demonstrated the greatest contraction gap (Table 4) and was statistically different from the other materials ($p<0.05$). The Z100 and Definite composites obtained intermediate contraction gap values and there were no significant differences between them ($p>0.05$). The Alert, Surefil, P60 and Z250 composites presented the smallest contraction gap values, without significant difference ($p<0.05$).

The contraction gap obtained by the photo-activation method at the top surface of the specimens demonstrated that the Flow-it and Alert composites presented significantly greater gap values with the continuous light technique, which produced statistically different

Table 2: *Means of Contraction Gap According to Analyzed Region*

Region	Mean (μm)	Standard Deviation
Bottom surface	15.84 a	6.73
Top surface	12.11 b	4.36

Means followed by different letters are statistically different at 5% by Tukey's test.

Table 3: *Means of Contraction Gap Using Different Photo-Activation Methods*

Photo-Activation Method	Mean (μm)	Standard Deviation
Continuous light	15.88 a	6.61
Stepped light	13.26 b	5.65
Intermittent light	12.79 b	5.10

Means followed by different letters are statistically different at 5% by Tukey's test.

Table 4: *Means of Contraction Gap According to Restorative Composite Used*

Composite	Mean (μm)	Standard Deviation
Flow-it	23.09 a	7.61
Z100	15.84 b	4.77
Definite	14.06 b	3.40
Alert	12.02 c	3.60
Surefil	11.86 c	3.24
Z250	10.81 c	3.18
P60	10.17 c	2.40

Means followed by different letters are statistically different at 5% by Tukey's test.

Table 5: *Means of Contraction Gap According to Photo-Activation Method for Top Surface of the Specimens*

Composite	Photo-Activation Method: Continuous Light			Stepped Light			Intermittent Light			
Flow-it	21.30	a	(4.94)	17.46	b	(2.91)	16.51	b		(3.98)
Z100	14.69	a	(2.13)	9.47	b	(3.34)	12.58	a	b	(3.39)
Definite	14.95	a	(3.87)	12.39	a	(2.85)	12.74	a		(1.89)
Alert	15.10	a	(4.88)	10.03	b	(1.21)	9.84		b	(1.95)
Surefil	12.93	a	(2.34)	9.48	a	(2.21)	9.73	a		(2.51)
Z250	9.86	a	(1.45)	9.17	a	(2.21)	8.22	a		(2.02)
P60	10.39	a	(2.05)	7.81	a	(1.27)	9.68	a		(3.24)

Means followed by different letters, in line, are statistically different at 5% level by Tukey's test. ( ) – standard deviation.

values from the other methods ($p<0.05$). The other methods demonstrated no statistical differences (Table 5). The Z100 composite revealed no significant differences between the continuous light and intermittent light methods or between the stepped light and intermittent light methods. However, this material had higher values with continuous light than with stepped light. Finally, the Definite, Surefil, P60 and Z250 composites presented no significant differences in relation to the photo-activation methods used ($p<0.05$).

DISCUSSION

Restorative resin composites have been extensively utilized in dentistry for the morphofunctional recovery of anterior teeth and posterior teeth. However, these materials shrink during polymerization, sometimes resulting in marginal gaps in the restorations and, consequently, marginal leakage (Rees & Jacobsen, 1989; Ferracane, 1992). This study investigated shrinkage behavior in relation to the region of the specimen and measured the gap produced by polymerization shrinkage of restorative composites when cured by three different methods.

The results, presented in Table 2, show that the average contraction gap values at the bottom surface were greater than those at the top surface of specimens ($p<0.05$). These results demonstrate that the composite shrunk freely from the deeper areas towards the superficial regions (Hansen, 1982; Versluis & others, 1998). The probable explanation for this is that the fast-reacting composite closest to the curing light may be partially relieved by flow caused by "rearrangement" of the network more deeply located polymer material. The composite should react more slowly in deeper regions due to lower light intensity (Versluis & others, 1998).

When an adequate bond to the dental structure restrains the shrinkage, the flow occurs from the free surface of the restoration in the direction of the bonded margins (Versluis & others, 1998; Asmussen, 1998). However, if polymerization is fast, in conditions of initial high light intensity, more stress is induced at the bonded interfaces, which may result in bond disruption and marginal gap (Jörgensen & others, 1985; Uno & Shimokobe, 1994).

Thus, the programmed use of different light intensities in a determined period may control the undesirable effects of polymerization shrinkage (Uno & Asmussen, 1991; Unterbrink & Muessner, 1995; Miyazaki & others, 1996; Sakaguchi & Berge, 1998). First, when reduced light intensity is applied, a molecular "rearrangement" occurs, reducing the internal stress since the conversion reaction speed is reduced. This promotes better adjustment of the material to cavity margins. The lower initial light intensity can be obtained by increasing the distance of the curing tip from the composite surface. Later, high light intensity is applied, which provides an adequate degree of conversion so that a material with satisfactory physical and mechanical properties is achieved (Uno & Asmussen, 1991; Pires & others, 1993; Feilzer & others, 1995; Unterbrink & Muessner, 1995; Hansen & Asmussen, 1997; Koran & Küerschner, 1998; Burgess & others, 1999; Kinomoto & others, 1999; Bouschlicher, Rueggeberg & Boyer, 2000). The results, presented in Table 3, agree with these authors' findings on the reduction of polymerization shrinkage resulting from the use of different light intensity.

During the initial stage of polymerization, the composite is sufficiently fluid to flow from the free surfaces toward the bonded surfaces or regions of material already cured. This ability to flow when the material is polymerized at a reduced rate occurs as a result of slower formation of the polymer network and cross-links, which supply favorable conditions to the adaptation of molecules within the polymeric chain that has been developing (Asmussen, 1975; Davidson & de Gee, 1984; Versluis & others, 1998; Koran & Küerschner, 1998; Burgess & others, 1999). This phenomenon probably had occurred in the stepped and intermittent light methods, where the gap values were smaller when compared to that of the continuous light method.

Restorative composites present significant differences in the resin composition matrix as well as in the filler, which influences the properties of the materials, including polymerization shrinkage (Feilzer, de Gee & Davidson, 1988; Rees & Jacobsen, 1989; Peutzfeldt, 1997; Asmussen & Peutzfeldt, 1998).

Table 4 shows that the Flow-it composite presented the largest contraction gap values. This may be explained by its composition (Table 1). This material has high viscosity Bis-GMA monomer admixtured with TEGDMA, which has a lower molecular weight and approximately 55% (by volume) filler content. Thus, Flow-it has a low viscosity but results in high polymerization shrinkage as suggested by Bayne & others (1998) and is shown in this study.

The Z100 composite also has Bis-GMA diluted with TEGDMA in its composition, but the volume of the filler is greater (66% in volume). However, this material still shows high contraction gap values even though they are statistically lower than the Flow-it values. It seems that the dilution of Bis-GMA by TEGDMA monomer results in increased shrinkage values. This may be explained by the presence of the TEGDMA molecule which has a low molecular weight, high mobility and low viscosity, in turn, providing a greater quantity of this monomer in a determinate volume of material when compared to the amount of Bis-GMA molecules (Peutzfeldt, 1997; Lovell, Newman & Bowman, 1999). According to Asmussen & Peutzfeldt (1998), more flexible monomers provide a higher degree of conversion and increase the reaction speed.

The Definite composite contains ORMOCER, which has a poorly understood complex composition. The ORMOCER refers to an organically modified ceramic matrix, which therefore has an inorganic portion, a connection unit and organically polymerizable molecules (Wolter, 1995). Definite composite still contains barium glass and silica, which act as inorganic fillers. This material demonstrated high contraction gap values but did not statistically differ from Z100 composite, although Wolter (1995) assigned a volumetric shrinkage of between 1 and 3% to ORMOCER when the filler amount was greater than 67% (in volume).

The other materials Alert, Surefil, P60 and Z250 demonstrated the lowest polymerization shrinkage values, with no statistical difference. Alert composite has an organic matrix of PCDMA monomer, which, according to Leinfelder & Prasad (1998), has lower shrinkage values because of the length of the carbon backbone for the single-bonded carbon groups that are somewhat longer in dimension than double-bonded carbon atoms. In addition, Alert composite has a high inorganic filler level (about 70% in volume) of conventional filler and glass fibers.

The Surefil resin matrix is formed by Bis-GMA modified urethane. The urethane bond is characterized by a lower viscosity than the Bis-GMA monomer (Asmussen & Peutzfeldt, 1998), which makes greater mobility of the molecules within the organic matrix of material possible during polymerization without causing essentially greater shrinkage

The resin matrices of Z250 and P60 composites are made up of Bis-GMA, UEDMA and Bis-EMA. The UEDMA monomer has a high molecular weight but presents considerable flow (Asmussen & Peutzfeldt, 1998). On the other hand, Bis-EMA monomer is Bis-GMA derived with the hydroxyl groups removed (Peutzfeldt, 1997). Thus, the combination of these molecules form the Z250 and P60 organic matrices that contribute to lower polymerization shrinkage.

Restorative resin composites may act in different ways if variations in photo-activation methods exist. This phenomenon may result from the flow capacity that occurs in the network polymer "rearrangement" that each material presents when there is a change in intensity and/or manner by which the light is applied to excite the conversion molecule reaction.

The results, presented in Table 5, show that Flow-it and Alert composites had similar behaviors. These materials showed the greatest contraction gap values in response to the continuous light technique, while they had lower values for both the stepped and intermittent light methods with no statistical difference. The explanation for these results could be based on the fact that the initial high light intensity may decrease the time of the conversion molecule phase, resulting in less flow and greater shrinkage.

Z100 composite behavior, under the three techniques utilized, was different. This material showed no significant difference between the continuous and intermittent light methods and between the stepped and intermittent light techniques. However, there was a significant difference between the continuous light and stepped light methods. It seems that when the process occurs more slowly, less internal stress is produced, providing material flow that results in reduced polymerization shrinkage.

The other materials revealed no differences with any of the techniques used, demonstrating that, independent of the photo-activation method, these materials were able to flow.

Thus, it was possible to verify that the shrinkage pattern of composites depends on the photo-activation method used as well as its composition.

CONCLUSIONS

- Polymerization shrinkage of composites occurs toward the top surface, which was the first to polymerize.
- The continuous light method resulted in the greatest contraction gap values. The stepped light and intermittent light techniques showed an effective reduction in polymerization shrinkage.
- The low viscosity composite, Flow-it, revealed the greatest contraction gap values, demonstrating

that the composition of the material has a significant influence on polymerization shrinkage.

- Different restorative composites had distinct behaviors in response to the three photo-activation methods.

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References

Asmussen E (1975) Composite restorative resins: Composition versus wall-to-wall polymerization contraction *Acta Odontologica Scandinavica* **16(4)** 337-344.

Asmussen E (1998) Direction of shrinkage of light-curing resin composites *Journal of Dental Research* **658** 77 (Abstract #212).

Asmussen E & Peutzfeldt A (1998) Influence of UEDMA, Bis-GMA and TEGDMA on selected mechanical properties of experimental composite resins *Dental Materials* **14(1)** 51-56.

Bayne SC, Thompson JY, Swift EJ Jr, Stamatiades P & Wilkerson M (1998) A characterization of first-generation flowable composites *Journal of the American Dental Association* **129(5)** 567-577.

Bouschlicher MR, Rueggeberg FA & Boyer D (2000) Effect of stepped light intensity on polymerization force and conversion in a photo-activated composite *Journal of Esthetic Dentistry* **12(1)** 23-32.

Bowen RL (1963) Properties of a silica-reinforced polymer for dental restorations *Journal of the American Dental Association* **66(1)** 57-64.

Burgess JO, de Goes MF, Walker R & Ripps AH (1999) An evaluation of four light-curing units comparing soft and hard curing *Practical Periodontics Aesthetic Dentistry* **11(1)** 125-132.

Davidson CL & de Gee AJ (1984) Relaxation of polymerization contraction stresses by flow in dental composites *Journal of Dental Research* **63(2)** 146-148.

Feilzer AJ, de Gee AJ & Davidson CL (1988) Curing contraction of composite and glass-ionomer cements *Journal of Prosthetic Dentistry* **59(3)** 297-300.

Feilzer AJ, Dooren LH, de Gee AJ & Davidson CL (1995) Influence of light intensity on polymerization shrinkage and integrity of restoration-cavity interface *European Journal of Oral Science* **103(5)** 322-326.

Ferracane JL (1992) Using posterior composites appropriately *Journal of the American Dental Association* **123(1)** 53-58.

Hansen EK (1982) Visible light-cured composite resins: Polymerization contraction, contraction pattern, hygroscopic expansion *Scandinavian Journal of Dental Research* **90(4)** 329-335.

Hansen EK & Asmussen E (1997) Visible-light curing units: Correlation between depth of cure and distance between exit window and resin surface *Acta Odontologica Scandinavica* **55(3)** 162-166.

Jörgensen KD, Itoh K, Munksgaard EC & Asmussen E (1985) Composite wall-to-wall polymerization contraction in dentin cavities treated with various bonding agents *Scandinavian Journal of Dental Research* **93(3)** 276-279.

Kinomoto Y, Torri M, Takeshige F & Ebisu S (1999) Comparison of polymerization contraction stresses between self- and light-curing composites *Journal of Dentistry* **27(5)** 383-389.

Koran P & Kürschner R (1998) Effect of sequential versus continuous irradiation of light-cured resin composite on shrinkage, viscosity, adhesion, and degree of polymerization *American Journal of Dentistry* **11(1)** 17-22.

Leinfelder K & Prasad A (1998) A new condensable composite for the restoration of posterior teeth *Dentistry Today* **17(2)** 112-116.

Lovell LG, Newman SM & Bowman CN (1999) The effects of light intensity, temperature, and comonomer composition on the polymerization behavior of dimethacrylates dental resins *Journal of Dental Research* **78(8)** 1.469-1.476.

Lutz F, Krejci I & Oldeenburg TR (1986) Elimination of polymerization stresses at the margins of posterior composite resin restorations: A new restorative technique *Quintessence International* **17(12)** 777-784.

Miyazaki M, Oshida Y, Moore BK & Onose H (1996) Effect of light exposure on fracture toughness and flexural strength of light-cured composites *Dental Materials* **12(6)** 328-332.

Peutzfeldt A (1997) Resin composites in dentistry: The monomer systems *European Journal of Oral Science* **105(2)** 97-116.

Pires JAF, Cvitko E, Denehy GE & Swift EJ Jr (1993) Effects of curing tip distance on light intensity and composite resin microhardness *Quintessence International* **24(7)** 517-521.

Rees JR & Jacobsen PH (1989) The polymerization of composite resins *Dental Materials* **5(1)** 41-44.

Sakaguchi RL & Berge HX (1998) Reduced light energy density decreases post-gel contraction while maintaining degree of conversion in composites *Journal of Dentistry* **26(6)** 695-700.

Tarle Z, Meniga A, Ristic M, Sutalo J, Pichler G & Davidson CL (1998) The effect of the photopolymerization method on the quality of composite resin *Journal of Oral Rehabilitation* **25(6)** 436-442.

Tolidis K, Nobecourt A & Randall RC (1998) Effect of a resin-modified glass-ionomer liner on volumetric polymerization shrinkage of various composites *Dental Materials* **14(6)** 417-423.

Uno S & Asmussen E (1991) Marginal adaptation of a restorative resin polymerized at reduced rate *Scandinavian Journal of Dental Research* **99(5)** 440-444.

Uno S & Shimokobe H (1994) Contraction stress and marginal adaptation of composite restorations in dentinal cavity *Dental Material Journal* **13(1)** 19-24.

Unterbrink GL & Muessner R (1995) Influence of light intensity on two restorative systems *Journal of Dentistry* **23(3)** 183-189.

Unterbrink GL & Liebenberg WH (1999) Flowable resin composites as "filled adhesives." Literature review and clinical recommendations *Quintessence International* **30(4)** 249-257.

Venhoven BAM, de Gee AJ & Davidson CL (1996) Light initiation of dental resins: Dynamics of the polymerization *Biomaterials* **17(24)** 2313-2318.

Versluis A, Tantbirojn D & Douglas WH (1998) Do dental composites always shrink toward the light? *Journal of Dental*

Research **77(6)** 1.435-1.445.

Walls AWG, McCabe JF & Murray JJ (1988) The polymerization contraction of visible-light activated composite resins *Journal of Dentistry* **16(4)** 177-181.

Wolter H (1995) Bulk-ORMOCER and ORMOCER composites in Annual Report 1995, Fraunhofer: Institut für Silicatforsghung

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Amalgam Repair: Evaluation of Bond Strength and Microleakage

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Clinical Relevance

Silver amalgam is still the best material for amalgam repairs, however, dual-cured resin bonding materials are strongly suggested to prevent microleakage and improve the tensile bond strength of repaired parts.

SUMMARY

This study evaluated the tensile bond strength of "repaired" amalgams and compared the degree of microleakage. Amalgam (Cavex avalloy) was condensed into plastic tubes (3 mm in diameter, 10 mm in height) to the half-length. After storage in water at 37°C for two days, the remaining parts of tubes were filled with amalgam (A), cavity varnish (CV)+A, Liner Bond 2V (LB2V)+A, 3M Opal Luting Cement (3MOLC)+A, Panavia F(PF)+A, Metabond(MB)+A, Fuji BondLC(FB)+A, HytacOSB(HOSB)+Hytac Aplitip (H), Liner Bond2V+Clearfil AP-X(CAP). The bond strengths for 15 samples of each restoration group were determined. For the microleakage study, MOD cavities of 90 extracted human premolars were used. The distal half of cavities were filled with amalgam. After storage in water at 37°C for two days, the mesial half of the cavities were filled to simulate a clinical repair. The "repair" was placed using the procedures applied in the bond strength study. The teeth were stained with basic fuchsine (0.5%), sectioned and evaluated for dye penetration. In both parts of study, the data were analyzed by ANOVA and Duncan's multiple range tests. Bond strength values (MPa) were: A+PF+A 3.84±1.08, A+LB2V+A 3.15±0.97, A+LB2V+CAP 3.05±0.53, A+MB+A 2.86±0.88, A+HOSB+H 2.58±0.51, A+3MOLC+A 2.11±0.75, A+FB+A 0.68±0.59. The repaired A+A and A+CV+A groups were separated before testing. The A+PF+A group showed the highest bond strength ($p<0.05$). Microleakage in the cervical margins of repaired restorations was lower in the amalgam groups than microleakage in the resin composite and compomer groups. PF, MB, 3MOLC and FB performed better at the amalgam "repair" interface. The A+LB2V+A group showed no microleakage at both the occlusal and gingival test regions.

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INTRODUCTION

Dental amalgam has been used successfully for more than a century as a restorative material. The popularity of this material is a result of its several distinct advantages, such as its relatively low cost, ease of manipulation, adequate physical properties, proven longevity, good wear resistance, low technique sensitivity and self-sealing ability. Thus, it remains the restorative material of choice in many clinical situations (Leinfelder, 1993,

Anderson & McCoy, 1993). However, its lack of adhesion to tooth structure and fractured amalgam part, marginal leakage, susceptibility to tarnish and corrosion and inadequate marginal integrity have either restricted its use or limited its success.

Preparation features that incorporate parallel or undercut walls, dovetails, box forms and retention grooves, retain traditional amalgam restorations. Such preparations often require removing healthy tooth structure. The development of bonded amalgams resulted from an attempt to determine whether the advantages of bonding resin composites could be used to overcome some inherent limitations of traditional amalgam restorations (Setcos, Staninec & Wilson, 2000).

Amalgam restorations sometimes fracture due to faults made during cavity preparations and restoration procedures or where recurrent caries has rendered a portion of them defective. A fracture in amalgam commonly occurs at the weakest point, such as an area of impurity, porosity and at macrocracks or microcracks. When the restoration is complex and large, repair of the fractured restoration should be considered in lieu of complete replacement. In certain complex cases, complete replacement can be time-consuming, costly and potentially traumatic to the pulp.

An important factor related to the quality of the amalgam repair is the strength of the joined amalgam surfaces. Repaired amalgam occlusal surfaces (either marginal ridges or supporting cusps) are often exposed to lateral and vertical masticatory forces that introduce considerable shear and flexural stresses (Gordon & others, 1987). Variables that may affect the degree of bond strength of a repaired amalgam restoration include the types of amalgam alloy used, surface treatments of the aged amalgam, age differences between old and new amalgam and the test methods employed. Terkla, Mahler & Mitchem (1961) reported that repair of fractured amalgam was a hazardous procedure from a strength standpoint. It was possible that if mechanical locking by undercutting and dovetailing was used, this low-strength hazard might be mitigated. In recent years, 4-META based adhesive system (Amalgambond, Parkell, Farmingdale, NY 11735 USA) has been promoted to improve the bond strength of fresh amalgam to an existing amalgam restoration (Hadavi & others, 1991). Various studies on the strength of repaired amalgam reported different results (Jorgensen & Saito, 1968; Gordon & others, 1987; Hibler & others, 1988; Diefenderfer, Reinhardt & Brown, 1997; Jessup & others, 1998). The conflicting nature of the conclusions of these previous studies causes suspicion as to whether amalgam repair is a clinically acceptable technique.

The objectives of this study include: (1) evaluating the tensile bond strength of amalgam "repaired" with a resin material or amalgam by applying different restorative procedures, (2) determining microleakage by dye penetration between the original amalgam and the "repair" interface, (3) comparing microleakage at gingival margins of the amalgam "repair."

METHODS AND MATERIALS

Tensile Bond Strength Test Procedure

One hundred and thirty-five cylindrical specimens of amalgam (Cavex Avalloy, 2003 RW, Haarlem, Holland)

Table 1: *Restoration Procedures of Specimens and Groups*

Groups	First Part of Specimens	Intermediate Bonding Material	Second Part of Specimens
1	Amalgam (A) (Cavex, 2003 RW, Haarlem, Holland)	-	Amalgam (A)
2	Amalgam (A)	Cavity Varnish (CV) (Cooley & Cooley Ltd, Houston, TX 77041, USA)	Amalgam (A)
3	Amalgam (A)	Liner Bond 2V (LB2V) (Kuraray, Osaka, 530-8611, Japan)	Amalgam (A)
4	Amalgam (A)	3M Opal Luting Cement (3MOLC) (3M Dental Products, St Paul, MN 55144, USA)	Amalgam (A)
5	Amalgam (A)	C&B Meta Bond (MB) (Sun-Medical, Japan)	Amalgam (A)
6	Amalgam (A)	Fuji Bond LC (FB) (GC, Japan)	Amalgam (A)
7	Amalgam (A)	Panavia F (PF) (Kuraray, Osaka, 530-8611, Japan)	Amalgam (A)
8	Amalgam (A)	Liner Bond 2V (LB2V) (Kuraray, Osaka, 530-8611, Japan)	Composite (CAP) Clearfil AP-X (Kuraray, Osaka, 530-8611, Japan)
9	Amalgam (A)	Hytac OSB (HOSB) (ESPE, Germany)	Compomer (H) Hytac Aplitip (ESPE, Germany)

Liner Bond 2V, Meta Bond and Panavia F has the special instructions for amalgam repair.

mixed according to manufacturers' instructions, were fabricated by condensing the material into half length of the plastic tubes (3 mm in diameter, 10 mm in height) with an amalgam condenser that has a long condensing head (10 mm). After storage in water at 37°C for two days, the remaining parts of the tubes were filled with test materials (Table 1). However, before applying the test materials, an inverted cone diamond bur 19 mm in length (North Bel, Italy, 805/018) was used to flatten the attached faces of original amalgam parts. The materials were applied strictly according to manufacturers' instructions.

The bond strengths were determined for 15 samples of each restoration group. After removing the plastic tubes, the cylindrical specimens were subjected to the tensile bond test in a Universal Testing Machine (Bencor-Multi T, Danville Engineering Co, CA, USA) at a cross-head speed of 1 mm/minute. Microtensile bond strength values were calculated in MPa.

Microleakage Test Procedure

Ninety extracted human premolars were used for the microleakage study. Mesio-occluso-distal Class II (MOD) cavities were prepared in each tooth. The occlusal depth of the cavities was approximately 2 mm. The width of the gingival wall was approximately 2 mm. The gingival margins were prepared 1 mm above the cemento-enamel junction (CEJ). The distal half of the cavities was restored with amalgam. After storage in water at 37°C for two days, a plain fissure diamond bur (Denta GmbH, Germany, G837.010) was used in a high speed contra-angle to flatten the contact areas where the "repair" would be placed, then the remaining cavities (mesio-occlusal) were filled following the procedures applied in the bond strength study (Table 1). The teeth were painted with nail varnish to within 2 mm of the restoration margins and the root apices were sealed with a chemically-cured resin composite. Thermocycling was carried out in 0.5% basic fuchsin dye solution at a temperature of 4°C (±2°C) and 55°C (±2°C) alternately 250 times for five seconds at each temperature. After thermocycling, the teeth were stored in the dye solution for 48 hours at 37°C and divided into nine groups of 10 samples each. They were then sectioned with an Isomet saw (Isomet Buehler Int, Evanston, USA) in a mesio-distal direction through the center of the restorations. Dye penetration was assessed between the amalgam and the repaired parts of the restoration at the occlusal regions. Microleakage at the gingival margins of repaired restoration parts was also compared with a stereomicroscope at a magnification level of x20 according to the following scoring system (Figure 1):

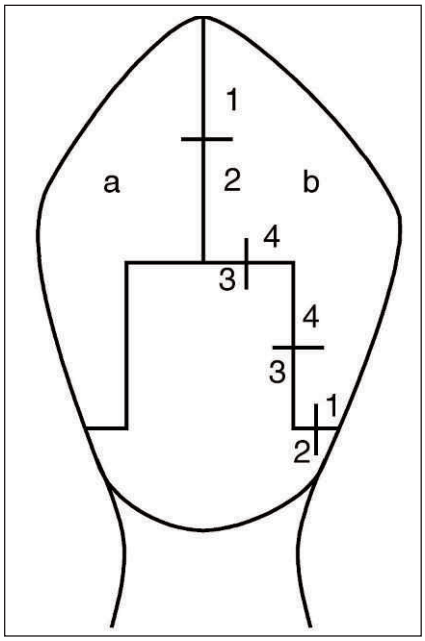

Figure 1. *Diagram of microleakage scoring system:*
a= Original amalgam part
b= Repaired restoration part

0: No dye penetration.

1: Dye penetration less than half way to the pulpal floor at the occlusal amalgam "repair" interface (cervical—less than half way to the axial wall).

2: Dye penetration up to the pulpal floor at the occlusal amalgam "repair" interface (cervical—to the axial wall).

3: Dye penetration along half the pulpal floor at the occlusal amalgam "repair" interface (cervical—along half the axial wall).

4: Dye penetration along the entire pulpal floor at the occlusal amalgam "repair" interface (cervical—along the entire axial wall).

In both parts of study, the data were analyzed by ANOVA and Duncan's multiple range tests.

RESULTS

Tensile Bond Strength Test Results

The results were presented in Table 2. Specimens of the A+A and A+CV+A groups broke off at the attached line before testing procedures. They showed no bonding ability.

The strongest "repaired" group was A+PF+A ($p<0.05$). The A+LB2V+A group followed it. The tensile strength of A+FB+A was the lowest ($p<0.05$). No statistically significant differences were evident regarding the tensile bond strength of the A+3MOLC+A group when compared to the A+HOSB+H group ($p>0.05$). In addition, there was no statistically significant difference among the tensile bond strength values of the A+HOSB+H, A+LB2V+A, A+LB2V+CAP and A+MB+A groups ($p>0.05$).

Microleakage Test Results

Table 3 represents the mean values of microleakage at the occlusal repair interface and at gingival margins of repaired restoration parts.

Table 2: *Mean Values and Standard Deviation (SD) of Tensile Bond Strengths of the Repaired Amalgam Groups (n=15)*

Groups	Mean (SD) (MPa)
A+PF+A	3.84 (1.08) d
A+LB2V+A	3.15 (0.97) c
A+LB2V+CAP	3.05 (0.53) c
A+MB+A	2.86 (0.88) c
A+HOSB+H	2.58 (0.51) b c
A+3MOLC+A	2.11 (0.75) b
A+FB+A	0.68 (0.59) a

Means with same letter were not statistically different.

Table 3: *Mean Values and Standard Deviation (SD) of Microleakage of the Repaired Amalgam Groups (n=10)*

Groups	Mean (SD) (Occlusal)	Mean (SD) (Gingival)
A-A	0.30 (0.48) a b c	0.60 (0.97) a b c
A-CV-A	0.00 (0.00) a	0.20 (0.42) a b
A+LB2V+A	0.00 (0.00) a	0.00 (0.00) a
A+3MOLC+A	0.60 (0.97) a b c	1.20 (1.03) b c d
A+MB+A	0.00 (0.00) a	1.30 (1.70) c d
A+PF+A	0.00 (0.00) a	1.20 (1.62) b c d
A+FB+A	0.60 (1.26) a b c	2.20 (1.62) d e
A+LB2V+ CAP	0.00 (0.00) a	2.10 (1.60) d e
A+HOSB+H	0.40 (1.26) a b c	2.50 (1.72) e

Means with same letter were not statistically different.

In general, microleakage in gingival margins of repaired restorations was lower in amalgam groups than microleakage in gingival margins of resin composite (CAP) and compomer (H). The A+FB+A group showed the highest mean microleakage value among the amalgam groups at the gingival margins. Of all groups, the A+HOSB+H, A+FB+A and A+LB2V+A groups showed the worst performance at the gingival margins. However, the microleakage values of these three groups showed no significant difference ($p>0.05$).

Although CV, LB2V, MB and PF performed best in preventing microleakage at the "repair" interface restorations, there was no statistically significant difference among the groups ($p>0.05$). In the A+A, A+CV+A, A+LB2V+A and A+3MOLC+A groups, there was no significant difference between the microleakage values of the occlusal and gingival regions ($p>0.05$). The A+LB2V+A group was the only one that did not show any microleakage at both the occlusal and gingival test regions.

DISCUSSION

Most studies on durability of repaired amalgam evaluate the flexural or bond strength and microleakage of the repaired amalgam. The effect of masticatory stresses on teeth either restored or unrestored is variable. Since tension is likely to be encountered in the mouth, especially across the occlusal isthmus of Class II restorations under occlusal load, tensile properties have been critical parameters for the strength of amalgam restorations. In a study by Mahler, 1958, it was concluded that disto-occlusal amalgam restorations that failed at the isthmus were caused by tensile stresses.

This study was designed to assist practitioners in selecting a material for repair of a failed amalgam restoration. The study assessed and compared the results derived from two laboratory testing methods, one for tensile bond strength and the other for microleakage. Study results showed that the use of resin bonding materials increased bonding ability of an amalgam to another amalgam part. Without using any bonding material, amalgam did not join to the original amalgam block. PF was found the best material to enhance the bonding mechanism of amalgam to the original amalgam part. However, glass ionomer-based FB performed the worst during tensile bond testing.

Some previous studies reported that repaired amalgam has lower bond strength than an intact specimen. Kirk (1962) reported that the tensile strength of repaired conventional amalgam ranged from 23% to 98% of the intact controls. Consani, Ruhnke & Stolf (1977) investigated the tensile strength of repaired amalgam and concluded that the tensile strength of repaired specimens ranged from 14% to 33% of the control group. Hadavi & others (1992) reported tensile bond strength to be between 33.36-16.92 MN/mm2 for the repaired test samples. They concluded that the repaired amalgam exhibited a reduced tensile strength when compared with intact restorations; the tensile strength of repaired amalgam was greater when the same type of amalgam was used and the interfaces were uncontaminated. All samples contaminated with copalite were fractured during removal from the specimen molds. This study also revealed that cavity varnish application caused a complete failure between the two amalgam parts. In this study, intact amalgam was not used as a control group. Only the test materials were compared with each other. The amalgam, itself, was found to be the best material when was used with bonding agents to join an old amalgam block. In a similar study by Leelawat & others (1992), the dentin bonding agent and the 4-META adhesive produced significantly higher shear strength than the test group in which no lining material was used in repair procedures. On the other hand, Hadavi & others (1991) showed that the use of a 4-META based adhesive material did not increase shear bond strength between amalgam parts. However, this *in vitro* study found that 4-META containing MB was as successful as LB2V in tensile bond test.

Cooley, McCourt & Train (1989) demonstrated that a 4-META based adhesive for bonding of resin composite to amalgam developed strengths in the 6 to 7 MPa ranges. In this study, the mean bonding value of resin composite (CAP) to amalgam was 3.05±0.53. The composite was used with LB2V. Compomer material (H) also showed similar bond strength (2.58±0.51) without any significant difference. But these bond strengths were lower than the bond strength of the A+PF+A group (3.84±1.08).

Since amalgam failures were characteristic for the isthmus of Class II amalgam restorations, in this study microleakage was assessed in the MOD cavities. The microleakage results of this study support the results of the bond strength study. LB2V, MB and PF performed better than other materials in preventing microleakage between original and repaired amalgam parts. LB2V was also good between amalgam and CAP composite material. The same results apply as in the bond strength study—3MOLC and FB were not as successful as other bonding materials. Cavity varnish was found to be very effective in preventing microleakage.

Since microleakage in gingival margins is an important issue for marginal sealing ability of restorative materials, microleakage in gingival margins of the "repaired" parts was also investigated. The study indicated that microleakage in gingival margins of "repaired" restorations was lower in amalgam groups than microleakage in gingival margins of resin composite and compomer. Cardash & others (1990) stated that microleakage was significantly less at the amalgam/cementum, amalgam/resin composite interfaces than at the composite/cementum interfaces. Their results were consistent with the findings of this study. In the current study, no microleakage was observed between amalgam/composite occlusal interfaces, but there was significant leakage of repaired composite parts at the gingival regions. Microleakage was reduced at the gingival regions of repaired amalgam parts.

CONCLUSIONS

1. The tensile bond strength of "repaired" amalgam was higher when dual-cured resin cement (PF) and dual-cured bonding materials (LB2V) were used between the two amalgam parts.
2. Glass ionomer-based FB resin-bonding material did not withstand tensile stresses.
3. Microleakage at gingival margins of amalgam "repairs" was higher than microleakage at gingival "repairs" of composite and compomer.
4. Cavity varnish, LB2V, MB and PF prevented microleakage between interfaces of original amalgam and "repairs."

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References

Anderson MH & McCoy RB (1993) Dental amalgam: The state of the art and science *Dental Clinics of North America* **37** 419-431.

Cardash HS, Bichacho N, Imber S & Liberman R (1990) A combined amalgam and composite resin restoration *Journal of Prosthetic Dentistry* **63** 502-505.

Consani S, Ruhnke LA & Stolf WL (1977) Infiltration of a radioactive solution into jointed silver-amalgam *Journal of Prosthetic Dentistry* **37** 158-163.

Cooley RL, McCourt JW & Train TE (1989) Bond strength of resin to amalgam as affected by surface finish *Quintessence International* **20** 237-239.

Diefenderfer KE, Reinhardt JW & Brown SB (1997) Surface treatment effects on amalgam repair strength *American Journal of Dentistry* **10(1)** 9-14.

Gordon M, Ben-Amar A, Librus S & Liberman R (1987) Bond strength of mechanically condensed repaired high-cooper amalgam *Quintessence International* **18(7)** 471-474.

Hadavi F, Hey JS, Ambrose ER & Elbadrawy HE (1991) The influence of an adhesive system on shear bond strength of repaired high-cooper amalgams *Operative Dentistry* **16** 175-180.

Hadavi F, Hey JH, Czech D & Ambrose ER (1992) Tensile bond strength of repaired amalgam *Journal of Prosthetic Dentistry* **67(3)** 313-317.

Hibler JA, Foor JL, Mirand FJ& Duncanson MG (1988) Bond strength comparisons of repaired dental amalgams *Quintessence International* **19(6)** 411-415.

Jessup JP, Vandewalle KS, Hermesch CB& Buikema DJ (1998) Effects of surface treatments on amalgam repair *Operative Dentistry* **23(1)** 15-20.

Jorgensen KD & Saito T (1968) Bond strength of repaired amalgam *Acta Odontologica Scandinavica* **26** 605-615.

Kirk EEJ (1962) Amalgam to amalgam bond: A preliminary report *Dental Practitioner* **12** 371-372.

Leelawat C, Scherer W, Chang J, Vijayaraghavan T& LeGeros J (1992) Bonding fresh amalgam to existing amalgam: A shear and flexural strength study *Journal of Esthetic Dentistry* **4(2)** 46-49.

Leinfelder K (1993) Current developments in dentin bonding systems: Major progress found in today's products *Journal of the American Dental Association* **124(5)** 40-42.

Mahler DB (1958) An analysis of stresses in a dental amalgam restoration *Journal of Dental Research* **44** 977-988.

Setcos JC, Staninec M & Wilson NHF (2000) Bonding of amalgam restorations: Existing knowledge and future prospects *Operative Dentistry* **25(2)** 121-129.

Terkla LG, Mahler DB & Mitchem JC (1961) Bond strength of repaired amalgam *Journal of Prosthetic Dentistry* **11** 942-947.

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Clinical Technique/Case Report

R_X for Caries Prevention: Time Line for Home Care

A Software Aid for Communication of Patient Instructions for Management of Dental Caries

DA Newitter • JC Meiers • RB Kazemi

PURPOSE

Treatment of a caries active patient requires the clinician to be knowledgeable in the restorative and risk management issues with which these patients often present. Modifications of risk factors that promote dental caries play an important part in the long-term restorative success in these patients. Patient compliance to recommendations addressing modifiable caries risk factors for maintenance of oral health is important to long-term caries risk management. Effective dentist-patient or hygienist-patient communication is a first step to encouraging a proactive role by the patient. Others have reported verbal communication accompanied by written communication to result in better compliance compared to verbal communication, alone (Tagliacozzo & Ima, 1970; MacDonald, MacDonald & Phoenix, 1977; Baker & others, 1991; Harvey & Plumridge, 1991; Vukmir & others, 1993; Makoul, Arntson & Schofield, 1995). Further evidence shows that medical patients who misunderstand their treatment plans and associated instructions usually exhibit poor compliance to following directions (Cargil, 1992; Counsell, Geddis & Smith, 1993; Vukmir & others, 1993; Makoul & others, 1995; Mayeaux & others, 1996). Computer-generated (printed) instructions were shown to significantly increase compliance to emergency room instructions when compared to verbal or verbal + handwritten instructions (Vukmir & others, 1993). Written instructions for use in management of dental caries have not been widely addressed in the literature (Fuller & Harding, 1991; Benn & others, 1997). This report presents a novel computer-generated, graphic approach to written communication that recognizes the patient's need to be reminded that home care consists of daily cyclic events. The objective of this approach is to promote communication with and comprehension by a wider population range

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than what might be affected by text-only instructions. The software for this method is pre-loaded with recommendations that can be modified by the dentist or hygienist and can be easily adapted as part of a comprehensive disease management program used in the office.

DESCRIPTION OF COMMUNICATION INSTRUMENT

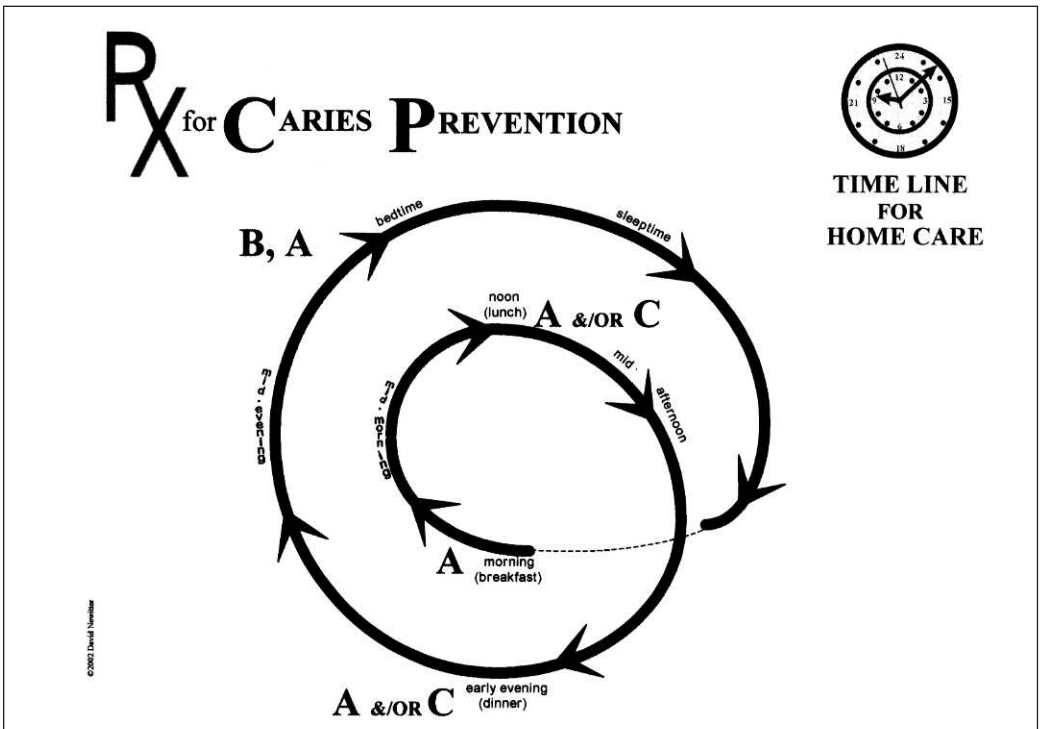
The communication instrument presented in this article (Figure 1) is a prescription for prevention of dental caries, that is, R_X for Caries Prevention. This instrument is a computer-generated graphic presentation tool centered upon the Cyclic Time Line, that is, Time Line for Home Care. The cyclic format helps to emphasize the continuing attention required by a caries management program. Graphically placing a 24-hour clock in the top right corner helps to visually communicate the relationship of the abstract timeline to real time.

An instructional statement is placed below the timeline, which serves to inform the patient that this program is user-friendly. That is, it is expected that people will miss recommended events and they are expected to resume at the next event.

Data entry begins with typing the patient's name, then using the Tab key to scroll to the dentist's name and date. This individualized format could be adapted to document the recommendations as a file attachment in an electronic record or as a printed copy in the form of a chart. Pressing the Tab key will then scroll the user to the recommendation boxes.

There are two types of recommendation boxes. Boxes A through H feature drop-down menus (Figure 2) that contain treatment recommendations. In any or all of these eight boxes, A through H, a different treatment recommendation can be posted. The drop-down menus are modifiable and can contain the same or different content for each box (A–H). If the practitioner wishes to add recommendations that are not on the menus, or needs to add additional instructions, this can be printed in boxes I–N, (Figure 1). These six boxes will automatically expand as needed to accommodate text.

The prescription can then be printed after the recommendations have been entered. The dentist or hygienist can then review the recommendations with the patient, using a marker pen to place the letter of each recommendation at the appropriate location(s) on the timeline, or a computer entry of the letters can be made prior to printing (Figure 1). The letter for



These recommendations were prepared for **Mr. Ed Smith** by **Dr. Jones**. Date: **January 24, 1998**

INSTRUCTIONS: Dental Care is a 24 hour event. The *letter* for each recommendation listed below is hand written on the above Time Line for Home Care. This time-line tells you when to follow each recommendation. Adjust the recommended daily routine to fit your life style. If you miss an item, just continue with the next item at the appropriate time.

RECOMMENDATIONS:

A. Fluoride paste(Colgate,Crest,etc):brush 2 minutes	B. Floss/Proxibrush: Clean the sides of each tooth	
C. Sugarless gum:chew after eating for 15-20min	D.	
E.	F.	
G.	H.	
I. Tooth Brushing: Also brush the top surface of your tongue. After brushing, spit out the toothpaste, do not rinse, and try not to eat or drink for 30 minutes; this prolongs fluoride contact with the teeth.	J. Chewing gum after eating stimulates saliva that has higher capacity to buffer acids than unstimulated saliva.	K. If you have any questions, you should not hesitate to call me.
L.	M.	N.

Figure 1. *Prescription is ready for printing. Prior to making entries, the patient and dentist name spaces, the date space and the recommendation boxes were blank.*

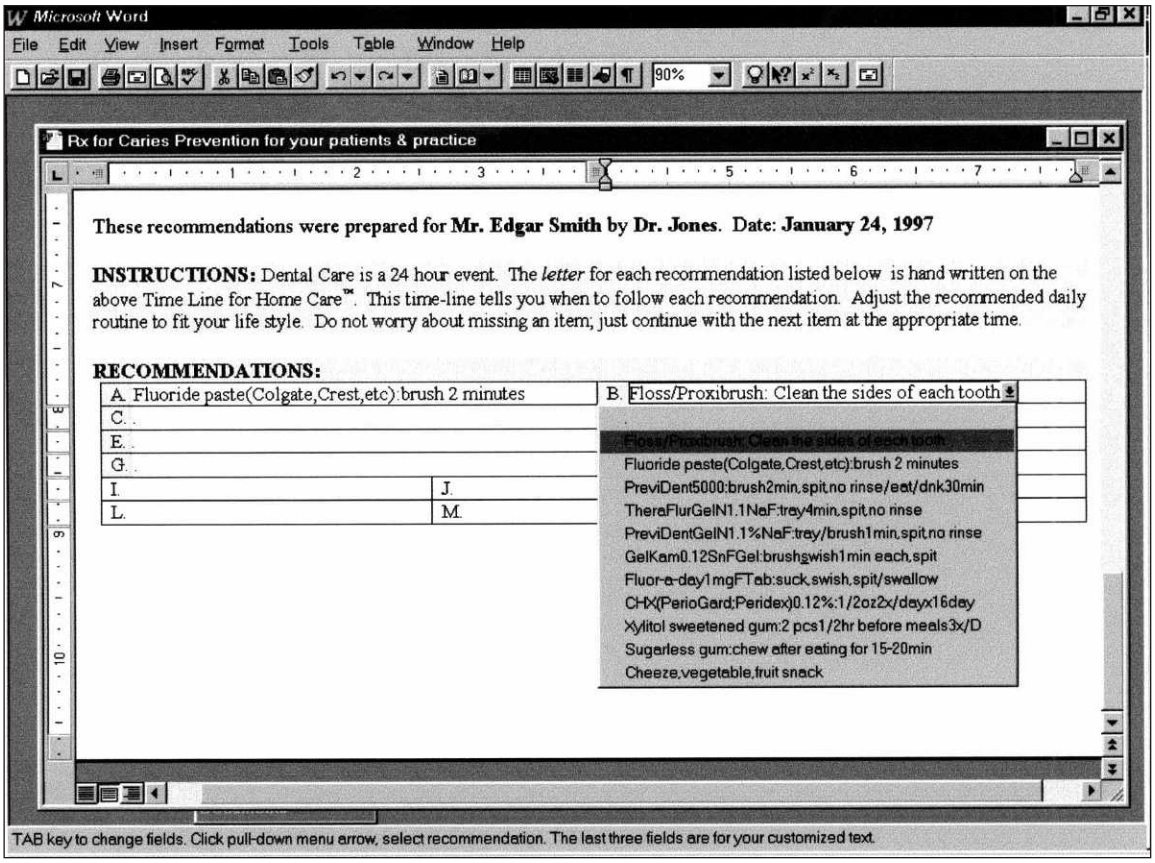


Figure 2. *A selection has been made from the pull-down menu in Recommendation box B.*

any recommendation that is indicated for multiple implementations during the day may be placed on the timeline at all relevant locations. The patient can then be instructed to place the record on his/her bathroom mirror with sticky tape. This will serve as a reminder to the patient that oral care needs attention and provides a script for what needs to be done.

This software was rendered in Microsoft Word 97 (Microsoft Corporation, Redmond, WA 98052-6399, USA) and IBM (Armonk, NY 10504, USA) format. Although the software is copyrighted, it is available at no cost on a disk or hard copy for clinical use (non-commercial distribution) upon request from the corresponding author. The disk also contains instructions and a version designed for handwritten entry. Computer and software compatibility can be a potential problem for those who want to use the program. As stated on the Microsoft Corporation Website (Microsoft, 2001), Word 97 is the leading word processing program; it is likely that most dental offices have a compatible application on their office computer.

SUMMARY

Kanellis (2000) called for the need to encourage efforts to develop effective caries-management educational/instructional approaches. Developing specific caries risk factor management strategies for high-risk patients requires an organized approach that should lead to customized, easily understood instructions for the patient (Benn & others, 1997). The method presented in this article addresses an instructional aspect of caries management.

It can be anticipated that not all patients will respond similarly to a motivational method. Therefore, it is important to have alternative methods. This communication tool has been used in our faculty practice on an ad hoc basis for patients presenting with high-risk for dental caries with encouraging results, and a pilot study is being planned.

Documenting efforts to prevent the recurrence of disease may become important to the reimbursement process where there is third-party involvement or where litigation is a factor. Just like physicians, attorneys and accountants who charge a fee for their recommendations, clearly defining the path leading to recommendations and documenting them should likewise justify a fee from the dental practitioner. The fee defines value. The paradigm in operative dentistry may be changing (Löe, 1995).

Advantages and disadvantages of using the method described include:

Advantages

- Ancillary office staff can prepare the prescription based upon the dentist and hygienist's recommendations. The program is user-friendly and modifiable.
- Reinforcement of verbal instructions.
- Source of memory reference for patient.
- Conceptually visual, requiring minimal reading.

- Designed to visually attract patient's attention after posting at home.
- Documents recommendations made to patient.
- Potential for inclusion in electronic or hard copy record.
- The application software is in widespread use.

Disadvantages

- Requires time, thought and effort to codify instructions for a patient.
- Compensation for this activity will likely be nonexistent from third-party payers and will likely be resisted by many direct pay patients.
- Computer, application software and printer are required to generate printed copies.

Note

To receive a free copy of the software on disk, correspond with the first author by e-mail (newitter@nos2.uchc.edu), and include your postal mailing address.

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References

Baker D, Roberts DE, Newcombe RG & Fox KAA (1991) Evaluation of drug information for cardiology patients *British Journal of Clinical Pharmacology* **31** 525-531.

Benn DK, Dankel DD, Clark D, Lesser RB & Bridgwater, AB (1997) Standardizing data collection and decision making with an expert system *Journal of Dental Education* **61(11)** 885-894.

Cargill JM (1992) Medication compliance in elderly people: Influencing variables and interventions *Journal of Advanced Nursing* **17** 422-426.

Counsell AM, Geddis DC & Smith AR (1993) Parental perceptions of information about medication prescribed for their children *New Zealand Medical Journal* **106** 205-206.

Fuller SS & Harding M (1991) The use of the sugar clock in dental health education *British Dental Journal* **170** 414-416.

Harvey JL & Plumridge RJ (1991) Comparative attitudes to verbal and written medication information among hospital outpatients *DICP: Drug Intelligence and Clinical Pharmacy: The Annals of Pharmacotherapy* **25** 925-928.

Kanellis MJ (2000) Caries risk assessment and prevention: Strategies for Head Start, Early Head Start, and WIC *Journal of Public Health Dentistry* **60** 210-217.

Löe H (1995) Changing paradigms in restorative dentistry *Journal of the American College of Dentists* **62(3)** 31-6.

MacDonald ET, MacDonald JB & Phoenix M (1977) Improving drug compliance after hospital discharge *British Medical Journal* **2** 618-621.

Makoul G, Arntson P & Schofield T (1995) Health promotion in primary care: Physician-patient communication and decision making about prescription medications *Social Science and Medicine* **41** 1241-1254.

Mayeaux EJ Jr, Murphy PW, Arnold C, Davis, TC, Jackson RH & Sentell T (1996) Improving patient education for patients with low literacy skills *American Family Physician* **53(1)** 205-211.

Microsoft Corporation (2001) Microsoft® Word 97 for Windows® 95 http://www.microsoft.com/catalog/display.asp?subid=22&site=188&x=57&y=15.

Tagliacozzo DM & Ima K (1970) Knowledge of illness as a predictor of patient behavior *Journal of Chronic Diseases* **22** 765-775.

Vukmir RB, Kremen R, Ellis GL, DeHart DA, Plewa MC & Menegazzi J (1993) Compliance with emergency department referral: The effect of computerized discharge instructions *Annals of Emergency Medicine* **22(5)** 819-823.

Departments

Classifieds: Faculty Positions

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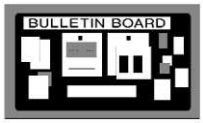
University of Illinois at Chicago

The Department of Restorative Dentistry at the University of Illinois at Chicago is seeking applications for faculty positions (tenure and non-tenure track) beginning July 1, 2002 at the assistant to full professor levels. Responsibilities include pre-clinical and clinical instruction in all aspects of the restorative sciences. Qualifications include a DDS/DMD degree, advanced training in operative dentistry, prosthodontics (board eligibility desirable, but not required) or prior teaching experience. Candidates must be eligible for licensure in Illinois. Research experience is desirable. Participation in continuing education and the faculty practice is mandatory for both positions; participation in research is mandatory for a tenure track position only. For fullest consideration, applications should be received by March 31, 2002. Salary and academic rank commensurate with experience and qualifications. Applicants should forward their curriculum vitae and the names of three references to Dr. Stephen Campbell, Professor and Head, UIC Restorative Dentistry, M/C555, 801 S Paulina Street, Chicago, Illinois 60612. AA/EOE.

Announcements



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A five-day clinical course in conservative gold castings, mentored by Dr Richard V Tucker, will be conducted on June 10-14, 2002 at the University of Washington Dental School

For course information, please contact Dr Dennis Miya at 206/244-1618 or via e-mail at diichi@aol.com.

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