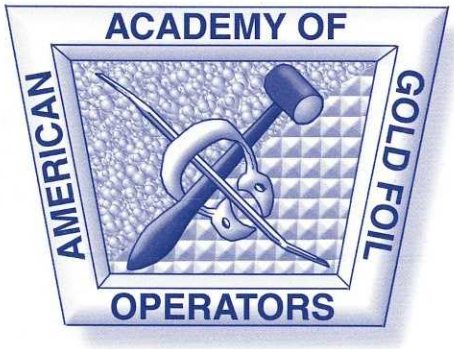
OPERATIVE DENTISTRY



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Aim and Scope

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

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Editorial

Tradition and Transition

Welcome to Operative Dentistry's first issue for the year 2000! We're entering the next millennium and our 25th publication year with a new editorial team, a new home for the journal–Indiana–and equal amounts of excitement and apprehension. Well, perhaps more apprehension than excitement. Fortunately, the move has gone smoothly, thanks to the wonderful cooperation, support, and encouragement of Dick McCoy, Marty Anderson, Darlyne Bales, Kate Flynn Connolly, and Judy Valela. This group of dedicated professionals has made the journal transition possible, and our editorial team, the academies, and readership owe them a debt of gratitude. I also want to express my appreciation to the parent academies–the American Academy of Gold Foil Operators and the Academy of Operative Dentistry. Both were extremely generous in providing funding for the move and replacing well-used equipment. In addition, the outstanding support of the Indiana University School of Dentistry provided the necessary time and facilities to establish our new office.

Finally, I must acknowledge the tremendous contribution of our Editorial Board, who agreed to continue their review duties for the journal. We're very fortunate to have an international group of researchers and clinicians who represent the best in academics, private practice, organized dentistry, and the military. Their efforts provide the critical quality you have come to expect from this publication.

This transition has given us the opportunity to accomplish some renovation of the journal. In addition to our new cover design and internal style changes, we've added an "Invited Papers" section that should allow us to provide more clinical and state-of-the-art technique articles. The editor will solicit these papers from recognized authorities, and they'll be reviewed by the editorial staff for content. Dr. John Osborne has written the first in this series. Suggestions for topics and/or contributors are welcome. We'll also publish occasional "Commentaries" (see Mjör in this issue) and, as a special tribute to our first 24 years, I've asked each of the previous editors and managing editor to provide a series of editorials outlining their unique perspectives on the journal, the academies, and our discipline. I hope that you enjoy these alterations, and I strongly encourage all who read this journal to send me critiques and suggestions for improving Operative Dentistry to better help us provide a publication that truly meets your expectations and needs as a restorative dentist.

Perhaps the most important innovation has been the institution of a Corporate Sponsorship program. While the journal is committed to a policy of not accepting commercial advertising, dental manufacturers can now become sponsors of Operative Dentistry for an annual fee. This program will help us maintain our nominal subscription rate, while allowing for improvements in quality and size, such as our current increase from 64 to 72 pages. It will also permit sponsors to become associated with the journal and show our readers their support for dental research and excellence in clinical dentistry. Please note the logos of our Corporate Sponsors displayed on our inside back cover. These companies have joined Operative Dentistry in our commitment to publish quality dental literature in a timely manner.

We've made changes in our Web page, as well. They're outlined in the Departments section of the journal, and I hope that they'll make our Internet service even more helpful and informative. We anticipate greater electronic involvement in the future, both in handling submitted manuscripts and in our publication of the journal.

It's an extremely daunting task to move a journal of the stature of Operative Dentistry away from the place where it was conceived, nurtured, and brought to maturity. It's equally intimidating to be expected to maintain the outstanding quality infused into this journal by Ian Hamilton, Dave Bales, Max Anderson, Dick McCoy, and Marty Anderson during their tenures. My pledge to our readership is that we're committed to maintaining the tradition of excellence and integrity that was established in Seattle by the previous editors, and to moving your journal into the 21st Century with substance and style.

Michael A Cochran
Editor

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Original Articles

Bond Strengths of Single-Bottle Dentin Adhesives to Caries-Affected Dentin

M Nakajima • H Sano • I Urabe
J Tagami • D H Pashley

Clinical Relevance

When bonding single-bottle adhesives to caries-affected dentin, 32-35% phosphoric acid is required as an etchant to achieve optimal bond strength.

SUMMARY

There is concern that some acidic conditioners may not be strong enough to adequately etch sclerotic or caries-affected dentin. The hypothesis that was tested was that there were no significant differences in the bond strengths of single-bottle bonding systems to normal or caries-affected dentin, regardless of the strength of the phosphoric-acid conditioner. Extracted teeth with coronal caries extending into mid-dentin were prepared by grinding the occlusal surface flat. This left a central region of caries-affected dentin surrounded by normal dentin. The One-Step bonding system was used to bond dentin following etching with 10 or 32% phosphoric acid. The Single Bond system was used after etching dentin with 10 or 35% phosphoric acid. After 24 hours in water, serial vertical sections were made through the bonded teeth to create slabs 0.7 mm thick. Each tooth yielded four to five slabs, some of which included normal dentin, while others included caries-affected dentin. Each slab was trimmed into an hourglass configuration to limit the test area to normal or caries-affected dentin. The results obtained with One-Step following etching with 10% phosphoric acid showed lower ($p<0.05$) tensile bond strengths to caries-affected dentin compared to normal dentin (36.9 ± 8.0 MPa vs 47.7 ± 6.5 MPa, respectively). This difference disappeared when using 32% phosphoric acid (49.7 ± 6.1 MPa vs 45.0 ± 7.2 MPa, respectively). Bonds made to caries-affected dentin with Single Bond were always lower than bonds to normal dentin regardless of the strength of the phosphoric acid. Scanning electron microscopy of polished cross sections sequentially challenged with acid and NaOCl revealed loss of the middle of the hybrid layers created by either bonding system in caries-affected dentin etched with 10% phosphoric acid. It is clear that 32-35% phosphoric acid is required to adequately etch caries-affected dentin in order to produce high bond strengths and well-infiltrated demineralized dentin.

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INTRODUCTION

Recently, many manufacturers have introduced so-called "single-bottle" resin adhesive systems in an attempt to simplify the multiple steps required for bonding resins to dentin. Generally, this has been accomplished by mixing monomers that were previously packaged separately as primers, with their corresponding adhesive monomers. Most manufacturers now recommend the moist bonding technique (Kanca, 1992, 1996). By eliminating the priming steps, the demineralized dentin may shrink less, since there may be less evaporation of water. However, these monomers must still compete with the water that surrounds the collagen fibrils and covers the surface. Many of the single-bottle systems recommend the application of their single solution in two separate steps. That is, the first application may serve as a priming step to wet the demineralized dentin and displace and evaporate much of the water, while the second step fills in any voids and completes the resin sealing of the dentin surface (Kanca, 1996).

All published reports on the performance of single-bottle bonding systems have used normal dentin as the substrate, even though caries-affected dentin and sclerotic cervical dentin are often the clinically relevant bonding substrates. Caries-affected dentin is the hard, sometimes stained dentin beneath excavated carious lesions that often forms a portion of many cavity preparations. It is not normal dentin, because the tubules are occluded with mineral crystals, but it is free of bacteria. The recent development of the microtensile bond-testing method permits the measurement of resin-dentin bond strengths in areas as small as 0.5 mm^2 (Sano & others, 1994; Pashley & others, 1995). Using this method, Nakajima and others (1995) measured the bond strengths of several resin bonding systems to normal and caries-affected human dentin. Using All-Bond 2 (an acetone-based system) with the moist bonding technique, Nakajima and others (1995) obtained lower tensile bond strengths to caries-affected dentin (13.0 ± 3.6 MPa) than to normal dentin (26.9 ± 8.8 MPa). Using the dry bonding technique and Scotchbond Multi-Purpose, a water-based bonding system, there was no difference in the tensile bond strengths between caries-affected (18.5 ± 4.0 MPa) and normal dentin (20.3 ± 5.6 MPa). The All-Bond 2 system used a 10% phosphoric acid gel conditioner, while Scotchbond Multi-Purpose used 10% maleic acid. There was concern that these acids might not be strong enough to adequately etch sclerotic or caries-affected dentin.

The purpose of this study was to evaluate the SEM morphology and bond strengths of two single-bottle bonding systems to normal and caries-affected dentin following etching with 10, 32, or 35% phosphoric acid. The two systems were One-Step–an acetone-based system, and the Single Bond adhesive system–an alcohol-based system. The hypothesis to be tested was that there were no significant differences in the bond strengths of either bonding system to either substrate, regardless of the strength of the phosphoric-acid conditioner.

Table 1. *Dentin Adhesive Systems*

Adhesive Systems/ Experimental Groups	Etchant (Code/Lot #)	Adhesive (Code/Lot #)	Procedures*
One-Step, 32% PA (Bisco, Schaumberg, IL 60193)	Uni-Etch 32% PA semigel (019306)	BPDM, BIS-GMA, HEMA acetone, photoinitiator (0129145)	a (15 seconds); b; c; d e (10 seconds)
One-Step, 10% PA (Bisco)	All-Etch 10% PA semigel (091067)	BPDM, BIS-GMA, HEMA acetone, photoinitiator (0129145)	a (15 seconds); b; c; d e (10 seconds)
Single Bond, 35% PA (3M Dental Products, St Paul, MN 55144)	3M Etchant 35% PA gel (7EE)	BIS-GMA, HEMA polyalkenoic acid copolymer water, ethanol, photoinitiator (7AB)	a (15 seconds); b; c; d e (10 seconds)
Single Bond, 10% PA (3M Dental Products)	All-Etch (Bisco etchant) 10% PA semigel (019067)	BIS-GMA, HEMA polyalkenoic acid copolymer water, ethanol, photoinitiator (7AB)	a (15 seconds); b; c; d e (10 seconds)

*Procedures: a = acid etching; b = rinse; c = blot dry; d = apply two coats of adhesive; e = light cure
Abbreviations: PA = phosphoric acid; BIS-GMA = bisphenyl-glycidyl-methacrylate; BPDM = bisphenyl-dimethacrylate; HEMA = 2-hydroxyethylmethacrylate.

METHODS AND MATERIALS

Specimen Preparation

The teeth that were used in this study were obtained by protocols that were reviewed and approved by the appropriate institutional review board and with the informed consent of the donors. Twenty-four extracted human third molars with coronal dentin caries extending approximately halfway through the dentin were employed in this study. All teeth were stored at 4°C in physiological saline, to which several crystals of thymol were added. The occlusal surface was ground perpendicular to the long axis of the tooth to expose a flat surface of normal dentin surrounding the carious lesion. In order to obtain caries-affected dentin, grinding was performed using the combined criteria of visual examination and staining with a caries-detector solution (Kuraray Co, Ltd, Osaka, Japan) as previously described (Nakajima & others, 1995). That is, the dentin was hard to an explorer and no longer stained bright red with the caries-detector dye.

Bonding Procedure

The 24 teeth were randomly divided into four groups, each containing six teeth. Two commercially available single-bottle adhesive systems were used: One-Step (Bisco Inc, Itasca, IL 60143) and Single Bond (3M Dental Products, St Paul, MN 55144). The flat dentin surface, polished with 600-grit silicon carbide paper under running water, was etched with one of three phosphoric acid solutions for 15 seconds (Table 1). There were four experimental groups: One-Step bonded to dentin treated with 32% phosphoric acid; One-Step bonded to dentin treated with 10% phosphoric-acid gel; Single Bond bonded to dentin treated with 35% phosphoric-acid gel; and Single Bond bonded to dentin treated with 10% phosphoric-acid gel. Each group was further divided into normal and caries-affected substrates. After the acid etchant was rinsed off, excessive water was removed by blotting with a small piece of moist absorbent paper, which left the dentin surface "visibly moist" (Kanca, 1996). Following the application of adhesive according to the manufacturer's instruction (Table 1), a resin composite crown was built up using three layers of Clearfil AP-X (Kuraray Co, Ltd, Osaka, Japan) to a height of 4 to 5 mm (Sano & others, 1995). Each layer was cured for 20 seconds. Specimens were then stored in water at 37°C for 24 hours.

Bond Strength Testing

Four or five vertical slices, approximately 0.7 mm thick, were made through the caries-affected and normal portions of each tooth perpendicular to the bonded surface, using a low-speed diamond saw (Isomet; Buehler Ltd, Lake Bluff, IL 60044) under water cooling (Figure 1). Each slice was carefully examined in a dissecting microscope (X20) to ensure that the selected test site was homogeneous with regard to the type of dentin (normal or caries-affected). The slices were then trimmed and shaped to form a gentle curve along the adhesive interface from both sides using superfine diamond burs (c-16ff; GC Ltd, Tokyo, Japan), to form a rectangular cross-sectional shape with a surface area of approximately 0.9 mm^2. Trimming was done to exclude normal dentin if it was a caries-affected specimen or vice versa. The final width and thickness of bonded surfaces were measured to the nearest 0.01 mm by means of a digital micrometer (Sylvae Ultra-Cal II; Fowler Inc, Newton, MA 02166). The specimens were attached to a Bencor Multi-T testing apparatus (Danville Engineering Co, Danville, CA 94583) with a cyanoacrylate adhesive (Zapit; DVA, Anaheim, CA 91720), and subjected to tensile stress in an Instron testing machine (Instron Corp, Canton, MA 02021) at a crosshead speed of 1 mm/min (Sano & others, 1994). After testing, the fracture mode(s) of each specimen was determined using a stereomicroscope.

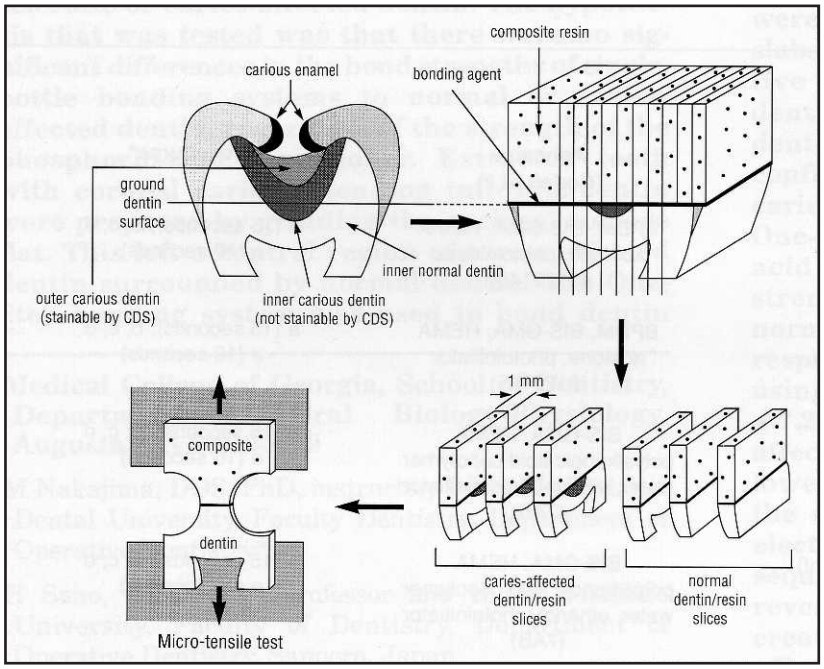

Figure 1. *Schematic illustration of the extent of dentin caries, the location of the prepared dentin surface in relatively hard, caries-affected dentin, how the bonded surface was built up in composite, then vertically sectioned into multiple slabs, each of which was trimmed to an hourglass shape for measurement of tensile bond strength (from Nakajima & others, 1995).*

Microhardness Measurements

Each fractured specimen was fixed in 10% neutral buffered formalin for 24 hours and then highly polished with diamond pastes down to 1 μm, for measuring subsurface microhardness

Table 2. *Tensile Bond Strength (MPa) to Normal vs Caries-affected Dentin*

Adhesive Systems	Normal		Caries-affected
One-Step, 32% PA	49.7 ± 6.1 (13)a	NS	45.0 ± 7.2 (9)a
One-Step, 10% PA	47.7 ± 6.8 (11)a	$P < 0.05$	36.9 ± 8.0 (10)b
Single Bond, 35% PA	49.5 ± 9.3 (16)a	$P < 0.05$	40.2 ± 11.1 (12)a
Single Bond, 10% PA	51.7 ± 4.3 (9)a	$P < 0.05$	41.2 ± 0.6 (13)a,b

All values are mean ± SD (number of specimens).
PA = phosphoric acid; NS = not statistically different.
Groups designated by the same letter are not significantly different (p<0.05).

of the resin-dentin interface. Formalin fixation has been previously shown to have no effect on dentin hardness but improves the quality of subsequently performed microscopy (Fusayama, Okuse & Hosoda, 1976; Sano, 1987). Knoop hardness numbers (KHN) were determined on the dentin side of debonded specimens 50 µm below the bonded surface, using a microhardness tester (Akashi MVK-E hardness tester; Akashi Co, Tokyo, Japan) under a load of 50 g and duration of 15 seconds (Perinka & others, 1992). Dentin hardness was used to help define the quality of the caries-affected or normal dentin.

Scanning Electron Microscopy

After measuring the KHN, the specimens were gold sputter-coated and the adhesive interface and the underlying dentin were observed by SEM (JXA-840; JEOL, Tokyo, Japan). Using the results of the KHN measurements and SEM observation, final selection of caries-affected or normal dentin bond strengths were made (Ogawa & others, 1983) prior to statistical analyses.

Additionally, some of the polished resin-bonded cross-sectioned specimens were subjected to 10% phosphoric acid treatment for 3-5 seconds (Gwinnett & Kanca, 1992; Sano & others, 1995) followed by immersion in 5% sodium hypochlorite for 5 minutes (Wang & Nakabayashi, 1991) to enhance the surface relief between the resin-infiltrated zone and the underlying mineralized dentin for SEM observations. Hybrid layer thickness was measured from SEM prints only in regions between resin tags. This was done to avoid overestimates of hybrid layer thickness.

Statistics

All debonded specimens were examined by SEM to make certain that 100% of the bond was in normal or caries-affected dentin. If a specimen exhibited mixtures of both types of dentin, it was rejected from the data set. The load at failure divided by the cross-sectional area of the specimen was used to calculate the ultimate tensile stress in MPa. The data were analyzed by a three-way ANOVA (type of dentin, concentration of acid, and hybrid layer thickness). Multiple comparisons were made using the Student-Neuman-Keuls test. All statistical analyses were carried out using the SigmaStat software system (SPSS, Chicago, IL 60197). Statistical significance was considered as p<0.05.

RESULTS

The results of microtensile bond testing and Knoop hardness determinations (KHN) are shown in Tables 2 and 3. For One-Step, ANOVA analysis showed significant differences in mean values of bond strengths for different types of dentin (normal vs caries-affected, p< 0.001) and for different concentrations of phosphoric acid (10% vs 32%, p=0.025), although their interactions were not significant (p=0.160). When using 32% phos-

Table 3. *Comparisons of the Relative Hardness and Hybrid Layer Thicknesses in Normal vs Caries-affected Dentin*

	Knoop Hardness Numbers		Hybrid Layers Thickness (µm)	
Bonding Systems	Normal	Caries-affected	Normal	Caries-affected
One-Step, 32% PA	58.3 ± 5.8 (13)a	25.5 ± 4.4 (9)b	2.9 ± 0.2 (6)c	5.6 ± 1.1 (6)e
One-Step, 10% PA	52.2 ± 7.5 (11)a	31.0 ± 9.3 (10)b	2.7 ± 0.3 (6)c	3.6 ± 0.8 (6)c
Single Bond, 35% PA	56.3 ± 7.7 (16)a	26.9 ± 9.7 (12)b	2.3 ± 0.4 (6)c	5.8 ± 1.0 (6)e
Single Bond, 10% PA	60.8 ± 3.9 (9)a	31.1 ± 6.9 (13)b	1.5 ± 0.2 (6)d	3.6 ± 0.3 (6)e

All values are mean ± SD (number of specimens); Knoop hardness numbers in kg mm^{-3}. PA = phosphoric acid.
Groups designated by the same letter are not significantly different (p>0.05).

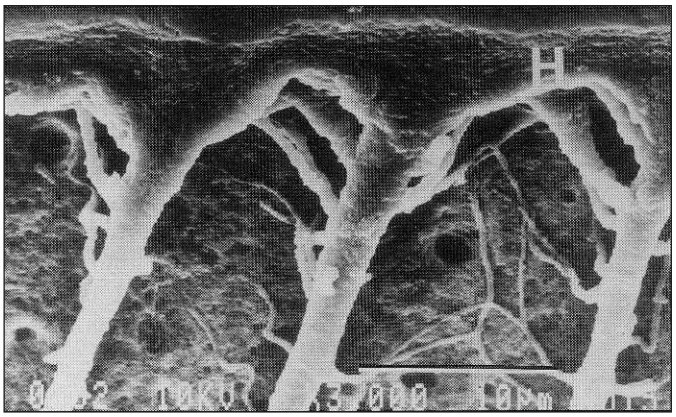

Figure 2A. *SEM of the resin-dentin interface of a polished cross section of normal dentin etched with 32% phosphoric acid (PA), rinsed, and bonded using One-Step. The polished surface was briefly exposed to 10% PA, followed by 5% NaOCl to remove the subsurface dentin, exposing the morphology of the hybrid layer (H), resin tags, and their lateral branches. (magnification X1830)*

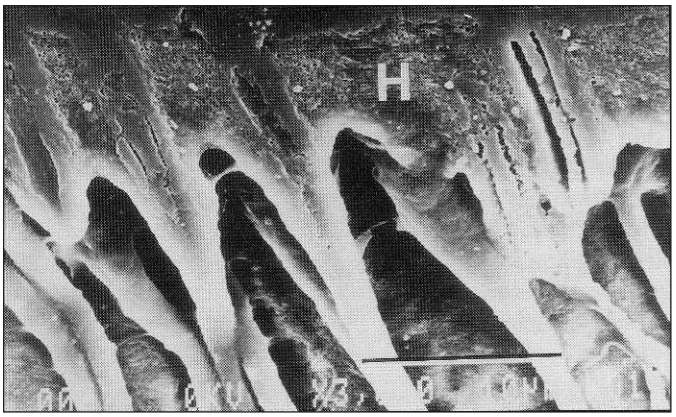

Figure 2B. *SEM of the resin-dentin interface of a polished cross section of caries-affected dentin etched with 32% PA, rinsed, and then bonded using One-Step. The hybrid layer (H) in caries-affected dentin was thicker than that of normal dentin. There were fewer lateral branches filled with resin. (magnification X1830)*

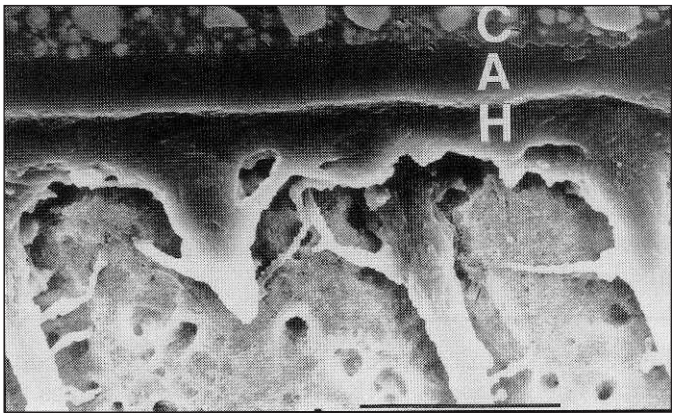

Figure 3A. *SEM of the resin-dentin interface of a polished cross section of normal dentin etched with 10% PA, rinsed, and bonded using One-Step. The polished surface was briefly exposed to acid/base challenge. The hybrid layer (H), funnel-shaped resin tags, and their lateral branches are seen. The adhesive layer (A) is seen between the hybrid layer and the overlying resin composite (C). (magnification x1830)*

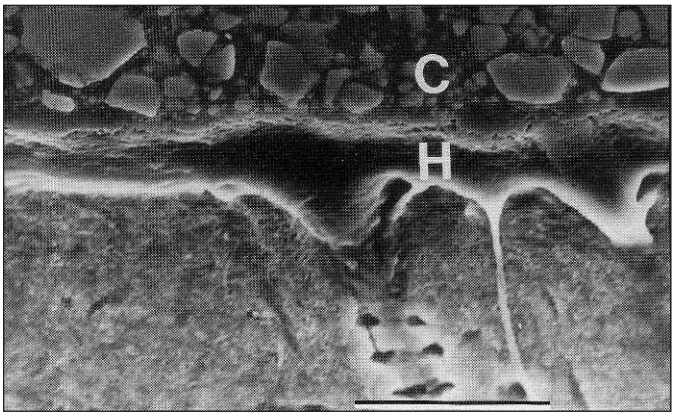

Figure 3B. *SEM of resin-dentin interface of a polished cross section of caries-affected dentin etched with 10% PA, rinsed, and bonded using One-Step. Note that the middle of the hybrid layer (H) was partially removed by acid/base challenge; there were fewer resin tags seen compared to caries-affected dentin etched with 32% PA (compare with Figure 2B). C = composite.(magnification X1830)*

phoric acid etchant, there were no significant differences (Table 2) between One-Step bond strengths to caries-affected dentin and normal dentin (p=0.1985). However, using 10% phosphoric acid etchant, bond strengths of One-Step to caries-affected dentin were significantly lower than normal dentin (p=0.0036).

On the other hand, for Single Bond, ANOVA analysis showed significantly lower bond strengths to caries-affected dentin compared to normal dentin (p<0.001), but no significant effect of phosphoric acid concentrations (P = 0.550) within a given type of dentin (Table 2). Bond strengths of Single Bond indicated that there was no statistically significant interaction between the etchant conditions and the type of dentin (p= 0.819). When normal dentin was tested with 10% or 35% phosphoric acid, the resin-dentin bond strengths of Single Bond were statistically similar. However, the bond strengths of Single Bond to caries-affected dentin were significantly lower than those to normal dentin using both etchants (p< 0.05, Table 2).

For normal dentin, there were no statistically significant differences between the bond strengths developed by either material (p>0.05). For caries-affected dentin, there was a statistically significant difference between One-Step, with 32% and 10% phosphoric acid (p= 0.0358). However, there were no statistically significant differences among the other groups (p>0.05, Table 2).

Scanning electron microscopy of the polished cross sections of the bonded specimens treated with 10% phosphoric acid followed by 5% NaOCl clearly revealed the resin-infiltrated demineralized zone. Examination

Table 4. Distribution of the Modes of Bond Failures

Test Groups	Adhesive*	Mixed**	Cohesive Failure	
			In Dentin	In Composite
One-Step, 32% PA				
normal dentin	10	3	0	0
caries-affected	6	1	1	1
One-Step, 10% PA				
normal dentin	9	2	0	0
caries-affected	8	2	0	0
Single Bond, 35% PA				
normal dentin	10	5	1	0
caries-affected	8	4	0	0
Single Bond, 10% PA				
normal dentin	5	3	1	0
caries-affected	8	5	0	0

*Adhesive failure = between resin and dentin; PA = phosphoric acid.
**Mixed failure = partially adhesive and partially cohesive failure in bonding resin or hybrid layer.

of normal dentin treated with One-Step using 32% and 10% phosphoric acid revealed 2.3 to 2.9 µm-thick hybrid layers (Table 3, Figures 2A and 3A, respectively). The hybrid layers were thicker when created by either bonding system following 32% or 35% phosphoric-acid etching of caries-affected dentin (Table 3, Figures 2B and 4B, respectively) than those of normal dentin (Figures 2A and 4A). The quality of the hybrid layers in caries-affected dentin was different between the two etchants. The middle region of the hybrid layer created by One-Step following conditioning with 10% phosphoric acid was susceptible to effects of acid/base treatment (Figure 3B). That is, much of its mass was removed by acid/base treatment, unlike hybrid layers formed by One-Step on caries-affected dentin etched with 32% phosphoric acid (Figure 2B).

When caries-affected dentin was bonded with Single Bond conditioned with 10 and 35% phosphoric acid, the hybrid layers were thicker ($p<0.05$) than those formed in normal dentin (Table 3). The hybrid layers created with Single Bond in caries-affected dentin etched with 35% phosphoric acid resisted the action of subsequent acid/base challenge (Figures 4-6). The Single Bond hybrid layer created in caries-affected dentin etched with 10% phosphoric acid appeared well-filled by acid/base-resistant resin in the bottom region. However, the top and middle thirds of the hybrid layer were removed by acid/base challenge (Figure 5B).

For each material, the mean of hardness values for caries-affected dentin was approximately half that of normal dentin (Table 3). There were no significant differences in the KHN within the normal or caries-affected groups (Table 3). The modes of failure in the various groups are shown in Table 4. Most of the failures were either adhesive or the bonds failed cohesively within the hybrid layer or the adhesive layer. Few failures occurred in the mineralized dentin.

DISCUSSION

The results of this study indicated that both single-bottle systems produced bond strengths to normal dentin that were almost twice as high as those achieved by their

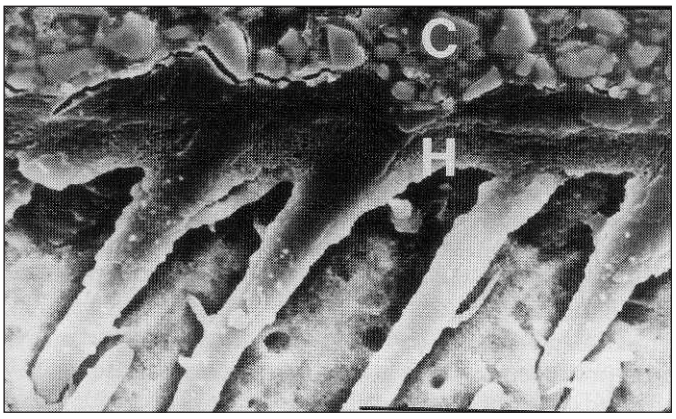

Figure 4A. *SEM of the resin-dentin interface of a polished cross section of normal dentin etched with 35% PA, rinsed and bonded using Single Bond. The polished surface was briefly exposed to 10% PA, followed by 5% NaOCL to remove the subsurface dentin, exposing the morphology of the hybrid layer (H), under the composite (C), resin tags, and their lateral branches. (magnification X1830)*

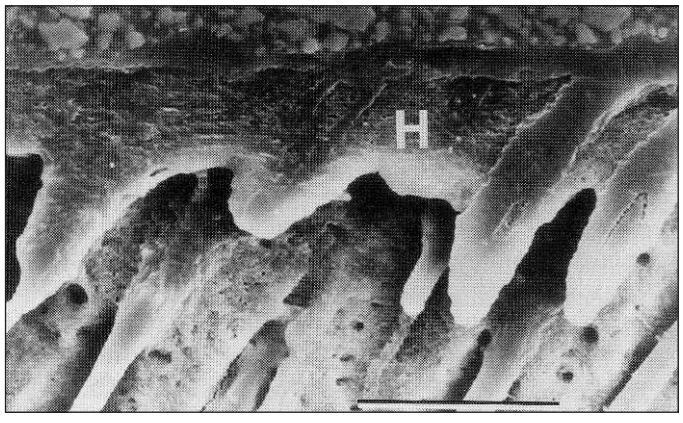

Figure 4B. *SEM of resin-dentin interface of a polished cross section of caries-affected dentin etched with 35% PA, rinsed, and bonded using Single Bond. The hybrid layer (H) in caries-affected dentin was thicker than that of normal dentin (compare with Figure 4A. (magnification X1830)*

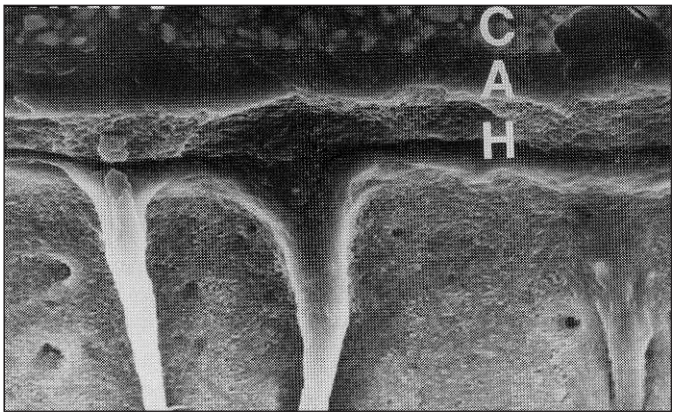

Figure 5A. *SEM of the resin-dentin interface of a polished cross section of normal dentin etched with 10% PA, rinsed, and bonded using Single Bond. The polished surface was briefly exposed to acid/base challenge. The hybrid layer (H), funnel-shaped resin tags, and their lateral branches are seen. (magnification X1830)*

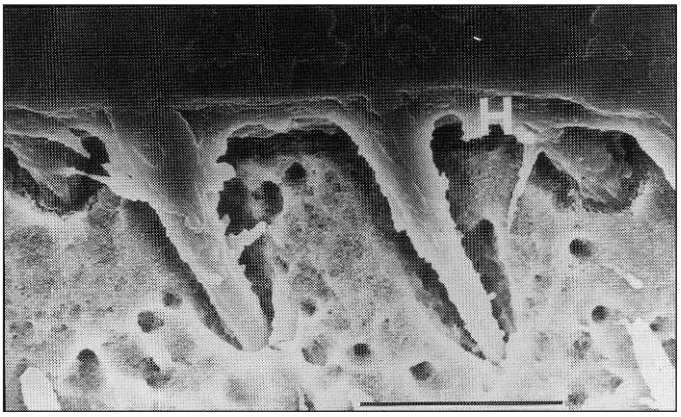

Figure 5B. *SEM of resin-dentin interface of a polished cross section of caries-affected dentin etched with 10% PA, rinsed, and bonded using Single Bond. Note that much of the top and middle of the hybrid layer (H) was partially removed by acid/base challenge. The adhesive layer (A) is seen between the overlying resin composite (C) and the underlying partially dissolved hybrid layer. (magnification X1830)*

predecessors to both normal and caries-affected dentin (Nakajima & others, 1995). There was no statistically significant difference between the tensile bond strength of One-Step to normal and caries-affected dentin, when the product was used following etching with 32% phosphoric acid according to the manufacturer's instructions. On the other hand, Single Bond, which used a similar 35% concentration of phosphoric acid gel, produced slightly lower bond strengths to caries-affected dentin than normal dentin. However, even these lower bond strengths are among the highest that we have ever measured and indicate a significant improvement in bonding formulations.

Earlier studies reported that phosphoric acid concentrations over 30% were ideal to bond resin to enamel (Buonocore, 1955). Fusayama and others (1979) proposed a total etching system that used 37% phosphoric acid to simultaneously etch both enamel and dentin. Most manufacturers used other acid etchants or lower concentrations of phosphoric acid to etch dentin because of the notion that high concentrations of phosphoric acid might cause pulpal irritation. However, a review of the literature indicated that the danger was exaggerated (Pashley, 1992). Recently, most marketed adhesive systems have utilized concentrations of phosphoric acid over 30% to etch cavity surfaces for 15 seconds, in order to optimize enamel etching. There have been a few reports of bond strength to normal dentin etched with different concentrations of phosphoric acid (Kato & Nakabayashi, 1996; Toida & Nakabayashi, 1996; Chan & others, 1997). Little is known about the effects of different concentrations of phosphoric acid on the bond strengths of resin to caries-affected dentin.

When phosphoric acid conditioners are applied to dentin substrates to remove the smear layer, the dentinal subsurface is demineralized and the collagen fibrils are exposed. In order to produce good resin-dentin adhesion, resin monomers must penetrate into this demineralized dentinal subsurface, to produce resin hybridization of dentin (Nakabayashi, 1982). The degree of penetration of resin monomers is thought to depend, in part, on the characteristics of the demineralized collagen fibril network before application of the resin adhesive. The structural or physical characteristics of the caries-affected collagen fibrils that are exposed by etching with phosphoric acid may be different from that of normal dentinal collagen fibrils. The spaces between the collagen fibrils in normal dentin are occupied by normal calcium-deficient, carbonate-rich apatite (LeGeros, 1991). In caries-affected intertubular dentin, the mineral occupying the interfibrillar spaces may be different from that of normal apatite due to cyclic demineralization-remineralizations. Indeed, the KHN of caries-affected dentin indicate that it was softer, even though many of the tubules were occluded with mineral crystallites.

A dentin bonding system containing a polyalkenoic acid copolymer (Scotchbond Multi-Purpose Plus; 3M Dental Products) was reported to form a polyalkenoic-acid complex at the top of the hybrid layer (Eliades, 1993). This separate layer has been identified in TEM studies (Van Meerbeek & others, 1996, 1997, 1998; Tay, 1997). In the present study, the Single Bond system, which also contains the same polyalkenoic acid copolymer, produced slightly lower bond strengths to caries-affected dentin than normal dentin (Table 2). SEM observation failed to reveal any difference in the appearance of the resin at the top of hybrid layer created by Single Bond compared to One-Step. This indicated that the polyalkenoic acid layer seen on top of the hybrid layer primed with Scotchbond Multi-Purpose

Plus did not form at the top of the hybrid layer created by the comonomers of Single Bond. Presumably, the manufacturers have combined the primer(s) and adhesive bonding comonomers in a new single-bottle blend, whereas Scotchbond Multi-Purpose Plus, a two-step system, utilizes separate application of the primer (a polyalkenoic acid/HEMA/water mixture) and adhesive comonomers, which results in the polyalkenoic acid accumulating on the surface of the hybrid layer (Van Meerbeek & others, 1996, 1997, 1998; Tay, 1997).

The etching systems developed by Bisco include All-Etch (10% phosphoric acid) and Uni-Etch (32% phosphoric acid) systems, which are gelled with a polymer. It was reported that Uni-Etch had a pH of -0.17 (Perdigão & others, 1996). On the other hand, Single Bond etchant is a 35% phosphoric-acid gel thickened with fumed silica. Phosphoric-acid etchants made into a gel with silica have a higher pH (0.02) than if the acid was thickened with polymer (pH of - 0.17, Perdigão & others, 1996). This group reported a highly significant correlation between the depth of dentin etching and the pH of the etchants. That is, All-Etch (10% phosphoric acid) and Scotchbond Multi-Purpose etchant (35% phosphoric acid) were reported to demineralize dentin to similar depths of 3.0 μm, while Uni-Etch (32% phosphoric acid) demineralized dentin to a depth of 4.0 μm (Perdigão, 1995). Additionally, a residual cuff of peritubular dentin was present following etching with silica-thickened gel, but not with polymer-thickened gel, which may have interfered with radial diffusion of resin monomers from the tubules into the surrounding intertubular dentin (Perdigão & others, 1996). In the present study, Single Bond applied to dentin etched with 35% phosphoric acid gelled with silica or 10% phosphoric acid thickened with polymer produced similar bond strengths to normal dentin, but lower bond strengths to caries-affected dentin. This may be due to the fact that both systems have similar depths of demineralized dentin even though they have different phosphoric acid concentrations. The residual cuff of peritubular dentin, which was reported to remain within dentinal tubules of normal dentin etched with 35% phosphoric acid gelled with silica (Perdigão & others, 1996), may be responsible for the lower bond strengths to caries-affected dentin than normal dentin. The peritubular dentin of caries-affected dentin may be more difficult to demineralize than normal dentin due to intratubular deposition of acid-resistant crystals. Indeed, there were fewer resin tags and resin-filled lateral branches of tubules in caries-affected dentin etched with 10% phosphoric acid (Figures 3B and 5B). Any residual peritubular dentin is thought to mask the lateral branches of the tubules, which are important for resin infiltration of the hybrid layer (Tay & others, 1996a; Tay, Gwinnett & Wei, 1996b).

There was no significant difference between bond strengths to normal dentin and to caries-affected dentin etched with 32% phosphoric acid and bonded with One-Step (Table 2). However, the bond strength of One-Step to caries-affected dentin etched with 10% phosphoric acid gel was lower ($p<0.05$) than that to normal dentin. Additionally, conditioning caries- affected dentin with 10% phosphoric acid gel, followed by bonding with One-Step, created a hybrid layer that was partially removed by acid and base challenge. These results are in agreement with our previous study, where All-Bond 2 was used to bond to caries-affected dentin etched with 10% phosphoric acid gel (Nakajima & others, 1995). That is, the bond strength of All-Bond 2 to caries-affected dentin was lower than bonds made to normal dentin, and the middle of the hybrid layer created by All-Bond 2 was partially removed by acid and base challenge. In the present study, similar poor-quality hybrid layers were created in caries-affected dentin etched with 10% phosphoric-acid gel prior to bonding with Single Bond. This indicated that etching caries-affected dentin with 10% phosphoric-acid gel might create a different type of demineralized zone than those created in normal dentin.

Little is known regarding the ability of adhesive monomers in either water-based or acetone-based solvents to penetrate into the demineralized intertubular dentin matrix following etching with any concentration of phosphoric acid. The bond strength of resins to wet dentin etched with 10% phosphoric acid solution for 30 seconds was reported to be improved, compared to dry dentin (Kato & Nakabayashi, 1996). However, there was no significant difference between bond strength to wet and dry dentin etched with 35% phosphoric acid solution for 30 seconds (Kato & Nakabayashi, 1996). It was concluded that the concentration of phosphoric acid in the etchant influenced the permeability of demineralized dentin. During the development of the carious lesion, it is possible that the collagen fibrils of the dentin matrix may be partially denatured (Dung & others, 1994, 1995) and may respond to bonding reagents and procedures differently than normal dentin.

CONCLUSION

In the current experiment, all groups exhibited high bond strengths to normal dentin. However, bond strengths varied to caries-affected dentin. The permeability of the caries-affected dentin matrix to comonomers may be different from that of normal dentin that might be completely demineralized by either 10, 32, or 35% phosphoric acid. The repeated cycles of demineralization and remineralization that occur during the development of carious lesions may produce larger crystals of calcium phosphate in forms (ie, whitlockite) that are less soluble in acidic conditions than is normal apatite. Thus, stronger acids may be required to solubilize the

mineral phase of caries-affected dentin enough to obtain sufficient resin infiltration for high resin bond strengths. As caries-affected dentin often constitutes a significant fraction of the surface area of many cavity preparations, it is important to optimize etching conditions to maximize resin bond strengths to all types of dentin.

Acknowledgments

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Long-Term Effect of Dentin Primers on Enamel Bond Strength and Marginal Adaptation

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Clinical Relevance

Dentin primers alone do not decrease the bonding performance of resin composites to enamel. Intensive rubbing of adhesives deteriorates long-term enamel bond strength and marginal adaptation.

SUMMARY

Contamination of etched enamel with dentin adhesive systems is unavoidable in clinical situations. The aim of this in vitro **study was to evaluate the long-term effect of dentin adhesives and application technique on resin composite bond strength and marginal adaptation to enamel.**

Six hundred freshly extracted mandibular bovine incisors were used. Three hundred teeth were flat ground, and the enamel was etched for 30 seconds with 32% phosphoric acid. The etched surface was treated by different dentin adhesive systems with and without intensive rubbing by use of application brushes. As a control, only the enamel adhesive resin was applied and air thinned. Furthermore, contamination with saliva was performed after the etching process. Etched and silanated CEREC blocks were bonded onto the enamel specimens with different adhesive resins and stored for 1 and 365 days (37°C, aqua dest). After storage, the specimens were thermocycled for 24 hours (1150 cycles between 5°C and 55°C), and subjected to shear bond testing. Three hundred box-shaped cavities were prepared on buccal surfaces of the incisors and filled with one resin composite using the same pretreatment modes as in the shear bond test groups. After 1 and 365 days of storage, a margin analysis was performed using a SEM (X200 magnification).

Dentin adhesive systems did not show an adverse effect on long-term enamel bond strength and marginal adaptation. Rubbing application of the primers decreased the bond strength by values of ~20 % after 24 hours and ~40 % after 1 year of storage. Marginal adaptation showed 94-98% gap-free margins in the control and dentin adhesive system-only groups; however, after rubbing of primers, the proportion of gap-free margins decreased significantly to 85-88%. The lowest bond strength (8-10 MPa) and margin quality (49-69% gap-free margins) were recorded for the groups with saliva contamination.

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INTRODUCTION

Buonocore's epoch-making enamel-etch technique (Buonocore, 1955) was responsible for the growing clinical success of dentin adhesive systems. Total bonding of

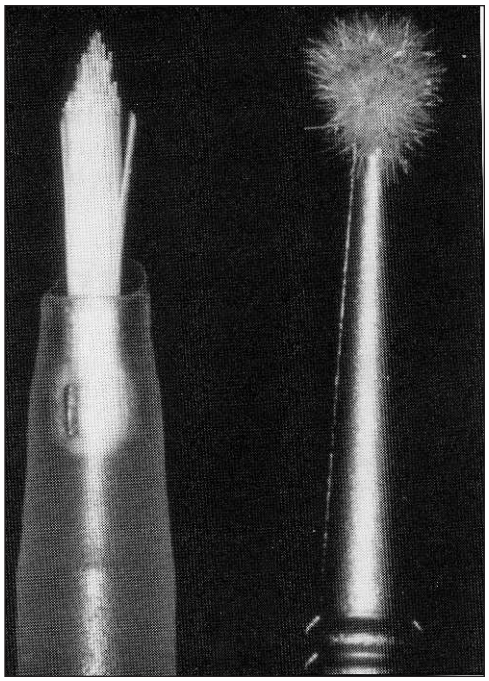

Figure 1. *Paintbrush (left), minibrush (right)*

tooth-colored restorations, such as resin composites, results in an enlarged bonding area preventing gap formation between tooth and restorative material (Barkmeier & Cooley, 1992; Swift, Perdigão & Heymann, 1995).

Within the clinical adhesive procedure, dentin primers are commonly applied after etching the enamel margins. Evaporating the primer solvent by using compressed air makes contamination of etched enamel unavoidable.

The literature shows several studies dealing with this particular subject, but resulting in different recommendations (Hadavi & others, 1993; Sung & others, 1996; Woronko, St Germain & Meiers, 1996).

The manufacturers of dentin adhesive systems offer different types of application tips, such as minibrushes, paintbrushes, or sponges (Figure 1). To achieve enhanced dentinal adhesion, manufacturers recommend scrubbing the primer into the dentinal areas of the cavity (Frankenberger, Sindel & Krämer, 1996). May (1998) reported increased dentin adhesion for ESPE Bonding System (ESPE, Seefeld, Germany) when the primer was rubbed for 20 seconds in comparison to applying and leaving the primer on for 30 seconds only. However, with decreasing cavity size, selective rubbing on dentin areas becomes more difficult to perform. In cavities, such as minimally invasive approximal box-only preparations, selective brushing on dentin is impossible, and the dentist must simultaneously rub the etched enamel. Also, without rubbing, the effect of dentin adhesive systems on enamel bonding performance is still unclear. For example, Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144) decreased enamel bond strength due to primer application (Woronko & others, 1996).

Another possibility for contamination is unintentional and unnoticed access of saliva (Powers, Finger & Xie, 1995; Xie, Powers & McGuckin, 1993). So this problem also was taken into account during the present investigation to clarify the requirement of using a rubber dam during adhesive bonding procedures.

The purpose of this study was to investigate short- and long-term enamel bonding when primer and saliva

Table 1. Materials and Application Modes Used

Dentin Adhesive System	Manufacturer	Components	Composition	Application Mode	Lot
ESPE Bonding System (EB)	ESPE, Seefeld, Germany	Etchant Primer Bond	32% phosphoric acid water, HEMA BIS-GMA, water	Brushing	137 HP-7 MC-3
Scotchbond Multi-Purpose Plus (SB)	3M Dental Products, St Paul, MN 55144	Primer Bond	HEMA, water HEMA, BIS-GMA	Painting	5 HX 5 BR
Syntac Classic (SY)	Vivadent, Schaan, Liechtenstein	Primer Adhesive Heliobond	TEGDMA, maleic acid, water, acetone PEGDMA, glutaraldehyde, water BIS-GMA, TEGDMA	Painting	6143 34 6143 37 6115 89
Prime&Bond 2.0 (PB)	DeTrey Dentsply, Konstanz, Germany	Primer/ Bond	elastomeric dimethacrylate resins, PENTA, acetone	Brushing	9501 48 9503 66

Table 2. Overview of SBS Results after 1 Day + Thermocycling and 365 Days + Thermocycling

Adhesive System	Contamination	SBS [MPa] (SD)	Failure Mode	SBS [MPa] (SD)	Failure Mode
		1 Day		365 Days	
EB	---	23.5(3.8)^{A}	80%c/20%a	22.7(3.5)^{A}	90%c/10%a
	DAS only	22.1(3.0)^{A}	80%c/20%a	22.1(3.3)^{A}	90%c/10%a
	DAS rubbed	19.6(2.4)^{A}	70%c/30%a	16.9(2.0)^{c}	70%c/30%a
	saliva	10.3(3.1)^{D}	100%a	08.9(3.6)^{D}	100%a
SB	---	23.8(3.2)^{A}	90%c/10%a	23.1(2.7)^{A}	90%c/10%a
	DAS only	22.8(3.9)^{A}	90%c/10%a	22.6(4.0)^{A}	100%c
	DAS rubbed	22.5(2.8)^{A}	80%c/20%a	18.3(2.0)^{BC}	60%c/40%a
	saliva	10.5(2.5)^{D}	100%a	09.3(2.8)^{D}	100%a
SY	---	24.2(3.9)^{A}	90%c/10%a	24.3(4.0)^{A}	100%c
	DAS only	20.7(3.5)^{AB}	80%c/20%a	20.0(2.6)^{AB}	60%c/40%a
	DAS rubbed	19.1(3.5)^{B}	60%/40%a	16.9(2.0)^{C}	60%c/40%a
	saliva	10.5(2.6)^{D}	100%a	09.2(2.3)^{D}	100%a
PB	DAS only	19.2(3.4)^{B}	60%c/40%a	18.2(3.1)^{B}	60%c/40%a
	DAS rubbed	16.2(3.5)^{C}	30%c/70%a	13.4(1.9)^{C}	40%c/60%a
	saliva	09.8(2.4)^{D}	100%a	08.6(3.4)^{D}	100%a

SBS = shear bond strength; DAS = dentin adhesive system; SD = standard deviation.
Failure modes: a = adhesive between bonding resin and enamel; b = cohesive enamel; c = mixed failure with enamel pulled out.
Groups with the same superscript letters are not significantly different (p>0.05).

contamination were present and different application modes were used.

METHODS AND MATERIALS

Six hundred caries-free bovine mandibular incisors stored in 0.1% thymol solution at ambient temperature for less than 4 weeks after extraction were used in this investigation. The teeth were debrided and examined to ensure that they were free of defects, such as cracks or carious lesions. The incisors were embedded in autopolymerizing resin (Paladur, Kulzer, D-61273 Wehrheim, Germany), leaving the buccal surface uncovered.

Shear Bond Strength Procedure

Three hundred teeth were flat ground (600-grit) to an area of 10 mm^2. The prepared enamel surface was covered with adhesive tape (Tesafilm, Beiersdorf, D-20253 Hamburg, Germany) with a round hole 3 mm in diameter. The uncovered enamel surface was etched for 30 seconds with 32% phosphoric acid (MiniTip etching gel; ESPE). Subsequently, the surface was rinsed for 30 seconds with air-water spray and dried for 30 seconds with compressed air.

The specimens were randomly assigned to 15 groups (n=20, Table 1). Contamination of the etched enamel surface was carried out with four dentin primers, with and without rubbing, for the entire application time (Tables 2, 3). The individual brushes provided by the manufacturers were used, so SB and SY primers were painted with small paintbrushes (Figure 1), while EB and PB primers were rubbed with minibrushes (Figure 1). Rubbing was carried out carefully without forced pressure for all groups.

Table 3. *Overview of Margin Analysis Results after 1 Day + Thermocycling and 365 Days + Thermocycling: Percentages of Gap-free Margins and Standard Deviations*

Adhesive System	Contamination	Gap-free Margins, % (SD)	Gap-free Margins, % (SD)
		1 Day	365 Days
EB	---	98.2(2.7)^{A}	96.1(4.1)^{A}
	DAS only	97.5(3.2)^{A}	95.2(3.9)^{A}
	DAS rubbed	93.3(5.7)^{AB}	87.9(5.1)^{C}
	saliva	64.7(11.6)^{D}	49.5(13.5)^{E}
SB	---	97.8(3.1)^{A}	97.4(3.8)^{A}
	DAS only	97.1(4.1)^{A}	95.2(5.0)^{A}
	DAS rubbed	94.5(4.8)^{A}	88.6(6.5)^{C}
	saliva	69.1(14.3)^{D}	66.1(9.6)^{D}
SY	---	97.0(3.4)^{A}	96.0(3.8)^{A}
	DAS only	97.7(2.5)^{A}	95.4(2.8)^{A}
	DAS rubbed	96.3(3.6)^{A}	88.5(7.3)^{C}
	saliva	69.9(13.3)^{D}	62.3(11.8)^{D}
PB	DAS only	94.0(5.2)^{A}	91.9(4.5)^{B}
	DAS rubbed	90.2(4.9)^{AB}	85.6(6.4)^{C}
	saliva	63.9(10.5)^{D}	60.4(13.3)^{D}

DAS = dentin adhesive system; SD = standard deviation.
Groups with the same superscript letters are not significantly different (p>0.05).

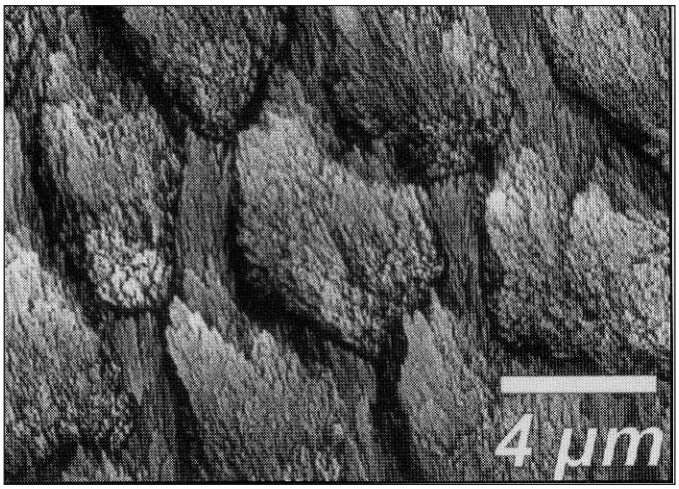

Figure 2. *Etching pattern after etching, rinsing, and drying (X2310). The surface is unharmed.*

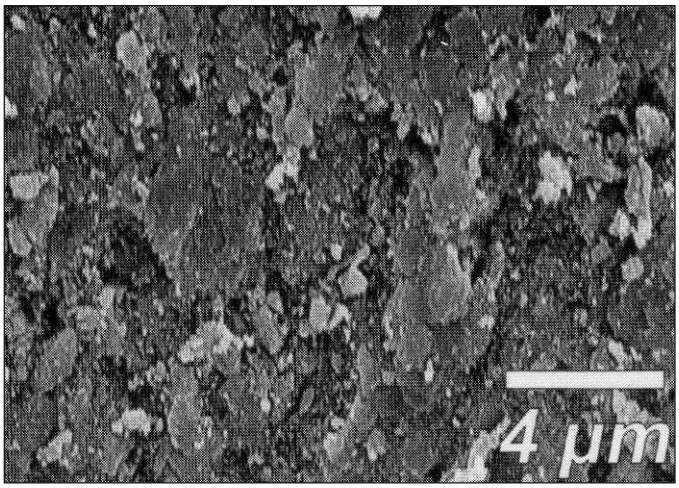

Figure 3. *Etching pattern after 10 seconds of rubbing with minibrush (X2310). The surface is destroyed for bonding.*

The bonding resin was applied, air-thinned, and consecutively light cured for 40 seconds from a distance of 5 mm with an Elipar II curing light (ESPE). The intensity of the light used for all curing procedures in this study was checked periodically with a radiometer (Demetron Research Corp, Danbury, CT 06810) to ensure that 400 mW/cm^2 was always exceeded. A group with saliva contamination (mixed sample of 10 dental students) was formed (Tables 2, 3). As controls, equal groups without any contamination were tested (Tables 2, 3). In these groups the enamel adhesive was applied to the etched area exclusively and air thinned.

For the PB groups, primer and adhesive resin are provided in one solution, therefore, in this particular case the "primer-only" groups served as control.

CEREC cylinders (Ø2.9 mm) were etched with 5% hydrofluoric acid (Vita CEREC etch; Vita Zahnfabrik, D-79713 Bad Säckingen, Germany), for 60 seconds, rinsed, and dried. A silane coupling agent (Monobond S; Vivadent, FL-9494 Schaan, Liechtenstein) was applied and air-thinned.

The ceramic cylinders were bonded onto the pretreated enamel areas using the corresponding enamel bonding resin, then cured from three directions for 40 seconds each. The specimens were stored for 1 or 365 days in distilled water at 37°C. After storage, the specimens were subjected to an alternating thermal cycle of +5°C and +55°C in a thermocycling apparatus for 1150 cycles. The dwell time at each temperature was 30 seconds, and the transport time between the water baths was 15 seconds.

Finally, the specimens were positioned inside a shear test device and mounted in a Universal Testing Machine (Zwick Corp, D-89075 Ulm, Germany). A chisel-shaped rod attached to a compression load cell and traveling at a crosshead speed of 0.5 mm/min was applied to each cylinder until failure occurred. The rod was 0.1 mm from the enamel surface.

The shear bond strength was determined by computing the quotient of maximum load (N) and adhesion area. After performing the shear bond test, the specimens were mounted on aluminum cylinders, sputter coated with gold (sputter device: Balzers SCD 40; Balzers, FL-9494 Vaduz, Liechtenstein), and observed using a scanning electron microscope (Leitz ISI 50; Akashi, Tokyo, Japan) at X100 magnification to determine the fracture modes of the detached ceramic cylinders.

Margin Analysis

Three-hundred teeth were prepared with cylindrical diamond burs (average grit size 80 µm/preparation and 40 µm/finishing; Comet Corp, D-32657 Lemgo, Germany) on their buccal aspects including box-shaped cavities of 4 mm diameter and 2 mm depth with all margins located in enamel.

The specimens were randomly assigned to 15 groups (n=20) with identical pretreatments and modes of contamination and rubbing, as in the shear bond strength groups.

The adhesives were light cured for 40 seconds from a distance of 5 mm from the tooth surface. The cavities were restored with one composite resin (Tetric; Vivadent; batch #618465, shade A2), applied in one coronal and one apical layer, with each layer light cured for 40 seconds.

After polishing the restorations, an identical storage of 1 or 365 days, and an additional thermal cycle, as in the shear bond strength test groups, was performed. For both storage times, impressions were taken with a polyvinyl siloxane material (Permagum; ESPE), and epoxy replicas (Epoxy Die; Ivoclar-Vivadent) were produced for margin analysis.

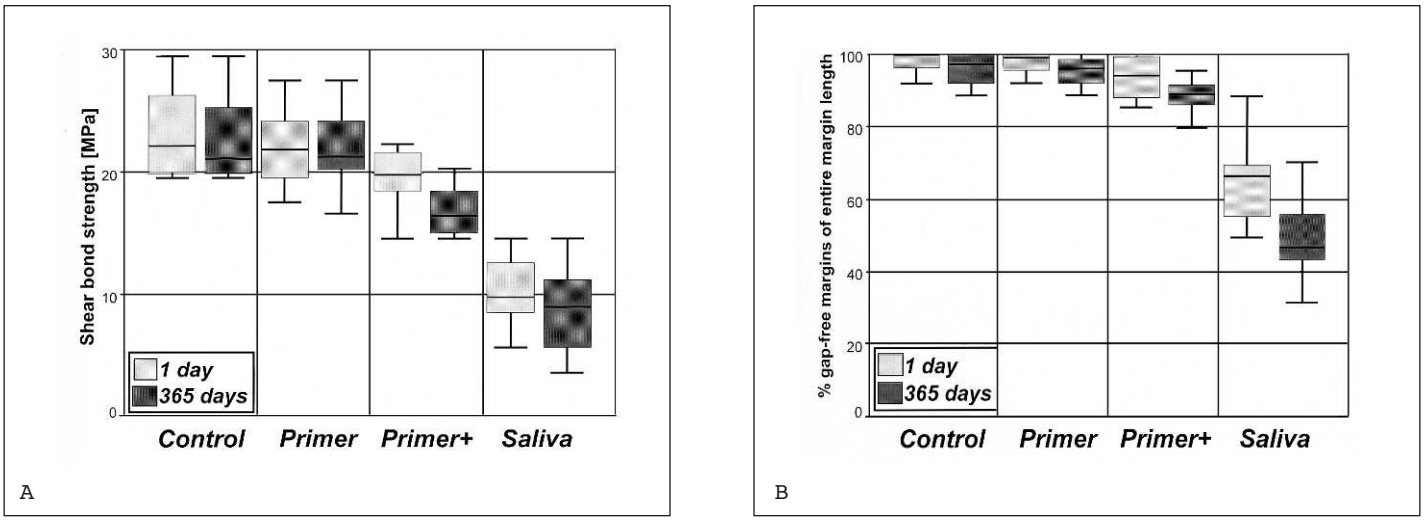

Figure 4. *Results for ESPE Bonding System (EB).* **A.** *Shear bond strength (SBS)* **B.** *Margin analysis (MA). Control = without primer; Primer = DAS only; Primer+ = DAS rubbed. The bars represent median values with 25/75% quartiles; vertical lines represent the complete range of values.*

The replicas were sputtered with gold (sputter device: Balzers SCD 40) and the interfaces analyzed by SEM (Leitz ISI 50) at X200 magnification.

A quantitative analysis of the margins, according to the criteria "gap-free margin" and "gap/irregularity," were performed using an image-analyzing system (TiffMes 1.9, University of Erlangen). Margin quality was calculated as a percentage of gap-free margins related to the entire length of the particular margin. Marginal gaps and marginal irregularities were not recorded separately.

Scanning Electron Microscopic Observations (SEM)

For qualitative evaluation, two types of specimens were produced. A conventionally-etched surface of one bovine tooth was graphically divided into two parts; one was left unaltered and the other half was brushed for 10 seconds under dry conditions (Figures 2, 3).

Furthermore, resin-enamel "sandwiches" were prepared using the different bonding systems with all modes of contamination. Etched-plane enamel samples were bonded together using adhesive and resin composite, cross sectioned, and polished (600-grit). The polished interface was again etched for 30 seconds using 32% phosphoric acid, rinsed for 30 seconds, and dried thoroughly. This way the formation of resin tags was detectable as a cast of the etching pattern generated by the phosphoric acid.

The specimens were sputtered with gold (sputter device: Balzers SCD 40), and the surfaces and interfaces were analyzed under SEM (Leitz ISI 50, X3000).

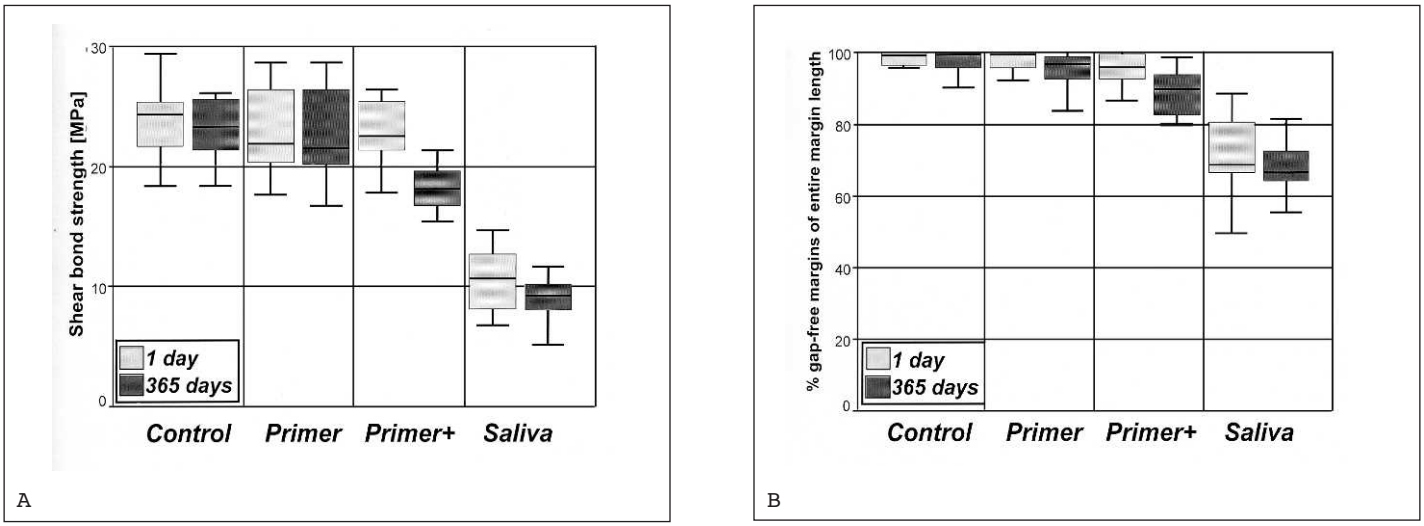

Figure 5. *Results for Scotchbond Multi-Purpose Plus (SB).* **A.** *SBS* **B.** *MA. Control = without primer; Primer = DAS only; Primer+ = DAS rubbed. The bars represent median values with 25/75% quartiles; vertical lines represent the complete range of values.*

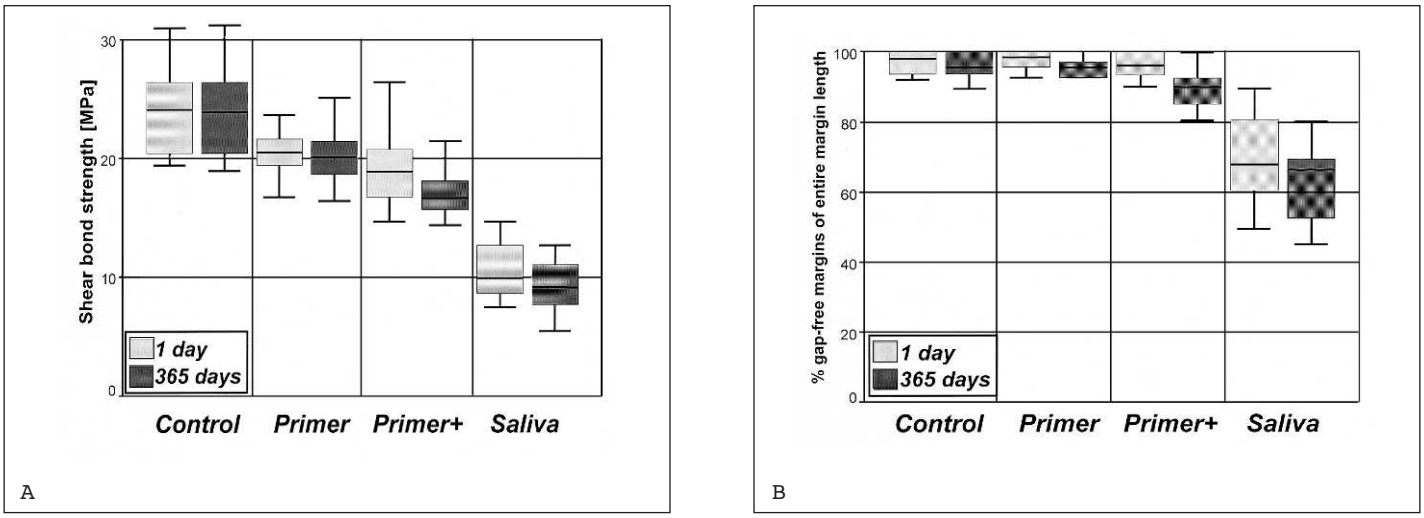

Figure 6. *Results for Syntac Classic (SY).* **A.** *SBS* **B.** *MA. Control = without primer; Primer = DAS only; Primer+ = DAS rubbed. The bars represent median values with 25/75% quartiles; vertical lines represent the complete range of values.*

Statistical Analysis

The statistical analysis was performed using SPSS/PC+, Vers 7.5, SPSS Inc, Chicago, IL 60611) for Windows 95/V 7.5. The values of shear bond strength and margin analysis were nonnormally distributed (proved by Kolmogorov-Smirnov test), so a nonparametric test (Mann-Whitney U test, correction according to Bonferroni-Holm) for pairwise comparisons at the 0.05 level of significance (a) was performed.

To assess the influence of the different materials in general, the levels of significance were adjusted to $a^*=1-(1-a)^{1/k}$ (k = number of performed pairwise tests).

RESULTS

Shear Bond Strength

After 1 day of storage and additional thermocycling, there was no statistically significant difference between the groups with and without applied dentin primers ($p< 0.05$; Figures 4A-7A; Table 2). After rubbing the primers for the entire application time, the shear bond strength to enamel decreased significantly except for SB ($p<0.05$).

Shear bond strengths in the PB groups were generally lower than in the groups EB, SB, and SY, respectively ($p< 0.05$; Figure 7A).

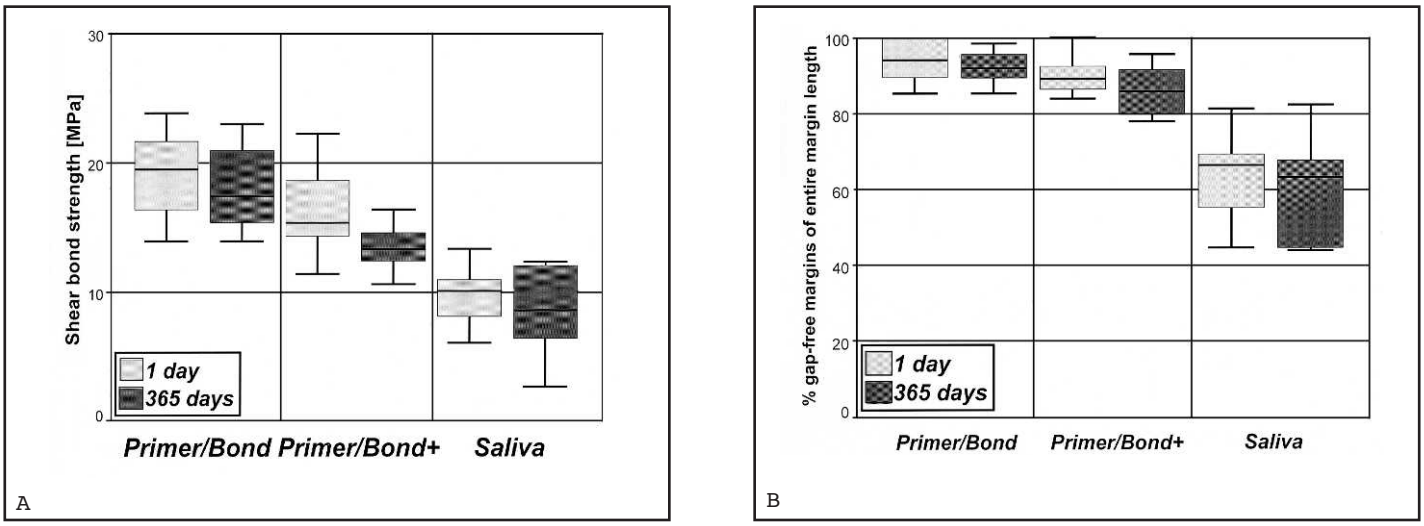

Figure 7. *Results for Prime&Bond 2.0 (PB).* **A.** *SBS* **B.** *MA. Control = without primer; Primer = DAS only; Primer+ = DAS rubbed. The bars represent median values with 25/75% quartiles; vertical lines represent the complete range of values.*

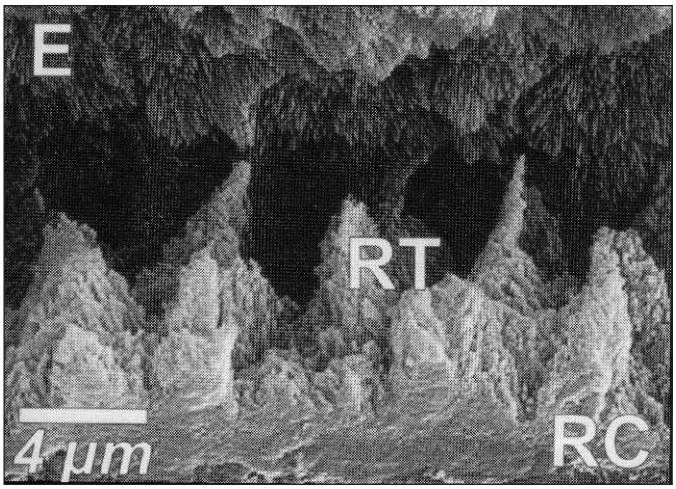

Figure 8. *Interface without contamination (EB, X1890). Characteristic stalagmite form. E = enamel; RT = resin tags; RC = resin composite.*

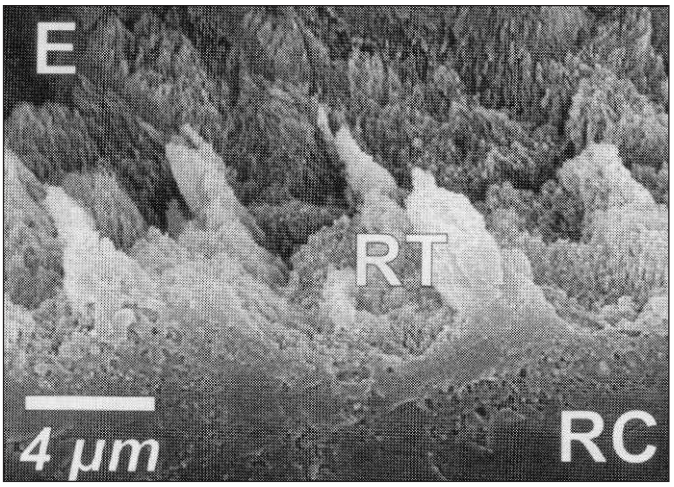

Figure 9. *Interface after contamination with EB primer (X1890). No difference between Figures 7 and 2 is detectable. E = enamel; RT = resin tags; RC = resin composite.*

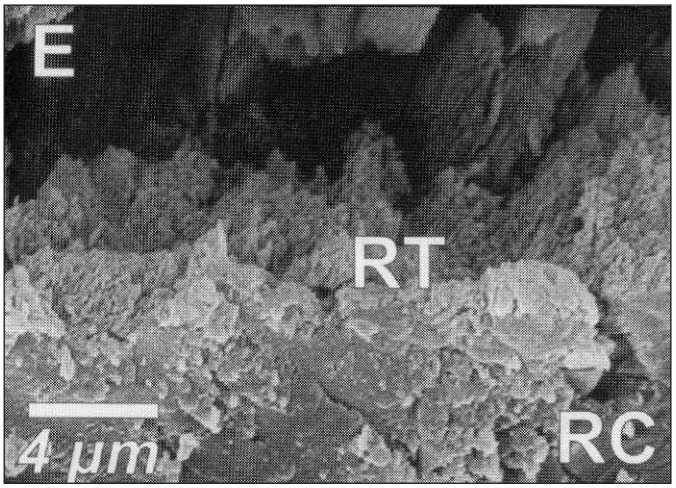

Figure 10. *Interface after rubbing of the primer and bonding, like displayed in the manufacturer's flowchart (EB, X1890). Irregular and short resin tags are the result of rubbing over the entire primer application period. E = enamel; RT = resin tags; RC = resin composite.*

Contamination with saliva resulted in dramatic decreases in shear bond strength after 1 year, with values below 10 MPa in comparison to 18.2 - 24.3 MPa for the control groups ($p<0.05$; Figure 4A-7A; Table 2).

After 365 days of storage and thermocycling, no statistically significant decrease in enamel shear bond strength from 1 day was observed in the control and dentin adhesive system-only groups, but the "rubbing groups" showed significant decreased shear bond strength values after 1 year of storage plus thermocycling ($p<0.05$; Figures 4A-7A; Table 2). In the groups performed with saliva contamination, no further significant decreases in shear bond strength occurred ($p>0.05$; Figures 4A-7A) after 1 day.

The SEM evaluation of the fracture modes revealed mixed failures in all specimens, with failures at the adhesive resin-enamel coupling zone. Most of the cases showed pulled-out enamel prisms. A total of 70 - 100% of the specimens in the control groups showed this form of mixed failures, while after contamination with dentin primers, the observed mixed failures decreased (Table 2).

The analysis of failure modes after 1 year of storage revealed slight changes, with more adhesive failures in the "rubbing" groups (Table 2).

Margin Analysis

After 1 day of storage and additional thermocycling, the SEM analysis of the enamel margins revealed high percentages of perfect margins of >94% in the control and dentin adhesive system groups (Figures 4B-7B). The groups with rubbed primer were not significantly different in marginal adaptation from the control and dentin adhesive groups ($p>0.05$; Figures 4B-7B). However, after 365 days of storage the percentages of gap-free margins decreased significantly in all groups with intensive rubbing ($p< 0.05$; Figures 4B-7B).

Contamination with saliva resulted in up to a 50% gap formation at the enamel-resin interface (Table 3; Figures 4B-7B). Additional marginal deterioration was not observed after 1 year of storage except for EB ($p>$ 0.05; Table 3) when compared to 1 day, except for EB ($p>$ 0.05; Table 3).

SEM Observations

SEM observations showed that an intact etching pattern (Figure 2) was completely destroyed after 10 seconds of dry brushing (Figure 3). Figure 8 represents the bonding resin-enamel interface of the EB control group without use of dentin primers. A characteristic "stalagmite"-shape occurred, characterized by extensive adhesive tag formation. By use of dentin primers without rubbing, the relief is similarly

pronounced as in the control group specimen (Figure 9).

With use of dentin primers in combination with rubbing activity on the etched surface over the whole period of time, a distinct decrease in adhesive tag formation was clearly evident (Figure 10). The performance of the dentin adhesive systems SB, SY, and PB was similar.

DISCUSSION

The aim of the present *in vitro* study was to evaluate the short- and long-term effects that enamel contamination by dentin adhesive system techniques had on bond strength and marginal adaptation.

The potential effect of dentin primers on enamel bonding behavior is an actual problem in adhesive dentistry (Hadavi & others, 1993; Sung & others, 1996; Woronko & others, 1996). Because of the increasing number of totally bonded restorations and the common use of dentin adhesive systems, primers are always contaminating etched enamel in daily dental practice.

To date, this problem has been discussed controversially in the literature (Xie & others, 1993). Recent investigations tend to confirm the hypothesis that dentin primers usually do not affect the bonding behavior to enamel (Woronko & others, 1996; Sung & others, 1996).

The manufacturers of dentin adhesive systems recently recommended the use of brushes to massage primers into the dentinal surface to obtain better and more reliable dentin bonding behavior (May, 1998; Uno & Finger, 1996). However, to date, there is no information about the effect of these brush- or sponge-shaped applicator tips on bonding performance to enamel.

Only the uncovered area was available for etching, priming, and bonding. In contrast to other studies, no resin composite material was bonded to the enamel surface. In the present investigation, ceramic cylinders were bonded directly without the use of luting composites, obtaining low film thicknesses. This methodology revealed advantages related to the mode of failure (Voss & Schmidt, 1998). Shear bond strength tests with results over 18 MPa either tended to pull out enamel prisms or showed failure within the resin or composite. Such shear test results only seemed to represent the bond strength between adhesive resin and composite. The present testing design with ceramic cylinders revealed mainly mixed failures at the enamel-resin interface, representing an exact identification of the real bond strength to enamel instead of testing the strength of the composite resin itself (Tables 2, 3). Hence, the present results are in the same range (16 - 24 MPa) as those previously published in other enamel shear bond strength studies (Barkmeier, Shaffer & Gwinnett, 1986; Barkmeier & Cooley, 1992; Tables 2, 3). The bonding substrate used in this study was bovine enamel, an acceptable substitute for human enamel (Attin & others, 1997; Nikaido & others, 1996; Trimpeneers & others, 1996).

The results of the shear bond strength procedure showed that dentin adhesive systems, alone, applied without touching the etched surface, exhibited no adverse effect on bond strength of resin composites to enamel even after 1 year of artificial aging. The SEM observations tended to confirm these results, because no differences between the primer-only and control groups were observed with regard to the micromechanical interlocking phenomena (Figures 8, 9). However, rubbing primers onto the etched enamel surface decreased shear bond strength values after 1 year of storage. SEM examination tended to verify the theory of slightly destroyed enamel etch patterns, although the destruction clearly was not as severe as after dry brushing (Figure 3). The etched surface was compared before and after 10 seconds of brushing under dry conditions to simulate the worst case clinically possible (Figures 2, 3). This comparison revealed that primers and adhesive resins seemed to support the sensitive etch pattern against complete destruction (Figure 10). The distinct decrease in bond strength in the rubbing groups over the long-term clearly demonstrated the dangerous potential of this procedure for the long-term performance of totally bonded, direct resin-composite restorations.

Enamel shear bond strengths were high enough to guarantee durable bonding to enamel under clinical conditions. The claimed bond strength for compensation of polymerization contraction stresses in a cavity is 17 MPa (Bastos & others, 1988; Swift & others, 1995). The groups using primers and rubbing were close to this borderline adhesion requirement, especially after 1 year of storage (Tables 2, 3).

Margin analysis showed similar results to shear bond test results, except for the dentin adhesive system rubbed category. Marginal adaptation in the "rubbing" groups was not statistically different from control and primer-only groups at the baseline after 1 day of storage plus thermal loading. Only after 1 year did marginal adaptation in these groups decrease significantly. But in the same groups, enamel shear bond strengths decreased to values under 17 MPa. This could explain the significantly different marginal adaptation in these particular groups.

Furthermore, statistically lower shear bond strengths in the PB groups without rubbing of the adhesive did not correlate with lower percentages of gap-free margins in the marginal gap test. However, the shear bond strengths in the range of 20 MPa were obviously sufficient for preventing gap formation under wall-to-wall shrinkage stress conditions.

Dramatic lower results for both bond strength and marginal adaptation were recorded for the contamination

with saliva test groups. This procedure was conducted without removing the unfavorable substances to simulate unintentional contamination.

Results confirmed the need for fluid control in adhesive dentistry (Gwinnett, 1990; Powers & others, 1995; Xie & others, 1993).

CONCLUSIONS

Under the conditions of this study, the use of the tested dentin adhesive systems did not decrease the bond of resins to enamel. However, rubbing on the etched enamel surface with paintbrushes or minibrushes during the entire application period endangered the intact etching pattern and decreased the long-term bond of resin to enamel. Therefore, rubbing of primers should be avoided in small cavities where selective rubbing on dentin only is impossible.

Saliva contamination of etched enamel surfaces decreased bonding to enamel, which reaffirmed the need to have adequate fluid control during bonding procedures.

Dedication

In memory of our colleague and dear friend Jürgen Sindel, who died on 3 May 1998 at the age of 33 years.

(Received 21 July 1998)

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Fluoride Release from Three Glass Ionomers, a Compomer, and a Composite Resin in Water, Artificial Saliva, and Lactic Acid

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S Theodoridou-Pahini • Y Papadogiannis

Clinical Relevance

The pH of the environment strongly affected fluoride release from the materials tested.

SUMMARY

The amounts and the pattern of fluoride release from one metal-reinforced glass ionomer cement, two resin-modified glass ionomer cements, one compomer, and one composite resin placed in double-distilled water, artificial saliva, and lactic acid were evaluated in this study. Measurements of fluoride ion release were made for a total of 105 cylindrical specimens (10 mm in diameter and 1.5 mm in height). They were taken over a period of 16 weeks at the intervals of 4, 8, 12, and 24 hours, as well as 2, 3, 7, 14, 28, 56, and 112 days. The pattern of fluoride release was similar for all of the examined materials. The greatest amount of fluoride was released from the metal-reinforced glass ionomer Argion. The resin-modified glass ionomers Vitremer, Fuji II LC; the compomer Dyract; and the composite resin Tetric followed in ranking order. The pH of the environment strongly affected the fluoride release from the materials. There was a significant difference ($p<0.001$) in the amounts of fluoride released in lactic acid vs water and artificial saliva, whereas, there was no significant difference ($p>0.05$) in the amounts of fluoride released in water vs artificial saliva.

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INTRODUCTION

Since the introduction of silicate cements, fluoride release from restorative materials has been advocated as having the ability to prevent secondary or contact surface caries (Norman, Phillips & Swarts, 1960; Retief & others 1984; Hicks, Flaitz & Silverstone, 1986; Seppa, Forss & Ogaarb, 1993; Hattab, Mok & Agnew, 1989). Glass-ionomer cements and their modified formulations are the main fluoride-releasing materials used today. Also, fluoride components have been added to other restorative materials such as composites (Forsten & Paunio, 1972; Forsten, 1976) and amalgam (Tveit & Lindh, 1980; Tveit & Gjerdet, 1981; Fazzi, Vieira & Zucas, 1977) to offer the advantage of fluoride release.

Numerous studies have been conducted to examine the pattern and the amount of fluoride release from the above materials, but some questions remain. The amount of fluoride released by a given material is not always consistent. This is not surprising, since many

factors affect fluoride release. The elution of fluoride from glass-ionomer cements is a complex process for which an adequate fundamental physicochemical model is not yet available (Crisp, Lewis & Wilson, 1976; Cranfield, Kuhn & Winter, 1982; Kuhn & Wilson, 1985; Tay & Braden, 1988). There are many variables related to the chemical and physical formulations of the many glass-ionomer products which are mainly determined by manufacturers, eg, the composition of the aluminosilicate glass and the polyalkenoate acid used in the formulation, as well as the methacrylate-containing components of the hybrid glass ionomers, and the polymerization systems (dual-cured, tri-cured) (Wilson & others, 1989, Mitra, 1994; Hammesfahr, 1994; Forsten, 1994).

The use of different experimental conditions in the respective studies also affects the results, such as the manipulation of the materials, powder-liquid ratio, mixing, different amount of exposed area for the specimens, or the nature of the storage medium (Prosser, Powis & Wilson, 1986; Verbeeck & others, 1993; Takahashi, Emilson & Birkhed, 1993; Muzynsky & others, 1988; Tveit & Lindh, 1980, McKnight-Hanes & Whitford, 1992).

Despite the wide variations in the reported amounts of fluoride released from dental materials in previous studies, the pattern of fluoride release remained consistent. There is an initial high burst of fluoride release followed by a low, prolonged elution (Sturdevant & others, 1995; Verbeeck & others, 1993; Takahashi & others, 1993; Tay & Braden, 1988).

It must also be pointed out that most of the studies have been conducted *in vitro*. Therefore, the actual results in clinical conditions could only be speculated. Since clinical trials require an extended time frame, many of the tested materials have already been withdrawn from the market and have been replaced by new materials.

The purpose of this study was to evaluate the pattern and the amounts of fluoride release of three representative types of glass-ionomer cement, a poly-acid-modified resin composite (compomer), and a composite resin containing fluoride. In an effort to simulate clinical conditions, the following solvents were used: distilled water, artificial saliva, and lactic acid.

METHODS AND MATERIALS

Twenty-one cylindrical specimens 10 mm (in diameter) by 1.5 mm (in height) were made from each material (total of 105 specimens) following the manufacturers' instructions. The specimens were divided into three groups. Each group consisted of seven specimens of each of the five materials. Each specimen was placed in a plastic beaker containing 7 ml of double-distilled water for the specimens of Group I, 7 ml of artificial saliva (composition: $CaCl_2$ 1mM=0.111gr, $NaH_2PO_42H_20$ 1mM=0.156gr, NaCl 35mM=2.05gr, $CH_3COONa3H_2O$ 15 mM=2.05 gr; pH=7 adding KOH) for the specimens of Group II, and 7 ml lactic acid (composition 4cc lactic acid, 5 cc TCP; pH =5.2 adding KOH) for the specimens of Group III. All specimens were stored at 37°C during the time of each measurement.

Before each measurement, the specimens were removed from the beakers and rinsed with 1 ml of double-distilled water. This water was added to the previous storage solution, and each specimen was then returned to a new plastic beaker with fresh storage solution. Measurements were made at the intervals of 4, 8, 12, and 24 hours, as well as 2, 3, 7, 14, 28, 56, and 112 days (16 weeks).

The 7 ml of each storage solution, plus the 1 ml used for washing the specimens, were mixed with 4 ml of TISAB Aluminon buffer solution and analyzed for fluoride (mg/mm^2) using an ion-specific electrode (combination electrode Fluoride 960900; Orion Research Inc., Boston MA 02129) in a Crison apparatus (Crison micro pH 2002 Crison Instruments, SA Riera Principal 34-36. E-08328 ALELLA-Barcelona, Spain). The solution was stirred during the analysis in a Heidolph magnetic stirrer (Heidolph Instrument GmbH, 9105 Schwaben, Germany).

The materials evaluated were: the metal-reinforced glass-ionomer cement, Argion (AR, a conventional glass-ionomer cement mixed with silver alloy particles, Voco, Cuxhaven, Germany); the two resin-modified glass ionomer cements, Fuji II LC (F II LC, GC Int. Corp, Tokyo, Japan) and Vitremer (VI, tri-cure, 3M Dental Products, St. Paul, MN 55144); the compomer, Dyract (DY, Caulk/Dentsply, Weybridge, UK); and one composite resin containing fluoride, Tetric (TE, Vivadent Liechtenstein).

RESULTS

All the materials evaluated in this study released fluoride during the entire period of the experiment. The greatest amounts of fluoride were released from the metal-reinforced glass ionomer, followed in ranking order by the resin-modified glass ionomers, the compomer, and the composite resin.

The amounts of fluoride released from the tested materials in the three dissolving media during 2688 hours are presented in Figures 1-5. Figures 6 provides the cumulative amounts of fluoride released from the materials in the three storage media during the experiment period.

Although great differences in the amounts of fluoride released from the materials exist, the pattern was similar in all media. The greatest amounts of fluoride release occurred during the first 24 hours, especially during the first 4 hours. Then this release decreased, but the materials continued to release fluoride, even in small amounts, until the end of the experiment (16 weeks).

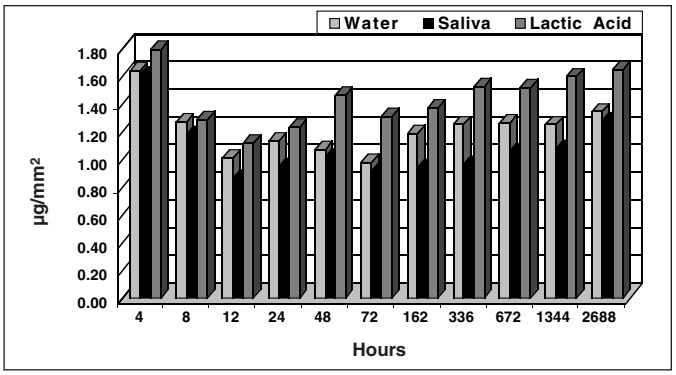

Figure 1. *Fluoride released from Argion (AR) in water, artificial saliva, and lactic acid.*

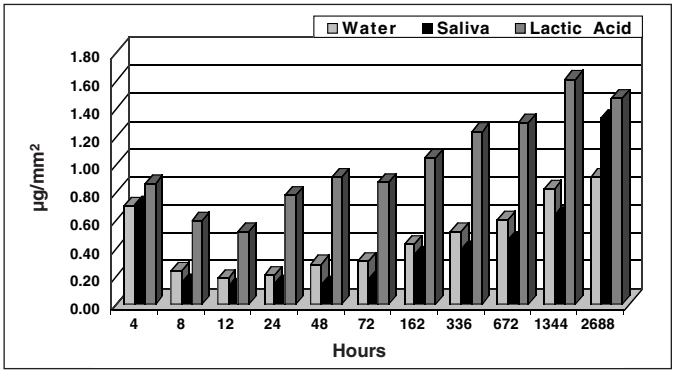

Figure 2. *Fluoride released from Vitremer (VI) in water, artificial saliva, and lactic acid.*

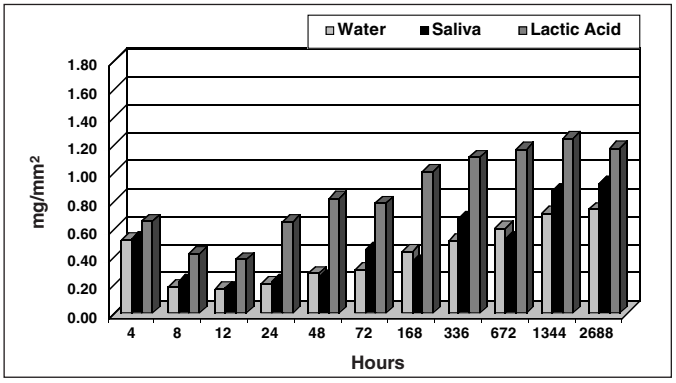

Figure 3. *Fluoride released from Fuji II LC (F II LC) in water, artificial saliva, and lactic acid.*

The greatest amounts of fluoride the materials released were in lactic acid, whereas in water and artificial saliva, the amounts were similar. Comparison and one-way Analysis of Variance (ANOVA) indicated that the relative amount of fluoride release was dependent on both the material and the environment. The most important observations were the following: There was a significant difference ($p<0.001$) in the amount of fluoride released from all the materials in water vs lactic acid and in artificial saliva vs lactic acid, except in the case of AR, where the fluoride release was not significantly different in water vs lactic acid. There was no significant difference ($p<0.05$) in the amounts of fluoride release from all the materials in water vs saliva.

Among the examined materials, AR released significantly higher amounts of fluoride ($p<0.001$) than all the other materials in all storage media. There was no significant difference ($p>0.05$) in the amount of fluoride released from VI vs F II LC in any of the storage solutions. The difference between VI and F II LC vs compomer DY and composite resin TE was significant. Also, there was no significant difference ($p>0.05$) in the amounts of fluoride released from DY vs TE in water and artificial saliva, whereas DY released significantly ($p<0.001$) more fluoride over the 16-week period than TE when stored in lactic acid.

DISCUSSION

The common finding for all the evaluated materials in the results of this study was the similar pattern of fluoride release in the three storage media. The highest fluoride dissolution occurred during the first 24 hours, especially during the first 4 hours. During the second week the fluoride release was substantially lower, but the materials continued to release fluoride until the end of the experiment, 16 weeks later. Many previous reports support this finding, and as mentioned in the introduction, two elution processes occurred. One short-term and rapid, and the other more gradual and prolonged (Muzynski & others, 1988; Diaz-Arnold & others, 1995; Sturdevant & others, 1995; Verbeeck & others, 1993; Takahashi & others, 1993; Tay & Braden, 1988; and De Moor, Verbeeck & DeMaeyer, 1996).

Since the short-term fluoride loss occurs rapidly but then is significantly reduced during the rest of the time, the length of time for evaluating the amount of fluoride released would be important when trying to compare results with other studies. Since Process I apparently occurred only during the first days after placement, the amount of fluoride loss may be associated with the setting and maturation reactions of the materials (DeShepper & others, 1991; DeMoor & others 1996).

The significant difference ($p<0.001$) in the amounts of fluoride released from the materials in lactic acid vs saliva and water could be attributed to the fact that the dissolution of the materials was dependent on the solvent (Skinner & Phillips, 1967; Fazzi & others, 1977; Tveit & Lindh, 1980). In fact, according to previous reports (Crisp, Lewis & Wilson, 1980), glass ionomers release more fluoride in acidic media. Also, Forsten (1994) stated that a decrease in pH increased the release of fluoride in glass ionomers because the dissolution of the materials increases with decreasing pH. The same appeared to happen with resin-modified glass ionomers.

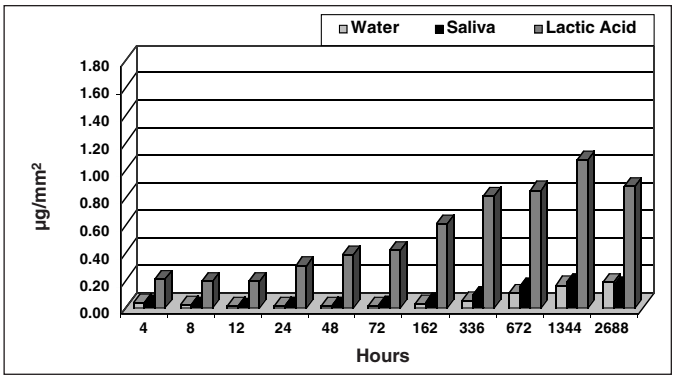

Figure 4. *Fluoride released from Dyract (DY) in water, artificial saliva, and lactic acid.*

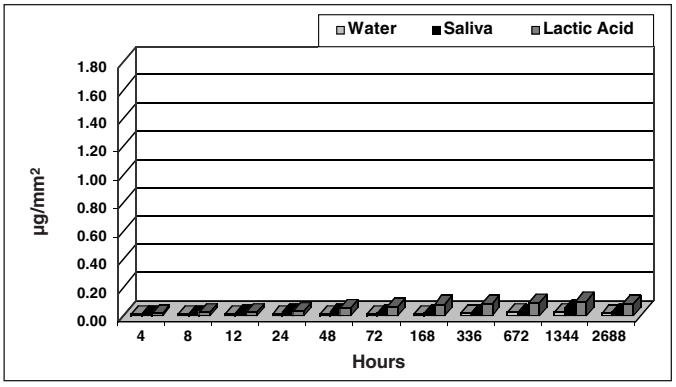

Figure 5. *Fluoride released from Tetric (TE) in water, artificial saliva, and lactic acid.*

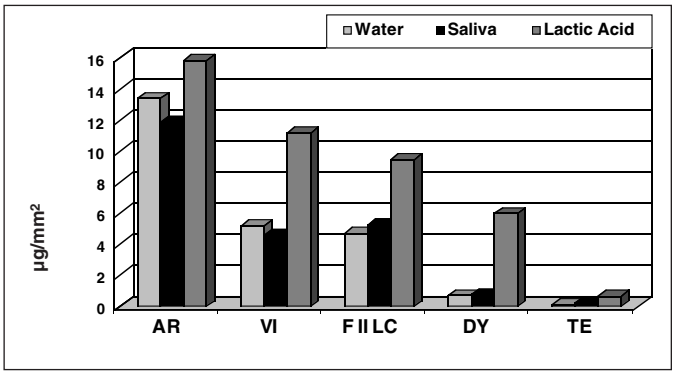

Figure 6. *Cumulative amounts of fluoride released from the examined materials in water, artificial saliva, and lactic acid; AR = Argion; VI = Vitremer; F II LC = Fuji II LC; DY = Dyract; TE = Tetric..*

Despite previous reports (el-Mallakh & Sarkar, 1990) that glass ionomers released less fluoride in slightly acidic (pH 5.5) artificial saliva than in deionized water, in this study there was no significant difference ($p>0.5$) in the amounts of fluoride released in artificial saliva vs water. This might be explained by the difference in the pH (7) of the artificial saliva in the present study and also by the fact that double-distilled water was used in this study, which differs in pH from deionized water.

Among the examined materials, the metal-reinforced glass ionomer Argion released a higher level of fluoride than all the other examined materials. Argion is a conventional glass-ionomer cement with admixed silver alloy particles added to it. As expected, the coarse alloy particles are not bound to the glass, nor to the polyalkenoate matrix. The addition of such particles results in an increase in the microporosity of the cement, thus increasing the effective surface area available for an elution of fluoride (DeSchepper & others, 1991; DeMoor & others, 1996). The drop in pH in the case of lactic acid did not affect the elution of fluoride from AR to the same degree as it did in the other materials. This could be attributed to the fact that this material consists of particles that might be less sensitive to slightly acidic conditions.

The fluoride release from F II LC and VI was not significantly different. Both of these materials are resin-modified glass ionomers formed by different processes. F II LC consists of polymerizable monomer/prepolymer in addition to polyalkenoic acid. An acid/base reaction takes place between the polyacid and the glass filler, which is responsible for fluoride release. Also, free radical polymerization mechanisms exist due to the presence of the reactive methacrylates (Hammesfahr, 1994). In the resin-modified glass-ionomer material, Vitremer, the pendant carboxylic acid of the polyacid has been modified by attaching polymerizable side groups that can then be cured through free radical mechanisms. In this way, the polyacid backbone remains essentially intact, with additional polymerizable side chains as part of the structure. Since the polyacid remains in a modified form, the elements of the conventional glass-ionomer system remains and an acid/base reaction takes place between the glass filler and the modified polyacid (Mitra, 1994, Hammesfahr, 1994).

Unlike F II LC and VI, Dyract is a compomer material containing a mixture of a methacryloyl carboxylic acid monomer (substitute for the polyalkenoic acid) and reactive glass fillers (Hammesfahr, 1994). It is classified as a polyacid-modified composite resin. The initially light-cured material takes up water with time, and the carboxylic groups (COOH) of the acidic monomer can undergo an acid/base reaction with metal ions of the glass filler. This, in turn, leads to the formation of carboxylate salts and the release of fluoride (DeTrey Dentsply, 1993). It seems that this reaction is too weak and results in low fluoride release. The release of fluoride by DY was similar to the composite resin TE, except for lactic acid, where DY released significantly higher amounts of fluoride ($p<0.001$) than TE did. The findings of fluoride

release from F II LC, VI and DY are in agreement with previous results (Forsten, 1994).

The least amount of fluoride was released from the composite resin TE. This result also agrees with previous reports (Temin & Csuros, 1988; Takahashi & others, 1993). It seems that fluoride compounds added to the composition of composite resin lead to low fluoride release. In the case of glass ionomers, their powder consists of fluoride compounds, and fluoride is being released when acid/base reaction is taking place during hardening. After that, the flow will decline fairly rapidly over the next two months to finally stabilize at a low but steady level (Mount, 1994). Maintenance of this level has been monitored for 2.5 years (Tay & Braden, 1988) and even more for 5 years without a significant decline (Forsten, 1993).

It was surprising that the drop of the pH by use of the lactic acid solution affected the fluoride release to such a degree for resin-modified glass-ionomer cements, the compomer, and the composite resin, since these materials would be expected to be more resistant to dissolution in acidic conditions than conventional glass-ionomer cements. Mueller and others (1982) showed that the BIS-GMA-based polymer is highly susceptible to chemical softening. Asmussen (1984) and Wu (1982) demonstrated a softening and a decrease in compressive strength for composites stored in solvents, such as ethanol and organic acids that are present in the plaque. Perhaps this may hold true for the methacrylates contained in resin-modified glass ionomers. This potential for surface degradation should be considered and warrants further investigation.

It is well known that fluoride enhances the rate of remineralization of dental tissues (Norman & others, 1960; Koulourides, Phantumvanit & Housch, 1975) and multiple fluoride treatments on tooth structure with low fluoride concentrations are more beneficial than a single high-concentration treatment (Norman & others, 1960; Koulourides & others, 1975; Silverstone, 1985). The exact minimal fluoride concentration for caries inhibition has not been determined. Also, due to the multifactorial nature of dental caries, every individual may require a minimal fluoride concentration. Until these data are determined, the use of dental materials with the highest long-term fluoride release would be preferable, especially in patients with moderate-to-high caries activity.

CONCLUSIONS

Fluoride release occurred from all the selected materials for the 16 weeks of this project. However, there was considerable variation in the rate of release between the materials.

The pattern of fluoride release from the materials was similar, peaking within the first few days after being placed in the storage solutions.

The pH of the environment affected the fluoride release differently among the materials.

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Marginal Adaption of Class V Restorations With and Without "Softstart-Polymerization"

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KA Hiller • A Märkl

Clinical Relevance

"Softstart-polymerization" using a very low start curing light intensity does not provide better marginal adaption in Class V composite resin and polyacid-modified resin restorations.

SUMMARY

Polymerization shrinkage causing marginal gap formation is still a major problem in light curing restorations. The aim of the present study was to test the influence of "softstart polymerization" (prepolymerization at a low light intensity followed by a final cure at a high light intensity) on the marginal integrity of polyacid-modified resin and composite resin restorations in Class V cavities using a commercially available curing unit with two defined curing intensities.

Sixty standardized Class V cavities were prepared. Twenty cavities at a time were filled either with a composite resin [Spectrum + Prime & Bond 2.1 (SP)], or with polyacid-modified resins [Dyract + Prime & Bond 2.1 (DY); Hytac + OSB Primer (HY)]. Ten fillings of each group were either conventionally cured (40 seconds, 800 mW/cm²), or they were cured with a lower starting intensity (10 seconds, 150 mW/cm²) and then with the full intensity (30 seconds, 800 mW/cm²). Margins were evaluated before and after thermomechanical loading (TCML) by quantitative margin analysis. Microleakage was assessed by dye penetration.

The softstart polymerization showed no significant influence on gap formation for each material and interface before and after TCML. Quantitative margin analysis after TCML showed significantly fewer marginal gaps at the enamel/restoration interface for SP (0%) compared to DY (15.5%) and HY (44.5%) using softstart polymerization. At the dentin/restoration interface the corresponding results for gap formation were 29.6% for SP, 8.5% for DY, and 21.0% for HY. These results were not significantly different from each other. Dye penetration was significantly higher for SP at the dentin/restoration interface. SP showed significantly more marginal swelling at the dentin/restoration interface compared to DY.

In conclusion, softstart polymerization using a very low starting intensity did not improve the marginal adaptation of polyacid-modified resins or composite resins in Class V cavity preparations. The best marginal adaptation in Class V

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cavities at the enamel/restoration interface was achieved with SP, using the acid-etch technique. In dentin, however, the polyacid-modified resins showed a superior marginal adaptation.

INTRODUCTION

Recently a number of new and effective bonding systems have been developed. However, polymerization shrinkage is still a major problem in light curing restorations. The conversion of the monomer molecules into a polymer network is accompanied with a closer packing of the molecules, causing bulk contraction (Venhoven, de Gee & Davidson, 1993). There have been no reports of any currently available system completely withstanding contraction forces during polymerization. Besides the bond strength of the adhesive system, there are several factors influencing the marginal quality of restorations (Davidson & Feilzer, 1997), ie, modulus of the restorative material (Feilzer, de Gee & Davidson, 1990b), cavity design (C-factor) (Feilzer, de Gee & Davidson, 1987), light intensity (Reinhardt, 1991), curing time (Pilo & Cardash, 1992), hygroscopic expansion (Feilzer, de Gee & Davidson, 1990a), and type and size of the filler (Feilzer, de Gee & Davidson, 1988; Miyazaki & others, 1991). For chemically curing composites, it has been found that a positive relation exists between setting time and flow characteristics (Feilzer & others, 1990b). For light curing composites, a decrease in light-curing intensity will result in an increase in setting time, thereby reducing the polymerization stress. Therefore, polymerization using a lower light intensity would cause a significant reduction in gap formation (Feilzer & others, 1995; Uno & Asmussen, 1991; Unterbrink & Muessner, 1995). However, below a certain intensity level, the composite layers may not be cured adequately (Rueggeberg & others, 1993), and physical and mechanical properties may be influenced negatively (Uno & Asmussen, 1991; Unterbrink & Muessner, 1995). Recently, some studies have shown that a controlled polymerization of composite resin restorations using prepolymerization at a low light intensity followed by a final cure at a high light intensity may result in improved marginal integrity without losing the achievable material properties (Mehl, Hickel & Kunzelmann, 1997a; Mehl, Sobota & Hickel, 1997b). However, the starting intensity of the curing light controlled by modified, not commercially available curing units used in those studies seemed to be crucial for the gap formation of composite resins (Mehl & others, 1997a,b). The aim of the present study was to test the influence of softstart polymerization on the marginal integrity of two polyacid-modified resins and a composite resin restoration in box-shaped Class V cavity preparations using a commercially available curing unit with two defined curing intensities.

METHODS AND MATERIALS

Specimen Preparation

Sixty human third molars without caries were stored in a 0.5% chloramine solution for a maximum of 1 week after extraction and thereafter at 4°C in distilled water in a refrigerator for less than 1 more week (International Standards Organization, 1994). The teeth were scaled, cleaned with pumice, and the apices sealed with gutta-percha. Then they were embedded in a methylmethacrylate resin (Palavit G; Heraeus Kulzer, 61273 Wehrheim, Germany) up to 3 mm below the cemento-enamel junction (CEJ) in molds matching the clamps of the thermocycling machine. After that, the teeth were stored again in deionized water at 37°C for 24 hours. Standardized box-shaped buccal Class V cavity preparations with parallel walls were prepared using rounded cylindrical diamond burs and the matching diamond finishing burs (40 µm particle size) (Brasseler, 32567 Lemgo, Germany). Preparations were 5 mm in the mesiodistal and 3 mm in the occlusocervical direction, the depth of the box was 1.5 mm, and the gingival cavosurface margins were placed 1 mm below the CEJ. The teeth were randomly assigned to six groups of 10 teeth each.

Bonding Procedures

Two polyacid-modified resins [Dyract (DY), Hytac (HY)] and one composite resin [Spectrum (SP)] were inserted according to the manufacturers' instructions using the corresponding adhesive systems. (Note that only Spectrum used acid etching as part of the procedure.) The composite resin and the polyacid-modified resins were light cured in one increment using either conventional or softstart polymerization (Elipar highlight; ESPE, 82229 Seefeld, Germany) (Table 1). The curing light was monitored with a light meter (Cure Rite; Caulk/Dentsply, Milford, DE 1996).

Restorations were finished and polished using finishing diamonds (Composhape; Intensiv, Viganello-Lugano, Switzerland), and flexible polishing disks (Sof-Lex polishing disks; 3M Dental Products, St Paul, MN 55144). The filled teeth were stored in deionized water for 7 days at 37°C.

Thermomechanical Loading (TCML)

All teeth were subjected to an alternating thermal cycle of 5°C and 55°C in a thermocycling apparatus for 5000 cycles. The dwell time at each temperature was 30 seconds. During the 5000 thermal cycles there were 500,000 load cycles in the center of the occlusal surface, with a frequency of 1.7 Hz and a load of 72.5 N.

Scanning Electron Microscope (SEM) Evaluation

Before and after TCML, impressions were made of the same teeth using a vinyl polysiloxane impression mate-

Table 1. Bonding procedures, batch numbers, and manufacturers of products tested.

Adhesive System (Batch-No.)	Enamel and Dentin Pretreatment	Restoration Material (Batch-No.)	Curing Mode	Manufacturer
Prime & Bond 2.1 (9709000557)	1. Apply Etchant for 30 s (beginning with enamel, rinse, and dry 2. Apply Prime & Bond for 30 s, air thin, and light cure for 10 s 3. Repeat step 2.	Spectrum (960916) Composite resin	Conventional polymerization (n=10) 40 s (800 mW/cm^2) "Softstart-polymerization" (n=10): 10 s (150 mW/cm^2) + 30 s (800 mW/cm2)	DeTrey/Dentsply 78467 Konstanz, Germany
Prime & Bond 2.1 (9709000557)	1. Apply Prime & Bond 2.1 for 30 s, air thin,and light cure for 10 s 2. Repeat step 1.	Dyract (9608124) Polyacid modified resin	Conventional polymerization (n=10): 40 s (800 mW/cm^2) "Softstart-polymerization" n = 10): 10 s (150 mW/cm^2) + 30 s (800 mW/cm^2)	DeTrey/Densply
OSB Primer (001)	1. Scrub OSB Primer for 30 s, air thin, and light cure for 10 s 2. Repeat step 1·	Hytac (001) Polyacid modified resin	Conventional polymerization (n=10) 40 s (800 mW/cm^2) "Softstart-polymerization" n = 10) 10 s (150 mW/cm^2) = 30 s (800 mW/cm^2)	ESPE, 82229 Seefeld, Germany

rial (Permagum; ESPE) with replicas made using a bisphenol A epoxy resin (Araldit; Ciba Geigy, 79664 Wehr, Germany). The replicas were gold sputtered and the luting interfaces (enamel/restoration and dentin/restoration) examined under a scanning electron microscope (Stereoscan 240; LEO Elektronenmikroskopie, 73446 Oberkochen, Germany) at X200-400 magnification. A quantitative analysis of the margins according to the criteria described in Figures 1-4 was performed using an image analyzing system (Optimas 6.2; Optimas Corp, Bothell, WA 98011). The marginal qualities (Figures 1-4) were calculated as percentages of the entire length of the particular margin.

Dye Penetration

After thermocycling, the teeth were covered with nail varnish up to 0.5 mm from the margins of the restorations. They were stored for 16 hours at 37°C in a 0.5% basic fuchsin solution (Fluka, 9471 Buchs, Switzerland). After that, they were cut in 200 µm-thick slices in a buccolingual direction using a water-cooled low-speed saw (Microtome 1600; Leitz, 35578 Wetzlar, Germany). Immediately after cutting, the slices were photographed at X16 magnification on both sides. The slides were scanned using a computer scanner (Arcus II; Agfa-Gevaert, 2640 Mortsel, Belgium) and the corresponding software (Fotolook 2.08; Agfa-Gevaert). Dye penetration at the restoration/dentin and the restoration/enamel interfaces was measured as a percentage of the entire depth of the restoration using an image analyzing system (Optimas 6.2).

Analysis

Medians and 25- and 75%-quantiles were determined from 10 replications for each material, time (before and after thermomechanical loading), interface, and curing mode. Because of the non-normal distribution of the data and the varying standard deviations, statistical analysis was performed using the Mann-Whitney test (SPSS/PC+, Vers 5.01; SPSS Inc, Chicago, IL 60611) for pairwise comparisons at the 0.05 level of significance (α). In order to assess the influence of material, interface, time, and curing mode in general, the levels of significance were adjusted to $\alpha^* = 1 - (1 - \alpha)^{1/k}$ (k = number of performed pairwise tests) using the error-rates method (Miller, 1981).

RESULTS

Figure 5 shows SEM results and statistical analysis at the restoration/enamel interface before and after TCML. In both curing modes SP showed significantly less gap formation before and after TCML, compared to DY and HY. There were no significant differences between the compomers DY and HY after TCML. TCML caused significantly more marginal gap formation with DY and HY in both curing modes.

Figure 6 shows SEM results and statistical analysis at the restoration/dentin interface before and after TCML.

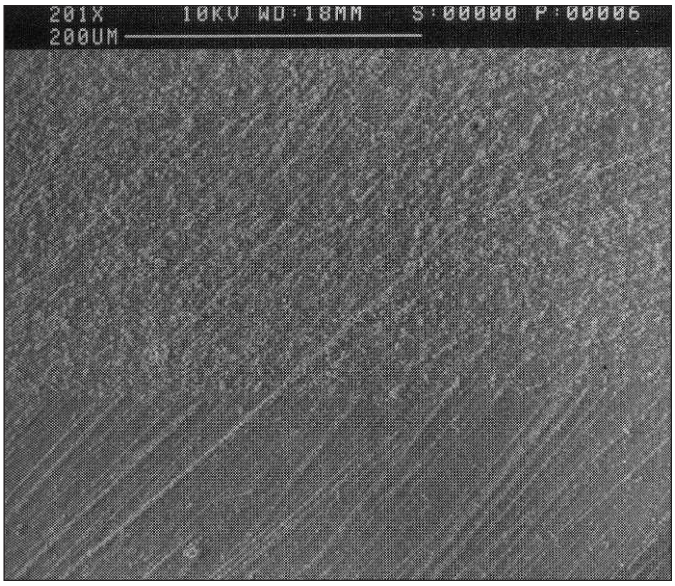

Figure 1. *Perfect margin: Restoration/tooth (enamel or dentin) interface are completely smooth without any interruptance of continuity (201x magnification).*

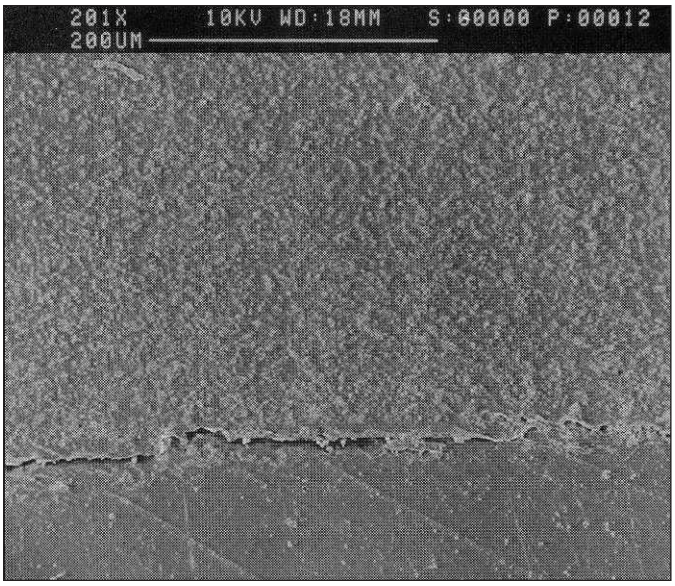

Figure 2. *Marginal gap: Restoration/tooth (enamel or dentin) interface are separated by a gap caused by an adhesive or cohesive failure (201x magnification).*

Figure 3. *Marginal imperfection: Any kind of incontinuity of the restoration/tooth (enamel or dentin) interface but no marginal gap, eg, overhang or underfilled margin (201x magnification).*

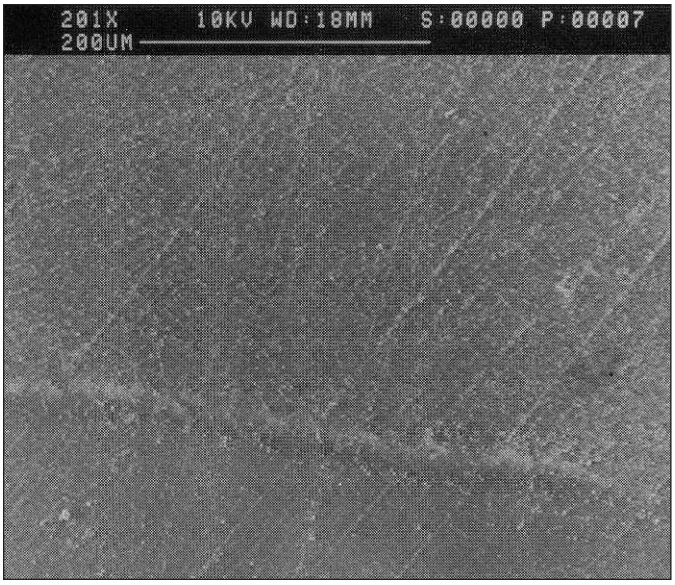

Figure 4. *Marginal swelling: Swelling at the cavity margin. The actual restoration/tooth interface cannot be exactly defined, nor can the criteria described in Figures 1-3 be applied (201x magnification).*

HY showed significantly more gap formation after TCML than DY and SP using conventional curing, whereas there was no difference among the materials using softstart polymerization. HY and SP showed significantly more marginal gaps after TCML in both curing modes.

Marginal swelling could be found only at the restoration/dentin interface. After TCML, SP showed a significantly higher percentage of marginal swelling with a median value of 72% for conventional curing and 42% for softstart polymerization compared to HY, which showed 16% for conventional curing and 19% for softstart polymerization, and DY, which showed no swelling at all for either curing mode.

Both SEM and dye penetration results (Figure 7) showed that there was no significant difference between the curing modes for all materials in enamel and dentin. DY showed a significantly worse adaptation in enamel

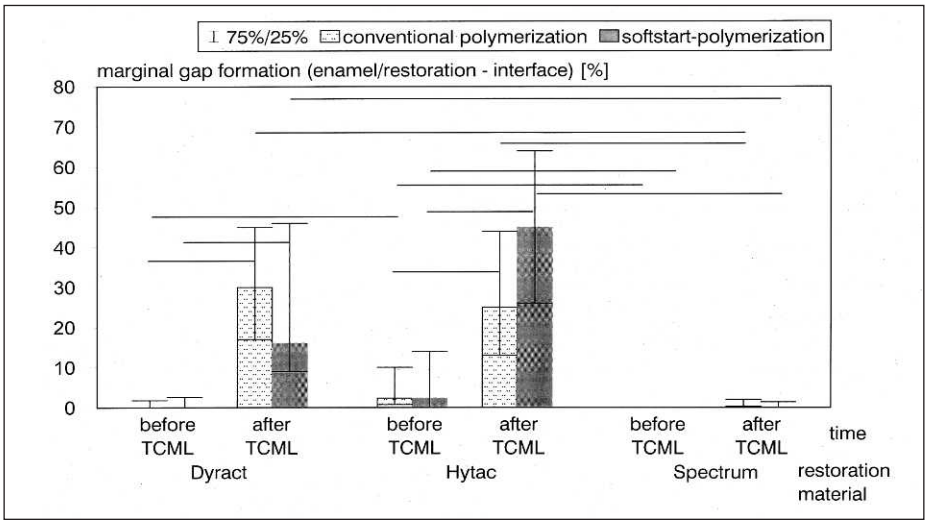

Figure 5. *Marginal gap formations (%) at the restoration/enamel interface before and after thermomechanical loading (TCML). Histograms represent median values and vertical lines represent 25/75%–qualities of 10 replications. Significant differences ($p \leq 0.05$) between medians are labeled with horizontal bars.*

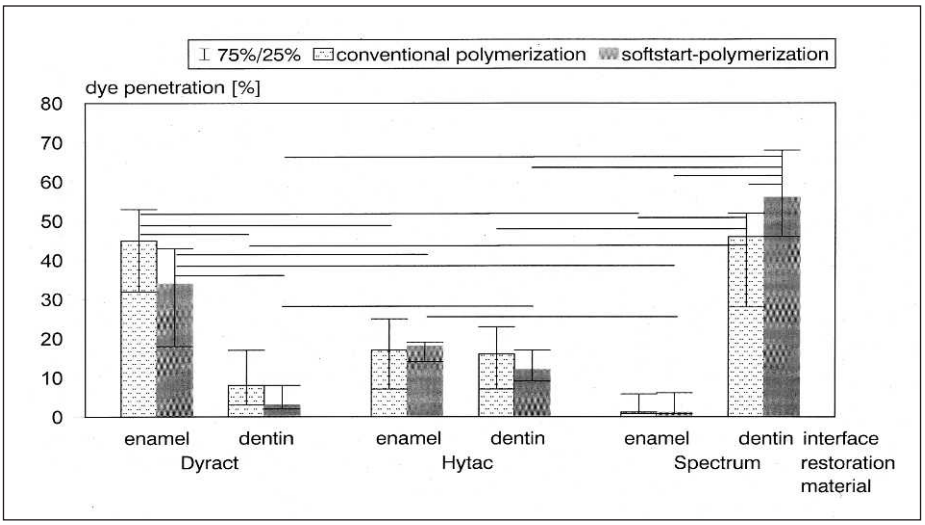

Figure 6. *Marginal gap formations (%) at the restoration/dentin interface before and after thermomechanical loading (TCML). Histograms represent median values and vertical lines represent 25/75%–qualities of 10 replications. Significant differences ($p \leq 0.05$) between medians are labeled with horizontal bars.*

compared to dentin, whereas there was no difference in HY. SP, however, showed significantly more gaps in dentin compared to enamel.

In general, the error-rates method showed that the parameter curing mode had no significant influence on microleakage or marginal gap formation, whereas TCML had a significant influence on marginal gap formation.

DISCUSSION

Polymerization shrinkage is a complex process depending on several factors. The volumetric contraction causes debonding forces at the material/tooth interface. However, a part of these forces is compensated during the first, viscous phase of polymerization by the flow of the material (Bausch & others, 1982; Davidson & de Gee, 1984; Davidson, de Gee & Feilzer, 1984) before the gel point of the material is reached. The time span before reaching the gel point depends on the speed of the reaction, which is dependent on the curing-light intensity and the concentration of initiator molecules (Goracci, Casa de Martinis & Mori, 1996). The aim of softstart polymerization is to prolong the time span before reaching the gel point by low light-curing intensities and to increase the flow capability of the material. Afterwards, high light intensities are necessary for a complete polymerization and optimal mechanical properties. In the present study, a commercially available curing unit was used to test the influence of softstart polymerization on the marginal adaptation of two polyacid-modified resins and one composite resin material using the corresponding bonding systems. The cavity design was chosen to resemble most closely the clinical situation resulting in a C-Factor of about 3, where relatively high shrinkage stresses can be expected (Bausch & others, 1982; Kinomoto & Torii, 1998). Since modern adhesive systems have bond strengths approximately as high as the stress caused by polymerization shrinkage (Retief, Mandras & Russell, 1994), the restoration may not debond initially after curing. However, the restoration remains under stress, and debonding may occur after loading under clinical conditions. Therefore, the restorations in this study were subjected to 5000 thermocycles in cold (5°C) and warm (55°C) water, with mechanical loading (X500.000/72.5N). The results of the study showed that TCML had a significant effect on marginal gap formation, which was supported by findings of Mehl and others (1997a,b). Both the quantitative margin analysis and the dye-penetration results showed that SP had the best marginal adaptation in enamel after TCML and was the only material not susceptible to TCML. This is a clear indication that enamel acid etching using phosphoric acid is still the most reliable method to provide a satisfying marginal adaptation in enamel, whereas prim-

ing of enamel only, as performed with the two polyacid-modified resins, could not withstand the forces caused by TCML. In dentin there was no significant difference in marginal gap formation among the materials before TCML and after TCML using softstart polymerization. However, it has to be considered that the high percentage of marginal swelling in Spectrum and Hytac probably interfered with a correct diagnosis of gap formation in the area of the swelling by masking marginal gap formation (Friedl & others, 1997; Thonemann & others, 1995). Therefore, dye penetration remains an important tool in assessing the marginal adaptation, especially if materials show marginal swelling. DY showed no marginal swelling at all, which is in accordance with the findings of Friedl and others (1997). Considering the fact that Prime & Bond 2.1 was used in DY without conditioning and in SP with conditioning, the marginal swelling seemed to be closely related to the opening of the fluid-containing dentinal tubules by phosphoric acid etching. Thus, the hygroscopic expansion causing marginal swelling, as first described by Kemp-Scholte and Davidson (1989), may have been an expansion of the bonding resin rather than of the restoration material itself, because the water uptake of DY should have been almost twice that of SP.

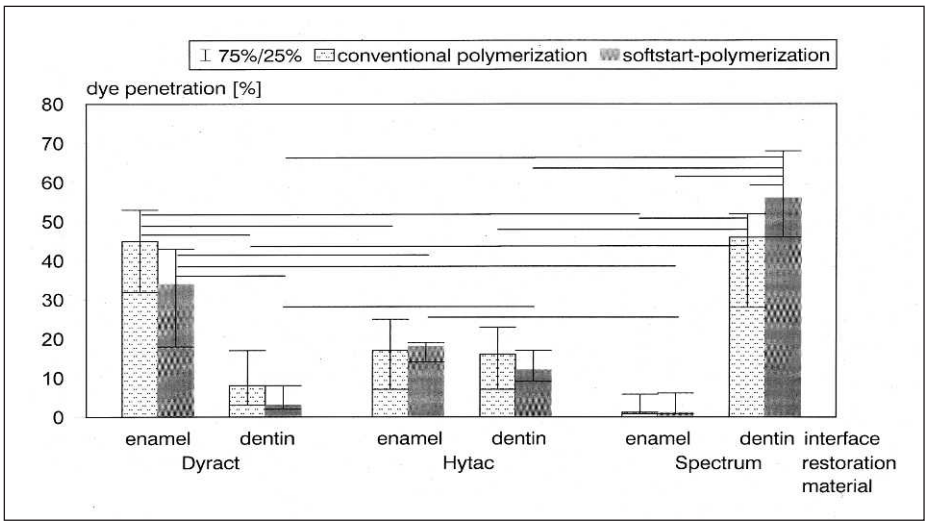

Figure 7. *Dye penetration (%) at the restoration/enamel and at the restoration/dentin interface after thermomechanical loading (TCML). Histograms represent median values and vertical lines represent 25/75%–qualities of 10 replications. Significant differences ($p \leq 0.05$) between medians are labeled with horizontal bars.*

In the present study the marginal adaptation of all restorations in enamel and dentin was not superior using softstart polymerization compared to conventional polymerization. At first, results seemed to be contradictionary to findings of Mehl and others (1997a,b), who pointed out that softstart polymerization improved the marginal adaptation of composite resin restorations in Class V cavities. However, Mehl and others (1997a,b) also showed that this positive effect was strongly dependent on the initial curing intensity and the relationship between initial and final curing intensity. Whereas starting intensities of 180 mW/cm^2 and 166 mW/cm^2 and final intensities of 600 mW/cm^2 and 450 mW/cm^2 caused even worse marginal adaptation compared to conventional curing of 600 mW/cm^2 and 450 mW/cm^2, initial curing at higher intensities (360 and 315 mW/cm^2) provided a much better marginal adaptation. The results of the present study using a similarly low initial intensity of 150 mW/cm^2 also supported the theory that this intensity may not have activated a sufficient number of initiator molecules to start an adequate polymerization reaction. Therefore, the final cure at 800 mW/cm^2 of the nearly unpolymerized material may have corresponded to an immediate full-intensity curing. Rueggeberg and others (1993) have shown that an adequate cure of composite resin layers of 1 mm thickness was not provided below a level of 233 mW/cm^2. The results of the present study indicate that the low starting intensities may have also resulted in negative effects caused by delayed curing (Manabe & others, 1993; Tao & Pashley, 1989), ie, the much higher percentage of dye penetration and marginal swelling of SP compared to DY using the same adhesive system was possibly caused by liquid rising through the open dentinal tubules after acid etching when using SP before an adequate cure had been achieved.

CONCLUSIONS

Softstart polymerization using very low starting intensities did not improve the marginal adaptation of two polyacid-modified resins and a composite resin in Class V cavities. Thermocycling and mechanical loading were important in determining marginal adaptation of composite resins, and dye penetration tests were important to evaluate marginal adaptation when a high percentage of marginal swelling occurred.

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Effect of Cavity Form and Setting Expansion of Refractory Dies on Adaptability of Fired Ceramic Inlays

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F Takeshige • S Ebisu

Clinical Relevance

The cavity form and the setting expansion of refractory die materials have significant effects on the adaptability of fired ceramic inlays.

SUMMARY

The purpose of this study was to investigate the effect of cavity form and setting expansion of refractory die materials on the adaptability of fired ceramic inlays.

Standardized Class I cavities with three kinds of lateral wall divergences (10°, 20°, and 30°) and three kinds of surface roughnesses were prepared in epoxy resin blocks. A refractory die was prepared from an impression of the epoxy resin cavity, whose setting expansion ranged from 0.01 to 1.13%. A ceramic inlay was fired on each die. The fabricated inlay was inserted into the epoxy resin cavity, and the interfacial distance between the ceramic inlay and the cavity wall at the margin was measured using a reflecting microscope at X100 magnification. The internal fit was measured after sectioning the specimen longitudinally. The results were analyzed by ANOVA and Sheffé's F test.

Good adaptation was achieved with the smooth-surface cavity. The adaptability depended on the angle of the cavity divergence, and small gaps were observed in 20° and 30° cavities ($p<0.05$). The inlays fabricated on the refractory dies with a small setting expansion demonstrated small internal gaps. Significantly good adaptation was achieved when the setting expansion was less than 0.2% ($p<0.05$).

The results indicated that the cavity form and the setting expansion of the refractory die material had significant effects on the adaptability of fired ceramic inlays.

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INTRODUCTION

The ceramic inlay restoration is regarded as one of the esthetic and conservative restoration options for molars, because the color and the translucency of ceramics approximate those of natural teeth, and the amount of tooth preparation is minimized compared to porcelain-fused-to-metal crown restoration (Kelly, Nishimura & Cambell, 1996; Roulet & Degrange, 1996; Noack &

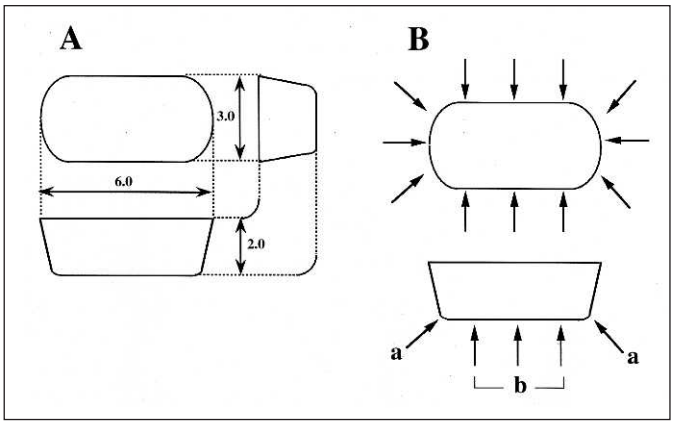

Figure 1. A. *Standardized Class I cavity form. Units shown are millimeters. B. (top right) Measuring points for marginal adaptability; (bottom right) Measuring points for internal adaptability; a = angle two points; b = bottom three points.*

Roulet, 1991; Piddock & Qualtrough, 1990; Qualtrough, Wilson & Smith, 1990). Recent improvements in the physical properties of ceramics and the development of an adhesion technique between tooth structure and ceramics with resin composite cement has led to the expanded use of ceramic inlay restorations. Therefore, a variety of esthetic restorative techniques using ceramics have been devised and developed in response to the increasing demand (Hayashi & others, 1998; Friedl & others,1996; Aberg, van Dijken & Olofsson, 1994; Stenberg & Matsson, 1993; Krejci, Krejci & Lutz, 1992; Sjögren & others, 1992; Bessing & Molin, 1990).

At the present time, ceramic inlays are produced by sintering, casting, heat-pressing, or milling techniques. Among these methods, the sintering technique is the most popular and easiest to employ by a general practitioner because most of the equipment for fabricating the inlays is already present in general laboratories (Kelly & others, 1996; Roulet & Degrange, 1996). However, many technicians have found that it is extremely difficult to achieve perfect adaptation without adjustment after firing the inlay. Some technicians shave off the inner surface of the fired inlay, and others control the expansion of die materials by increasing the liquid/powder ratio and/or decreasing the concentration of colloidal silica liquid according to the types of cavity form and the technician's expertise. As these methods are uncertain and time consuming, the fabricating procedure of fired ceramic inlays is regarded as difficult to master. Therefore, a fabricating procedure that is easy and understandable is required.

In general, ceramic inlay restorations have some advantages over resin composites, such as wear resistance, esthetics, and biocompatibility (Noack & Roulet, 1991; Piddock & Qualtrough, 1990; Qualtrough & others, 1990). However, weak points, such as marginal adaptability and marginal fractures were revealed in long-term clinical studies (Hayashi & others, 1998; van Dijken, Aberg & Olofsson, 1996). Wide marginal gaps, over 100 µm, caused marginal disintegration, such as wear of resin cement or microfractures of ceramics (O'Neal & others, 1993). Marginal adaptability of ceramic inlays has been reported, and the gap width was almost equal to or greater than 100 µm (Kawai & others, 1995; Siervo & others, 1994; Krejci, Lutz & Reimer, 1993; O'Neal & others, 1993). These results indicate that it is difficult to achieve acceptable adaptability of ceramic inlays, and that adaptability should be improved.

Cavity form and the expansion rate of the refractory die material were examined for fired ceramic inlays to identify the best method to achieve precise adaptation without additional adjustment after firing.

METHODS AND MATERIALS

A standardized box-shaped Class I inlay cavity (Figure 1) was prepared in an epoxy resin block. The cavity had a length of 6.0 mm, a width of 3.0 mm, and a depth of 2.0 mm. A standardized preparation was made with a tapered flat-ended diamond bur mounted on a high-speed handpiece with a rotation speed of 250,000 rpm using a specially designed cavity preparation device (Ito Engineering Ltd, Kyoto, Japan). The tapered flat-ended diamond burs had three different divergences (10°, 20°, and 30°) and three different grits of diamond particles (r:150 µm, f: 50 µm, sf: 25 µm). Using these diamond burs, the divergence of the approximal walls and the surface roughness of the cavity walls were precisely regulated. The preparations were assessed using a stereomicroscope (SMZ-10A, Nikon, Tokyo, Japan) at X20 magnification to confirm the desired shape of the cavity and the fracture-free margin. Then the master cavity was duplicated with epoxy resin (Epostick Resin, Nissin Co, Kyoto, Japan), and five cavities were prepared for each divergence.

Two porcelain systems were employed to evaluate the adaptability of inlays (Table 1). A plaster model

Table 1. *Materials Tested*

Ceramic System	Porcelain	Refractory Die Materials	Manufacturer
G-Cera Cosmotech II	G-Cera Cosmotech II Porcelain Batch #110321	G-Cera Cosmotech II Vest Powder Batch #281161 Liquid Batch #170372	GC Co, Tokyo, Japan
Lamina	Lamina Porcelain Batch #069611	Lamina Vest Powder Batch #039799 Liquid Batch #039747	Shofu Ltd, Kyoto, Japan

Table 2. *Influence of Concentration of the Colloidal Silica Solution on the Setting Expansion of Cosmotech II Vest*

Concentration of Colloidal Silica Solution (%)	0	25	50	75	100
Setting Expansion (%)*	0.13 ± 0.01	0.23 ± 0.01	0.50 ± 0.01	0.89 ± 0.07	1.13 ± 0.04

*Mean ± SD of five specimens for each

Table 3. *Influence of Concentration of the Colloidal Silica Solution on the Setting Expansion of Lamina Vest*

Concentration of Colloidal Silica Solution (%)	0	33.3	50	66.7	100
Setting Expansion (%)*	0.01 ± 0.01	0.11 ± 0.02	0.21 ± 0.01	0.37 ± 0.02	0.44 ±

*Mean ± SD of five specimens for each

was cast from the precise impression of the epoxy resin cavity using impression material (Exaflex, GC Co, Tokyo, Japan). A refractory die was prepared from the duplicated impression with another type of polyvinylsiloxane impression material (Protesil, Krupp Medizintechnik, Essen, Germany).

The setting expansion rate of refractory die materials was controlled from 0.01% to 1.13% by varying the concentration of the colloidal silica solution from 0 to 100% as shown in Tables 2 and 3. The measuring procedure of the setting expansion rate for the refractory die materials is described below.

Ceramic inlays were prepared according to the manufacturer's instructions by only one person. Porcelain was built up on the refractory model and fired in a porcelain furnace (Ceramimat FA-IV, GC Co) at 970°C. After overhanging marginal edges were removed with diamond burs using a microscope at X4 magnification to check the precise margin, the refractory model was removed using a sandblaster (Hi-Blaster, Sho-Fu Ltd, Kyoto, Japan) with glass beads at 4 atm of pressure, and the inlay was replaced in the epoxy resin cavity to evaluate its fit.

The marginal adaptability was determined by measuring the minimal distance between the inlay and the cavity margin at 12 preselected points (Figure 1) using a reflection microscope (Optiphot, Nikon) at X100 magnification.

The inlay was then fixed in the epoxy resin cavity with cyanoacrylate bonding agent (Labo Sianone, Koatu Gas Kogyo Co, Tokyo, Japan) and the specimen was sectioned longitudinally into two pieces with a slow-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL 60044). The internal adaptability was measured at five points, two at the angle portion and three at the bottom (Figure 1).

The data on gap size were analyzed with a one-way analysis of variance. Scheffé's F test was employed to identify the statistically significant differences in gap width among the different types of cavities and the different setting expansions of die materials at the 95% confidence level.

The setting expansions of two kinds of refractory die materials were measured to assess their influence on adaptability of ceramic inlays. The apparatus to measure the setting expansion is shown in Figure 2. The lateral wall of the casting ring (30 mm in diameter and 40 mm in height) was lined with a ceramic liner (New Casting Liner, GC Co). Fifty grams of powder was hand mixed with colloidal silica liquid and/or distilled water for 15 seconds and mechanically mixed under vacuum for 45 seconds. The concentration of the colloidal silica liquid was set between 0 and 100% (Tables 2 and 3). The mixed slurry was poured into the ring, and the longitudinal setting expansion of the specimen was measured over a period of 2 hours with a digital linear gauge (D-10S, Ozaki Seisakusyo Co, Tokyo, Japan). To eliminate the influence of the measuring factors, the measuring force (118 g), the test temperature (23°C), and other measuring conditions were maintained at constant levels. All tests were performed five times, and the setting expansion was expressed as a percentage of the original length of the specimen, and mean values with standard deviations were calculated. Then the setting expansion was corrected using simple regression ($p<0.05$).

RESULTS

Figure 3 shows the internal adaptability of Cosmotech II ceramic inlays with different divergences of lateral walls and surface roughnesses of cavity walls. Smaller gaps were observed in the cavities with larger divergences and smoother surfaces. The effect of surface roughness was more marked in the cavities with smaller divergences of lateral walls.

The marginal gap width was measured only in 20° and 30° smooth-surface cavities, and those were 38±14 μm and 45±28 μm respectively. In other cavities, the marginal gap width could not be detected precisely, because large vertical gaps caused focusing of the microscope to be difficult.

In every cavity with different divergences, the smallest internal gaps were observed with the smooth-surface cavities prepared with super fine diamond points. Thus, these types of cavities were employed for further evaluation.

Figure 4 shows the setting expansion of two refrac-

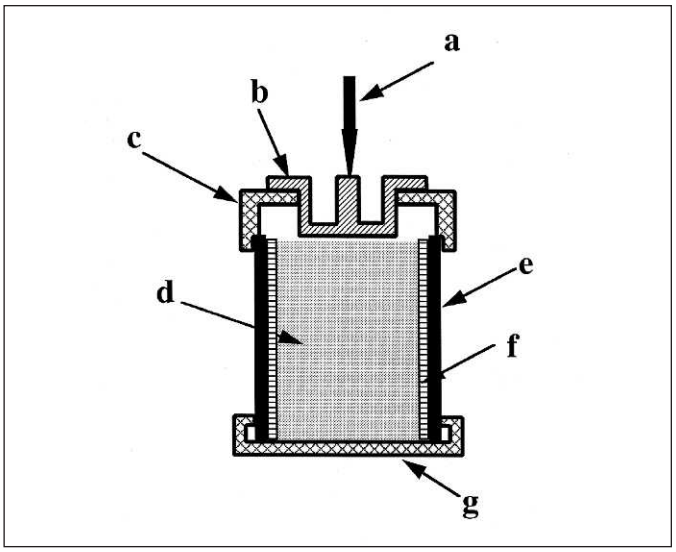

Figure 2. *Measuring apparatus for setting expansion of refractory die materials. a = digital gauge; b = stainless steel cap; c = stainless steel outer cap; d = refractory die material; e = stainless steel ring; f = ceramic liner; g = stainless steel cap.*

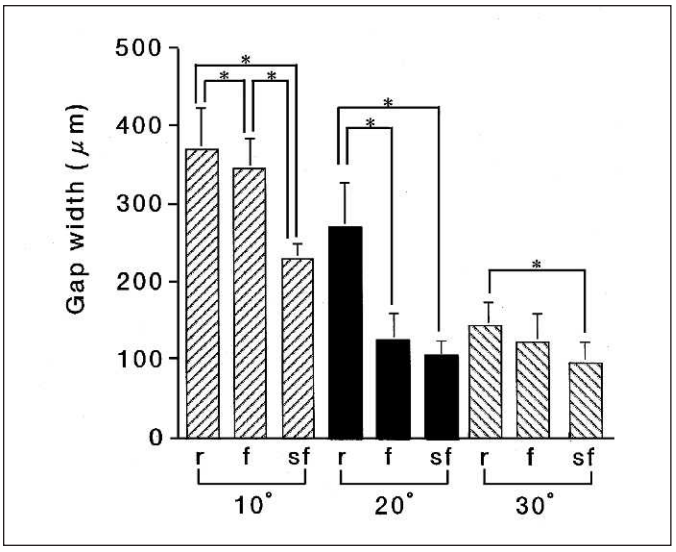

Figure 3. *Influence of the cavity form on the internal adaptability of Cosmotech II ceramic inlays. Class I cavities show three kinds of surface roughness (r = regular; f = fine; sf = superfine) and divergences of lateral walls (10°, 20°, 30°). According to the manufacturer's instruction, the concentration of the colloidal silica liquid was 37.5%. Vertical lines denote SD, and asterisks (*) are significantly different at the 95% confidence level.*

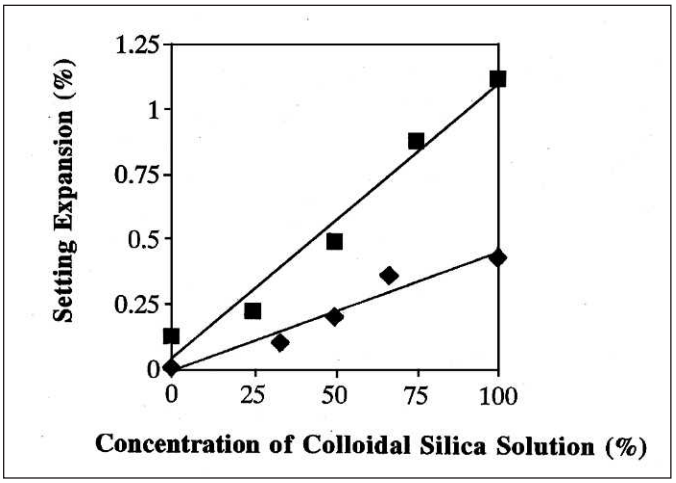

Figure 4. *The influence of the concentration of the colloidal silica liquid on the setting expansion of two kinds of refratory die materials.* n = *Cosmotech II Vest (y = 0.011x + 0.044; r^2 = 0.97);* u = *Lamina Vest (y = 0.005x - 0.004; r^2 = 0.95).*

tory die materials when the concentration of the liquid changed between 0 and 100%. The two materials had different ranges of the setting expansion. Cosmotech II Vest ranged from 0.13 to 1.13% and Lamina Vest from 0.01 to 0.45%. Cosmotech II consistently showed a larger setting expansion than Lamina Vest. The setting expansion, which was recommended by the manufacturer for Class I cavities, was different for the two materials. Both materials demonstrated a high correlation, over 0.95, by simple regression ($p<0.05$). Therefore, the corrected values were employed for further evaluation. After correction, Cosmotech II Vest ranged from 0.04 to 1.14% and Lamina Vest from 0.00 to 0.46% as shown in Tables 4 and 5.

Table 4 shows the marginal adaptability of the Cosmotech II system. The marginal gap width could be measured only when the setting expansion was 0.32% or less in 10° cavities, and 0.87% or less in 20° cavities. The marginal gap widths for 10° and 20° cavities ranged from 21.3 μm to 27.9 μm, and there were no significant differences among the groups ($p>0.05$).

Figures 5 and 6 show the influence of the setting expansion of the die material on the internal adaptability of the Cosmotech II system. Figure 5 shows a 10° cavity and Figure 6 a 20° cavity. For both types of cavities, significantly smaller gaps were observed when the setting expansion was 0.32% or less ($p<0.05$). The smallest gap widths for 10° and 20° cavities were 41.7 ± 20.4 μm and 31.2 ± 16.6 μm, respectively.

Table 5 shows the marginal adaptability of the Lamina system. The marginal gap width was measured only when the setting expansion was 0.22% or less in 20° cavities, and the marginal gap width ranged from 22.8 μm to 25.0 μm. There were no significant differences among the groups ($p>0.05$).

Figures 7 and 8 show the internal adaptability for the Lamina system. Figure 7 shows a 10° cavity and Figure 8 a 20° cavity. For both types of cavities, significantly smaller gaps were observed when the setting expansion was 0.22% or less ($p<0.05$). The smallest gap widths for 10° and 20° cavities were 134±108.9 μm and 74.5±58.5 μm, respectively.

Table 4. *Influence of the Setting Expansion of the Refractory Die Material on the Marginal Adaptability of the Class I Cosmotech II Ceramic Inlays*

Setting Expansion (%)	0.04	0.32	0.59	0.87	1.14
10° cavities	25.7 ± 9.1	24.5 ± 4.3	---	---	---
20° cavities	21.3 ± 8.3	23.5 ± 7.7	27.9 ± 3.9	25.9 ± 5.8	---

Mean ± SD; unit = μm; n = 5; --- = Measurement was impossible due to the large vertical dimension. There were no significant differences among the groups ($p>0.05$).

Table 5. *Influence of the Setting Expansion of the Refractory Die Material on the Marginal Adaptability of the Class I Lamina Ceramic Inlays*

Setting Expansion (%)	0.00	0.14	0.22	0.31	0.46
10° cavities	---	---	---	---	---
20° cavities	22.9 ± 4.3	25.0 ± 8.2	22.8 ± 7.1	---	---

Mean ± SD; unit: μm; n = 5; --- = Measurement was impossible due to the large vertical dimension. There were no significant differences among the groups (p>0.05).

For both systems, significantly good internal adaptability was achieved when the setting expansion was less than 0.2%. Furthermore, 20° cavities showed significantly smaller internal gaps compared with 10° cavities ($p<0.05$).

DISCUSSION

Expansion of the refractory die material is calculated as the sum of the setting and thermal expansions. Only the setting expansion was measured and discussed in the present study because the setting expansion is almost four times more sensitive to changes in the concentration of the colloidal silica liquid than the thermal expansion (Anusavice, 1996).

In general, the setting expansion is a property of phosphate-bond refractory die materials due to the chemical reaction ($MgO + NH_4H_2PO_4 + 5H_2O$ ® $Mg\ NH_4PO_4 \cdot 6H_2O$). To obtain general results, two refractory materials were tested.

Good adaptation was achieved in smooth-surface cavities whose divergences were large, suggesting that finishing the cavity wall using diamond burs with small diamond particles was effective in obtaining good clinical adaptation. Therefore, the use of tapered diamond burs may be a prudent recommendation.

The cavities with divergences of 20° and 30° demonstrated smaller internal gaps and exhibited no significant differences. In 30° cavities, the amount of tooth preparation was maximum in the three types of cavities, while the marginal thickness of the ceramic inlay was the thinnest. These disadvantages may cause restoration failure. In 10° cavities, the adaptability was always inferior to 20° cavities. This finding suggested that the 10° divergences were too steep for fired ceramic inlays; therefore, 20° cavities were the most suitable for Class I fired ceramic inlay restorations clinically in terms of adaptability.

In the present study, the marginal gap width was measured in limited conditions because large vertical gaps, over 100 μm, caused focusing of the microscope to be difficult. However, the measurable marginal gap width ranged from 21.3 μm to 27.9 μm.

It is difficult to define an optimum marginal gap width

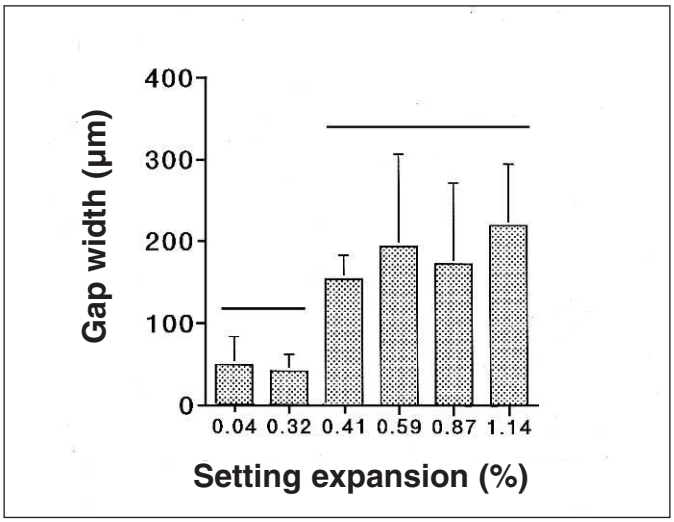

Figure 5. *The influence of the setting expansion of the refractory die material on the internal adaptability of the ceramic inlays fabricated with Cosmotech II in 10° cavities. Vertical lines denote SD, and bars joined by a horizontal line are not significantly different at the 95% confidence level.*

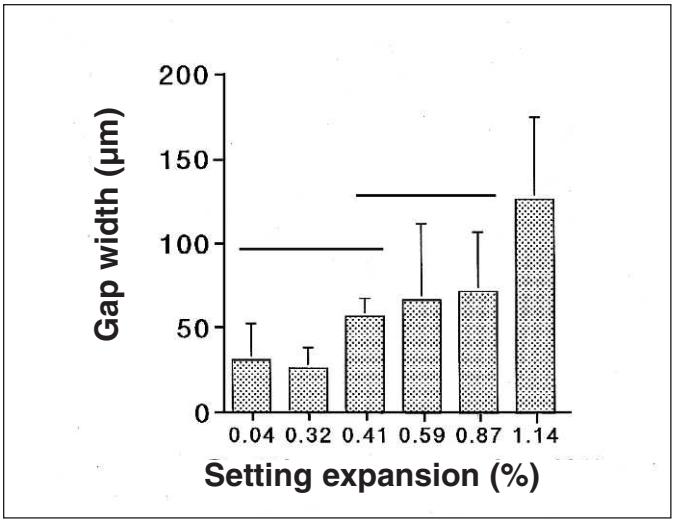

Figure 6. *The influence of the setting expansion of the refractory die material on the internal adaptability of the ceramic inlays fabricated with Cosmotech II in 20° cavities. Vertical lines denote SD, and bars joined by a horizontal line are not significantly different at the 95% confidence level.*

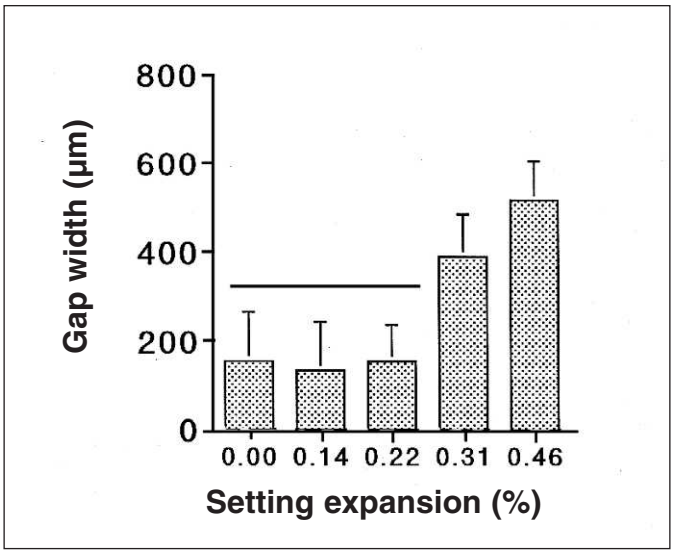

Figure 7. *The influence of the setting expansion of the refractory die material on the internal adaptability of the ceramic inlays fabricated with Lamina in 10° cavities. Vertical lines denote SD, and bars joined by a horizontal line are not significantly different at the 95% confidence level.*

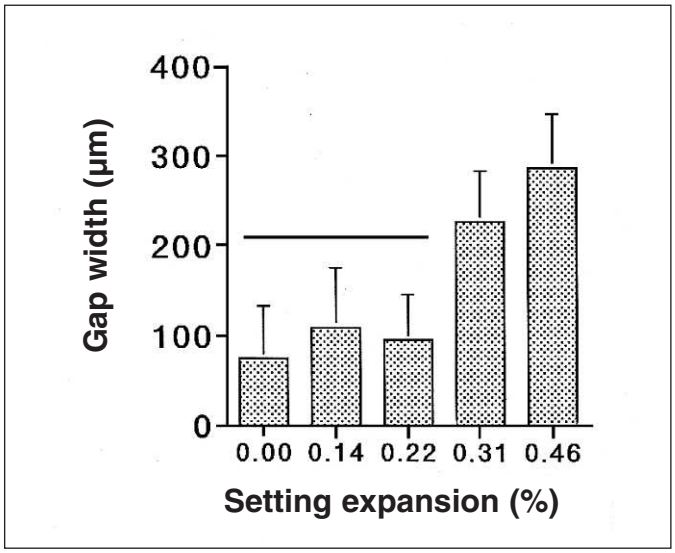

Figure 8. *The influence of the setting expansion of the refractory die material on the internal adaptability of the ceramic inlays fabricated with Lamina in 20° cavities. Vertical lines denote SD, and bars joined by a horizontal line are not significantly different at the 95% confidence level.*

for ceramic inlays. It was reported that wear of resin composite cement proceeded rapidly when the marginal gap width was over 100 μm (O'Neal & others, 1993). The thickness of resin cement ranged from 3 μm to 59 μm (Inokoshi & others, 1993); therefore, these widths are required for adequate luting. The marginal adaptability of other ceramic inlay restorations has been reported. The mean gaps of fired ceramic inlays and Dicor inlays were approximately 90 μm, and the mean gap of Cerec inlays was approximately 150 μm (Krejci & others, 1993). Other studies have reported that the mean gap was 80 μm for both fired ceramic and Celay inlays and 170 μm for Cerec inlays (Siervo & others, 1994). Moreover, it was reported that the mean gap was 216 μm for fired ceramic and 169 μm for Cerec inlays (O'Neal & others, 1993).

Based on these results, the marginal gap width observed in the present study may be regarded as clinically acceptable and equivalent or superior to other reported ceramic inlays.

The adaptability of restorations should be evaluated regarding both internal and marginal adaptability because a uniformly thin cement layer is ideal. Only a few reports have investigated internal adaptability (Kawai & others, 1995; Siervo & others, 1994), while most reports on adaptability have investigated the marginal adaptability only (Krejci & others, 1993; Siervo & others, 1994; O'Neal & others, 1993).

In the present study, the points at the bottom of the cavity were selected to measure the internal fit because these points were most precisely found to represent the internal adaptability. The size of the fired ceramic inlay became larger than that of the original cavity due to expansion of the refractory die material. In this situation, there was insufficient space to insert the inlay into the cavity, and the gap width at the approximal portion became very thin. It was difficult to determine whether or not the values at the approximal portion represented the adaptability; therefore, the measuring points were selected from the bottom portion only.

The effect of cavity form and setting expansion of refractory die materials on the adaptability was clearly demonstrated by evaluating the internal adaptability. Moreover, marginal adaptability is the most critical clinical criteria for quality of fit. Therefore, the adaptability should be evaluated both marginally and internally.

To achieve good adaptation in intracoronal cavities, such as Class Is, the setting expansion of refractory die material should be under 0.2% because a ceramic inlay fired on a refractory die with a large setting expansion becomes larger than the original cavity size. A larger ceramic inlay cannot be completely inserted into the cavity. Based on our results, the setting expansion should be less than 0.2% to achieve clinically acceptable adaptation. This rate is specific for Class I cavities, and other cavities, such as Class IIs (MO and MOD), may have their own superior expansion rate. This study was conducted to analyze the effect of the setting expansion of refractory die materials on adaptability. Initially, only Class I cavities have been investigated as a very simple internal cavity. Class II (MO and MOD) ceramic inlay preparations, which are popular esthetic restorations, will be investigated in the next series. Based on the results, the conditions required to achieve adequate adaptability in terms of

cavity form and setting expansion of the refractory die materials will be defined.

CONCLUSION

Cavities with smooth surfaces and larger divergences demonstrated good adaptation for Class I ceramic inlay restorations.

The setting expansion of the refractory die materials had a significant effect on adaptability. For Class I cavities, the setting expansion should be set at less than 0.2% to achieve good adaptation.

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Dentin Bond Strength and Marginal Adaption After NaOCl Pre-Treatment

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H Oberschachtsiek • A Petschelt

Clinical Relevance

Sodium hypochlorite treatment after etching dentin exhibited detrimental effects on marginal adaptation of totally bonded direct composite resins, independent of the adhesive system tested.

SUMMARY

The aim of this in vitro **study was to compare the dentin bond strength and marginal adaptation of direct composite resins with and without additional NaOCl treatment after the etching process. A total of 150 cavities were prepared into disks of freshly extracted human third molars and filled with direct composite resins. Dentin adhesives of the fourth (with total etching: Scotchbond Multi-Purpose Plus, EBS, and Solid Bond), and fifth generation (one-bottle adhesives: Prime&Bond 2.1, Syntac Sprint) were used in combination with corresponding composite resin materials. Dentin disks without cavity preparation treatment served as controls. After 24 hours of storage and 24 hours of thermocycling (1150 cycles), replicas were made and push-out testing was performed. Replicas were examined regarding marginal adaptation using SEM (X200 magnification).**

In general, fourth-generation dentin adhesives produced better results in bond strength and marginal adaptation than fifth-generation one-bottle systems (p<0.05). Within the fourth generation, Scotchbond Multi-Purpose Plus and EBS achieved significantly higher push-out values and percentages of gap-free margins than Solid Bond (p<0.05).

After hypochlorite treatment, dentin bond strength (-25%) and marginal adaptation (-30%) decreased significantly (p<0.05) in all groups.

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INTRODUCTION

Effective bonding to tooth-hard tissues is an absolute necessity for clinical success using tooth-colored materials, like resin composites (Walshaw & McComb, 1996). Good marginal adaptation prevents microleakage, recurrent caries, and pulpal irritations (Swift, Perdigão & Heymann, 1995). Etched enamel shows an irregular surface representing a perfect substrate for bonding of unfilled resins (Buonocore, 1955). However, clinically successful retention and marginal seal were limited on enamel adhesion for decades (Eick & others, 1991). Success in bonding to dentin was observed considerably later (Nakabayashi, Ashizawa & Nakamura, 1992).

Dentin is a less favorable bonding substrate due to the high organic content, the variation in the degree of mineralization, and the presence of outward fluid movement (Walshaw & McComb, 1995; Eliades, 1994). Since the early 1990s, more and more encouraging clinical results have been reported, and therefore, the development of new dentin adhesive systems has progressed very quickly in recent years (Watanabe & Nakabayashi, 1994; Swift & others, 1995). Adhesion to dentin was achieved using several steps with separate components for priming and bonding (Triolo, Swift & Barkmeier, 1995; Miyazaki & others, 1998). Meanwhile the fifth generation of dentin adhesive systems is commercially available, and the process of development continues (Finger & Fritz, 1996; Mason, Calabrese & Craif, 1997; Kanca, 1997). One-bottle dentin adhesive systems are providing promising effective bonding to dentin with only one chemical formula for priming and bonding, combining hydrophilic and hydrophobic resins (Finger, Inoue & Asmussen, 1994; Mason & others, 1997; Kanca, 1997; Wilder & others, 1998). Because of multiple coating, most of these dentin adhesive systems require several treatment steps, like the multistep dentin adhesive systems, but above all, simplified handling properties make them very popular with dental practitioners all over the world (Vargas, Fortin & Meckes, 1995; Kanca, 1997; Swift & others, 1997).

One of the keys in the field of dentin adhesion was the observation of the hybrid layer, resulting from resin penetration into the acid-demineralized dentin (Nakabayashi & others, 1992; Walshaw & McComb, 1995). Due to its elastic modulus, this resin-dentin interdiffusion zone may act as a stress-absorber between dentin and resin composite (Uno & Finger, 1996). However, some reports of considerably higher bond strengths after elimination of the collagen network provided contradictory results (Boschian & others, 1997; Chersoni & others, 1997; Inai & others, 1998). These studies concluded that the function of the hybrid layer might be unnecessary for successful bonding to dentin. Vargas demonstrated enhanced bond strengths after NaOCl pretreatment for the acetone-based All-Bond 2 system, but no effect for the water-based system Scotchbond Multi-Purpose (Vargas, Cobb & Armstrong, 1997). Nevertheless, Vichi reported significantly increased microleakage for Scotchbond Multi-Purpose after applying sodium hypochlorite *in vivo* (Vichi, Ferrari & Davidson, 1997).

The present *in vitro* study should help to clarify this problem using a simulated cavity design for testing push-out bond strength and marginal adaptation of the restorations simultaneously. Therefore, the selected testing design for the present investigation was Haller's push-out model (Haller & others, 1991). Extrusion testing in operative dentistry was introduced by Roydhouse (1970) by pushing out composite cylinders from dentin disks (Watanabe & Nakabayashi, 1994). Recently, the push-out design was used for testing bond strength of composite resins applied *in vivo* (Mason & others, 1997) or in internal dentin for endodontic reasons (Patierno & others, 1996). The extrusion design generates polymerization stresses similar to clinical situations, because our design reveals a configuration factor (relation of bonded to unbonded composite surface) of ~1.7, whereas shear or tensile procedures with bonded composite cylinders only have a configuration factor of ~0.2 (Feilzer, de Gee & Davidson, 1987; Frankenberger & others, 1999). A recent study investigated the mechanical fatigue of the resin-dentin interface, concluding that bond strength to dentin ideally should be measured using specimens subjected to polymerization shrinkage stress prior to testing (Mello & others, 1997).

Therefore, the purpose of this *in vitro* study was to evaluate the dentin adhesion behavior of resin-bonded direct composite resins with and without hypochlorite treatment after dentin etching.

METHODS AND MATERIALS

Specimen Preparation and Bonding Procedures

A total of 165 caries-free human third molars, stored in 0.1% thymol solution at ambient temperature for less than 4 weeks after extraction, were used in this investigation. The teeth were debrided and examined to ensure that they were free of carious lesions. Disks of 2 mm thickness were cut from the midcoronal level of the tooth, perpendicular to the tooth axis. One central conic cavity (diameter 2.3 mm) was prepared in 150 disks using standardized bullet-shaped finishing diamond burs (grit size 40 m; Komet Inc, D-32657 Lemgo, Germany). After preparation, the dentin disks were embedded around their periphery in a temporary resin material (Provipont; Vivadent Inc, FL-9494 Schaan, Liechtenstein) (Figure 1), then ground to ensure that the surfaces of the disk were free of embedding material. The specimens were randomly assigned to 11 groups (n = 15).

Seventy-five cavity surfaces were treated with dentin bonding agents of different generations according to the

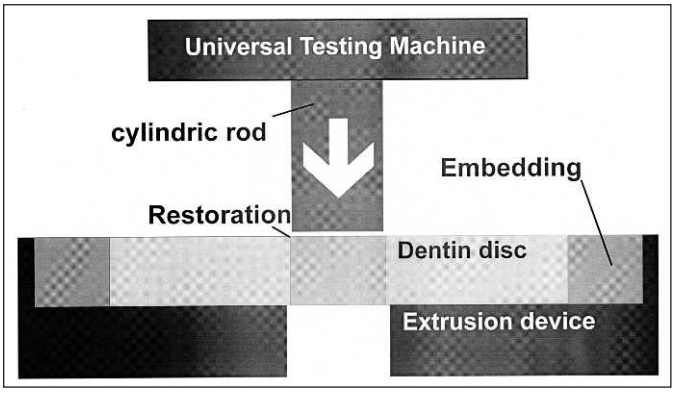

Figure 1. *Diagram of the push-out device.*

Table 1.

Adhesive System (Code)	Composite Resin	Adhesive Steps	Dentin Pretreatment	Manufacturer
Scotchbrand Multi-Purpose Plus (SZ)	**Z 100**	Etchant Primer Bond	Apply etchant for 15 seconds, rinse, and dry gently. Apply primer, air-thin. Apply adhesive, air-thin, and light cure for 10 seconds.	3M Dental Products St. Paul, MN 55144
ESPE Bonding System (EP)	**Pertac II**	Etchant Primer Bond	Apply etchant for 15 seconds, rinse, and dry gently. Scrub in primer for 20 seconds, dry. Scrub in Bond for 20 seconds, air thin. Light cure for 20 seconds.	ESPE Germany Seefeld, Germany
Solid Bond (S0)	**Solitaire**	Etchant Primer Sealer	Apply etchant for 15 seconds, rinse, and dry gently. Apply primer for 30 seconds, dry. Apply sealer, air thin, and light cure for 20 seconds.	Kulzer Dormagen, Germany
Prime & Bond 2.1 (PT)	**Spectrum TPH**	Etchant Adhesive	Apply etchant for 15 seconds, rinse, and dry. Apply primer/adhesive for 30 seconds, air thin, and light cure for 10 seconds.	De Trey Konstanz, Germany
Syntac Sprint (ST)	**Tetric Ceram**	Etchant	Apply etchant for 15 seconds, rinse, and dry gently. Apply adhesive for 30 seconds, air thin, and optionally light cure for 10 seconds or light cure together with first increment.	Vivadent Schaan, Liechtenstein

manufacturers' instructions. The several steps of dentin pretreatment are displayed in Table 1.

Seventy-five specimens were subjected to an additional 5% hypochlorite treatment step (60 seconds of treatment, 60 seconds of rinsing with water spray) after the etching process.

The cavities were filled with corresponding hybrid composite resins of the same manufacturer, like the dentin adhesive systems used in this investigation (Table 1). As a positive control, 15 disks were left intact without cavity preparation.

During the application of the composite resin, the specimens were placed on a glass sheet. The direct composite resin was inserted in one increment and condensed with a plugger. Excess composite was carefully removed with an explorer. The composite was cured for 60 seconds from each of two directions with contact to the composite surface using a transparent matrix band (Frasaco strip; Franz Sachs & Co, D-88069 Tettnang, Germany) as a separating medium. Bonding agent and composite were cured with an Elipar II curing light (ESPE Germany, D-82229 Seefeld, Germany). The intensity of the light was checked periodically with a radiometer (Demetron Research Corp, Danbury, CT 06810) to ensure that 400 mW/cm^2 was always exceeded.

Thermal Loading

After storage, the specimens were subjected to an alternating thermal cycle of +5°C and +55°C in a thermocycling apparatus for 24 hours (1150 cycles). The dwell time at each temperature was 30 seconds; the transport time between the water baths was 15 seconds. Then impressions were taken using a polyvinylsiloxane impression material (Permagum, ESPE Germany) and replicas (Epoxy Die, Vivadent) were produced for analyzing marginal adaptation.

Push-Out Testing

Finally, the specimens were positioned into the extrusion device (Figure 1) and mounted in a Universal Testing Machine (Zwick Corp, D-89075 Ulm, Germany). A cylinder-shaped rod (Ø2.2 mm) was attached to a compression load cell and, traveling at a crosshead speed of 0.5 mm/min, was applied to each filling until failure occurred. Failure was defined as the loss of 30% of the maximal push-out force. The push-out bond strength was determined by computing the quotient of maximum load (N) and adhesion area (cylinder coat; mm^2).

Scanning Electron Microscopic (SEM) Evaluation

The replicas were sputter coated with Au (Sputter device: Balzers SCD 40; Balzers, FL-9494 Vaduz, Liechtenstein)

Table 2. Bonding procedures, batch numbers, and manufacturers of products tested.

Restorative System	Push-Out Bonding Strength (SD) NI Pa	Significance Level	Percentage of Gap-free Margins (SD)	SL
Dentin	96	-	-	-
EP	31.2 (3.3)	A	97.5 (3.2)	A
EP+NaOCl	23.7 (3.4)	C	76.7 (11.3)	C
SZ	30.6 (4.5)	A	96.4 (3.8)	A
SZ+NaOCl	23.9 (3.2)	C	78.3 (9.8)	C
SO	27.6 (3.0)	B	93.1 (3.2)	B
SO+NaOCl	22.7 (3.0)	C	74.1 (13.9)	C
PT	26.1 (5.5)	B	73.0 (5.7)	C
PT+NaOCl	21.8 (4.3)	C	59.3 (12.7)	D
ST	21.8 (3.2)	C	78.3 (7.2)	C
ST+NaOCl	16.1 (2.5)	D	54.7 (12.2)	D

and the interfaces analyzed under an SEM (Leitz ISI 50; Akashi, Tokyo, Japan) at X200 magnification. A quantitative analysis of the margins according to the criteria "gap-free margin" or "gap/irregularity" was performed using an image analyzing system (TiffMes 1.9; University of Erlangen, Germany). Marginal quality was calculated as a percentage of gap-free margins related to the entire length of the particular margin. Marginal gaps and marginal irregularities were not recorded separately.

After the push-out procedure, the original specimens were mounted on aluminum cylinders, sputter-coated, and observed by SEM at X100 magnification to determine the fracture modes of the extruded restorations.

Statistical Analysis

The statistical analysis was performed using Windows 95/V 7.5 (SPSS Inc, Chicago, IL 60611). The values of push-out bond strength and marginal adaptation were non-normally distributed (proved by Kolmogorov-Smirnov test); therefore, the nonparametric Mann-Whitney U test and Kruskal-Wallis H test for pairwise comparisons at the 0.05 level of significance (α) were performed. The levels of significance were adjusted to $\alpha^*=1-(1-\alpha)^{1/k}$ (k=number of performed pairwise tests) to assess the influence of the different materials in general.

RESULTS

Push-out Bond Strength

The unfilled control group as simulation of a restitutio integrum showed values of 96 MPa strength tested with the push-out procedure. The mean push-out bond strength for the tested groups are displayed in Table 2. According to the manufacturers' recommendations, the restorative combinations EP and SZ achieved significantly higher bond strengths than SO and PT, whereas SO and PT obtained significantly higher push-out bond strength than ST. In the hypochlorite groups, EP, SZ, SO, and PT were not statistically different, but had significantly higher push-out bond strength than ST.

The observed fracture modes were found between the dentinal surface and adhesive resin.

Marginal Adaptation

The means of gap-free margins in all groups are displayed in Table 2.

In the groups following the manufacturers' instructions, the percentages of gap-free margins were significantly higher using multistep adhesive systems of the fourth generation (EP 97.5%, SZ 96.4%, SO 93.1%) compared to the single-bottle fifth-generation dentin adhesive systems (PT 73.0%, ST 78.4%). For the hypochlorite groups, the values were significantly lower than for those following the manufacturers' recommendations for use without additional NaOCl pre-treatment.

Within the NaOCl groups, an identical relationship was found in the push-out bonding procedure between fourth-generation (EP 76.7%, SZ 78.3%, SO 74.1%) and fifth-generation adhesives (PT 59.3%, ST 54.8%).

DISCUSSION

The results of this study indicated that additional NaOCl pretreatment has detrimental effects on the dentin bonding performance of all dentin adhesive systems tested. Due to the cavity design revealing wall-to-wall shrinkage stresses, the stress-absorbing effect of the hybrid layer was evaluated by investigating bond strength and margin analysis simultaneously (Haller & others, 1991; Uno & Finger, 1996; Frankenberger & others, 1999).

The reported differences between this and other studies may be due to the test configuration in the present study. An additional hypochlorite pretreatment after etching always resulted in lower bond strengths and

worse marginal adaptation. Due to the unhindered free shrinkage towards the bonded area, the demonstrable rougher dentin surface after NaOCl pretreatment may have produced higher bond strengths in shear tests (Haller & others, 1991; Versluis, Tandbirojn & Douglas, 1998). Furthermore, the often observed larger diameters of the investigated resin tags (Vargas, Cobb & Armstrong, 1997) may have helped increase the shear bond strength. An influence of the solvent used for priming of the dentin was not detectable. However, a test design with a configuration like the present study considerably prevents free shrinkage, allowing the transfer of curing contraction stresses towards the tooth-restoration interface (Uno & Finger, 1996). Therefore, the resulting bond strengths and percentages of gap-free margins seem to correlate with the presence of a hybrid layer as a stress breaker. These observations tend to confirm the reports of Vichi and others, demonstrating that sodium hypochlorite showed detrimental effects on microleakage *in vivo* (Vichi & others, 1997).

In this study, products of the same manufacturer were combined exclusively to avoid interferential effects of bonding agents and resin composites of different companies.

The simulated restitutio integrum testing of unfilled disks showed that the most effective dentin adhesive system fell far short of the measured 96 MPa of the control group.

An important point in discussing the present results is the direction and distribution of dentinal tubules. Whereas the angle of tubules to the bonding surface is rectangular in shear and tensile bond procedures, the angle in push-out procedures approaches 0°. Consequently, there might be considerably less intertubular dentin involved. However, intertubular dentin is perfect for creating a hybrid layer, and bonding to peritubular dentin results in very thin diameters of hybrid layer (Schüpbach, Krejci & Lutz, 1997).

The observation of fracture modes showed adhesive failures only, which is characteristic in push-out testing, indicating that cohesive fractures within dentin, like in shear bond procedures, may occur only when indirect composite restorations with much less shrinkage volume are pushed out (Haller & others, 1991; Frankenberger & others, 1999).

The results of the different adhesive systems support the results of previous studies using the push-out design, revealing better results for multistep adhesive systems like Scotchbond Multi-Purpose Plus or Syntac Classic (Frankenberger & others, 1999). Even recent single-bottle dentin adhesive systems had lower bond strengths to dentin than multistep adhesives. One-bottle adhesive shear bond strength values are reported to be in a lower range (Swift & others, 1997; Vargas, Fortin & Meckes, 1995) than multistep systems. High bond strengths to dentin are not exclusively due to good penetration into the demineralized surface, but also may be due to the mechanical properties of the enamel/dentin adhesive resin (Finger, Inoue & Asmussen, 1994). After hypochlorite treatment, this penetration into demineralized dentin is not necessary, but the values of the one-bottle systems were still less than those of the multistep system. This confirms the assumption that despite the absence of demineralized dentin, the mechanical properties play an important role in the dentin bonding behavior of adhesive systems.

Also, the marginal analysis of the present study revealed poor adaptation by use of the tested single-bottle adhesive systems. The results in total may, therefore, indicate that separate steps of dentin treatment with different skills, like penetration and fracture strength, are improving the bonding efficacy to dentin.

Another critical point is light curing the bonding agent. The importance of precuring to direct composite restorations was previously reported (McCabe & Rusby, 1994). However, due to easy handling conditions of simplified one-bottle adhesive systems, the manufacturers tend to omit this step. The tested adhesive Syntac Sprint represents this characteristic feature because the manufacturer states that separate light curing is optional. This might have been the reason for the poor adhesive performance of this adhesive system for both bond strength and marginal adaptation.

Future research needs to be directed towards bonding to caries-affected and/or sclerotic dentin.

CONCLUSIONS

Within the limits of the present *in vitro* study, it can be concluded that additional hypochlorite treatment after etching dentin does not enhance dentin bond strength or marginal adaptation of composite resin materials by use of the tested dentin adhesive systems.

The multistep fourth-generation bonding systems showed superior bonding performance over the fifth-generation adhesive systems. After one-step sodium hypochlorite treatment, this difference was less for bond strengths and marginal adaptation.

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Two-Year Clinical Comparison of a Microfilled and a Hybrid Resin-Based Composite in Non-Carious Class V Lesions

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Clinical Relevance

Two groups of subjects received restorations in noncarious Class V lesions, one group with a microfilled composite and the other a small-particle hybrid composite. After 24 months there was no difference in the proportion of restorations retained.

SUMMARY

The purpose of this double-blind clinical trial was to compare the retention rate in noncarious Class V lesions of two resin-based composite restorative materials with contrasting stiffness. Isolation with retraction cord, pressed paper triangles, and cotton rolls was used to closely mimic the procedures generally used in a practice setting. Thirty pairs of restorations were placed, one using Silux Plus and one using Z100. The assignment of material was randomized, and the subjects were unaware of the material used. All restorations were placed with a fourth-generation adhesive liner, Scotchbond Multi-Purpose. Evaluations were performed at baseline, 6, 12, 18, and 24 months by two independent examiners using criteria developed by Cvar and Ryge in a forced consensus model. Examiners were unaware of the restoration's group identity. No difference between the retention rates for the two groups was found after 24 months, bringing into question the role that a material's stiffness plays in determining retention in a noncarious Class V lesion.

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INTRODUCTION

Noncarious cervical lesions represent a difficult challenge to the dental profession because they are common, because it is likely their prevalence will increase as the nation's population ages, and because the position of these lesions makes it difficult to provide a long-lasting restoration. The prevalence of noncarious Class V lesions has been estimated at between 31 and 56%, and it has been estimated that 85% of the population shows some loss of tooth structure at the cervical (Levitch & others, 1994). Secondary caries is common around this type of restoration (Baum, Phillips & Lund, 1985), and the longevity of Class V resin-based composite restorations compared to that of other classes of restorations is unfavorable (Browning & Dennison, 1996).

That the dental profession has tried many materials and techniques in an attempt to obtain the best performance possible for its patients reflects the difficulty of this challenge. Amalgam, resin-based composite, and glass ionomers have all been used to restore these

lesions (Bader & others, 1993; Iacopino & Wathen, 1993; Kaplan & others, 1993; Powell, Johnson & Gordon, 1995; Van Meerbeek & others, 1993).

This project compares the retention rates of two resin-based composite restoratives that have widely different elastic modulus values. The hypothesis that a material with a higher elastic modulus will exhibit inferior retention in noncarious Class V lesions was tested against the hypothesis that there was no difference at the 5% significance level. The project is part of an ongoing investigation into the clinical performance of six different brands of materials that are commonly used in noncarious Class V lesions. This line of research will eventually cover three major classes of restoratives: glass ionomers (Brackett & others, 1999), resin-based composites (Browning, Brackett & Gilpatrick, 1998), and compomers.

Table 1: *Modified USPHS Rating System*

Category	Score	Criteria
Retention	Alfa	No loss of restorative material
	Charlie	Loss of restorative material
Color Match	Alfa	Matches tooth
	Bravo	Acceptable mismatch
	Charlie	Unacceptable mismatch
Marginal Discoloration	Alfa	No discoloration
	Bravo	Discoloration without axial penetration
	Charlie	Discoloation with axial penetration
Secondary Caries	Alfa	No caries present
	Charlie	Caries present
Anatomic Form	Alfa	Continuous
	Bravo	Discontinuous, no dentin exposed
	Charlie	Discontinuous, dentin exposed
Marginal Adaptation	Alfa	Closely adapted, no visible crevice
	Bravo	Visible crevice, explorer will penetrate
	Charlie	Crevice in which dentin is exposed

METHODS AND MATERIALS

Thirty patients with at least one pair of noncarious cervical lesions were chosen at random from the health sciences campus and the surrounding community. All subjects ranged in age from 40 to 75 years old. All were in good health and all anticipated living in the area for the next 2 years. In order to assure that the results of this research could be easily generalized to the population of the United States as a whole, no restrictions were placed on the size or position of the lesions. One tooth in each pair received a restoration placed with a microfilled, resin-based composite (Silux Plus; 3M Dental Products, St Paul, MN 55144) while the other received a small-particle hybrid (Z100 3M Dental Products). The order of the materials was on a random basis, and patients were unaware of the type of restorative used. All restorations were placed by one operator using the Scotchbond Multi-Purpose primer and adhesive system (3M Dental Products), and all were placed using a minimum of two increments of composite. All materials were used according to the manufacturer's directions.

Informed consent was obtained from each patient before the procedure was started. The use of anesthesia was left to the individual patient. Isolation was accomplished with retraction cord, cotton rolls, and Dri-angles (Dental Health Products, Youngstown, NY 14174). A small bevel was placed on the incisal margin using a fine diamond (Brasseler USA, Savannah, GA 31419). No attempt to place mechanical retention on the gingival margin was made, so all restorations were retained by micromechanical means only. Next, each tooth was cleansed with flour of pumice and water, rinsed thoroughly, and both the enamel and dentin were etched with 37% phosphoric acid (Ultraetch; Ultradent Products Inc., South Jordan, UT 84095) for 15 to 20 seconds. Before the application of Scotchbond Multi-Purpose, the tooth was rinsed thoroughly and dried for 1 to 2 seconds with a gentle stream of air to avoid overdrying the dentin. Finally, finishing and polishing of the restoration was accomplished with extrafine diamonds (Brasseler).

The operator was not involved in the evaluation of the restorations. Instead, two examiners unaware of which material had been used did all evaluations, creating a double-blinded study. Color match, retention, marginal discoloration, secondary caries, anatomic form, and marginal adaptation were evaluated using the criteria developed by Cvar and Ryge (1971) in a forced consensus model (Table 1). Evaluations were performed at 6, 12, 18, and 24 months. Color photographs were made at each evaluation.

RESULTS

Two pairs of restorations were lost to further follow-up and not included in the statistical test to compare retention rates. One pair was lost because the patient relocated before the completion of the study, and one pair was lost because the Silux Plus restoration developed secondary caries. The remaining 28 pairs were available for evaluation at 24 months. In 21 pairs both the Silux Plus and the Z100 restoration were rated alfa (retained). In three pairs the Z100 restoration was rated alfa, and the Silux Plus, charlie (restorative material was lost). In four pairs the Z100 restoration was rated charlie, and the Silux Plus rated alfa. No pairs were rated charlie for both materials (Table 2).

This equates to 89% retention for Silux Plus and 86% retention for Z100 restorations after 2 years.

Comparing the proportion of restorations retained for the two groups, there was no statistically significant difference ($p>0.05$; exact binomial test). No Z100 restorations developed secondary caries.

The ratings at 24 months for each of the two groups can be found in Table 3. The groups appear comparable with the exception of the category of color match. Similarly, Table 4 shows no obvious differences between the two groups in terms of the number of restorations exhibiting a change in rating from baseline to 24 months, with the exception of color match. Z100 appears to be more color-stable than Silux Plus.

The two categories exhibiting the most clinically important decline in ratings are marginal discoloration and marginal adaptation. Marginal adaptation was the category in which a decline in rating was seen most often.

DISCUSSION

Since the routine use of rubber dam for resin-based composite restorations is unusual (Joynt, Davis & Schreier, 1989), the restorations were placed using isolation with retraction cord and cotton products to more closely mimic the technique used by practitioners. This protocol also allows for a direct comparison to results obtained in separate clinical studies being conducted by the authors using glass ionomer and compomer products.

The fact that the two groups were equivalent in terms of the proportion of restorations retained leads to the conclusion that the relative stiffness of the material was not associated with retention. It has been shown that results at 24 months are not consistent predictors for clinical performance over a longer span (McCoy & others, 1998). However, 24 months has been shown to be a sufficient time frame to detect significant differences in retention rates in noncarious Class V lesions between restorative materials with different elastic modulus values (Heymann & others, 1991).

The Heymann study found the retention rate for restorations with a lower elastic modulus to be significantly higher than a material with a higher elastic modulus. The present result does not support this finding. If it did, one would expect the Silux Plus group to exhibit a superior retention rate, since Z100 has an elastic modulus of 21.0 GPa and Silux Plus, 9.5 GPa (Willems & others, 1992). In addition, two recent studies using restorative materials with higher elastic modulus values than the Prisma-Fil used in the Heymann study, report higher retention rates over a 2-year time frame (Brackett & others, 1999; McCoy & others, 1998). The use of a newer resin adhesive, Scotchbond Multi-Purpose versus Scotchbond and Prisma Universal Bond, may be seen as accounting for the difference in results obtained for the present study and the Heymann study, since some liners are thought to provide a flexible interface between bonded dentin and composite. This seems doubtful because Scotchbond Multi-Purpose is not considered to provide for this intermediate flexible layer (Carvalho & others, 1996), and the Brackett and others study (1999) investigated two glass-ionomer products that do not use an intermediate resin liner.

It seems more likely that these flexible intermediate layers provide for stress relief while the composite material is undergoing polymerization shrinkage (Kemp-Scholte & Davidson, 1990) than that they resist forces that may dislodge the restoration by flexing with the tooth.

Table 2: *Retention*

		Silux Plus	
Z		Alpha	Charlie
1	Alpha	21	3
0	Charlie	4*	0
0			n+ 28 pairs

*$p>0.05$; exact binomial test

Table 3: *Comparison of the Two Groups at 24 Months*

Category	Silux Plus*	Z 100**
Color Match	15 Alfa 10 Bravo 0 Charlie	24 Alfa 1 Bravo 0 Charlie
Marginal Discoloration	19 Alfa 4 Bravo 2 Charlie	20 Alfa 4 Bravo 1 Charlie
Anatomic Form	24 Alfa 1 Bravo 0 Charlie	25 Alfa 0 Bravo 0 Charlie
Marginal Adaptation	4 Alfa 21 Bravo 0 Charlie	10 Alfa 15 Bravo 0 Charlie

* Silux Plus N = 25 (3 lost, one with secondary caries, and one subject lost to follow-up)
** Z100 N= 25 (4 lost and one subject lost to follow-up)

Table 4: *Changes in Ratings from Baseline to 24 Months*

Category	Silux Plus*	Z 100*
Color Match	7 Change to Bravo 0 Change to Charlie	0 Change to Bravo 0 Change to Charlie
Marginal Discoloration	3 Change to Bravo 2 Change to Charlie	4 Change to Bravo 1 Change to Charlie
Anatomic Form	1 Change to Bravo 0 Change to Charlie	0 Change to Bravo 0 Change to Charlie
Marginal Adaptation	18 Change to Bravo 0 Change to Charlie	14 Change to Bravo 0 Change to Charlie

* Number of restorations in which the rating changed

Another major factor in retention is the morphology of the dentin at the site to be restored. As a normal response to aging and as a response to trauma, dentin in the cervical area of the tooth becomes increasingly calcified, and the arrangement of the dentinal tubules becomes increasingly irregular. The increase in calcification leads to smaller dentinal tubules and to less collagen available for creation of a strong bond to dentin, one that is based on both penetration of resin into the tubules and the creation of an interdiffusion zone. In fact, the tubules can become totally obliterated. When present in the cervical dentin, the presentation of the tubules may be on a bias or from the side rather than end-on (Duke & Lindemuth, 1991). The age group represented by this sample has been shown to have two to three times as many retention failures than patients 21 to 40 years old (Heymann & others, 1991). Since there was no age difference between the two groups, there is no reason to suspect that age rather than differences in the two materials accounted for the results seen.

Problems obtaining and maintaining a good seal between restoration and tooth at the margin have been found to be a primary reason for failure of Class V resin-based composite restorations (Browning & Dennison, 1996). The present results would seem to confirm this since the category of marginal adaptation had the greatest number of restorations exhibiting a decline in rating, and the category of marginal discoloration recorded a substantial number of charlie ratings.

Studies have shown that beveled margins show superior ratings for marginal adaptation and have identified four different types of marginal defects (Fukushima, Setcos & Phillips, 1988; Bryant, Marzbani & Hodge, 1992). These defects have been defined as cavomarginal fracture, flash fracture, wear, and cavomarginal porosity. Fukushima and others (1988) found 88% of poor margins to be related to marginal fracture, and found these fractures more frequently in functional cusps, an area of high stress. This type of fracture is thought to be related to a reduction in flexural fatigue strength that has resulted from the decrease in particle size in more recent resin-based composite materials (Dickinson, Gerbo & Leinfelder, 1993; Wisniewski, Leinfelder & Isenberg, 1991). Since the shape of many of these noncarious Class V lesions provides for a feather-edged margin at the gingival, and the occlusal margin was beveled, it is quite possible that margin design contributed substantially to the large number of bravo and charlie ratings seen for marginal adaptation. It would seem that this type of marginal defect would lead as well to microleakage. However, no consistent relationship between marginal fracture and marginal discoloration was shown by Fukushima and others (1988), at least not during the time span of their study.

It is possible that a butt joint margin, especially on the cervical, may provide for better marginal adaptation by lessening the number of cavomarginal fractures. A butt joint margin is also likely to reduce the number of flash fractures at the margin. The effect of a butt joint margin design on microleakage and marginal discoloration is difficult to assess. Investigation into prep design is needed.

While retention was the one statistical comparison planned before the start of the experiment, an overall assessment of the two materials would be desirable. It would appear that the data for the other categories seem to indicate two materials that performed equally. It is, however, a difficult assessment to make over six categories. While the loss of a restoration or the presence of secondary caries is incontrovertible proof of clinical failure, it is a rather crude measure of clinical performance. With such a crude measure, the time required to accumulate enough failed restorations to demonstrate a statistical difference between groups becomes substantial. Couple this with the increasing pace at which new dental restoratives are being developed and marketed, and it seems likely that long-term clinical trials will become increasingly impractical. The introduction of products alleged to be new and improved between the start and finish of the study are likely to make the study results a moot point. Additionally, use of categorical measures of clinical performance, such as the ones used in this study, leads to a problem with multiple comparisons when performing statistical tests. One must either choose one or two comparisons before the start of the project or increase sample size so high that the project becomes overly difficult and costly. A global measure, a means of rating the clinical performance of the restoration as a whole, is needed. Such a rating system needs to take the length of trial into consideration. Marginal discoloration and marginal discrepancies occurring after 5 years are certainly a lot less indicative of a restorative whose performance is suspect than seeing the same conditions after only a few months. Accordingly, shortened clinical trials will need not only to be accompanied by a more sophisticated measure of performance but a more stringent measure as well.

CONCLUSIONS

No difference was seen in the proportion of restorations retained after 24 months between those restorations restored with Silux Plus and those with Z100. After 24 months, 89% of all Silux Plus and 86% of all Z100 restorations were retained.

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Effect of Dentin Primer on Shear Bond Strength of Composite Resin to Moist and Dry Enamel

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Clinical Relevance

The use of dentin primer on enamel seems to be essential to obtain acceptable bond strengths when enamel is moist and does not affect bond strengths when enamel is dry.

SUMMARY

The etched enamel-composite resin bond is the most reliable bond known to us. Moisture and dentin primers are the two most important variables that can interfere with this bond. This study investigated the effect of dentin primer on bond strengths of composite resin to moist and dry enamel. One hundred freshly extracted molar teeth were used for shear bond strength testing. The teeth were mounted in phenolic rings with an approximal enamel surface exposed. The exposed enamel surface on each tooth was flattened using 320- 400- and 600-grit silicon carbide papers and etched using 34-38% phosphoric acid gel. The teeth were then divided into 10 groups (n=10). Four groups were assigned to each of the two dentin bonding systems, Scotchbond Multi-Purpose and OptiBond FL. Two groups were assigned to the single-bottle bonding agent (Single Bond). Each bonding system was tested on moist and dry enamel. OptiBond FL and Scotchbond MP were tested with and without the use of primer. All samples were thermocycled and tested in shear. Fracture analysis was performed using a binocular microscope. For scanning electron microscopy, approximal samples of enamel (1 mm thick) were flattened, etched, and bonded with and without primer on moist and dry enamel. A 1 mm-thick layer of Z100 was bonded to the specimens, which were then immersed in 10% HCl for 24 hours to dissolve the enamel. The specimens were viewed under a scanning electron microscope. Results indicated that the use of primer on dry enamel did not significantly affect ($p > 0.05$) shear bond strengths for the two bonding systems, Scotchbond MP (primed 24.10 ± 4.83 MPa, unprimed 29.57 ± 7.49 MPa) and OptiBond FL (primed 26.82 ± 4.44, unprimed 25.66 ± 2.95). However, the use of primer was found to be essential on moist enamel to obtain acceptable bond strengths with both Scotchbond MP (primed 25.61± 10.29 MPa, unprimed 3.26 ± 0.95 MPa) and OptiBond FL (primed 30.28 ± 3.49 MPa, unprimed 8.37 ± 3.31 MPa). Moisture on enamel did not significantly affect ($p > 0.05$) bond strengths for the single-bottle bonding agent, Single Bond (moist enamel 31.34 ± 9.03 MPa, dry

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enamel 27.93 ± 5.41 MPa). Fracture analysis revealed that most fractures were adhesive or mixed, with a greater percentage being cohesive for the groups with dry enamel or with primer on moist enamel. Scanning electron micrographs corroborated the shear bond strength data. The specimens without primer on moist enamel showed very poor penetration of adhesive and composite resin into the etched enamel microporosities.

INTRODUCTION

As substrates for bonding to composite resins, enamel and dentin behave very differently. This may be because of the differences in their mineral, protein, and water contents (McGuckin, Powers & Li, 1994). Enamel contains 95% to 98% inorganic matter by weight as compared to dentin, which consists of about 75% inorganic matter by weight (Sturdevant & others, 1995). Therefore, different protocols are followed for enamel and dentin bonding.

Enamel bonding consists of acid etching followed by application of a low-viscosity resin. Etching removes approximately 10 microns of the enamel surface and creates a porous layer 5-50 microns deep (Gwinnett, 1971). When a low-viscosity resin is applied, it flows into the microporosities of this layer and polymerizes to form a micromechanical bond with enamel (Gwinnett & Matsui, 1967; Buonocore, Matsui & Gwinnett, 1968).

Dentin bonding differs from enamel bonding in that a hydrophilic primer is applied to the etched dentin surface before application of a low viscosity resin. Primer components, such as HEMA (hydroxy ethyl methacrylate), BPDM (biphenyl dimethacrylate), and 4-META (4-methacryloxy ethyl trimellitate anhydride), contain two functional groups–one hydrophilic and the other hydrophobic. The hydrophilic group has an affinity for the moist dentinal surface and the hydrophobic group for the resin. Therefore, the primer penetrates the collagen network exposed by etching the dentinal surface. Primers also increase surface energy, and therefore, wettability of the dentinal surface (Swift, 1998). Low-viscosity resin is then applied to the primed dentin, and it copolymerizes with the primer. A layer of collagen and resin is thus formed and is known as the hybrid layer (Nakabayashi, Kojima & Masuhara, 1982). This hybrid layer is believed to be the primary component of the dentin-resin bond (Gwinnett, 1993).

Clinically, where enamel and dentin are juxtaposed, it is very difficult and inconvenient to treat each substrate differently (McGuckin & others, 1994). Most manufacturers of universal dentin bonding agents now recommend the total-etch technique followed by application of dentin primer to moist dentin. For clinical purposes, moist dentin is defined as dentin with a glistening appearance without any water pooled on the surface. It is quite impractical to attempt to leave dentin moist and completely dry the enamel adjacent to it. Also, it is unavoidable that when dentin is being primed, some primer will get on the enamel as well (Hadavi & others, 1993). Therefore, the effect of dentin primer on moist and dry enamel needs to be evaluated very carefully.

Hayakawa and Horie (1992) reported that the use of a primer solution on enamel etched with 0.5 M EDTA increased tensile bond strength between enamel and composite resin significantly. It did not affect bond strength when used on enamel etched with 40% phosphoric acid. On the basis of this study, it appears that dentin primer enhances bond strengths when enamel has been etched with a weak acid, but enamel etched with a stronger acid (40% phosphoric acid) is not affected by application of dentin primer.

Swift and Triolo (1992) studied bond strengths of Scotchbond Multi-Purpose to moist dentin and enamel and found that the Scotchbond Multi-Purpose adhesive system provided stronger bonds to both enamel and dentin when the tooth surface remained visibly moist after etching. They used 10% maleic acid for 15 seconds for etching enamel and dentin and applied primer as well as adhesive resin on all etched surfaces.

Hadavi and others (1993) studied the effect of dentin primer on enamel-composite resin shear bond strength with four dentin bonding systems–Gluma Dentin Bond, Scotchbond, Prisma Universal Bond 2 and 3. They reported a decrease of 31-44% in shear bond strength values when dentin primer was applied on etched enamel surfaces with all the four systems tested.

Barkmeier and Erickson (1994) evaluated shear bond strength of composite resin to enamel etched with 10% maleic acid or 37% phosphoric acid, with and without the use of primer. They found that the use of primer on enamel etched with 10% maleic acid significantly reduced bond strength values. The use of primer on enamel etched with 37% phosphoric acid also reduced shear bond strength values, but this decrease was not statistically significant.

McGuckin and others (1994) reported that the effect on bond strength of the use of dentin primer on enamel was material specific. They found that dentin primer on enamel significantly improved bond strengths of the Prisma Universal Bond 3/Prisma APH and XR Bond/ Herculite systems, had no effect on the Denthesive/ Charisma, Scotchbond 2/Silux and Tenure/ Perfection systems, and decreased bond strength of the Gluma/ Pekalux system.

Thoms and others (1994) tested four dentin bonding agents to evaluate the influence of dentin primer on

the tensile bond strength to human enamel. Their results demonstrated that dentin primer significantly improved tensile bond strength of All-Bond 2, significantly decreased tensile bond strength of Scotchbond Multi-Purpose, and OptiBond, and had no significant effect on Prisma Universal Bond 3.

Woronko, St Germain, and Meiers (1996) studied the effect of primer application on enamel-composite resin shear bond strength with four dentin bonding systems—Scotchbond Multi-Purpose, ProBond, All-Bond 2, and Syntac. They found a significant difference between primed and unprimed groups only with Scotchbond Multi-Purpose. The primed group showed significantly lower bond strengths.

In all these studies, the effect of dentin primer on etched and dried enamel surfaces was evaluated. Thus, although the effect of primer application on dry enamel has been evaluated by a few authors, its influence on composite resin bond strengths is still debatable. The effect on moist enamel has not been studied so far. Most dentin bonding systems recommend leaving the dentin moist after rinsing the etchant off. Clinically, it is impractical to leave dentin moist and completely dry the enamel in the same tooth preparation.

The purpose of this investigation was to evaluate the effect of dentin primer on shear bond strength of composite resin to moist and dry enamel with three different dentin bonding systems.

METHODS AND MATERIALS

Shear Bond Strength Testing

One hundred extracted molars stored in isotonic saline with 0.2% sodium azide were used for the bond strength testing. The teeth were mounted in phenolic rings with acrylic resin with an approximal enamel surface facing up. A flat area about 4 mm in diameter was created on the exposed enamel surface of each tooth by moist grinding with 320-, 400-, and 600-grit silicon carbide papers in that order. These samples were randomly assigned to 10 groups (n=10). The three dentin bonding systems tested were: OptiBond FL (Kerr Corp, Orange City, CA 92667), Scotchbond Multi-Purpose (3M Dental Products, St Paul, MN 55144), and Single Bond (3M Dental Products). Four groups each were assigned to OptiBond FL and Scotchbond MP. Each of these two bonding systems was tested with and without primer on moist and dry enamel. Two groups were assigned to Single Bond—one for moist enamel and the other for dry enamel. The composition of the three bonding systems tested is presented in Table 1.

The treatments for each group are also seen in Table 1. The enamel surface of each tooth was rinsed with distilled water, dried with oil-free air, and etched with Scotchbond Multi-Purpose etchant (34-38% phosphoric acid gel) for 15 seconds. In Groups 3, 4, 7, 8, and 10, the enamel surface was dried thoroughly after rinsing the etchant off with oil-free air until the classical frosted appearance of etched enamel was seen. In Groups 1, 2,

Table 1. Groups for shear bond strength

Group n=10	Condition of enamel surface-post etching	Primer	Adhesive
1	Moist	Optibond FL primer (2-hydroxyethyl methacrylate (HEMA), GPDM, mono (2-methacryloxy ethyl) phthalate, ethanol, camphoroquinone, water)	Optibond FL adhesive (BIS-GMA, HEMA, barium aluminum borosilicate glass, fumed silica, disodium hexaflurosilicate, triethylene glycol dimethacrylate, alkyl dimethacrylates, camphoroquinone)
2	Moist	No primer	Optibond FL adhesive
3	Dry	Optibond FL primer	Optibond FL adhesive
4	Dry	No primer	Optibond FL adhesive
5	Moist	Scotchbond MP primer (HEMA, polycarboxylic acid copolymer, water)	Scotchbond MP adhesive (Bisphenol A diglycidyl ether dimethacrylate, HEMA, photoinitiator)
6	Moist	No primer	Scotchbond MP adhesive
7	Dry	Scotchbond MP primer	Scotchbond MP adhesive
8	Dry	No primer	Scotchbond MP adhesive
9	Moist	Single Bond (primer+adhesive) (Bisphenol A diglycidyl ether dimethacrylate, HEMA, dimethacrylates, polyalkenoic acid copolymer, ethanol, water)	
10	Dry	Single Bond (primer+ adhesive)	

Scotchbond MP etchant (34-38% H_3PO_4) was used for etching and Z100 was used as the restorative material in all the groups.

5, 6, and 9, the enamel was left moist after rinsing the etchant off. The etchant was rinsed off with an air-water spray. Oil-free compressed air was used to lightly dry the enamel until there was no water pooled on the surface. The enamel surface was left glistening moist in all cases. The primer and adhesive of each bonding system were applied according to the manufacturers' instructions, except in Groups 2, 4, 6, and 8, which were tested without the use of dentin primer.

For the Scotchbond Multi-Purpose specimens, two layers of Scotchbond Multi-Purpose primer were applied to etched enamel using an applicator tip (Kerr applicators; Kerr Corp). No agitation was used in accordance with manufacturers' instructions. Each layer was dried with a gentle air stream for 5 seconds. A thin layer of adhesive resin was then applied and light cured for 10 seconds using Optilux 401 dental curing light (Kerr/Demetron, Kerr Corp).

For the OptiBond FL specimens, primer was applied to etched enamel using an applicator in a light scrubbing motion for 30 seconds and lightly air dried for 5 seconds. Adhesive resin was applied and light cured for 30 seconds.

For the Single Bond specimens, two coats of the primer-adhesive solution were applied to etched enamel using an applicator such that the enamel surface was kept continuously wet for 20 seconds. It was air dried for 5 seconds and light cured for 10 seconds.

A cylinder of Z100 composite resin (3M Dental Products) 3 mm in diameter and 2 mm in height was bonded on each treated enamel surface using a split Teflon mold. Care was taken to ensure that each cylinder was bonded at a 90° angle to the enamel surface. All bonded samples were stored in distilled water at 37°C for 24 hours. These samples were then thermocycled for 300 temperature cycles from 5-55°C. Each cycle was 36 seconds in duration with 12 seconds of dwell time at each temperature and 12 seconds of transfer time. The samples were tested in shear using a Zwick Universal Testing Machine (Zwick of America Inc, East Windsor, CT 06088). A crosshead speed of 5 mm per minute was used. The data were analyzed using a two-factor ANOVA followed by Scheffé's F-test for multiple comparisons.

Fracture analysis was performed using a binocular microscope at X20 magnification. Fractures were classified as: cohesive if more than 80% of the resin was found remaining on the enamel surface, adhesive if less than 20% of the resin remained on the enamel surface, or mixed if certain areas exhibited cohesive fracture while other areas exhibited adhesive fracture (Woronko & others, 1996).

Scanning Electron Microscopy

A flat area was created on approximal enamel surfaces of extracted teeth stored in 0.2% sodium azide. Approximal slices of enamel about 1 mm thick were then obtained from these teeth. These were rinsed thoroughly, dried, etched, and bonded similar to the samples for shear bond strength testing. Samples were prepared with and without the use of dentin primer on moist and dry enamel surfaces for each bonding system. A layer of composite resin (Z100) about 1 mm thick was bonded on each enamel sample. These samples were then immersed in 10% hydrochloric acid to dissolve away the enamel. After 24 hours of immersion, the samples were rinsed to remove all traces of acid and thoroughly dried. These samples were mounted on aluminum stubs with colloidal silver and sputter coated with gold-palladium. Scanning electron micrographs were obtained on T-55 film using the JSM 35 CF scanning electron microscope (Jeol USA, Inc, Peabody, MA 01961).

RESULTS

The mean shear bond strength values for the 10 test groups are presented in Table 2 and Figure 1. It was

Table 2. Mean Shear Bond Strength

Agents	Dry enamel (n=10) Mean ± S.D.	Moist enamel (n=10) Mean ± S.D.
Optibond FL with primer	26.82 ± 4.44	30.28 ± 3.49
Optibond FL without primer	25.66 ± 2.95	*8.37 ± 3.31
Scotchbond MP with primer	24.10 ± 4.83	25.61 ± 10.29
Scotchbond MP without primer	29.57 ± 7.49	*3.26 ± 0.95
Single Bond	27.93 ± 5.41	31.34 ± 9.03

*These groups were similar to each other and significantly different from all other groups at $p<0.05$.

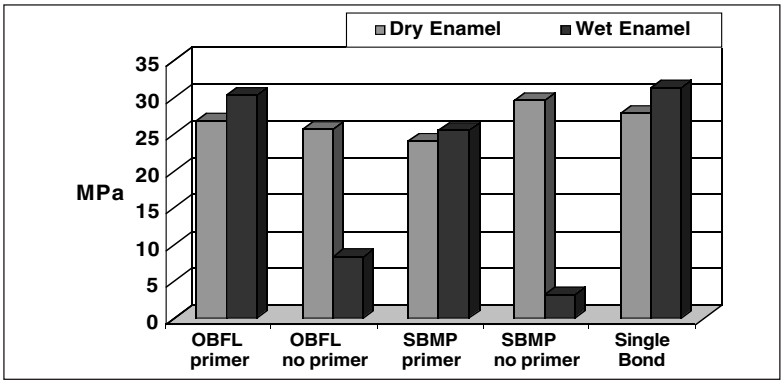

Figure 1. *Graph representing mean shear bond strength for all test groups.*

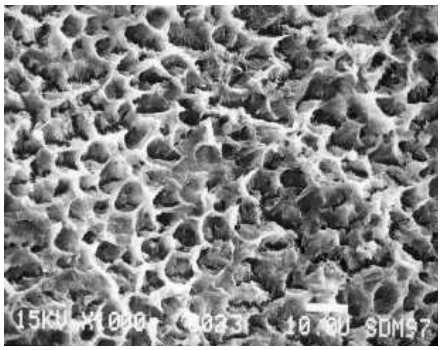

Figure 2. *Scanning electron micrograph (X1000) showing resin tags when Optibond FL was applied on dry enamel, without primer.*

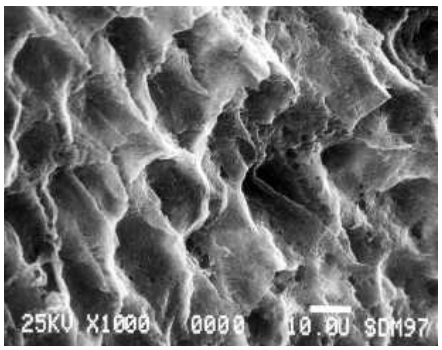

Figure 3. *Scanning electron micrograph (X1000) showing resin tags when Scotchbond MP was used on dry enamel, without primer.*

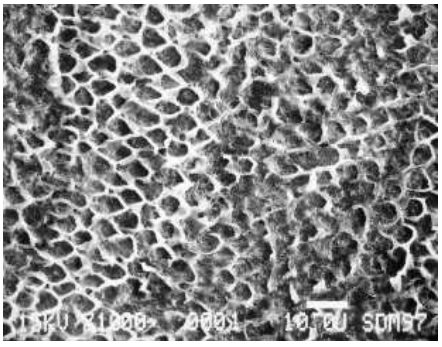

Figure 4. *Scanning electron micrograph (X1000) showing resin tags when Optibond FL was applied on dry enamel, with primer.*

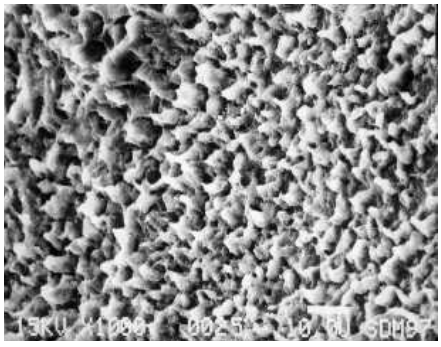

Figure 5. *Scanning electron micrograph (X1000) showing resin tags when Scotchbond MP was applied on dry enamel, with primer.*

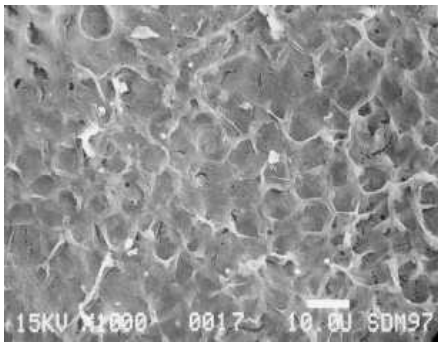

Figure 6. *Scanning electron micrograph (X1000) showing resin tags when Optibond FL was applied on moist enamel, without primer.*

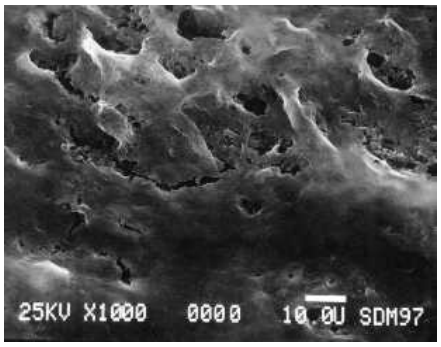

Figure 7. *Scanning electron micrograph (X1000) showing resin tags when Scotchbond MP was applied on moist enamel, without primer.*

found that on etched and dried enamel surfaces, dentin primer did not significantly influence enamel-composite resin shear bond strength values ($p>0.05$) for both dentin bonding systems Scotchbond MP and OptiBond FL. However, on moist enamel surfaces, shear bond strength was significantly reduced when dentin primer was not used ($p<0.05$). There was no statistically significant difference between shear bond strength of composite resin to moist and dry enamel with Single Bond.

Fracture analysis revealed that most of the fractures across all test groups were adhesive in nature, ie, the fracture occurred at the tooth-composite junction. The groups where no primer was used on moist enamel exhibited 100% adhesive fractures. In general, a greater percentage of the fractures were cohesive within the composite resin with OptiBond FL than with the other two bonding systems.

The scanning electron micrographs shown in Figures 2-11 represent the composite resin tags that penetrated etched enamel. The enamel has been dissolved away. These micrographs reflect the shear bond strength values obtained for the test groups. The micrographs of OptiBond FL and Scotchbond MP on dry enamel when primer was not used (Figures 2 and 3) show the classical type II etched enamel pattern (Gwinnett, 1971; Silverstone & Dogon, 1975). The enamel prism cores were left intact and the prism peripheries were selectively removed by the acid. Composite resin tags penetrated into the spaces left by the prism peripheries. The use of primer on dry enamel (Figures 4 and 5) did not significantly alter this pattern. When primer was not used on moist enamel, there was a notable difference in the penetration of composite resin into the etched enamel surface microporosities (Figures 6 and 7). Adaptation and penetration of composite resin into the etched enamel surface, with both OptiBond FL or Scotchbond MP, were significantly reduced. Figure 7 shows the composite resin tags obtained when primer was not used on moist enamel with the Scotchbond Multi-Purpose system. There are distinct areas where little or no penetration at all is observed. This explains the extremely low bond strength value obtained. However, when primer was used on moist enamel (Figures 8 and 9), the pattern of resin tags was similar to that seen in Figures 2, 3, 4, and 5. The pattern of penetration of composite resin tags did not change significantly on moist or dry enamel with Single Bond (Figures 10 and 11).

DISCUSSION

Traditionally, the etched enamel-composite resin bond has been the most reliable adhesive bond known to den-

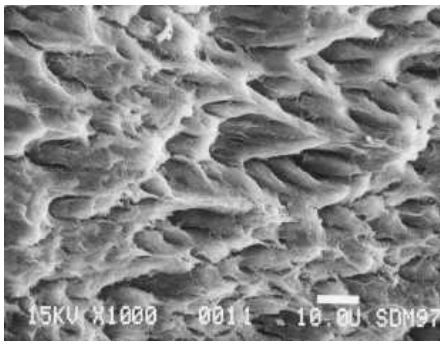

Figure 8. *Scanning electron micrograph (X1000) showing resin tags when Optibond FL was applied on moist enamel, with primer.*

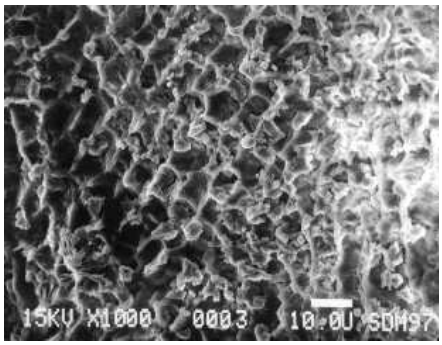

Figure 9. *Scanning electron micrograph (X1000) showing resin tags when Scotchbond MP was applied on moist enamel, with primer.*

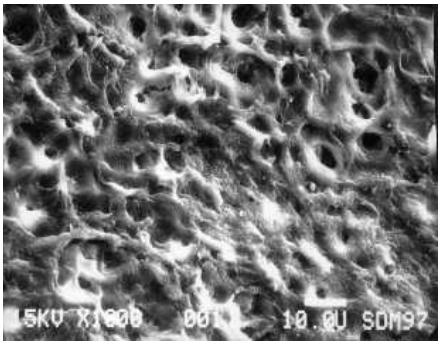

Figure 10. *Scanning electron micrograph (X1000) showing resin tags when Single Bond was applied on dry enamel.*

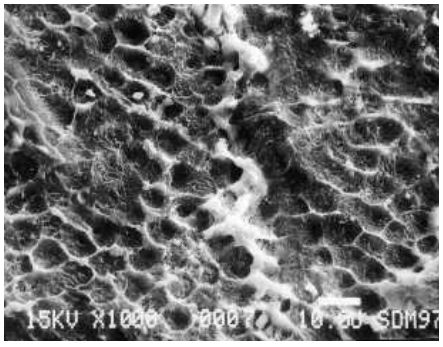

Figure 11. *Scanning electron micrograph (X1000) showing resin tags when Single bond was applied on moist enamel.*

tistry. Munksgaard and Asmussen (1985) suggest that bond strengths of bonding agents and composite resins to enamel be used as controls and dentinal bond strengths be expressed as percentages of enamel bond strengths.

For bonding, enamel is etched with a weak acid; low-viscosity resin is then applied, light cured, and composite resin placed. However, with the advent of universal enamel/dentin bonding systems, additional variables of moisture and dentin primers have been introduced to enamel bonding. It is very important that these variables be studied carefully in order to ensure that they do not interfere with the enamel-resin bond. McGuckin and others (1994) have said, "Enamel and dentin differ greatly from each other in mineral, protein and water contents. Clinically, it is very difficult and inconvenient to treat each substrate differently; therefore, investigation of the effect of specialty dentinal bonding agents on enamel is a worthy endeavor."

To obtain good bond strengths of composite resin to enamel, stringent isolation procedures need to be followed. The way in which a composite resin adapts to tooth substance depends more on the nature of the tooth surface than on the properties of the composite resin (Barnes, 1977). Contamination of etched enamel with moisture, debris, dentin primers, and other contaminants, such as saliva, plasma, cements, and handpiece lubricants has been shown to interfere with the enamel-resin bond (Silverstone & Dogon, 1975; Soetopo, Beech & Hardwick, 1978; Hormati, Fuller & Denehy, 1980; Powers, Finger & Xie, 1995; Xie, Powers & McGuckin, 1993).

Most enamel/dentin bonding systems on the market are comprised of an acid etchant, dentin primer, and low-viscosity adhesive resin. Some single-bottle bonding agents combine the primer and adhesive in one bottle. Most manufacturers recommend etching the enamel and dentin surfaces and leaving the dentin surface moist after rinsing the etchant and before application of the hydrophilic primer or the hydrophilic primer/adhesive combination (as in Single Bond). No comment is made on whether the enamel in the same tooth preparation should be left moist or dry before application of primer. Clinically, however, it is quite impractical to leave the dentin moist after rinsing the etchant off but thoroughly dry the enamel adjacent to it. Therefore, in all probability, in most clinical tooth preparations involving both enamel and dentin, the enamel surface is left moist along with the dentin. This problem has been realized by clinicians, and Mannocci and Ferrari 1996, published a simple technique for priming dentin while keeping it moist and simultaneously drying the enamel in Class V composite resin preparations.

Kanca (1992) studied the effect of enamel surface wetness on enamel-composite resin bond strengths and found that with the All-Etch/All-Bond system, bond strengths to etched and moist enamel were equal to or higher than those to etched and dry enamel. Wakefield and others (1996) reported that surface wetness had no effect on shear bond strength of seven different dentin bonding agents to enamel. Iwami and others (1998) studied the effect of humidity on enamel-composite resin (OptiBond FL/Prodigy) bond strengths and found that humidity of oral ambient air did not significantly influence shear bond strengths of enamel to composite resin. However, several clinical studies have reported significant lowering of bond strengths to enamel when moisture contaminates etched enamel surfaces. In a clinical study by Barghi, Knight, and Berry (1991) where composite resin tabs were bonded to flattened, etched surfaces of teeth that were scheduled for extrac-

tion, two different methods of isolation were evaluated, and it was reported that use of the rubber dam, which allowed etched enamel surfaces to be kept dry, resulted in significantly higher shear bond strengths than the use of cotton rolls and a saliva ejector, which may have allowed some moisture contamination of etched enamel surfaces. In a similar clinical study by Knight and others (1993), a significant increase in microleakage was noted in the group where only cotton rolls and a saliva ejector were used for isolation versus rubber dam application. These reports suggest that moisture contamination of etched enamel surfaces does adversely affect composite resin adaptation to enamel.

The effect of primer on dry enamel surfaces has been studied by several researchers (Hayakawa & Horie, 1992; Hadavi & others, 1993; Barkmeier & Erickson, 1994; McGuckin & others, 1994; Woronko & others, 1996). However, the effect of dentin primer on moist enamel has not been studied comprehensively.

Hayakawa and Horie (1992) measured tensile bond strength of composite resin to etched and dried enamel with and without application of dentin primer. After bonding, the samples were stored in distilled water at 37^0C and then tested for tensile strength. They were not subjected to any thermocycling, and the influence of primer on moist enamel was not evaluated.

Barkmeier and Erickson (1994) reported that the use of primer on enamel etched with a weak acid significantly reduced shear bond strength values; however, application of primer on enamel etched with a stronger acid did not decrease bond strength values significantly. This finding was contradictory to that of Hayakawa and Horie (1992). Therefore, it is not clear from these two studies whether dentin primer application on enamel etched with a weak acid enhances or reduces bond strength values. It does appear that application of primer on enamel etched with a stronger acid, ie, 37-40% phosphoric acid, does not affect bond strength values. It is to be kept in mind that these studies used etched and dried enamel surfaces for bonding. The influence of primer on moist enamel was not evaluated.

Hadavi and others (1993) reported a decrease of 31-44% in shear bond strength values when primer was applied on etched and dried enamel, for all the four bonding systems tested. The influence of primer on moist enamel was not evaluated and the bonded samples were stored in distilled water at 37°C for 24 hours. No thermocycling was performed before testing the samples for bond strength.

McGuckin and others (1994) and Thoms and others (1994) found the effect of primer on enamel to be material specific. Woronko, St Germain, and Meiers (1996) found that primer application on enamel reduced shear bond strength values only for Scotchbond Multi-Purpose. Again, these studies evaluated etched and dried enamel surfaces only. Also, no thermocycling was performed.

All the studies reported on the influence of dentin primer on enamel have evaluated etched and dried enamel surfaces. The influence of dentin primer on moist enamel has not been evaluated. Also, the bonded samples in all the studies reviewed were stored in water at 37°C for 24 hours prior to testing. Thermocycling was not performed in any of the *in vitro* studies reported. Therefore, it is questionable whether the long-term influence of the application of dentin primer on moist and dry etched enamel was evaluated in these studies.

The results of our study suggest that primer application on etched and dried enamel surfaces does not significantly influence bond strength values for the two bonding systems tested (Scotchbond Multi-Purpose and OptiBond FL). This finding is in agreement with that of Hayakawa and Horie (1992) and Barkmeier and Erickson (1994), who found that primer application did not influence bond strength values when enamel was etched with 37% or 40% phosphoric acid. Our study also pointed out that the use of primer on moist enamel surfaces is essential in order to obtain acceptable bond strength values. This is a very important finding in light of the fact that most dentin bonding systems require that the dentin be left moist after rinsing the etchant off, to allow for penetration of the hydrophilic primer or primer/adhesive combination (as in the single-bottle bonding systems). It is very difficult to leave the dentin moist and yet thoroughly dry the enamel next to it. Therefore, in real clinical situations, enamel is probably left moist along with the dentin in most cases. Most clinicians attempt to avoid application of dentin primer on etched enamel surfaces, as it has been shown that any contamination of the etched enamel surface negatively affects bond strength values (Silverstone & Dogon, 1975; Soetopo & others, 1978; Hormati & others, 1980; Hadavi & others, 1993; Woronko & others, 1996). This combination of inadvertently leaving the enamel moist and not applying dentin primer on it can lead to serious problems. The enamel-composite resin bond, which has been the most reliable bond known to us, can become the weakest link in the restoration. Some clinical failures with composite resin restorations in the form of marginal leakage and staining, loss of restorations through debonding, or recurrent decay may be attributable to lack of primer application on moist enamel. The low bond strength values obtained when dentin primer was not applied on moist etched enamel is explained by the fact that unfilled resin (dentin adhesive) is hydrophobic and does not penetrate etched enamel surfaces that are moist.

CONCLUSION

For the two multi-component dentin bonding agents tested, dentin primer did not influence enamel-composite resin bond strength values when used on etched and dried enamel. On etched, moist enamel, the use of primer significantly improved bond strength values for both dentin bonding systems. The single-component bonding agent, Single Bond, was not affected by moisture on enamel. Based on the findings of our study, it is recommended that dentin primer be used on enamel as well as dentin in all tooth preparations for composite resin restorations. The use of the single-component bonding agent tested, Single Bond, is recommended, as it ensures the use of primer on enamel as well as dentin and does not seem to be influenced by moisture on enamel, which makes the bonding procedure considerably less technique sensitive.

Further research is required to (a) simulate clinical situations by testing samples consisting of enamel and dentin juxtaposed to each other, (b) measure microleakage with and without the use of dentin primer on moist and dry enamel surfaces, and (c) evaluate other bonding agents under similar conditions.

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Invited Paper

Operative Dentistry for the New Millennium: A Problem Specific Approach to Operative Dentistry

JW Osborne

ABSTRACT

This paper presents an alternate view of current preclinical education in Operative Dentistry and suggests a course that uses a cause and appropriate response action rather than the traditional material specific cavity preparation. This approach considers caries as a disease, could foster a better understanding of prevention and its application in maintaining teeth for a lifetime for the patient, and encourage critical thinking for both student and faculty.

INTRODUCTION

Webster's dictionary (1988) defines dentistry (n) as "the diagnosis, prevention, and treatment of the diseases of the teeth, gums, and related structures." Two out of three is not going to carry our discipline of Operative Dentistry into the 21st century. The broad spectrum of prevention does not receive its due emphasis in our world of "cutting and rebuilding" mentality, yet as Moline (1999) indicated, little or no emphasis on prevention is not due to a lack of knowledge.

Looking back, we find that Operative Dentistry has been taught the past 100 years primarily based on GV Black's works (Black, 1891, 1908). Black gave us principles of cavity preparation, caries etiology, and restorative techniques, and discussed prevention. His thoroughness in many ways was so complete that little attempt has been made to rethink our operative dentistry education process. Different schools teach variations of Black's basic procedures, and several new dental restorative materials have been marketed since Black's time, yet the preclinical Operative Dentistry education has been a pattern of teaching cavity preparation for a specific material. Usually, the use of an amalgam for Class I, II, and V lesions was first. Then the preclinical education program teaches composite resin materials for different Classes of cavities and continues for cavity preparations for other dental materials. When coupled with Black's first principle of cavity preparation, ie, obtain outline form, this process led to a standardized cavity preparation for most situations. The classic "dog bone" preparation for a Class I amalgam is a good example. This type of preparation will occur regardless of the size of the fissure caries defect, and for small defects is a standard width as dictated by the head of the department. Even if advances in our basic knowledge of cariology, risk assessment, diagnosis, and prevention were added to preclinical courses, the education process seems stagnate, illogical, and in many ways counter productive to the thought process used in the clinic environment to treat patients.

Maybe the dental education process for preclinical Operative Dentistry should be rethought to effect a cause and appropriate intervention response rather than the traditional process of a material-based cavity preparation with a standardized cavity for each Class of carious lesion. In other words, we need to tailor a solution to the problem.

There is a need to approach Operative Dentistry understanding the difference between lesion and the disease in the carious process. We need to emphasize evaluation of factors that result in the formation of carious lesions and how to control these factors, including the restorative phase. In addition, to ensure that teeth are preserved for a lifetime, dentistry needs to separate and emphasize

both patient-manifested prevention, ie, brush, floss, fluoride, diet; and dentist manifested prevention, ie, when to treat and not treat, minimal intervention, evidence based criteria, and appropriate material selection. We need to reevaluate cutting for prevention of caries (Black's extension for prevention) and consider a concept of preventing the extension of lesions. The latter could involve cutting sound tooth structure, but also prevention strategies, use of sealants, and minimal intervention. We need to place more emphasis on maintenance of serviceable restorations and reduce the 50+% of replacement work.

The purpose of this paper is to briefly outline an approach to preclinical Operative Dental education that will take our students beyond the present day ideology.

DEFINITION AND OUTLINE

Operative Dentistry: Science of cariology, prevention, and risk assessment; and the art and science of diagnosis and the non-surgical and surgical intervention of single teeth.

These have certainly been elements of this program, ie, preventive resins, minimal intervention strategies, and questions regarding extension for prevention, and this brief outline (Table 1) is not intended to cover all

Table 1

Introduction

- A. Basic cariology (Newbrun, 1989)
- B. Prevention methods and strategies (ADA Council 1995)
- C. Risk Assessment (ADA Council, 1995)
- D. Prevention of the extension of decay (Webb, 1877 and Osborne & Summitt, 1998)

II. Nomenclature

III. Instrumentation

- A. Hand
- B. Rotary
- C. Maintenance and sharpening

IV. Universal Precautions for Infection Control

V. Controlling the Operating Field

- A. Rubber Dam
  - 1. Routine
  - 2. Special application
- B Cotton rolls
- C. High and low volume evacuation
- D. Tissue management/hemorrhage
- E. Periodontal Health

VI. Diagnosis and treatment planing

VII. Dental Materials for Clinical Applications in Operative Dentistry

VIII. Posterior Dentition

- A. Fissured Surfaces
  - 1. cariology for specific site
  - 2. risk assessment
  - 3. prevention
  - 4. non-surgical management
  - 5. surgical management
    - a. amalgam
    - b. composite
    - c. casting/porcelain
- B. Smooth Surfaces - Interproximal
  - 1. cariology for specific site
  - 2. risk assessment
  - 3. prevention
  - 4. non-surgical management
  - 5. surgical management
    - a. amalgam
    - b. composite
    - c. casting/porcelain
- C. Smooth Surfaces B/L
  - 1. cariology for specific site
  - 2. risk assessment
  - 3. prevention
  - 4. non-surgical management
  - 5. surgical management
    - a. amalgam
    - b. composite
    - c. glass ionomer
    - d. Casting/porcelain
- D. Combining Surfaces

IX. Anterior Dentition

- A. Cariology for specific site
- B. Risk assessment
- C. Prevention
- D. Non-surgical management
- E. Surgical management
  - 1. composite
  - 2. glass ionomer
- F. Esthetic considerations
  - 1. veneers
  - 2. composites
  - 3. bleaching

X. Restoring Extensively Damaged Teeth

- A. Retention Methods
  - 1. pins
  - 2. bonding resins
  - 3. slots and other internal features
- B. Materials
  - 1. amalgam, final and core
  - 2. composite core
  - 3. glass ionomer systems
  - 4. Casting/porcelain and cementation
- C. Vital and Non-vital teeth

XI. Root Caries

- A. Cariology
- B. Risk Assessment
- C. Prevention
- D. Non-surgical management
- E. Surgical management
  - 1. amalgam
  - 2. glass ionomer
  - 3. composite
- F. Desensitize areas

XII. Caries Removal and Pulpal Considerations

XIII. Perio-Operative Relationships

XIV. Maintenance

- A. Your Good Works
- B. Rehabilitation of Restorations

the areas needed to educate a student in Operative Dentistry. However, it does place emphasis on a direction in the preclinical course and ultimately the clinic thought process that could identify factors for the student, which would prevent ultimate loss of the natural dentition. Neither would this course be taught completely in the preclinical portion. Much of the "why" should be taught in the clinic and in lectures/problem-based learning seminars following the clinic sessions.

As we proceed into a new millenium, one of our goals should be to adjust our dental curriculum to take advantage of the progress made in prevention and risk assessment, diagnosis, minimal intervention strategies, evidence-based criteria, and better restoratives materials. By providing a mechanism for students to think in a logical sequence for clinical treatment and adding a philosophy of keeping our patients' teeth for a lifetime, the goal of excellent oral health is within the profession's grasp. In 1896, Black said to some of his students, "The day is surely coming, and perhaps within the lifetime of you young men before me, when we will be engaged in practicing preventive, rather than restorative dentistry" (Ring, 1985). Black missed the time line but not what should be paramount.

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Commentary

Excellence in Diagnosing Failures: A Challenge for the 21st Century

Excellence in Operative Dentistry is linked to well-adapted restorations, smooth cavosurface margins, detailed reproduction of anatomical characteristics, polished and gloss surfaces, and optimal relationships to adjacent and opposing teeth. The reestablishment of function and esthetics following disease or trauma to teeth of any sort has always been, and should continue to be, at the center of attention in Operative Dentistry.

Textbooks in Operative Dentistry define, describe, and illustrate ideal restorations. The teaching in this major area of dentistry during the last 100 years has focused on excellence. The Academy of Operative Dentistry has done its utmost to promote principles of excellence. Nobody will, or should, argue against these goals.

But how has Operative Dentistry been doing in defining failures? The blunt truth is that most of us have done poorly in this area. Although the groundwork was done 30 years ago by establishing the Ryge/USPHS criteria, implementation of these simple, clinical principles have been slow in reaching academic teaching programs and the grass roots of Operative Dentistry. Diagnosis of failed restorations is still subjective. Great variations exist among clinicians. Studies of restorations have shown up to a five-fold (500 percent!) difference between clinicians in diagnostic level of what constitutes a failed restoration.

Operative Dentistry has served the public well for more than 100 years but, as we move into the 21st Century, it is time to focus on what constitutes failed restorations. Replacement of functional restorations is done primarily to prevent further damage to teeth and adjacent tissues, and to reestablish esthetics when needed. Furthermore, delaying or preventing the replacement of restorations will save tooth structure which may be lost during the procedure.

"Recurrent caries" is the most common clinical diagnosis for the replacement of restorations in general dental practice, and invariably leads to such replacement. The scientific and clinical bases for this diagnosis are weak and major efforts should be devoted to differentiating between voids, crevices, marginal discrepancies, explorer "catches," and caries lesions. Recurrent lesions should be diagnosed using the same criteria as for primary lesions: changes in consistency/hardness of dental tissues, color changes/opacities/discolorations, and breakdown of tissues/cavitation. Marginal degradation or "ditching" is a characteristic limited to occlusal surfaces and, since recurrent caries rarely develops occlusally, such defects are not likely to be associated with active caries. A norm, or "gold standard" for making decisions regarding the significance of flaws associated with restorations needs to be defined, described, and illustrated. It should then be used in teaching programs and calibration exercises.

Refurbishing old restorations has been shown to reduce the number of replacements during treatment planning. Repair of localized defects should always be considered as a means to extend the longevity of restorations. Thus, simple measures may reduce the need for replacements, and we need to document the cost-effectiveness of such measures.

Well-defined criteria of failures are essential for improving the longevity of restorations and for the long-term cost of restoration therapy. Calibration and standardization in clinical diagnosis must come to the forefront in the teaching of Operative Dentistry, starting with faculty, including those in part-time positions, and involving dental students early in their curriculum. If the established criteria need to be revised or refined, let us do it. We can no longer sit back and let this urgent issue pass us by. The principles established must become an integral part of treatment planning in Operative Dentistry. Continuing education courses must follow to update colleagues in general practice in these diagnostic skills.

The Academy of Operative Dentistry should be a driving force in focusing on excellence in diagnosing failures. The responsibility is ours, and we must face up to it.

Ivar A. Mjör, Professor
Academy 100 Eminent Scholar
University of Florida College of Dentistry

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American Academy of Gold Foil Operators

Distinguished Member Award

Dr Norman C Ferguson

Norman C Ferguson

This evening we honor Dr. Norman Charters Ferguson, a gifted and singularly unusual and talented gentleman. I have enjoyed an enduring friendship with Norm for more than 61 years.

Norm was born in 1922 of Irish background, in New Westminster. His parents were working people who gave what little money they could spare to support Norm's quest for a University education, for which he is eternally grateful. He married Francis and has a daughter, Jane, and a son, Jim.

In 1939, at the outbreak of war, Norm was doing his pre-dental education at the University of British Columbia, while I was teaching senior high school. We joined the Canadian Officers Training Corps at UBC and became associated in the same platoon. In the spring of '41 we found ourselves in Portland, registering for dentistry at North Pacific College. We enrolled in the war time course that went for three years.

Norm is a most competent scholar with a phenomenal memory. He reads a book or scans a procedure and retains it. After 77 years, he has acquired a vast reservoir of knowledge and a remarkable fund of trivia. Want to know when William the Conqueror came to England, the tonnage of the Queen Mary, or the distance between the tracks of a standard railway? Just ask Norm and he will give you a scholarly dissertation on the matter. His knowledge of dentistry is also legendary and he fully credits three men who challenged his interest and gave him a vision of what excellence in dentistry could be. Lloyd Jacobson (our first real contact with excellence), Walter Sproule, the first mentor of our gold foil study club, and Dr. Gerry Stibbs, "Mr. Gold Foil," who succeeded Dr. Sproule following his death. These relationships provided an opportunity to match wits as sharp as his, and opened doors to meet such dental greats as George Ellsperman, George Hollenback, and W. I. Ferrier.

Norm's dental memberships include the Walter K Sproule Gold Foil Study Club, Canadian Dental Association, Vancouver and District Dental Societies, and the Academies of Operative Dentistry, Restorative Dentistry, and Gold Foil Operators. He is an Honorary Fellow of the Royal College of Dentists and OKU Fraternity and has fellowship in the American and International Colleges of Dentists as well as the Academy of Dentistry International. Recently, the University granted Norm "Professor Emeritus" status, which speaks eloquently to his outstanding, outspoken and occasionally controversial academic career.

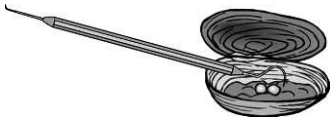
What has our "man of the hour" done to justify these honors? He has instructed in the dental clinic at UBC for more than 20 years and written papers and given clinics on general dentistry, occlusion, porcelain jacket crowns, gold inlays, and direct gold in Canada, the United States, Mexico, and the Orient. His research interests include developing a simple surgical treatment for eliminating the anterior diastema and the discovery of the "occlusal rock" in the vast majority of mouths. He served in the Canadian Dental Corps of the RCAF during the war and has generously given his time to organized dentistry. He has served on the Council of the College, the Provincial Examination Board, the CDA Dental Faculty Evaluation, and Accreditation Board and as an adjudicator for Medical Services Association. He has been President of this Academy, President of our study club several times and is now the club's mentor. Norm has a genuine desire to share his knowledge and skills with others. Many times he has taken a young dentist under his wing, invited them to his office, and given the neophyte a chance to actually see how a procedure was accomplished.

It is with the greatest pleasure that I present my friend Norman Ferguson with this "Distinguished Member Award." As we honor Norm, he, in turn, adds distinction and luster to our Academy.

Ludlow Beamish

Departments

Operative Pearls



Please submit your own clinical tips and techniques to share with your colleagues. Send "pearls" and/or comments on this section via FAX (317) 278-4900 or e-mail to **editor@jopdent.org**.

CUSTOM PROVISIONAL RESTORATIONS: SIMPLE, FAST AND ACCURATE

Contributed by:
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Introduction

An efficient technique that can produce a good quality custom provisional restoration is greatly desired by the dental profession. Newly improved dental materials have greatly simplified the fabrication of temporaries. Understanding the properties of these materials, their application and limitations will offer the clinician excellent and predictable results. This paper presents a technique using a Blue Mousse (Parkell. 155 Schmitt Boulevard, PO Box 376, Farmingdale, NY 11735)) super-fast set matrix and Integrity (Dentsply/Caluk, 38 West Clark Ave, PO Box 359, Milford, DE 19963-0358), a Bis-GMA temporary material.

Armamentarium

- Plastic cup
- Crown and bridge scissors
- Super-fast set Blue Mousse
- Vita shade guide
- Integrity
- Acrylic trimming bur
- Pumice and polishing compound
- Temporary cement of your choice

Procedure

1) Prior to preparing the tooth, use a plastic cup and cut a small piece approximately 1 inch x 1 inch and fold it into thirds. This will serve as a matrix (tray) to carry the impression material into the mouth.
2) Inject a small amount of super-fast set Blue Mousse into the matrix, but do not overfill. Be sure to bleed the cartridge prior to your injection. Seat the matrix on the unprepared tooth and hold it in place with light finger pressure. Within thirty seconds the Blue Mousse will set. Immediately retrieve the impression, examine for accuracy and disinfect. This produce a rigid matrix with superb details that you can use to fabricate your custom temporary. Relieve the inside of the impression around the prepared tooth to insure that you have adequate bulk of temporary material for trimming. This is easily done with an acrylic trimming bur.
3) Use the Vita shade guide to match the tooth color to the shade of the Integrity. Have the Integrity of the proper shade ready and start the tooth preparation.
4) Once the preparation is completed, inject a small amount of Integrity into the matrix of the prepared-tooth. Seat the impression and within one minute the material will partially set and can be easily removed. Allow to bench set for an additional minute. Separate the temporary crown from the matrix and properly trim the margins and proximal contacts. Very little trimming is required due to the accuracy of the Blue Mousse matrix and the minimal shrinkage of the Integrity. In addition, there is no heat generated or objectionable odor experienced as with methyl or ethyl methacrylate material. Try in the temporary and adjust occlusion as needed. Adding composite resin and light curing can easily increase proximal contact. Final polishing can be done with pumice and polishing compound and the provisional is ready to be luted with the cement of your choice.

Discussion/Limitations

The Super-fast set Blue Mousse is an excellent matrix for fabrication of provisional restorations. It produces a very accurate and detailed impression of the non-prepared tooth in 30 seconds. Upon setting, it becomes rigid and does not deform.

The Integrity resin material is extremely accurate. It does not generate heat or have any odor. It can easily be repaired by adding light-cured composite to fill voids, plus contacts or repair margins. Integrity comes in several Vita shades and sets in two minutes which significantly reduces chair time. A cartridge of Integrity cost approximately $80.00 and can be used to fabricate 18-20 provisional crowns. However, the Integrity tends to be slightly brittle and is not recommended for long span bridges. Furthermore, it does not have enough viscosity to flow into deeper subgingival marginal areas.

Conclusions

The technique described works well for single unit provisionals for anterior and posterior teeth. It is simple due to its uncomplicated armamentarium, fast since the entire procedure can be accomplished in less than

five minutes and accurate because the Integrity has almost no shrinkage on setting.

Abstracts

The editor wishes to thank the second-year Comprehensive Dentistry residents at the Naval Postgraduate Dental School, Bethesda, Maryland, for their assistance in preparing these abstracts.

Effect of fluorosis on shear bond strength of glass ionomer-based restorative materials to dentin. *Awiliya WY and Akpata ES (1999) The Journal of Prosthetic Dentistry **81(3) 290-294.**

(*King Saud University, College of Dentistry, Riyadh, 1666, Saudi Arabia)

There have been studies examining the adhesion of glass ionomer-based restorative materials to nonfluorotic teeth; however, there appears to be no information on the bond strengths of these materials to dentin in teeth exhibiting fluorosis. For the purpose of this study, 90 human molars and premolars with varying degrees of fluorosis were selected, cleaned with a rubber cup and fluoride-free pumice, and subsequently classified according to the Thylstrup and Fejerskov index (TFI). The teeth were divided into three equal groups (TFI=0, TFI=1-3, and TFI=4+). Nonfluorotic teeth (TFI=0) served as the control. Dentin was exposed by flattening the occlusal aspect of each tooth with an orthodontic model trimmer to a depth of 1.5 mm apical to the deepest occlusal pit. The samples were mounted in Jade-stone with nonstick fluorocarbon resin rings. Dentin surfaces were ground flush with the stone by using 600-grit silicone carbide paper on a polishing machine. The teeth were cleaned with distilled water in an ultrasonic and the dentin surfaces were dried with oil-free air. Three different materials were used for the study: (1) a conventional glass ionomer cement (Ketac-fil Aplicap), (2) a resin-modified glass ionomer cement (Vitremer), and (3) a compomer, a polyacid-modified resin (Dyract). Conditioners and primers were applied to the exposed dentin surfaces, followed by the restorative materials, in accordance with the manufacturers' recommendations. Shear bond strength was determined using an Instron testing machine at a crosshead speed of 0.5 mm/min. Data were analyzed with the 2-way analysis of variance (ANOVA) and the Tukey-B test for comparison of variables. The compomer (Dyract) exhibited the highest bond strength to dentin, regardless of the severity of fluorosis. As the severity of fluorosis increased from TFI 0-3, the bond strength to dentin dropped significantly (p=0.05) for both Vitremere and Dyract, but not Ketac-fil. However, TFI 4+ demonstrated a significant bond strength drop (p=0.05) in Ketac-fil, but not in the other two materials. The compomer (Dyract) appears preferable for bonding to dentin in severely fluorotic teeth.

Evaluating the effects of fluoride-releasing dental materials on adjacent interproximal caries. *Donly KJ, Segura A, Wefel J (1999) JADA**, Vol. 130, June.**

(*Dental School, University of Texas Health Sciences Center, Department of Pediatric Dentistry, and pre-doctoral program director, San Antonio, Texas)

The purpose of this study was to evaluate the de- and remineralization effects of fluoride-releasing dental materials on adjacent interproximal caries. Twenty-one (21) subjects in need of a full coverage crown restoration of a mandibular permanent molar that had an adjacent Class II interproximal carious lesion were used for this study. Crown appliances that contained enamel sections with artificial carious lesions placed on the interproximal surface were used. The crown appliance approximated the adjacent tooth containing an inlay restored with a fluoride-containing resin composite, a glass ionomer cement or a non-fluoride-releasing resin composite (control). Patients were given either fluoridated or non-fluoridated dentifrice and instructed to brush twice a day. This was a six-phase crossover study, each phase included the placement of a new enamel section in the crown appliance and a new Class II inlay restorative material in the adjacent tooth. Lesions were photographed with polarized light microscopy and characterized before and after 30-day intraoral exposures to determine if demineralization, caries arrestment or remineralization occurred. Analysis of variance indicated statistically significant differences in variance among the experimental phases. A Duncan multiple range test demonstrated that when subjects brushed with a fluoridated dentifrice, all three types of restorative materials demonstrated significantly less enamel demineralization than the non-fluoridated resin composite control restoration brushed with a non-fluoridated dentifrice. The resin-modified glass ionomer cement, when brushed with or without fluoridated dentifrice, demonstrated significantly less demineralization than the non-fluoridated resin composite control brushed with a non-fluoridated dentifrice. This study shows that resin-modified glass-ionomer cement has the potential to significantly

inhibit demineralization of the interproximal enamel of teeth adjacent to those restored with the cement.

All-ceramic posts and cores: The state of the art. *Koutayas SO & Kern M (1999) Quintessence International 30:383-392.

(*University of Freiburg, Department of Prosthodontics, Freiburg, Germany)

With today's ever-increasing demand for esthetics, all-ceramic restorations are swiftly gaining in popularity. The use of metal posts and cores in anterior teeth may result in compromised esthetics due to the translucency of ceramics. The post and core may show through the crown and may even possibly shine through the thin remaining cervical root structure. All-ceramic post and cores can appear more natural because of their dentin-like color and translucency. However, the relatively low fracture strength and fracture toughness of ceramics place limitations on their clinical indications. This article reviewed four different methods of all-ceramic post and core fabrication.

Slip-casting utilizes In-Ceram aluminum oxide ceramic in a one-piece post and core. These posts are cemented using a self-curing resin cement. Since the In-Ceram material has a limited fracture strength and unknown long-term clinical prognosis, it is only indicated for wide root canals with a minimum of circumferential dentin reduction.

The copy-milling technique uses a Celay milling chamber. A resin pattern of the post and core is developed using either a direct or indirect method and is duplicated in ceramic from a prefabricated aluminum oxide blank. A self-curing resin cement is used for luting. Again, due to the brittle nature of alumina, these restorations may be more susceptible to fracture and are recommended for the same teeth as conventional slip-cast post and cores.

The development of zirconia ceramic posts has expanded the use of all-ceramic post and cores into teeth with moderate-sized root canals (smaller than ISO size 110). The two-piece technique was conceived to combine the strength of a yttrium oxide-partially stabilized zirconia post with the optical properties of an all-ceramic core made of alumina or alumina-magnesia ceramics, fabricated either by the slip-casting or copy-milling technique. Using a self-curing adhesive resin, the core is first cemented in place, then immediately the post is inserted into the root canal through the canal of the core.

The heat-press technique utilizes the IPS Empress castable ceramic. A prefabricated zirconium dioxide post is heat-pressed to an Empress core forming a single solid uniform post and core.

The esthetic properties of all-ceramic post and cores provide excellent results, but the authors suggest long-term evaluation before recommending for general dental use.

Effect of disinfectant agents on dimensional stability of elastomeric impression materials. *Adabo GL, Zanarotti E, Fonseca RG, Alberto dos Santos Cruz C (1999) Journal of Prosthetic Dentistry **81; 621-624.**

(San Paulo State University, Araraquara Dental School, Araraquara, Sao Paulo, Brazil)

The purpose of this study was to determine the effect of two methods for disinfecting impressions obtained with six different elastomers. One-hundred eighty impressions were taken of a master model using six different impression materials - Permalastic, 3M, Xantopren, Provil L, Extrude Wash, and Impregum F. A one step impression technique was employed and these impressions were divided according to disinfecting treatments.

Group 1–had no treatment, Group 2–immersion in 5.25% sodium hypochlorite for 10 minutes followed by 20 minutes standing on the workbench, Group 3–immersion in a 2% glutaraldehyde solution for 30 minutes. Impressions were poured with Type IV die stone, each cast was read with a Nikon Profile projector between set reference points, and an average was calculated and compared to the original model. No significant difference was observed in either the type of disinfection treatment or any combination of impression material and disinfecting technique. There was a significant difference noted, however, among the accuracy of the different elastomers. The 3M, Xantropen VL and Extrude Wash showed a better representation of the master model dimension than the Impregum F. The Permalastic and Provil L groups showed no significant differences from the other materials.

A comparative study of fluoride uptake from dentin bonding agents and glass ionomer cements in permanent and primary tooth enamel. Eronat N, Kocatas N, & Alpoz AR (1999) Quintessence International **30 (7) 496-500.**

(*Department of Pedodontics, Aegean University, Faculty of Dentistry, Bornova, Izmir, Turkey)

Dentin bonding agents and glass-ionomer cements (conventional and photo-cured) are used extensively in restorative dentistry. The release of fluoride is important due to its cariostatic nature. The aim of this *in vitro* study was to compare fluoride uptake of enamel in permanent and primary teeth from 2 fluoride-releasing

dentin-bonding agents and 2 glass ionomer cements. Eighty sound permanent and 80 primary molars were washed under tap water after extraction and stored in 0.1% thymol solution at 4°C. They were cleaned with pumice and separated mesiodistally into buccal and lingual halves. The materials were placed in the buccal halves with the lingual halves serving as controls. 4mm2 rectangular windows were prepared with the remaining areas covered with pink wax. The dentin bonding agents used were Optibond (Kerr) and Liner Bond 2 (Kuraray). The glass-ionomer cements used were Fuji II (GC) and Fuji II LC. All materials were used according to the manufacturers' instructions. Specimens were suspended in synthetic saliva for one month at 37°C in the incubator. An acid biopsy technique was used for fluoride ion determination. Fluoride concentration was determined using a specific fluoride electrode. Taken into account was the depth of enamel removed during the acid biopsy. For statistical analyses, ANOVA and Student's t test were used.

In primary teeth, the highest fluoride uptake was found in the Fuji II LC group, while in the permanent enamel, the highest uptake was found in the Fuji II and Fuji II LC groups. The following represents the ranking, greatest to least of fluoride uptake from the materials: Fuji> Fuji II LC> Optibond> Liner Bond 2. In this study, the fluoride release from the two dentin-bonding agents was unsatisfactory. Fluoride uptake was found to be highly significant in Fuji II and Fuji II LC in both permanent and primary teeth. This shows that the release of fluoride from resin-modified glass ionomer cements is similar to that from conventional glass ionomer cements.

Long-term Durability of Dentin Bonds Made with a Self-etching Primer, in vivo**. Sano H, Yoshikawa T, Pereira PNR, Kanemura N, Morigami M, Tagami J and Pashley DH (1999)** Journal Dental Research **78 (4) 906-911**

(Hokkaido University School of Dentistry, Department of Operative Dentistry, Sapporo, Japan 060-0813, Tokyo Medical and Dental University, Department of Operative Dentistry, Tokyo, Japan 113-8549, and Medical College of Georgia, Department of Oral Biology, Augusta, Georgia 30912-1129)

In vitro studies have shown a dramatic decrease in adhesive resin-dentin bond strengths when stored in water. The disadvantage to these studies is that they all use non-vital teeth not subject to the forces of mastication. The purpose of this study is to evaluate the *in vivo* durability of resin-dentin bond strengths in the oral cavity and to show morphological changes of the adhesive interface over time. Shallow saucer-shape dentin cavity preparations (approximately 3mm wide, 4mm long, 1.5mm deep) were restored with a self-etching primer (Clearfil Liner Bond II Primer) adhesive (Clearfil Liner Bond II adhesive, and a layer of resin composite (Clearfil Photo Posterior) on four intact teeth of an adult Japanese monkey (Macaca fuscata) under general anesthesia. One-hunded eighty days and again 360 days later, the procedure was performed on four different intact teeth. The monkey was then sacrificed and the 12 teeth surgically removed. 3-5 mm of resin composite was added to the facial of the restorations, and then three or four dentin slices, approximately .7mm thick, were cut perpendicular to the bonded surface. The specimens of the three time-periods were subjected to the micro-tensile bond test at a crosshead speed of 1 mm/min. A stereomicroscope at 20x magnification initially classified most of the fracture specimen's failure modes as adhesive or mixed. Further observation of the microscopic fracture patterns and debonded interface with the field-emission scanning electron microscope revealed no specimens exhibited pure adhesive or interfacial fractures. The scanning electron microscope also revealed an increase in porosity at the top of the hybrid layer and within the adhesive resin over time. However, in spite of the increased porosity, the tensile bond strength for the one-day, six-month and one-year specimens remained stable between 18-20 Mpa, showing no statistically significant differences. The weakest portion of the hybrid layer seemed to be the resin within the inter-fibrillar spaces, rather than the resin enveloping the collagen fibrils.

Storage stability of dental luting agents *Hondrum, Steven, (1999) Journal of Prosthetic Dentistry 81: 464-8

(*US Army Dental Laboratory, Fort Gordon, GA, 30905)

The purpose of this study was to document changes in the properties of water-based dental luting agents over time and on exposure to various environmental conditions.

Zinc phosphate, zinc polycarboxylate, and glass ionomer were tested in this study. After baseline measurements were accomplished for each test, three batches of each cement were randomly divided into control, experimental (sent to military clinics in Panama, Europe, Korea and Alaska), and stressed groups (uncovered, unheated, and uncooled storage in Baltimore, MD). Cements were returned for testing at 24, 36, 48, 60, 72 and 84 months. Tests measured viscosity, diametral tensile strength, hardness, ultimate compressive strength, rigidity, working/setting times, and aging of the various cements.

The viscosity of the liquids was measured at 37°C, with a cone and plate viscometer at shear rates from 100s-1 to 375s-1. Diametral tensile strength (Mpa) and Ultimate compressive strength (Mpa) were determined using ADA specification Nos. 27 and 96, respectively. Rigidity was calculated as the slope of the compressive strength graphs. Hardness was measured with a Knoop indenter. Working/setting times were determined with an oscillating rheometer at 37°C. Aging was ascertained by using gel permeation chromatography. Analysis of variance and the Scheffe's F multiple comparison test were used to determine differences between baseline and succeeding test intervals. There were few significant differences between control, stressed, and experimental groups so all data for each cement at each interval was pooled. In general, liquid color change, increase in viscosity, decrease in compressive and tensile strengths, increase in hardness (except glass ionomers, which decreased), and alterations in working/setting time were observed. Storage conditions did not seem to affect cement performance. Glass ionomer was the strongest at 84 months. In conclusion, even though changes occur in cement properties after 36-48 months, they may still remain usable past the expiration date. Based on study findings, a good indicator of material instability is an increased viscosity of the liquid. Evaporation of water is the most important factor in storage stability and is directly related to the quality of the hermetic seal of the container system.

The Effect of Finishing and Polishing on the Decision to Replace Existing Amalgam Restorations *Cardoso M, Baratieri L, & Ritter A (1999) Quintessance International 30 (6) 413-18

(*University of North Carolina at Chapel Hill, School of Dentistry, Department of Operative Dentistry, Chapel Hill, North Carolina 27599-7450)

The purpose of this study was to evaluate the influence of finishing and polishing procedures on the decision to replace existing amalgam restorations. Twenty Class I and Class II amalgam restorations without evident failure were selected from six patients. Initial bitewing radiographs were obtained for each restoration. High quality slides were obtained before and after a standardized finishing procedure using rotary instruments at slow speed and polishing pastes under rubber dam isolation. The preoperative and postoperative slides were examined by three groups of examiners with a two-week interval between the reviews. Group I consisted of senior dental students. Group II consisted of clinicians with 5-10 years of practice experience. Group III consisted of clinicians with 15-20 years of practice experience. The slides were mounted to allow for 20X magnification. The questions asked during the slide evaluation included, "Does the restoration need replacement?" and, "If it requires replacement, for what reason?" Radiographs were available to the examiners upon request, as well as information about diet, oral hygiene, and fluoride use. Chi-square and kappa statistical tests were performed. The finishing and polishing procedure significantly reduced the number of decisions for replacement in all groups 44% to 21%, which was statistically significant (p=0.0504). The main reason for amalgam replacement was secondary caries. Fewer than 40% of the examiners asked for the radiographs to review and only 8% of the examiners asked for the information relating to diet, oral hygiene, and fluoride use to help make their clinical decision.

Crack propensity of porcelain laminate veneers: A simulated operatory evaluation. *Magne P, Kwon KR, Belser UC, Hodges JS, & Douglas WH. (1999) The Journal of Prosthetic Dentistry **81(3) 327-334.**

(*Minnesota Dental Research Center for Biomaterials and Biomechanics, School of Dentistry, Minneapolis, MN 55455-0329)

Postoperative cracks of porcelain laminate veneers are potentially caused by polymerization shrinkage of the resin composite luting agent, by use of the tooth during mastication, and by variations in temperature because of ingested food and drinks. The purpose of this investigation was to use cyclic thermal fatigue to identify the parameters associated with the development of cracks in porcelain veneers. Twenty-seven maxillary incisors were restored with porcelain laminate veneers. Each specimen was prepared by a different clinician. The specimens were subjected to thermocycling from 5°C to 50°C for 1,000 cycles. In 11 of the 27 porcelain laminate veneers, fractures were found within the ceramic. The specimens were sectioned and then prepared for scanning electron microscopy analysis. At the facial, incisal, and proximal surfaces, measurements of the thickness of ceramic and of the resin composite luting cement were made. There were no significant differences in the thickness of the ceramic or of the resin composite luting agent between the cracked and the uncracked specimens. Significant differences were seen in the ratio between the ceramic and the resin composite luting cement thickness. When looking at the facial surface, most fractured porcelain laminate veneer specimens had a ceramic thickness to resin-composite luting cement thickness ratio below 3.0 (2.6 ± 0.35). Most unfractured porcelain laminate veneer specimens had a ceramic thickness to resin-composite luting cement thickness ratio above 3.0 (3.9 ± 0.19). There was no significant difference between cracked specimens and uncracked specimens when comparing measurements

of the ceramic and resin composite luting cement thickness at the incisal or proximal surfaces. The ceramic was slightly thinner in the facial aspect than in the proximal aspect of the restoration. The ceramic at the proximal aspect of the veneer was thinner than the ceramic at the incisal aspect. The resin-composite luting cement was thinner in the cervical area than in the incisal third of the tooth when looking at the facial aspect. Significant cyclic changes in temperature can initiate the development of fractures in porcelain laminate veneers. Important points to consider are control of tooth reduction and the application of die spacer during laboratory procedures. In order to obtain a ceramic thickness to resin-composite luting cement thickness ratio greater than three, one must have a sufficient and even thickness of ceramic in concert with a minimal thickness of resin composite luting cement. When this occurs, there is a favorable configuration with regards to potential for preventing crack formation.

Book Reviews

Proceedings of the European Workshop on Mechanical Plaque Control

Niklaus P Lang, Rolf Attstrom, and Harold Loe

Published by Quintessence Publishing Co, Inc, Chicago, 1998, 314 pages, 100 tables and charts. $42.80, soft cover.

This text is a report on the proceedings of a four-day workshop held in Berne, Switzerland in 1998. The purpose was to readdress the "status of the art and science of dental plaque control" last discussed in 1985 at a three-day meeting held at the National Institute of Dental Research in Bethesda, Maryland. An additional goal of this latest conference was to carry the discussions on mechanical dental plaque control into the dental hygienist profession. The three editors of this text are well-known and respected in their fields and are eminently qualified to produce a text such as this. This book contains contributions from 51 additional authors, of which many will be familiar to regular readers of the literature.

The book is divided into four chapters, based on the topics presented during the four scientific sessions held during the workshop. The first chapter covers Session A: Epidemiology and Etiology of Periodontal Diseases and the Role of Plaque Control in Dental Caries. Five papers are presented here covering this session's stated purpose, as well as reviewing common indices used to assess oral hygiene and tissue health, and current theories on supragingival plaque formation.

The second chapter contains the reports from Session B: Role of Mechanical Dental Plaque Removal in Prevention and Therapy of Caries and Periodontal Diseases. The four papers here discuss the efficacy of plaque control in the maintenance of gingival health, as well as the roles of manual toothbrushes, electric toothbrushes, and interdental cleaning. The next chapter continues with Session C: Costs and Benefits of Mechanical Plaque Control. Here four papers are presented that discuss not only the cost-effectiveness of mechanical plaque control, but also needs-related measures based on risk prediction, the role of oral hygiene during the healing phase of periodontal therapy, and managing the use of oral hygiene aids to prevent damage.

The final chapter covers the last day's topic of Behavioral Aspects of Mechanical Plaque Control. This chapter is a nice addition to any discussion of plaque control and contains two well written papers; the first addressing plaque control from an oral health promotion perspective, and the second stressing individualized instruction with recommendations and means of delivery to improve compliance.

This book is extremely well written and comprehensive in its coverage of its stated topic. The topics covered in each section were well chosen and compliment each other nicely. Where indicated, relevant illustrations, charts, and diagrams are included. Although there is no index, the well-defined titles of the papers along with the numerous subheadings within each paper make it a relatively easy task to find a discussion of a particular topic of interest. Additionally, each section ends with a consensus report that reviews and highlights the important findings and opinions of all participants from each day's session. Finally, included at the end of the text, are the policy statements endorsed by the workshop regarding the importance of mechanical plaque control as a key issue for the prevention of oral disease.

This text accomplishes the editors' goal of showing that mechanical plaque control remains a key issue for successful primary and secondary prevention as well as for therapy of the dental caries and periodontitis. It is definitely a fine resource for all practitioners and dental hygienists, as well as for educators preparing the professionals of tomorrow.

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Esthetic Dentistry & Ceramic Restorations

Bernard Touati, Paul Miara and Dan Nathanson

Published by Martin Dunitz Ltd, London, 1999, 330 pages, 400 illustrations (350 Color). £125.00, hardbound.

Given the increasing interest in tooth-colored resin bonded restorations the publication of this book is timely. The authors, all experienced clinicians in the field, have produced a comprehensive, and richly illustrated text, which covers all aspects of the provision of ceramic resin-bonded restorations. The introductory chapters provide a clear description of the principles of adhesive dentistry and a classification of ceramic systems, together with their relative indications, available today.

A common problem with the provision of ceramic restorations, particularly laminate veneer restorations, is predicting the final color of a restoration. The author's have addressed this issue particularly well with excellent chapters on the color of natural teeth, color and light transmission and more importantly how this information is successfully communicated to dental laboratories. Another key concept necessary for successful esthetic dentistry, namely tooth shape and position, is similarly explored and often neglected or misunderstood principles are clearly explained.

Separate chapters dealing with bleaching, laminate veneers, inlays and onlays, and crowns are well laid out with clear illustrations and references to support the text. A novel feature of this text is that several of the chapters have case presentations that explain by example many of the techniques suggested by the authors.

Overall the text is well written and supported by illustrations of a very high standard which make the book both impressive and very easy to read. The book is written very much with the practitioner in mind with clinical tips and hints that will reduce the potential number of failures practitioners may experience with restorations of this type. For experienced practitioners looking to improve their practice in this area or for those new to the field, this book is essential reading. It would also be a valuable addition to university libraries as the text is current, well informed and supported by appropriate reverences. A recurrent theme of the book is the concept of partnership between practitioners and technicians which is a prerequisite for the successful prescription of resin-bonded ceramic restorations. As such, this book would be valuable reading for technicians as well.

Dr. Paul A Brunton
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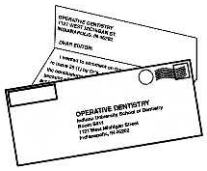
Letters



Correction

The Editor would like to correct a misprint in Dr. David Moline's letter, "A Dream of Preservative Health," (Operative Dentistry 1999, 24 (5): 318). In line 11, the word "greedy" should have been "openly." Therefore, the sentence should read "… a number of openly hostile… " The misprint occurred due to our misinterpretation of Dr. Moline's handwritten letter. As Dr. Moline points out, while we may have understandably misread his handwriting, the difference in words is very great, both in meaning and intent. We apologize for any confusion or embarrassment our error may have caused.

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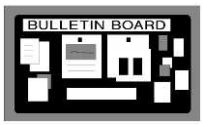

29th Annual Meeting of the Academy of Operative Dentistry

23-25 February 2000
Fairmont Hotel
Chicago, IL

The 29th annual meeting of the Academy of Operative Dentistry promises to be an exciting one. Drs. Vincent Kokich and Frank Spear open the Thursday session with "The Integration of Esthetics in Dentistry." The Buonocore Memorial Lecture follows with Prof. Dr. J. F. Roulet (Adhesive Dentistry in the 21st Century). Thursday afternoon features Dr. William Strupp, Jr. (Partial Coverage Restorations: Gold or Porcelain?) and Dr. Peter Yaman (Innovative Approach to Selecting Restorative Options). Friday's essayists include Dr. Pascal Magne (Redefinition of Esthetic Restorative Dentistry based on Adhesion and Biomimetics), Dr. Samuel Low (Treatment Planning the Restorative Dentition), and Dr. Maxwell Anderson (Evidence Based Dentistry-What it is and What it isn't). These speakers will be followed by an outstanding Table Clinic session in the afternoon. Companion activities include a "Continental Breakfast at the Fairmont" and a "Dance in Chicago" program on Thursday, followed on Friday by a "Shall We Dance?" tour with luncheon at Nonno Pino Italian Restaurant. In addition, the Gala Reception on Thursday evening will be as spectacular as ever. For meeting information, please contact Dr. Gregory Smith, P.O. Box 14996, Gainesville, FL 32604-2996; FAX (352) 371-4882. Hope to see you in Chicago!

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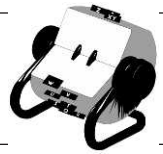

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