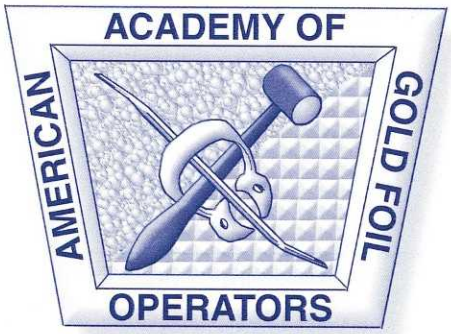
OPERATIVE DENTISTRY



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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 are also published.

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Guest Editorial

Progress and Excellence

Our new editor and my friend, Mike Cochran, asked me to give "my views on the *Journal*, the Academy and Operative Dentistry in general as we start a new century." I chose to approach these issues from a futuristic perspective, leaving the analysis of past performances to others.

I believe that it is helpful to contemplate the kind of world our *Journal*, the Academies and Operative Dentistry will serve 10 years from now. If we knew the future with certainty, we could formulate winning plans to provide the services and knowledge our profession will require. This is Gretsky's affirmation—"Skating to where the puck is going to be." Instead, I offer a brief view of several futures that I believe will have a high probability of occurring and their implications for our *Journal*, Academies and Operative Dentistry in general.

I believe that completing the decoding of the human genome will have a major impact in the near term. Shortly after that, we will complete the decoding of the proteins produced by these genes and their functionality. Not only are we solving the genetic coding of humans, but also the coding for the major pathogens associated with the two primary diseases of dentistry. As a result of this work, the health professions will quickly experience the greatest changes ever known. Armed with this genomic and protenomic knowledge, researchers will be able to synthesize new and robust strategies for diagnosing and treating caries and periodontal diseases, with significant reductions in surgical therapies.

How will our *Journal* and Academies support the required knowledge and technology transfer, including the social changes associated with applying this science? Simply publishing the data from this research will not be sufficient to cause meaningful changes in our system of care. The *Journal* and our Academies will need to exercise their leadership in critically analyzing these technologies and champion delivering the best in proven science. These will be no small tasks. There will be those among us who decry these efforts, preferring to cling to the past. At times they will be right in their reservations. No one can impose such massive changes in complex systems and foreknow all the impacts. We can expect that mistakes will be made, thus complicating the implementation of the change. Changes in social and delivery systems are, at best, difficult and will require continual thoughtful, knowledgeable leadership from our Academies and their *Journal*.

Another major impact will be the "boomers" who begin turning 65 at the rate of 10,000 per day in 2011. National data suggests that this population will have, on average, 26 teeth per person, many are part of the "fully-restored" generation. They will have a significant number of restored teeth requiring continued re-restoration. Without setting aside our proven materials, we need to participate in the developmental work in polymers, ceramics and alternative metal systems. Will we develop new clinical products in time to deliver restorations that are dimensionally stable on setting, with thermal coefficients similar to enamel? Will we be able to re-grow tooth structure to form and function as a result of biomimetics and tissue engineering? Given such materials or processes, what new rules for cavity form and caries removal will need to be developed and how will that knowledge be transferred to our profession? Our Academies and *Journal* will be challenged with providing careful research and disseminating the results.

Parenthetically, this aging sector of our society represents a growing component of our national population who are rapidly becoming sophisticated healthcare consumers. They seek and demand information on their own health and health care alternatives. Furthermore, they demand performance information on all aspects of our service delivery. They represent a wonderful opportunity to exercise our leadership in Operative Dentistry and challenge us to translate our science into a level designed for interested consumers.

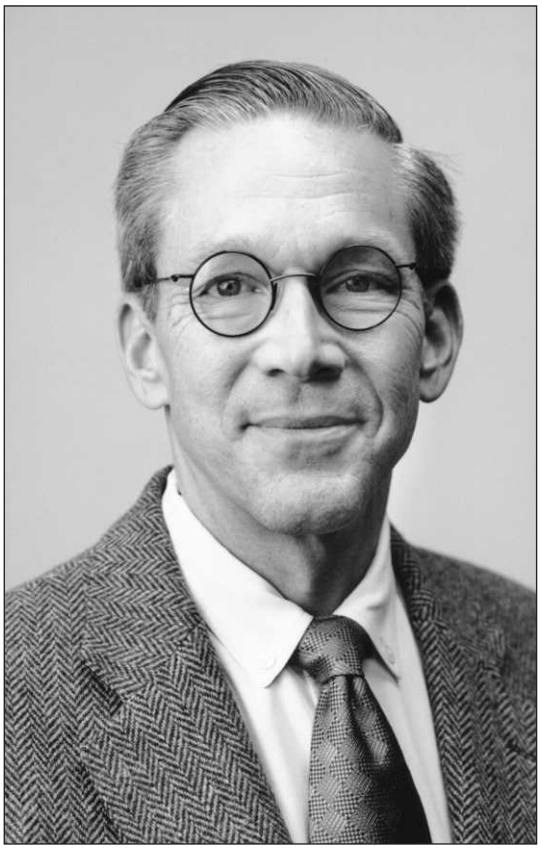
And what about the approximately 50% of our population not receiving regular dental services? This is a social concern that is, perhaps, not within our purview. I suggest that it is our responsibility as healing professionals to find new ways to deliver appropriate preventive and disease interception services to them. Not socialism, but for-profit delivery of population-based restorative and preventive services. Can our Academies and *Journal* find the forward thinkers to lend some answers to this continuing social conundrum?

Finally, can our Academies and *Journal* help implement change in the educational process to foster generations of critical thinkers? Can we be instrumental in

altering a seemingly-entrenched system and develop dentists that exercise critical thinking skills during the undergraduate experience? The AADS, some schools and some individual educators (many members of our Academies and the *Journal's* board) are moving toward achieving this end. It is both a noble and necessary goal. Given the skill sets associated with critical thinking, these new professionals will be able to adapt to the numerous changes in our profession that they will surely face during their practice lifetimes.

These are a few of the many changes that will likely occur in the next 10 years. I provide them as representative samples of the challenges we will be required to meet. My "views on the *Journal*, the Academy and Operative Dentistry in general as we start a new century" are best captured by James Thurber, who wrote, "In times of change learners shall inherit the earth, while the learned are beautifully equipped for a world that no longer exists." It is our collective responsibility through our Academies and *Journal* to be part of a systemic solution by facilitating learning and leading appropriate changes in our communities, while at the same time sustaining our traditions of excellence.

Maxwell H Anderson
Vice President and Dental Director
Washington Dental Service



Maxwell H Anderson

Commentary

Those who know Dr Maxwell Anderson would generally agree that he is something of a Renaissance man who possesses boundless energy, inquisitiveness and enthusiasm. Max can speak knowledgeably on a myriad of subjects, both within and outside his chosen profession and, during his Naval career, established an international reputation for teaching, mentoring, research, writing and presenting on a wide variety of topics. When he joined the faculty at the University of Washington, he was, therefore, a logical successor to Dr David Bales as editor of *Operative Dentistry*.

Although his tenure as editor–1993-1995–was relatively short (12 issues), Max certainly left his mark on our *Journal*. He recognized Kate Flynn Connoly's talent and encouraged increased computerization and utilization of pagesetting software to streamline our publishing process. Dr Anderson changed the format of *Operative Dentistry* from 7 x 9 1/2" to our current 8 1/2 x 11" publication. He also recognized the need to carry the clinical foundation of the parent Academies into the *Journal* and strongly solicited clinical technique articles, including writing specific guidelines for prospective authors of these papers (Vol **18(3)** pg 115). Finally, he required a "clinical relevance" statement for all original papers to offer the practitioner a better understanding of the practicality, application and usefulness of basic research.

I must also point out that Dr Anderson was an editor ahead of his time. He almost moved the *Journal* to Indiana upon accepting a faculty position at the Indiana University School of Dentistry (Vol 19, issues 1, 2 and 3 actually list IUSD as the *Journal* address). Unfortunately, circumstances prevented Max from leaving Washington, where he currently serves as Vice President and Dental Director for Delta Dental's Washington Dental Service.

I am happy that I was able to complete the relocation he began.

Michael A Cochran
Editor

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Clinical Research

Tooth-Colored Filling Materials for the Restoration of Cervical Lesions: A 24-Month Follow-Up Study

M Folwaczny • C Loher • A Mehl
KH Kunzelmann • R Hinkel

Clinical Relevance

The clinical performance of resin-based Class V restorations was significantly better than that of resin-modified glass ionomers when comparing the materials evaluated in this study.

SUMMARY

The recently developed resin-modified glass ionomer cements and the polyacid-modified composites are promising alternatives to conventional materials for restoring cervical defects. This clinical study evaluated the clinical condition of cervical fillings 24 months following placement. The study subjects were 197 cervical restorations placed on incisors, canines and premolars in 37 patients for restoration of erosion/non-carious lesions (69 cases), primary carious lesions (57 cases) and the replacement of deficient restorations (71 cases). The teeth were randomly divided into four groups for restoration with either Tetric (composite, Group A: n=36), Dyract (compomer, Group B: n=79), Fuji II LC (resin-modified glass ionomer cement, Group C: n=51) or Photac-Fil (resin-modified glass ionomer cement, Group D: n=31). The evaluation was done single-blind at baseline, 8 and 24 months after the placement of the fillings, according to a modified USPHS rating scale. The assessment criteria were color stability, anatomical form, surface texture, marginal integrity, marginal discoloration and loss of filling. Statistical analysis was completed using Pearson chi-square and Fisher's exact test at a significance level of 5% ($p<0.05$). After the 24-month period, the composite restorations showed superior results. The compomer fillings demonstrated conditions that were only slightly worse. A substantial number of the resin-modified glass-ionomer fillings were evaluated with bravo or even charlie scores in respect to at least one of the criteria assessed.

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Reichard Hickel

INTRODUCTION

Several different treatment modalities (eg, occlusal adjustment, toothbrushing instructions, dietary advice and restorations) have been described for cervical defects (Tyas, 1995). The individual needs for treatment depend on the etiology, the patient's complaints and the extension and depth of the defect (Bader & others, 1993; Hickel, 1992). Small cavities due to abrasion or erosion, causing no pain and no esthetic impairment, often do not need restoration but may require only toothbrushing instructions or occlusal adjustment in

order to stop further progression. In contrast, deep abrasion or erosion defects and carious lesions require thorough removal of infected enamel and dentin and subsequent restoration of the defect for protection against the continuous destruction of the tooth.

Considering the complex etiology and morphology of cervical defects with margins lying part in enamel as well as in dentin and cementum, restoration technique and material choice can be challenging (Tyas, 1995; Sidhu, 1993). Besides the need to meet esthetic demands, marginal sealing ability, especially in dentin or cementum, appears to be the major priority when choosing an appropriate filling material (Powell, Gordon & Johnson, 1991).

In addition to conventional glass ionomer cements and resin-based composites, more recently developed tooth-colored filling materials, particularly the resin-modified glass ionomer cements and the polyacid-modified resin composites, have now broadened the available therapeutic armamentarium (Fritz, Finger & Uno, 1996). All four types of materials have some advantages as well as shortcomings for their potential use in the restoration of cervical defects.

Glass ionomer cements have traditionally been used to restore cervical lesions due to their ease of use, adhesion to tooth substance and release of fluoride (Fritz & others, 1996; Maneenut & Tyas, 1995; Wilson, Groffman & Kuhn; 1985). The disadvantages of the conventional glass ionomer cements include sensitivity to moisture, poor wear resistance, low fracture toughness and high opacity, which cause poor esthetic results (Sidhu, 1993; Burgess, Norling & Summitt, 1994; McKinney, Antonucci & Rupp, 1987). Composites demonstrate satisfactory esthetic properties and high wear resistance (Neo & others, 1996). Considering the use of composites for the restoration of cervical lesions, concerns about the longevity of the bonding to dentin or cementum have been reported (Maneenut & Tyas, 1995). The extensive curing shrinkage of composite materials may lead to the formation of marginal gaps (Powell & others, 1991). In addition, there may be induced forces, especially tooth flexure due to occlusal loading, that cause the debonding of cervical composite restorations (Heyman & others, 1991).

New generations of resin-modified glass ionomer cements and polyacid-modified resin composites have been developed to overcome some of the shortcomings of conventional glass ionomers and composites while maintaining their clinical advantages (Sidhu & Watson, 1995). Resin-modified glass ionomer cements are cured in a dual process combining the fundamental acid-base reaction with a light-induced polymerization of resin monomers, eg, HEMA or BIS-GMA. Due to the small portion of resin molecules, the flexural strength of resin-modified glass ionomers compared to conventional glass ionomer cements has been improved, but they still do not achieve the high physical properties of composites (Fritz & others, 1996; Burgess & others, 1994; Hinoura, Miyazaki & Onose, 1991; Triana & others, 1994). In addition, the compressive and tensile strengths of resin-modified materials are higher compared to conventional glass ionomers, and their elasticity is more equal to that of tooth substance (Maneenut & Tyas, 1995). At the same time, the advantage of fluoride release has been maintained, at least in part (Momoi & McCabe, 1993). Esthetic properties seem to be improved because of the increase in translucency due to differences in the optical properties between the polyacid and the resin components (Sidhu & Watson, 1995). Finally, the wear resistance of the resin-modified glass-ionomer materials shows no increase compared to the conventional glass ionomer cements (Hickel, 1996).

Polyacid-modified resin composites or compomers are composed of a reactive glass and an acidic monomer system, which polymerizes during the primary hardening process to a polyalkenoic acid. A secondary reaction between the polyalkenoic acid and the glass component claims to be triggered by the penetration of moisture into the restoration (Tyas, 1995; Gladys & others, 1997).

Compomers are easy to handle and their physical characteristics, eg, compressive and flexural strength, are close to that of the composites (Attin, Vataschki & Hellwig, 1996). Using the acid-etch technique in combination with a dentin bonding agent, the adhesive strength of compomers to enamel and dentin is almost equal to that of the composite resins (Fritz & others, 1996; Triana & others, 1994).

Considering the individual advantages of the various types of tooth-colored materials and the special needs in restoring cervical lesions, there is still confusion over the most preferred filling material. The eight-month data from this study was reported in a previous publication (Loher, Kunzelmann & Hickel, 1997). Therefore, only 24-month data on restoring Class V lesions with three different classes of light-curing materials are considered in this paper.

METHODS AND MATERIALS

Patient Selection

Study subjects were 197 cervical defects on incisors, canines and premolars in 37 patients aged 26-67 years (n=197). The fillings were placed as a result of erosion/noncarious cervical defects in 69 cases, primary carious lesions in 57 cases and replacing deficient restorations in 71 cases (Table 1). All defects had mixed cavity margins in enamel as well as dentin. The teeth were randomly assigned to four groups for restoration, either with a composite in combination

Table 1: *Number of Teeth Restored and Reason for Restoration*

Material	Photac Fil		Fuji LCII		Dyract		Syntac/Tetric		Total	
Evaluation Period	**8 mos.**	**24 mos.**	**8 mos.**	**24 mos.**	**8 mos.**	**24 mos.**	**8 mos.**	**24 mos.**	**8 mos.**	**24 mos.**
Caries	5	5	13	10	27	19	12	9	57	43
Erosion/angular lesion	11	9	18	8	28	24	12	9	69	50
Non-sufficient filling	15	13	20	17	24	20	12	8	71	58
Total	31	27	51	35	79	63	36	26	197	151

Table 2: *Clinical Rating Scale*

Score	Alpha	Bravo	Charlie	Delta
Color stability	No change	Change of color comparing to baseline condition	-	-
Surface texture	Sound	Rough	-	-
Anatomical form	Sound	Slight loss of material (chipping, clefts), superficial	Strong loss of material (chipping, clefts), profound	Total or partial loss of the bulk
Marginal integrity (enamel)	Sound	Positive step, removable by finishing	Slight negative step, not removable, localized	Strong negative step in major parts of the margin, not removable
Marginal integrity (cementum)	Sound	Positive step, removable by finishing	Slight negative step, not not removable, localized	Strong negative step in major parts of the margin not removable
Marginal discoloration (enamel)	None	Slight discoloration, removable by finishing	Discoloration, localized not removable	Strong discoloration in major parts of the margin not removable
Marginal discoloration (cementum)	None	Slight discoloration, removable by finishing	Discoloration, localized not removable	Strong discoloration in major parts of the margin, not removable

with a dentin bonding agent (DBA) (Group 1: n=36; Tetric, DBA—Syntac; Vivadent, Schaan, Liechtenstein), a compomer with a dentin bonding agent (Group 2: n=79; Dyract, DBA—PSA; De Trey Dentsply, Konstanz, Germany) or one of two different resin-modified glass ionomer cements (Group 3: n=51, Fuji II LC; GC Dental Industrial Corp, Tokyo, Japan; Group 4: n=31, Photac-Fil; ESPE, Seefeld, Germany).

Preparation and Pretreatment of Cavities

In general, cavity preparation was done without creating any macroretention. Erosions were cleaned mechanically using a brush and polishing paste without fluoride (Zircate; L D Caulk/Dentsply, Milford, DE 19963). Deficient existing restorations were removed, carious tooth substance was excavated and the margins of the cavity were finished using ultrafine-grain diamond burs (Blend-a-mant D234-012f; Blendax, Mainz, Germany). Primary carious lesions were excavated, and the margins of the cavity were finished using the same diamond burs. Deep cavities located near the pulp were lined with a self-setting calcium hydroxide material (Dycal; DeTrey Dentsply). Prior to placing the composite resins, the margins in enamel were beveled and acid etched. According to the recommendations of the manufacturer, no acid etching of the enamel or dentin was done for the compomer restorations. In no case was a rubber dam placed prior to performing the restorations to facilitate comparability among the different types of materials.

Placement and Finishing of Restorations

The filling materials were placed with a special matrix as a modeling aid (Hawe Transparent No 850; Hawe-Neos Dental, Bioggio, Switzerland). Each restoration was light-cured for 60 seconds (Translux CL; Heraeus Kulzer, Wehrheim, Germany). Following the setting of the filling, gross contouring was completed using fine-grain diamond burs or special rotating finishing instruments (Blend-a-mant D249-012f, Blend-a-mant D202-010sf; Blendax). Finally, the restorations were polished using Sof-Lex Pop-on-disks (3M Dental Products, Leicestershire, UK) and the Enhance finishing system (De Trey). For the composite and compomer, the surface was further finished with a special polishing paste (Prisma Gloss, De Trey Dentsply).

Table 3: *Ratings of Four Restorative Materials at 24 Months*

		Tetric (group 1)	**Dyract** (group 2)	**Fuji II LC** (group 3)	**Photac** (group 4)
Criteria	Score				
Color	A	100.0	94.6	82.4	75.0
Stability	B	0	5.4	17.6	25.0
	C	0	0	0	0
	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1); (4)**	**(1)**	**(1); (2)**
	A	100.0	94.6	23.5	10.0
Surface	B	0	5.4	76.5	90.0
Texture	C	0	0	0	0
	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1); (3); (4)**	**(1); (2); (4)**	**(1); (2); (3)**
	A	100.0	96.4	58.8	45.8
Anatomical	B	0	5.4	35.3	20.8
Form	C	0	0	5.9	33.3
	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1); (3); (4)**	**(1); (4)**	**(1); (2); (3)**
	A	88.0	73.2	70.6	62.5
Marginal	B	4.0	12.5	8.8	8.3
Integrity	C	8.0	14.3	20.6	29.2
(Enamel)	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1); (4)**	**(1)**	**(1); (2)**
	A	100.0	85.6	58.8	33.3
Marginal	B	0	7.2	8.8	8.3
Integrity	C	0	7.2	32.4	58.3
(Cementum)	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1); (4)**	**(1)**	**(1); (2)**
	A	88.0	75.0	82.4	70.8
Marginal	B	8.0	16.1	8.8	12.5
Discoloration	C	4.0	8.9	8.8	16.7
(Enamel)	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (4)**	**(1); (4)**	**(4)**	**(1); (2); (3)**
	A	82.0	90.0	76.5	46.0
Marginal	B	18.0	4.0	17.6	16.5
Discoloration	C	0	6.0	5.9	37.5
(Cementum)	D	0	0	0	0
***p*<0.05 vs. group**		**(2); (4)**	**(1); (4)**	**(4)**	**(1); (2); (3)**
Loss of	retention	100.0	91.0	94.0	90.0
Fillings	loss	0	9.0	6.0	10.0
***p*<0.05 vs. group**		**(2); (3); (4)**	**(1)**	**(1)**	**(1)**

Reevaluation of Restorations

The fillings were evaluated single-blind according to a modified USPHS system (Pelka & others, 1994; Ryge, 1989) at baseline, 8 and 24 months after placement by two dentists using mirror and probe. Due to patient dropout, 151 restorations could be reevaluated after the two-year period (Table 1). Assessment was done in the categories of color stability, surface texture, anatomical form, marginal integrity and marginal discoloration. For each of the single criteria the scoring scale had four classes (Table 2). Complete loss of restoration was also recorded.

Statistical Analysis

Statistical analysis compared the ratings of each criterion among the four materials using the Pearson chi-

square and Fisher's exact test at a level of significance of 5% ($p<0.05$).

RESULTS

The results of the 24-month study are featured in Table 3.

Color Stability

None of the Tetric restorations had color changes, whereas the alpha score for Dyract was 94.6%. The color stability of the resin-modified glass ionomer cements, Fuji II LC and Photac-Fil, were evaluated with an 82.4% and 75% alpha rating, respectively (Pearson chi-square: p=0.0844).

Surface Texture

All Tetric restorations had a clinically smooth surface that corresponds to a 100% alpha rating. In contrast, only 10% of the Photac fillings were classified with an alpha rating. In the case of Dyract, 94.6% and of Fuji II LC, 23.5% of the fillings had a perfect surface structure (alpha) (Pearson chi-square: p=0.0001).

Anatomical Form

All of the Tetric restorations had an excellent anatomical form after 24-months. Of the Dyract restorations, 94.6% demonstrated no anatomical form (alpha) changes within this period. In the groups with the resin-modified glass ionomer cements, only 58.8% (Fuji II LC) and 45.8% (Photac Fil) of the fillings demonstrated a perfect anatomical form (Pearson chi-square: p=0.0001).

Marginal Integrity

In the case of Tetric, 8% of the fillings had a clinically non-acceptable (charlie or delta) integrity of the margins lying in enamel. In comparison, 14.3% (Dyract), 20.6% (Fuji II LC) and 29.2% (Photac) of the fillings showed clinically non-acceptable conditions at the margins placed in enamel. (Pearson chi-square: p=0.1832). The integrity of the margins placed on dentin or cementum was evaluated as acceptable in all of the Tetric restorations (100% alpha). In 7.2% (Dyract), 32.4% (Fuji II LC) and 58.3% (Photac) of the cases, the fillings had advanced alterations (charlie) of the marginal integrity in dentin or cementum (Pearson chi-square: p=0.0001).

Marginal Discoloration

Regardless of the material, each group showed some moderate (bravo) or severe (charlie) discoloration at the margins placed on enamel. In detail: in the case of Tetric (8%/4%), of Dyract (16.1%/8.9%), of Fuji II LC (8.8%/8.8%) and of Photac Fil (12.5%/16.7%) of the restorations demonstrated discoloration (bravo/charlie) at the margins adjacent to enamel (Pearson chi-square: p=0.7099). Of the Tetric restorations, 18% demonstrated moderate signs of discoloration (bravo) at the margins placed in dentin. The restorations with Dyract had in 4%/6% of the cases discoloration (bravo/charlie) at the dentin margins. The resin-modified glass ionomer cements demonstrated ratings of 17.6%/5.9% (Fuji II LC) and 16.5%/37.5% (Photac Fil) for the cases of moderate or severe discoloration at the margins placed on dentin (Pearson chi-square: p=0.0001).

Loss of Fillings

In the group of Tetric restorations, no filling was lost within the two-year period. In the case of Dyract, 9%, of Fuji II LC, 6% and Photac-Fil, 10% of the restorations had to be replaced during the evaluation period (Pearson chi-square: p=0.294).

DISCUSSION

Rating System

The clinical quality of the restorations in this study was evaluated according to a modified USPHS system. In the past, various protocols for the standardized examination of dental restorations have been described in the literature (Pelka & others, 1994; Ryge, 1980; Ryge & others, 1981). All are based on the rating of various clinical criteria into four quality categories. In this study the original rating system has been modified with respect to the special needs for evaluating cervical fillings. In most of the cases cervical lesions show mixed-cavity margins lying partly in enamel as well as in dentin or cementum. In addition to color stability, surface texture and anatomical form, the evaluation was, therefore, completed with marginal integrity and marginal discoloration measured separately for margins lying in enamel and in dentin or cementum.

Color Stability

The significantly higher rate of moderate color changes on resin-modified glass-ionomer restorations compared to the composite and compomer fillings agrees with results of *in vitro* experiments, which also demonstrated a poor color stability for these types of materials (Tyas, 1995). Maneenut and Tyas (1995) have reported a certain degree of color change on resin-modified glass-ionomer fillings after one year in an *in vivo* study. The esthetic results depend, at least in part, on the surface texture (Tyas, 1995). According to Sidhu and Watson (1995), a smooth surface is one of the most important conditions for preserving good esthetics by reducing the superficial discoloration due to the deposition of colored particles. Hence, the surface of the glass ionomer cements, even the resin-modified materials, is rather rough due to the large particle size of these materials and the poor wear resistance of the polyacid matrix (Gladys & others, 1997).

Surface Texture

Several reasons may account for the high percentage of resin-modified glass-ionomer fillings with rough sur-

faces. First, the average particle size of the glass powder of Photac and Fuji II LC was measured with 6.95 µm and 5.56 µm, respectively (Gladys & others, 1997). In comparison, the compomer Dyract contains inorganic particles with 1.89 µm on average, whereas the particle size of composites is even less. In addition, following the loss of superficial filler particles due to the wear of the restoration, the detached particles may act as an abrasive medium on the surface, inducing a higher surface roughness on glass-ionomer fillings (Attin & others, 1996). Therefore, due to the higher average size of the glass particles, a rougher surface might be produced. Second, the composite as well as the compomer are single-component materials, in contrast to the light-curing glass ionomers. Prior to use, the powder has to be mixed with a liquid phase for the resin-modified glass-ionomer materials, thereby risking the induction of air bubbles (Stanford & others, 1985). This porosity may contribute to the clinically detectable higher surface roughness of the glass-ionomer fillings.

Anatomical Form

The poor wear resistance of glass ionomer cements seems to reasonably explain the numerous examples of the resin-modified glass-ionomer restorations showing moderate or even severe changes of the anatomical form (Grippo, 1991). As mentioned by Tyas (1995) and Grippo (1991), the filling material is exposed to tensile stresses due to the cyclic flexural deformation of the cervical region during the occlusal loading of the tooth. The resin-modified glass ionomer cements have a significantly lower flexural strength when compared with Dyract and a hybrid composite material (Attin & others, 1996). With respect to the higher brittleness of the glass ionomer cements, the cyclic tensile stresses induced in the cervical filling may lead to the formation of fatigue cracks. Due to the propagation of these cracks, an abfraction of part of the bulk may finally result, which is then interpreted as wear of the filling (Braem & others, 1995).

Marginal Integrity

As for the anatomical form, tensile forces at the margins of the filling during occlusal loading of the tooth may also contribute to the higher prevalence of marginal defects for the glass-ionomer restorations, indicated by the charlie rating (Sidhu, 1993). Taking into account that the bond strength of glass ionomer cements is rather poor compared to compomers or composites, the low flexural strength of the resin-modified glass ionomer cements may be associated with microfractures along the marginal areas of the restorations (Attin & others, 1996). According to Braem and others (1995), the flexural fatigue limit and the restrained fracture strength of resin-modified glass-ionomer materials are significantly lower than Dyract or hybrid composites. Because of the growth of fatigue cracks due to the flexural deformation, chipping of the filling can cause marginal breakdown. Other data (unpublished), showing significantly greater breakdown along margins of restorations placed in erosion/non-carious defects, appears to support this model.

Marginal Discoloration

In the case of the Dyract fillings, the proportionally high percentage of marginal discoloration, especially in enamel, is most likely due to marginal gaps forming. Prior to restoration with the compomer, no acid etching of the cavity margins was completed (per the manufacturer's instructions). According to Fritz and others (1996) and Cortes, García-Godoy, and Boj (1993), the bond strength of Dyract to non-etched enamel ranges from 5-8 MPa, which is rather poor compared to composites used with acid etching. These findings are in accordance with the results of an *in vitro* study on the marginal leakage of a composite, a compomer and a resin-modified glass ionomer cement (Yap, Lim & Neo, 1995). In this work a significantly better marginal seal of the composite restorations in enamel was reported compared to the compomer and glass-ionomer restorations. The individual marginal conditions showing an excess or deficiency of the filling material may also contribute to the occurrence of marginal discoloration (Powell & others, 1991; Neo & others 1996). In fact, the ratings of marginal discoloration correspond within certain limits to that of the marginal integrity in this study. Especially in the case of Dyract restorations, several fillings showed an excess at the margins placed on enamel, which had a moderate discoloration. The prevalence of excess at the compomer restorations' margins is most likely due to the high tendency of water sorption, subsequently leading to the swelling of the material (Attin & others, 1995).

Loss of Fillings

The portion of total loss of fillings is mainly determined by the bond strength of the material to the cavosurface. None of the Tetric fillings was lost during the 24-month period, but some of the compomer and glass-ionomer restorations were. According to Triana and others (1994), the bond strength of resin-modified glass ionomer cements to dentin ranges from 9.7 to 15.96 MPa. In comparison, the adhesion of compomers and composites to dentin was reported to be about 20 MPa (Yoshiyama & others, 1996a,b). In contrast to the composite restorations, a significantly higher number of Dyract fillings were lost in this study. The reason for this observation presently remains obscure, but the rather poor bond strength of Dyract to unetched enamel is probably responsible for this finding. The elastic properties of the materials may, in addition, exert some influence on the rate of retention of the restorations (Matis, Cochran & Carlson, 1996). As mentioned above, the material of cervical restorations is exposed

to tensile stresses due to the cyclic flexural deformation during the occlusal loading of the tooth. Therefore, the higher elastic modulus of the resin-modified glass-ionomer materials prevented elastic deformation and caused the breakdown of the bonding of the material to the cavosurface, which may have resulted in the total loss of this type of material.

CONCLUSION

In general, the results of this study revealed a significantly better quality of the composite restorations, which showed no cases of non-acceptable clinical conditions in any respect. The ratings of the compomer fillings were only slightly worse. Several restorations of the resin-modified glass ionomer cements were evaluated clinically as non-acceptable in at least one or more of the criteria. The results of the two-year evaluation confirm the findings completed eight months after the placement of the restorations, indicating superior quality of the composite and compomer restorations compared to the resin-modified glass-ionomer fillings for the restoration of cervical lesions (Loher, Kunzelmann & Hickel, 1997).

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Class II Restorations with a Polyacid-Modified Composite Resin in Primary Molars Placed in a Dental Practice: Results of a Two-Year Clinical Evaluation

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Clinical Relevance

In the everyday situation, both a polyacid-modified composite resin and a hybrid composite can be recommended for restoration of Class II cavities in primary molars.

SUMMARY

This study evaluated the two-year success rate of a hybrid composite material (TPH-Spectrum®; Dentsply DeTrey, Konstanz, Germany) and a polyacid-modified composite resin (Compoglass®, Vivadent, Schaan, Liechtenstein) in Class II restorations placed in primary molars in a dental practice. In each of 52 children, at least two primary molars were restored. Ninety-six primary molars were filled with TPH-Spectrum® using the total-etching technique, and 94 with Compoglass® without acid etching prior to application of the bonding adhesive. At baseline, one and two years, the restorations were assessed according to the Ryge criteria. Forty-seven children with a total of 132 fillings (68 TPH-Spectrum, 64 Compoglass) were evaluated after two years. The cumulative success rate after 24 months amounted to 89.2% for the Compoglass and 89.7% for the TPH-Spectrum restorations. No significant differences were observed between the two materials with respect to color matching, cavosurface discoloration, anatomic form, margin integrity and caries assessment.

This investigation suggests that for a period of two years, the hybrid composite TPH-Spectrum and the polyacid-modified composite resin Compoglass, are suitable materials for restoration of primary molars.

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INTRODUCTION

In primary teeth, the use of glass ionomer cements, composite resins and polyacid-modified composite resins as restoratives is wide-spread. Children often show restricted compliance, which makes reduced operating time desirable. Polyacid-modified composite

resins seem to offer such an advantage over composites since their suggested application technique eliminates the acid-etching procedure. The success rate of both composite resins and polyacid-modified composite resins in deciduous teeth has been assessed in several investigations (Sturdevant & others, 1988; Bevan & Braham, 1989; Krejci & others, 1994; Ernst, Weckmüller & Willershausen, 1995; Andersson-Wenckert, Folkesson & van Dijken, 1997; Krejci, Wiedmer & Lutz, 1998). In a recently published study, we compared the failure rate of these materials after one year (Attin & others, 1998). The restorations were performed in a dental practice that reflected everyday treatment. After one year, 6.4% of the polyacid-modified composite resins and 3.1% of the composite restorations failed and had to be renewed. The one-year retention rates suggested that both materials might be suitable as restoratives for primary molars. However, the observation period was felt to be too short to support this assumption and a two-year evaluation was scheduled.

METHODS AND MATERIALS

Because the study population, material and procedure have been presented in the one-year evaluation (Attin & others, 1998), only the main features will be repeated here. The initial patient sample treated between December 1995 and April 1996 comprised 52 children (34 female, 18 male) aged 3 years, 10 months to 10 years, 8 months. The children's parents provided informed consents. No pre-selection with regard to appropriate compliance was made, and the children were treated at their regular appointments, ie, no additional time was set aside for their treatment. The children had at least two posterior primary teeth requiring a Class II restoration. Teeth with carious lesions and those requiring replacement fillings were included in the study. All teeth were vital and asymptomatic. Each of the 52 patients received one restoration with a hybrid composite material (TPH-Spectrum®; Dentsply DeTrey, Konstanz, Germany) and one with a polyacid-modified composite resin (Compoglass®, Vivadent, Schaan, Liechtenstein) at the same appointment. A total of 190 restorations (96 with TPH-Spectrum® and 94 with Compoglass®) were inserted by three dentists A-C working in the same dental practice. Initially, 93 restorations were applied in first and 97 in second primary molars. The respective materials were randomly assigned to teeth requiring treatment. The intent was to distribute the restorations with composite and those with the polyacid-

Table 1: *Rating System and Criteria for Evaluation of the Restoration*

Color matching	
Alfa	Restoration is matched to adjacent tooth structure in color.
Bravo	Mismatch is not outside the normal range of tooth color. Clinically acceptable.
Charlie	Mismatch is outside the normal range of tooth color. Clinically unacceptable.
Cavosurface discoloration	
Alfa	No discoloration is present.
Bravo	Discoloration has not penetrated along margin in pulpal direction.
Charlie	Discoloration has penetrated along margin in pulpal direction. Clinically unacceptable.
Postoperative hypersensitivity	
Alfa	No postoperative hypersensitivity occurred.
Bravo	Postoperative hypersensitivity occurred. Patients were asked for approximate duration of sensibility.
Sensitivity	
Alfa	Tooth shows vital reaction on sensitivity testing with ethyl chloride.
Bravo	Tooth does not show vital reaction on sensitivity testing.
Anatomic form	
Alfa	Restoration is continuous with existing anatomical form.
Bravo	Restoration is discontinuous with existing anatomical form, but missing material is not sufficient to expose dentin or base.
Charlie	Sufficient material is lost to expose dentin or base.
Margin integrity	
Alfa	No visible evidence of a crevice along the margin or the visible crevice is so small that the explorer just catches but does not "fall in."
Bravo	Visible evidence of a crevice along the margin into which the explorer penetrates, but no dentin or base is exposed.
Charlie	The explorer penetrates into a crevice and dentin or base is exposed.
Delta	The restoration is fractured or missing in part or in toto.
Caries assessment	
Alfa	No caries is present at the margin of the restoration.
Charlie	Caries is present at the margin, necessitating repair or replacement of the restoration.

Table 2: *Distribution of Restorations Examined After Two Years and Reasons for Non-Consideration at the Two-Year Examination*

	Compoglass	TPH-Spectrum
Restorations placed at baseline	94	96
Restorations failed after 1 year	6	3
Restorations of children, who moved during interval	13	13
Exfoliated primary molars after 2 years	10	11
Extractions (orthodontic reasons)	1	1
Restorations examined after 2 years	64	68

modified composite resin equally in each child. If a child required an unequal number of fillings, selecting the material for the remaining filling was randomly made. All subjects obtained a local anesthesia prior to the cavity preparation. Cotton rolls were used to isolate the working field. Although the manufacturers recommended using the rubber dam, it was not applied in order to replicate routine procedures followed in most dental practices when treating children. Cavity preparation and manipulation and placement of the restorative materials were performed as described previously (Attin & others, 1998). The composite resin TPH-Spectrum® was applied using the "total-etch-technique" in combination with the adhesive Prime&Bond™ 2.0 (Dentsply DeTrey). Cavities restored with Compoglass® were not etched prior to applying the adhesive SCA (Vivadent). With both materials the adhesives were applied in two thin layers which were light-cured as recommended by the manufacturers. The preparations were performed with a pear-shaped diamond bur (ISO 806 314 234534 012, Komet, Lemgo, Germany), resulting in slightly convergent cavities. No additional undercuts were prepared and the margins of the cavities were not bevelled. A self-curing calcium hydroxide liner (Life®, Kerr, Romulus, MI) was selectively applied to areas of deep excavation. Application of a pulp amputation paste (Agsa, Locarno, Switzerland) was necessary in 29 teeth (23 first and 6 second primary molars) due to pulpal exposure during excavation of the carious dentin. This paste was covered with zinc phosphate cement.

Evaluations were performed immediately upon completion of the restorations (= baseline), and after one and two years using modified Ryge criteria (Ryge, 1980). As shown in Table 1, all evaluations were performed by one operator (dentist A). In addition to the clinical examination, marginal integrity and anatomic form of the restorations were evaluated by using epoxy resin replicas (Zeiser Blue-Star®, Gierbach Dental, Pforzheim, Germany) and magnifying glasses (2x magnification). Restorations evaluated as failures and replaced at the one-year examination, were not evaluated after two years.

Differences between evaluation periods were statistically analyzed with Chi-Square-Tests and logistic regression analysis. A logistic regression procedure that considered overdispersion was applied since each child had received both filling materials. This was used to determine the influences of different parameters (operator, sex of the child, location of the tooth, material, vitality) on the results of the assessments of the Ryge criteria. The cumulative survival rate was calculated according to Kaplan-Meier-estimation (Kaplan & Meier, 1958). Significance was set at $p<0.05$.

RESULTS

Forty-seven (90.3%) of the children were recalled after two years. A total of 132 restorations (69.5%) were evaluated. Reasons for the dropouts are shown in Table 2. Statistical analysis did not reveal any impact on the outcome of the study resulting from the dentist applying the restoration, the sex of the patients or whether the restoration was located in the upper or lower jaw. These variables were, therefore, pooled. Eight restorations were scored clinically unacceptable and failed during the second year (3 Compoglass, 5 TPH-Spectrum). The numbers and reasons for failure are listed in Table 3. Table 4 presents the cumulative failure rate of the two restorative materials, which were

Table 3: *Distribution of Restorations According to the Reasons for Failure After One and Two Years, Respectively*

	Compoglass		TPH-Spectrum	
Reason	1 year	2 years	1 year	2 years
Caries alone	0	0	0	2
Caries and marginal desintegrity	4	1	2	2
Caries and loss of retention	1	2	1	1
Filling fracture	1	0	0	0
Total	6	3	3	5
Total (1y and 2y)	9		8	

Table 4: *Cumulative Survival Rate After One and Two Years for Restorations with Compoglass and TPH-Spectrum*

1 year		2 years	
Compoglass	TPH	Compoglass	TPH
93.6%	96.9%	89.2%	89.7%

similar after two years. One tooth restored with TPH-Spectrum lost vitality during the second year and was diagnosed as carious. All other teeth that tested vital at baseline remained vital during the two-year observation period. No postoperative sensitivity was reported at baseline, one or two years.

Table 5 presents the percentage distribution of the respective scores for color-matching, cavosurface discoloration, anatomic form, margin integrity and caries assessment at baseline, one and two year recall examinations. At the one- and two-year recall examinations, the assessments for color-matching, cavosurface discoloration, anatomic form and caries status were only recorded for those restorations still in service. Statistical analysis showed a significant difference between the two materials with respect to color matching (p=0.0170). No difference was observed for the other criteria evaluated (cavosurface discoloration: p=0.9977; anatomic form: p=0.9248; margin integrity: p=0.2205; caries assessment: p=0.1372).

Restorations in teeth with pulp amputation and fillings in first primary molars showed more deterioration than fillings in vital teeth and second primary molars. This observation was true regardless of the restoration material used. Only five (4.1%%) of the restorations inserted in vital teeth were clinically unacceptable, whereas three (23%) of the restorations placed after pulp amputation had to be redone at the two-year recall. Thus, the fact that a pulp amputation had to be carried out, exerted an influence on marginal integrity p=0.0124) but not on the other criteria evaluated. Furthermore, only two (2.5%) of the fillings placed in second primary molars, but six (11.1%) restorations inserted in first primary molars were clinically unacceptable at the two-year examination and had to be replaced. The differences between the first and second primary molars were statistically significant only with respect to margin integrity (p=0.0452).

DISCUSSION

The parameters concerning the materials and methods applied in this investigation were previously discussed in detail (Attin & others, 1998). Thus, only the outcome of the two-year examination needs further consideration and discussion.

After two years, the cumulative failure rate according to the Kaplan-Meier estimation amounted to 10.8 % for the fillings with the polyacid-modified composite resin and 10.3 % for the composite restorations. These restorations had to be replaced within the two-year observation period. The data from this study is similar to the results of previously published clinical investigations. These studies showed a need for replacement of 20-50% for amalgam and 7-50% for composite restorations in deciduous teeth after two years (Tonn, Ryge & Chambers, 1980; Oldenburg, Vann & Dilley, 1985; Qvist, Thylstrup & Mjör, 1986; Tonn & Ryge, 1988; Qvist, Qvist & Mjör, 1990; Barr-Agholme & others, 1991; Welbury & others, 1991; Östlund, Möller & Koch, 1992; Kilpatrick, 1993). Conventional glass ionomer cements have shown failure rates between 20-30% after two years (Welbury & others, 1991; Östlund, Möller & Koch, 1992; Kilpatrick, 1993; Andersson-Wenckert, van Dijken & Stenberg, 1995; Holst, 1996). Data concerning the failure rate of polyacid-modified composite resins in deciduous teeth after two years is scarce. Andersson-Wenckert & others (1997) reported a cumulative failure rate of 22% in a multicenter study evaluating 104 restorations after two years. Assessment of 22 polyacid-modified composite resin restorations by Krejci & others (1998) revealed that no fillings required replacement. The retention rate of about 89% reported in this study appears to be comparable.

In the present study no significant differences were observed with respect to operator variability. This finding does not correspond to the observation of Andersson-Wenckert & others (1997), who reported a significant operator impact on the failure rate of the polyacid-modified composite resin investigated in their study, resulting in their conclusion that the material was technique-sensitive. The lack of impact of operator variability in this study may be due to improved handling characteristics or simplified techniques. Restorations in teeth with pulp amputation and fillings in the first primary molars failed more frequently than restorations in vital teeth and secondary molars, respectively. This may be related to the size of the restoration, with the assumption that pulp amputation occurs primarily in severely decayed teeth. In addition, the earlier eruption of first primary molars may expose them to greater caries activity than secondary primary molars. Therefore, in both non-vital and in first primary molars, restorations with greater dimensions may result compared to the average dimension of restorations in vital molars and second primary molars. The results of this investigation lend credence to the concept of using stainless steel crowns for treatment in non-vital primary molars and extended carious lesions (van Waes & Ben-Zur, 1989; Einwag & Dünninger, 1996).

Table 5: *Percentage of respective scores (Alfa - Delta) for the categories colour matching, cavosurface discoloration, anatomic form, margin integrity and caries assessment at baseline (B), one-year (1y) and two-year (2y) recall examination for restorations with TPH-Spectrum and Compoglass*

	Alfa			Bravo			Charlie			Delta		
	B	1y	2y	B	1y	2y	B	1y	2y	B	1y	2y
Color matching												
TPH-Spectrum	100	94	98	0	5	2	0	1	0	-	-	-
Compoglass	100	87	84	0	12	16	0	1	0	-	-	-
Cavosurface discoloration												
TPH-Spectrum	100	85	76	0	14	21	0	1	3	-	-	-
Compoglass	100	80	67	0	15	33	0	5	0	-	-	-
Anatomic form												
TPH-Spectrum	100	94	92	0	6	5	0	0	3	-	-	-
Compoglass	100	87	85	0	13	15	0	0	0	-	-	-
Margin integrity												
TPH-Spectrum	97	86	82	3	10	13	0	2	0	0	1	0
Compoglass	99	79	73	1	15	22	0	4	2	0	2	3
Caries assessment												
TPH-Spectrum	100	98	93	0	2	7	-	-	-	-	-	-
Compoglass	100	95	95	0	5	5	-	-	-	-	-	-

In this study, caries assessment was performed clinically. Had radiographs been utilized, the interpoximal gingival margin could have been evaluated for caries, which might have improved the accuracy of this assessment. However, with respect to the x-ray load, no additional radiographic examinations were applied. Moreover, because of the large number of radiographic examinations involved and some concern that parents' consent for participation in the study might have been impaired, radiographs were not used.

It was found that recurrent caries occurred with equal frequency for both materials. The polyacid-modified composite resin Compoglass was shown to act as a fluoride-releasing material (Attin & others, 1996), whereas the investigated composite TPH-Spectrum does not contain fluoride. The fluoride release of materials should hamper demineralization at cavity margins. However, the maximum fluoride release of polyacid-modified composite resins occurs within the first day after hardening, thereafter falling to a plateau (Attin & others, 1996; Friedl & others, 1997). Moreover, discussion is controversial as to whether polyacid-modified composite resins can be recharged with fluoride by applying topical regimes (Knop & Schiffner, 1997; Attin & others, 1999). Our results support the finding of Klimek, Ganss & Bünker (1997) that the amount of fluoride released from dental materials after a few days is insufficient to be cariostatically effective.

CONCLUSIONS

Both the hybrid composite TPH-Spectrum® and the polyacid-modified composite resin Compoglass® showed similar success rates after two years in deciduous molars. The polyacid-modified composite resin requires less treatment steps for application, which may offer advantages in treating the pediatric patient. However, further clinical studies are necessary to evaluate the long-term clinical behavior of this kind of material.

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Laboratory Research

Antibacterial Activity of Resin Adhesives, Glass Ionomer and Resin-Modified Glass Ionomer Cements and a Compomer in Contact with Dentin Caries Samples

M Herrera • A Castillo • M Bravo
J Liébana • P Carrión

Clinical Relevance

Using chlorhexidine as a positive control, this study demonstrated considerable variation in the antimicrobial effects of the materials tested.

SUMMARY

A total of 103 clinical samples of carious dentin were used to study the antibacterial action of different dental resin adhesive materials (Gluma 2000, Syntac, Prisma Universal Bond 3, Scotchbond Multi-Purpose and Prime&Bond 2.0) glass ionomer cements (Ketac-Cem, Ketac-Bond, Ketac-Silver, Ketac-Fil) resin-modified glass ionomer cements (Fuji II LC, Vitremer and Vitrebond) and a compomer (Dyract). The agar plate diffusion method was used for the microbial cultures and a chlorhexidine control. The growth of the caries-producing microorganisms was effectively inhibited by the Vitremer and Vitrebond cements, and to a lesser extent by the Scotchbond Multi-Purpose adhesive system. Overall, there were statistically significant differences in the antibacterial activity of the products tested.

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INTRODUCTION

The prevalence of dental caries can be considered one of the most important pathological processes in humans. Although industrialized countries show a reduced presence of caries, populations from less-developed nations still manifest a 100% prevalence of caries at age 24 (Rioboo, 1994). Among school-age children in Spain, dental caries ranges from 65% to 70%, whereas 98.8% of Spanish citizens over age 30 are affected (Noguerol & others, 1994).

Bacteria play a key role in caries development. Acidogenic bacteria are the first microorganisms to contribute to the evolution of dental caries. In the wake of their demineralizing action, a second bacterial colonization occurs, with a large number and variety of bacteria (van Houte, 1994). When caries samples are obtained for analysis, the types of bacteria present depend on the exact origin of the sample on the tooth surface, the availability of the substrate, the pH of the medium, the oxygen pressure and other factors (van Houte, Lopman & Kent, 1996). Anaerobic and proteolytic bacteria may be active in already-established dentin caries. The metabolic by-products of oral microbiota can also contribute to the advancement of dentin carious lesions (Baca & Liébana, 1995).

Besides affecting the evolution of dental caries, oral bacteria play a role in the problems that may arise after

Table 1: *Principal Components of the Resin Adhesive Agents Tested*

Material	Code	Principal components	Manufacturer
Gluma 2000 Primer	Gl-A	Oxalic acid, aluminum nitrate, glycine water	Bayer Dental, Leverkusen, Germany
Adhesive	Gl-B	MMI, Bis-GMA, 4-META, acetic acid, ethanol, water	
Syntac NY	Sy-A Primer	TEGDMA, maleic acid, acetone,	Vivadent, Amherst, water
Adhesive	Sy-B	TEGDMA, glutaraldehyde,water	
Prisma Universal Bond 3 Primer	P-A	2-HEMA, PENTA, ethanol	LD Caulk/Dentsply, Milford, Delaware
Adhesive	P-B	Bis-GMA,PENTA,2-HEMA, TEGDMA, urethane dimetacrylate, camphoroquinone	
Scotchbond Multi-Purpose Primer	Sc-A	2-HEMA, MMA polycarboxylic-copolymer acid, water	3M Dental, St Paul, MN
Adhesive	Sc-B	2-HEMA, Bis-GMA, photoactivators	
Prime&Bond 2.0	Pr	PENTA,TEGDMA, acetone, photoinitiators	Dentsply De trey, Konstanz, Germany

Table 2: *Principal Components of the Glass Ionomers, Resin-Modified Glass Ionomers and the Compomer Tested*

Material	Code	Principal composition	Manufacturers
Ketac-Cem	KC	F- aluminum silicate	ESPE/Premier, Norristown, PA
Ketac-Bond	KB	F- aluminum silicate	ESPE/Premier, Norristown, PA
Ketac-Silver	KS	F- aluminum silicate, Silver	ESPE/Premier, Norristown, PA
Ketac-Fil	KF	F- aluminum silicate	ESPE/Premier, Norristown, PA
Fuji II LC	F II LC	F- aluminum silicate, HEMA	GC International Corp
Vitremer			
Primer	VM-A	HEMA, carboxylic acid copolymer	3M Dental, St Paul, MN
Dental restorative cement	VM-B	F- aluminum silicate, HEMA	3M Dental, St Paul, MN
Gloss	VM-C	Ascorbic acid, hydrogen peroxide	
Vitrebond	VB	F- aluminum silicate, HEMA	3M Dental, St Paul, MN
Dyract	Dy	UDMA,TCB, glass strontium fluorosilicate	Dentsply De trey, Konstanz, Germany

restorative therapy, such as dental sensitivity or recurrent caries (Brännström, 1986). Two benefits are dervied from the clinical use of filling materials with an inhibitory action on microbial growth: antibacterial substances can extend the longevity of restorations, and they can help alleviate postoperatory discomfort.

Meiers and Miller (1996), in an *in vitro* study, mentioned the complex synergic interactions of dentin caries microbiota and called for research based on clinical samples. This was the basis for this study, testing the inhibitory potential of several materials against bacteria present in samples of carious dentin lesions.

METHODS AND MATERIALS

The antibacterial activity of resin adhesives (Gluma 2000, Syntac, Prisma Universal Bond 3, Scotchbond Multi-Purpose, and Prime Bond 2.0) glass ionomer cements (Ketac-Cem, Ketac-Bond, Ketac-Silver, Ketac-Fil) resin-modified glass ionomer cements (Fuji II LC, Vitremer, and Vitrebond) and a compomer (Dyract) were tested. Systems involving more than one substance (eg, primer and adhesive) were broken down by components for analysis. Tables 1 and 2 indicate the basic composition of the products tested.

Samples

Microorganisms were obtained from carious dentin in 103 patients treated at the University of Granada School of Dentistry between January and June of 1997. The same criteria were consistently applied for the sampling procedure: only carious teeth without external evidence of cavitation were used. Using a rubber dam to avoid salivary contamination, each tooth was cleaned with a prophylaxis brush to remove bacterial plaque; then an antiseptic (5% chlorhexidine) was applied to the crown. All tools, including handpieces, burs and spoons, had been previously sterilized in an autoclave at 120°C for 15 minutes. Each of the 103 dentin caries samples was taken using a spoon and placed independently in tubes containing regenerated cooked-meat medium (Becton Dickinson & Co, Franklin Lakes, NJ 07417), then quickly transferred to the laboratory where they were incubated in an anaerobic atmosphere at 36±1°C for 72 hours.

Method

The agar plate diffusion procedure (Tobias, 1988; Prati & others, 1993; Meiers & Miller, 1996) was used to observe the antibacterial activity of the selected materials. A standardized inoculum of the 103 samples was prepared from the cooked-meat medium in a sterile isotonic saline solution with a turbidity scale compatible with a 0.5 concentration as developed by Mac Farland. (This scale allows the bacterial concentration of a suspension to be estimated by its turbidity; 0.5 corresponds to a concentration of 1.5 x 10^8 at an optic density of 550 nm.) Then, 150 µL of the inoculum was evenly distributed over the surface of each Petri dish (15 cm in diameter) containing a 4 mm layer of brain-heart infusion agar (BHI 0418-01-5; Difco Laboratories, Detroit, MI 48232).

Using the blunt end of a sterile Pasteur pipette, 6 mm diameter wells were made in the agar surface. Viscous materials were prepared according to manufacturers' instructions and deposited immediately in the agar wells until completely filled. The wells containing Fuji II LC, Vitrebond, Vitremer and Dyract were light cured for 40 seconds, using a polymerization lamp (Heliolux 533505; Vivadent, Schaan, Liechtenstein).

In order to test the activity of the liquid products, 6 mm diameter sterile paper disks (54991 Disques non imprégnés; bioMérieux SA, Marcy l'étoile, France) were placed on the agar surface using sterile tweezers, and 10 µL of the liquid substance was added. The disks were then light cured for 20 seconds.

As the positive control, a 0.2% chlorhexidine aqueous solution was applied on paper disks.

Due to the number of products tested, two plates were used for the solid products, and a separate plate was used for the liquid products in conjunction with each dentin sample.

The plates were incubated in an anaerobic atmosphere for 48 hours at 36±1°C. The experiment was repeated three times to confirm the homogeneity of the results. Variation was minimal (results not shown), and the mean of the three inhibition zones, rounded off to the nearest millimeter, was used for statistical analysis. Zones measuring 10 mm or more were recorded as positive (Herrera & others, 1999). For each product, we calculated: (a) the average diameter of the positive

Table 3: *Antibacterial Activity of the Restorative Materials Exposed to Dentinal Caries Microorganisms*

Product	Positives n (%)	Diameter (mm.) of Inhibition[a] $\bar{x}$±sd[b]	Comparison of % Values[c]
Dyract	0 (0.0%)		
Gluma 2000 B	0 (0.0%)		
Prime&Bond	0 (0.0%)		
Prisma Universal Bond A	1 (1.0%)	10.0±0.0	
Ketac-CM	2 (1.9%)	10.0±0.0	
Gluma 2000 A	3 (2.9%)	10.7±1.2	
Ketac-Silver	5 (4.9%)	10.0±0.0	
Ketac-Bond	14 (13.6%)	10.4±1.2	
Ketac-Fil	29 (28.2%)	10.6±0.9	
Vitremer C	31 (30.1%)	12.9±1.2	
Vitremer A	36 (35.0%)	14.1±1.2	
Syntac B	36 (35.0%)	10.2±0.4	
Prisma Universal Bond B	40 (38.8%)	11.2±1.4	
Fugi II LC	43 (41.7%)	10.8±1.1	
Syntac A	43 (41.7%)	11.1±1.7	
Scotchbond MP B	53 (51.5%)	14.9±4.7	
Scotchbond MP A	64 (62.1%)	12.8±3.0	
Vitrebond	102 (99.0%)	19.3±6.4	
Vitremer B	103 (100.0%)	16.2±0.9	
Chlorhexidine	103 (100.0%)	15.3±2.7	

a Calculated only from positive samples.

b $\bar{x}$: arithmetical mean, sd: standard deviation.

c Global comparison: Cochran test: Q=1002 (19 df), $p<0.001$.
Comparison by pairs: McNemar test, after Bonferroni correction for 190 comparisons; percentages that are not statistically significant ($p>0.05$) are joined by a line. For example, Vitrebond is not significantly different from Vitremer B, but is different from Scotchbond MP A.

zones produced, and (b) the mean and standard deviation of the positive zones. The overall percentage of positive inhibition zones (>10 mm) were then compared for the 20 products using the Cochran test. The McNemar test was used for comparison by pairs, after Bonferroni correction for 190 comparisons [(20x19)/2] (Altman, 1991).

RESULTS

Table 3 provides the results of the antibacterial activity of the different materials, expressed as a percentage of positive (>10 mm) results, and mean diameter (± standard deviation) of the positive inhibition zones.

Chlorhexidine was clearly inhibitory in all the assays, producing an average inhibition zone of 15.3±2.7 mm. Vitremer cement also showed activity in 100% of the assays, but with slightly greater inhibition zones (mean of 16.2±0.9 mm). Although Vitrebond was not positively inhibitory in all instances (99%), it gave the highest value for the mean diameter of its positive inhibition zones (19.3±6.4 mm).

Of the adhesive materials tested, Scotchbond Multi-Purpose Primer (A) exhibited the highest percentage of antibacterial activity (62.1%), producing zones with a mean diameter of 12.8±3.0 mm. Scotchbond MP adhesive (B) gave a somewhat lower percentage of positives (51.5%), yet a slightly greater mean for the zones produced (14.9±4.7 mm).

The compomer Dyract, the adhesive Prime&Bond and the adhesive component of the Gluma 2000 system all failed to inhibit bacterial growth (0.0% positive results). Prisma Universal Bond primer, Ketac-Cem, Gluma 2000 primer and Ketac-Silver showed very limited antibacterial action, with no statistically significant differences among their respective effectiveness.

DISCUSSION

No standardized methodology has been established to date for studies such as ours, though a variety of procedures have been proposed (Tobias, 1988; Meryon & Johnson, 1989; Loyola-Rodríguez, García-Godoy & Lindquist, 1994). We chose the agar plate diffusion method because it allowed us to test both the soluble and the insoluble substances selected for study (Orstavik, 1985).

Resin adhesives, glass ionomer and resin-modified glass ionomer cements and compomers are all widely used in restorative dentistry today. Previous studies have described their adhesive properties (Triolo & Swift, 1992; Staninec & Kawakami, 1993; Perdigão & Swift, 1994) and antibacterial capacity (Scherer, Lippman & Kaim, 1989; Emilson & Bergenholtz, 1993; Fraga, Siqueira & de Uzeda, 1996). For this study, third-, fourth- and fifth-generation adhesives were compared, along with chemically-cured and light-cured glass ionomer cements and the compomer Dryact, whose antibacterial potential has not been established in *in vitro* studies. Chlorhexidine was chosen as the positive control because of its widespread clinical use, plus it serves as a common point of reference for comparisons with other studies (eg, Emilson & Bergenholtz, 1993).

Previous research has focused on a variety of bacterial strains, mostly of international reference (DeSchepper, White & von der Lehr, 1989; Emilson & Bergenholtz, 1993; Loyola-Rodríguez & others, 1994; Fischman & Tinanoff, 1994; Costa & others, 1996). Eli and others (1995) hypothesized that the inhibitory capacity of dental materials may show variations even when testing with strains of international reference. These authors isolated *Streptococcus mutans* from dentinal caries lesions and included a second sample of this strain from an international collection, yet obtained similar results from the two samples.

Meiers and Miller (1996) point out the difficulties involved in extrapolating *in vitro* results to clinical environments because of the complex interactions of oral microbiota. Our results suggest that the clinical effectiveness of the tested materials may vary considerably with regard to antibacterial action.

Of the 20 distinct substances tested, chlorhexidine, Vitremer cement and Vitrebond presented the greatest percentages of positive inhibition zones, with no statistically significant differences among the action of the three. Similarly high levels of effectiveness were reported for Vitremer and Vitrebond by previous authors (Scherer & others, 1989; Palenik & others, 1992; Prati & others, 1993), though in pure cultured bacteria.

Fuji II LC and Ketac-Fil exhibited moderate action in our assays: less inhibitory than Vitrebond and Vitremer, yet more active than the other glass ionomer cements, with statistically significant differences ($p>0.05$) from both groups.

The Scotchbond Multi-Purpose adhesive, whose inhibitory action had previously been confirmed in conjunction with S. mutans by Imazato and others (1997), was shown in our assays to have the best antibacterial capacity of the five adhesive agents tested, proving effective in 51.5% of the cases. The Syntac adhesive was the second most effective in 35% of the tests. No statistically significant differences were found between the inhibitory action of these two products, however.

It is beyond the scope of this study to theorize which specific components (fluoride, acid, etc) may enhance or reduce the antibacterial potential of restorative materials. Other authors have offered a variety of interpretations (Felton, Bergenholtz & Cox, 1989; Emilson & Bergenholtz, 1993; Loyola-Rodríguez & others, 1994;

Fraga & others, 1996; Meiers & Miller, 1996). Our aim is to provide a point of reference for clinical professionals concerning which products are most effective from a microbiological standpoint.

CONCLUSIONS

We concluded that Vitremer, Vitrebond and Scotchbond Multi-Purpose cements afford antimicrobial benefits.

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The Use of Resin Composite Pins to Improve Retention of Class IV Resin Composite Restorations

HW Roberts • CB Hermesch • DG Charlton

Clinical Relevance

The use of an intracoronal resin composite pin may improve the retention of Class IV resin composite restorations.

SUMMARY

This study evaluated the effect of an intracoronal resin composite pin on Class IV resin composite restorations. A control group of 16 bovine teeth was prepared with standardized conventional Class IV preparations. For an experimental group, 16 similar Class IV preparations were made, with the addition of an intracoronal pin channel prepared with a #330 bur into the dentin. All specimens were restored with Herculite XRV and OptiBond according to the manufacturer's recommendations. After one week, specimens were placed in an Instron Universal Testing Machine and loaded at 90 degrees to the long axis until the restorations failed. Results indicated that the mean fracture load of the Class IV restoration group, with the resin composite pin, was 36% higher than the conventional Class IV group (p=0.02). An intracoronal resin composite pin may aid the retention and resistance form of complex resin composite restorations.

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INTRODUCTION

The development of the enamel bonding technique ushered in a new era of anterior tooth restoration. Although strong enamel-resin and comparable dentin-resin bonds are now possible, it has been reported that clinicians are occasionally faced with retention problems in restoring complex Class IV composite restorations (Potoky & Rothfuss, 1993; Browning & Dennison, 1996). Browning and Dennison (1996) reported that Class IV composite restorations fail up to 50% more frequently than Class III restorations. This same report indicated that even with current dentin bonding technology, over a third of Class IV resin composites were replaced at three years or less. The overall median age of Class IV resin composite restorations was only five years, compared to 10 years for Class III restorations. A survey of 42 American dental schools revealed that some schools treatment-plan indirect porcelain laminate or direct composite veneers as an alternative to large Class IV restorations (Potoky & Rothfuss, 1993).

Several clinicians have advocated intracoronal metal pins to assist in the retention of large Class IV restorations (Janis & Lugassy, 1972; Redtenbacher, 1975; Baum, Phillips & Lund, 1981; Sturdevant & others, 1985; Federick, 1987; Tjan, Dunn & Grant, 1992). With the development of reliable dentin bonding, however, the routine use of metal pins with resin composites was largely discontinued due to improved retention, poor esthetics of the pin and concerns for leakage (Chan, Chalkey & Reinhardt, 1980; Mount & Hume, 1998). Interestingly, Nasedkin (1998) has recently advocated both titanium (Filpin; Filhol Dental USA, Baltimore, MD 20218) and TMS (Brasseler USA, Savannah, GA 31419) pins to augment the retention and resistance of complex resin composite restorations.

To enhance the retention and resistance of extensive amalgam restorations, it has been reported that intracoronal preparation features in the form of slots or grooves are equivalent to intracoronal metal pins (Outhwaite, Garman & Pashley, 1979). The use of the amalgapin, another intracoronal retention feature with amalgam, has also been described (Shavell, 1986). Using intracoronal preparation features has been investigated (Summit, Chan & Dutton, 1993) for use with Class III resin composite restorations; however, no documentation exists for using intracoronal preparation features (other than metal intracoronal pins) for the retention of Class IV resin composite restorations. This study investigated the effect of intracoronal resin composite pins on the retention of Class IV resin composite restorations.

METHODS AND MATERIALS

Bovine maxillary incisor teeth were extracted from freshly slaughtered cattle and placed in 2% formalin solution. The teeth were debrided of all soft tissue, and all enamel surfaces were cleaned with nonfluoride pumice-water slurry with a slow-speed rubber cup. Teeth were randomly placed in two groups: Group 1)16 bovine teeth with a traditional Class IV composite preparation (control group), and Group 2)16 bovine incisors with a Class IV preparation and a pin channel placed into the dentin 1 mm from the dentinoenamel junction using a #330 bur in a high-speed handpiece with water spray. The technique for placing the pin channel followed the guidelines described by Roddy and others (1987). The resultant pin channel was approximately 0.8 mm in diameter by 1.0 mm deep (Figure 1). All enamel margins of the preparation were prepared with a 1 mm-wide, 45-degree bevel. One operator prepared the teeth to standardize as much as possible the preparation dimensions (3 mm in mesiodistal width by 4 mm in incisal-gingival height). The preparations were restored with Herculite XRV (Kerr Corp, Orange, CA 92867) with the OptiBond bonding system (Kerr Corp). The manufacturer's recommendations for material application and curing were followed. The dentin-bonding agent was applied with a brush, paying particular attention to the pin channel to avoid trapping air. After polymerization of the dentin-bonding agent, the resin composite was first placed into the pin channel with a flat-sided instrument and lightly condensed to avoid air entrapment. All preparations were restored with the resin composite in layers of 2 mm or less, and each layer was light cured for 40 seconds using a visible-light curing unit (Optilux 401; Demetron Research Corp, Danbury, CT 06810). The adequacy of the light unit's intensity was assessed immediately prior to use with a hand-held radiometer (model 100; Demetron Research).

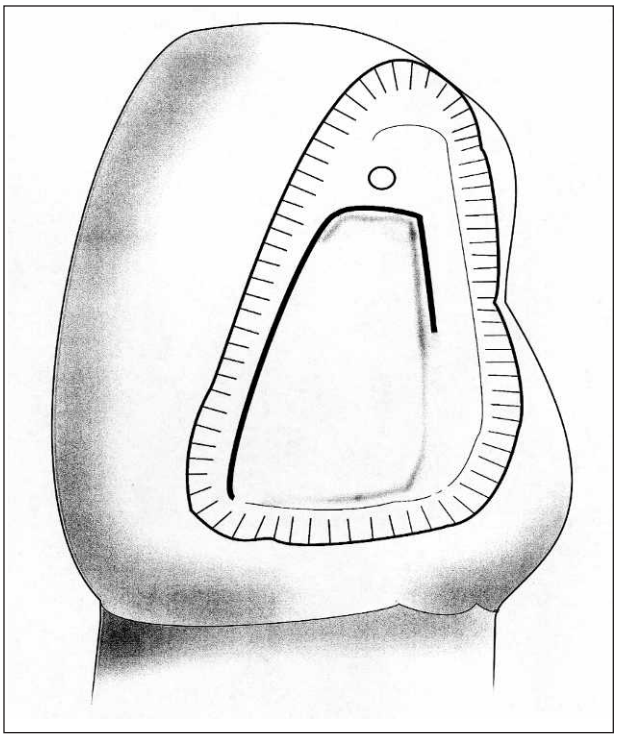

Figure 1.

The restorations were immediately finished with Sof-Lex disks (3M Dental Products, St Paul, MN 55144), then acid etched and glazed with OptiGuard (Kerr Corp). The restored teeth were stored in distilled water until they were prepared for testing.

The roots of the teeth were notched and placed in auto-polymerizing acrylic resin (LD Caulk/Dentsply, Milford, DE 19963). A small dimple was placed approximately 2 mm apical to the incisal edge on the lingual surface of the restoration with a 12-fluted carbide finishing bur in a high-speed handpiece to accommodate the testing apparatus. The samples were mounted in an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021), and the restorations loaded from the lingual surface at a 90-degree angle to the long axis

of the tooth at a crosshead speed of 0.5 mm/minute until the restoration or tooth fractured. Because an analysis of the data revealed that the groups had non-homogeneous variances, a two-sample *t*-test for data with unequal variances was used to determine if a significant difference existed between the group means at the 0.05 level of significance.

RESULTS

The fracture loads for the Group 1 specimens (teeth with conventional Class IV preparations) ranged from 23 to 133 newtons, with a mean of 71.2 ± 28.9 newtons). The fracture loads for the Group 2 specimens (teeth with Class IV preparations and a resin composite pin channel) ranged from 55 to 166 newtons, with a mean of 96.5 ± 33.1 newtons). The mean fracture load of teeth with the resin composite pin channel was significantly greater (p=0.02) than that of the teeth without the pin channel. One Group 1 specimen and four Group 2 specimens fractured within the root during testing and were not included in the data set.

DISCUSSION

The use of a resin composite pin in Class IV resin composite restorations significantly increased their resistance to dislodgment. This finding may have some significant clinical implications. Class IV preparations that are particularly large or have reduced or thin enamel may benefit from the use of resin composite pins. Such pins are esthetic, easy to place and do not require additional armamentarium to use. They also offer a less costly alternative to ceramic or metal-ceramic restorations. While these latter restorations may be preferred in the long run, a composite pin-retained resin composite restoration may be indicated for Class IV fractured anterior teeth in children and teenagers.

It is assumed that the composite pin-retained Class IV resin composite restorations in this study exhibited greater resistance to dislodgment than non-pin-retained restorations because the pin created mechanical interlocking into dentin and modestly increased the dentin surface available for bonding. As with any mechanical retentive feature, however, the composite pin sacrifices some healthy dentin. This fact may account for the higher incidence of root fracture observed in the composite pin group.

There was relatively high variability of the within-group data. The coefficient of variation (obtained by dividing the standard deviation by the mean) for the pin-retained and non-pin-retained groups was 41% and 34%, respectively. Higher variability is expected when preparations are made under standard clinical conditions without using precision milling equipment.

Bovine dental samples were used in this study due to the lack of available human incisor specimens. Investigators (Nakabayashi, Ashizawa & Nakamura, 1992; Burrow & others, 1996a; Burrow, Satoh & Tagami, 1996b; Miyazaki & others, 1997; Chan & others, 1997) have utilized bovine teeth for bonding studies, while some researchers (Nakabayashi & others, 1992; Fowler & others, 1992; Barkmeier & Erickson, 1994) have indicated that bovine bond strengths are comparable to human dentin. Using bovine teeth did, however, facilitate the use of a #330 bur for pin channel placement. The use of a #330 bur with human incisors may not be possible because of their smaller size. Burs such as 1/4 or 1/2 round may be more appropriate, and future studies should be performed to evaluate their effect in providing retention. As always, the direct transfer of laboratory findings to clinical practice warrants a degree of caution. The replication of these findings in human teeth is necessary before widespread clinical use can be recommended.

CONCLUSIONS

Under the conditions of this study, composite pins significantly increased the resistance to dislodgment of Class IV resin composite restorations.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

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Effect of Sealant Viscosity on the Penetration of Resin into Etched Human Enamel

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Clinical Relevance

High viscosity sealants tested did not penetrate far enough into etched enamel to reach the depth of acid etching which may affect their ability to maintain good marginal seals.

SUMMARY

This study was designed to investigate the relationship between the etched depth, penetration of sealants and marginal seal. Sixty unerupted lower first premolars extracted from patients for orthodontic reasons were thoroughly cleaned and stored in an antiseptic Ringer's solution at 4°C. A "window" on the occlusal of 15 of the premolars, including both mesial and distal pits, was developed by painting nail varnish around the border of the occlusal surfaces. Etching was then done with 35% phosphoric acid for 60 seconds to all 60 premolars.

Five of the "window" teeth were evaluated by microradiography to determine the etched depth of the superficial and subsurface enamel. Five were prepared for SEM analysis to observe the change of the superficial etched enamel surface. Another five "window" teeth were embedded in epoxy resin and sectioned parallel to the long axis of the tooth through the fissures in order to observe the subsurface depth of the etch by SEM analysis. The other 45 teeth were divided into three groups of 15 teeth each. Fissures of each group of teeth were sealed using Prisma-Shield (LD Caulk), Concise White Sealant (3M Dental Products) or Teethmate A (Kuraray) sealants and stored in water (37°C) for 24 hours. They were then sectioned and demineralized before being examined by a scanning electron microscope. Photographs of secondary electron image (SEI) were done to gradate the resin-infiltrated enamel and resin tags for these sealants. After SEM observation, the 15 samples of each applied sealant were polished to a high gloss again and placed in a silver nitrate solution for 24 hours before being examined under the SEM equipped with a back-scatter electron detector. Data were then analyzed using the Welch and Student *t*-tests.

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Results showed that fissured enamel of unerupted human lower first premolars became porous after etching with 35% phosphoric acid. The low viscosity sealant Teethmate A (approximately 260 mPa.s), penetrated fully and formed a resin-infiltrated layer in enamel beyond the etched depth. However, the high viscosity sealants (Prisma-Shield and Concise White Sealant) did not penetrate enough to ensure that the acid-etched enamel was infiltrated sufficiently by the sealant to insure good marginal seals.

INTRODUCTION

In 1955, Buonocore reported that autocuring acrylic resin adhered to enamel surfaces that were etched with phosphoric acid. This method has been used in dental practice ever since. Cueto and Buonocore (1965) applied the technique of enamel etching to fissure sealants, which is now widely used in dentistry. Many studies of fissure sealants have reported good short-term caries prevention results (Silverstone, 1982; Ripa, 1985). However, long term observations (seven to 10 years) showed a decrease year after year, thereby allowing development of new dental caries where loss of the sealant had occurred (Simonsen, 1987; Wendt & Koch, 1988).

In unsealed, etched enamel and enamel which has lost its sealant, increased caries susceptibility has been reported (Buonocore & others, 1968; Silverstone, 1977; Hicks & Silverstone, 1982). Results showed that acid-etched enamel had a higher solubility rate than sound enamel. In teeth that had been etched and sealed, removal of the sealant resulted in a surface less soluble than sound enamel. Retained resin tags in the abraded enamel were considered responsible for the increased resistance to acid dissolution. Since the development of several functional monomers, resins which possess both low viscosity and excellent wetting properties have been recommended for dental use. Dogon (1975) and Ten Cate (1975) found that tag distribution and length increased as the viscosity of the resin decreased. Adhesion of sealants to etched enamel has improved (Nakabayashi & others, 1978). However, over time, sealants undergo abrasive wear. Some manufacturers have added filler particles to their sealants to increase wear and abrasion resistance. This increases the viscosity of the sealant, which then lowers its penetration coefficient. This is an important property of the sealant (surface tension, viscosity and contact angle on the capillary wall) as well as its ability to penetrate into porous enamel via capillary forces, surface energy, surface tension, etc (Fan & others, 1975). However, it does not seem to lower sealant retention (Stephen & others, 1983). It increases wear resistance (Strang & others, 1986). It can be assumed that the sealant should penetrate reliably into the etched enamel, rendering the etched region beneath the sealant less prone to demineralization or caries attack in the event of sealant loss.

This study investigated the effect of viscosity on the penetration of sealants into etched enamel by morphological observation of the resin-infiltrated enamel at the enamel-sealant interface.

METHODS AND MATERIALS

A total of 60 experimental teeth were selected from patients aged 10.8±0.55 years. These were extracted lower first premolars lost due to orthodontic treatment. All teeth were unerupted and had no clinical cracks, white spots or hypoplasia that might affect acid-resistance. They were stored at 4°C in a preservative solution, antiseptic in Ringer's solution, (Daiichi Yakuhin, Tokyo, Japan) for no longer than three weeks prior to their use. The whole crown of each tooth was cleaned with a Robinson's brush under water for 30 seconds. Pits and fissures were cleaned for 90 seconds with a #6 K-file (Matsutani, Tochigi, Japan) attached to an ultrasonic instrument (modified ENAC type 3, Osada Electric, Tokyo, Japan). This was done in conjunction with GK-101 (0.05% N-monochloroglycine) solution (Kuraray, Osaka, Japan), which chemically removes carious dentin (Goldman & Kronman, 1976). The sealants studied were A (Prisma-Shield, L D Caulk, Milford, DE 19963), B (Concise White Sealant, 3M Dental Products, St Paul, MN 55144) and C (Teethmate A, Kuraray, Osaka, Japan). The viscosity of the sealants in centipoise units (mPa.s) was determined using an ultrasonic vibratile viscometer (Viscomate VM-1A-L, MH, Yamaichi Electric, Tokyo, Japan) at room temperature (24°C). Centipoise units are equal to 100 centimeter-gram-second units of dynamic viscosity. Ten samples were evaluated by the viscometer to determine the mean viscosity of each sealant.

After cleaning, a window was formed by painting nail varnish around the mesial and distal pits of 15 teeth, five each for surface SEM analysis, microradiography evaluation and subsurface SEM analysis of the depth of the enamel etch. The area within the window was etched by laboratory-made 35% phosphoric acid solution for 60 seconds, then the nail varnish was removed with acetone.

Microradiographic Observation

To measure the etched depth of the superficial and subsurface enamel, five teeth were prepared for contact microradiography as follows: faciolingual sections parallel to the long axis of each tooth about 300µm thick were cut with a low-speed saw (Isomet, Buehler Ltd, Evanston, IL 60204). These sections were ground and polished to 30 µm thickness using waterproof carbide paper from 800 to 2000 grit lapping film (12.0, 9.0, 3.0µm). The sections were then carefully dried and exposed to soft X-rays at 11 KV and 5 mA (SRO-M50C, Sofron, Soken, Tokyo, Japan) for 66 minutes. The film-focus distance was 55

mm. The film (Spectroscopic safety film, Type No. 649-0, Kodak, Tokyo, Japan) was in contact with the specimen and developed for five minutes at 20°C (Developer D-19, Kodak, Tokyo, Japan), rinsed with tap water and fixed for 10 minutes at 20°C (Fujifix, Fuji photo film, Tokyo, Japan). Microradiographs were scanned with a color image scanner (GT-1000, EPSON, Nagano, Japan) to gradate the radiographic density. This technique was used to determine any correlation between surface morphology identified by scanning electron microscopy (SEM) and histologic changes seen by microradiography. Ten measurement points, superficial-etched depth and radioparency depth in 10 sections from the five teeth, were measured using a personal computer (PC-286L, EPSON, Nagano, Japan). Gradation was accomplished by determining the distance from the baseline of normal enamel to the bottom of the etched enamel by gradation in color using a N88BASIC program (EPSON, Nagano, Japan). Superficial etching in this context was the obvious loss of tissue not including the morphologic and histologic change in enamel which comprised the floor of the etched area. Subsurface etching was the morphologic and histologic change in enamel beneath the superficial etched area. The baseline of normal superficial enamel in the non-etched region was clear. The top and bottom of the baseline of the subsurface etched enamel was judged by gradation of color.

Figure 1. *Microradiograph of the region of the fissured enamel etched with 35% phosphoric acid solution for 60 seconds. Shows loss of superficial enamel and a radioparency zone in the underlying enamel.*

Scanning Electron Microscopic Observation

Five teeth were sputter-coated with gold (IB-3 Ion Coater, Eiko Engineering, Ibaragi, Japan) for three minutes at 2.5 mA to observe the change of the superficial enamel surface under the scanning electron microscope (SEM)(JSM-6400FX, JEOL, Tokyo, Japan) at 3KV.

Another five teeth were prepared for observation and measurement of the superficial and subsurface characteristics of the etched enamel. Electroconductive carbon tape (Nisshin EM, Tokyo, Japan) was affixed on the occlusal surface, then embedded in epoxy resin (Epomount, Refine-tech, Yokohama, Japan). Faciolingual samples were sectioned parallel to the long axis of the tooth through the pits using a low-speed saw, then ground and polished to a high gloss with waterproof carbide paper from 800 to 2000 grit and alumina powder (1.0, 0.3, 0.05μm). Polished surfaces were sputter-coated with gold for three minutes at 2.5 mA and observed under the SEM at 3KV.

Photographs of secondary electron images (SEI) were scanned with the color image scanner to gradate contrast. Ten measurement points, superficial etched depth and subsurface etched depth in 10 sections of five teeth, were measured using the personal computer previously described.

Observation of the Enamel-Sealant Interface

After cleaning, pits and fissures were etched for 60 seconds with a 35% phosphoric acid solution followed by rinsing with water. Sealant A, B and C were applied to 15 teeth, each, allowed to stand for 60 seconds, then light cured by a visible light, 400 ~ 500 nm, (Quick light, Kuraray, Osaka, Japan) for 20 seconds. After curing, all samples were kept at room temperature for 30 minutes, then placed in water (37°C) for 24 hours. They were then dehydrated in a series of ascending alcohol concentrations and embedded in epoxy resin. Four 3-millimeter thick faciolingual sections parallel to the long axis of each tooth through the mesial and distal pits were obtained using the low-speed saw. These sections were then ground and polished to high gloss with waterproof carbide paper from 800 to 2000 grit and alumina powder (1.0, 0.3, 0.05μm). The polished surfaces were immersed in 40% phosphoric acid gel (K-etchant, Kuraray, Osaka, Japan) for 15 seconds to etch away

Table 1: *Etched Depth with 35% Phosphoric Acid Solution for 60 Seconds (μm)*

Observation	Measurement Points	Superficial Enamel			Subsurface Enamel		
		Mean	S.D.		Mean	S.D.	
Microradiograph	100	10.6	1.0	*	15.6	1.0	*
SEI	100	11.4	1.5		15.1	1.8	

*: $p<0.05$, according to Welch *t*-test.

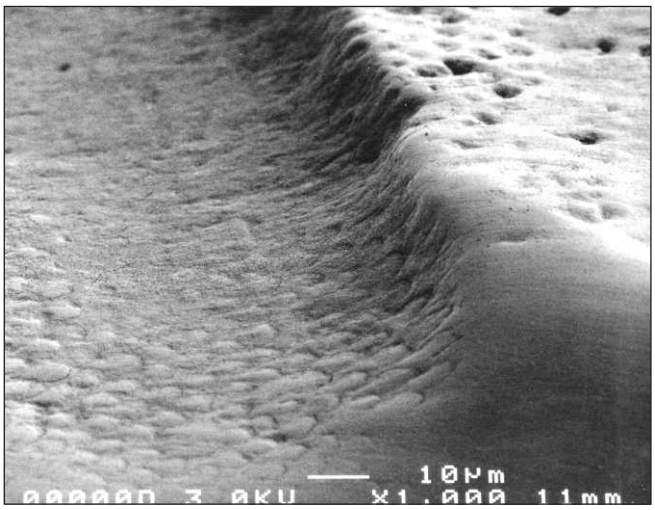

Figure 2. *Secondary electron image of superficial enamel etched with 35% phosphoric acid solution for 60 seconds. Shows loss of superficial enamel and an etching pattern in which the prism peripheries have been removed preferentially.*

any enamel mineral components not protected by sealants, rinsed and sputter-coated with gold for three minutes at 2.5 mA before being observed under SEM at 3KV.

Photographs of SEI were scanned with the color image scanner to gradate the resin-infiltrated enamel and resin tags. Ten measurement points of the resin-infiltrated enamel and resin tags in each sample were measured using the N88 Basic Measurement program as was done for the other sections.

Observation Beneath the Enamel-Sealant Interface (Silver Nitrate Staining)

After SEM observation of the enamel-sealant interface, the samples were polished to high gloss again, as previously outlined, and placed in a silver nitrate solution (25% by weight) for 24 hours (Wu & others, 1983; Wieczkowski & others, 1992; Sano & others, 1994a, 1994b). They were then rinsed in tap water and immersed for eight hours in photographic developing solution (Korectol, Fuji photo film, Tokyo, Japan) under fluorescent light. Samples were rinsed in tap water to remove the developing solution, then sputter-coated with gold for three minutes at 2.5 mA and observed under the SEM equipped with a back-scatter

Table 2: *Source and Viscosity of the Sealants*

	Sealant: Trade Name	Manufacturer	Viscosity (mPa.s) Mean	S.D.
A	Prisma-Shield	Caulk	9380	1.0
B	Concise White Sealant	3M	562	0.6
C	Teethmate A (red)	Kuraray	265	0.7

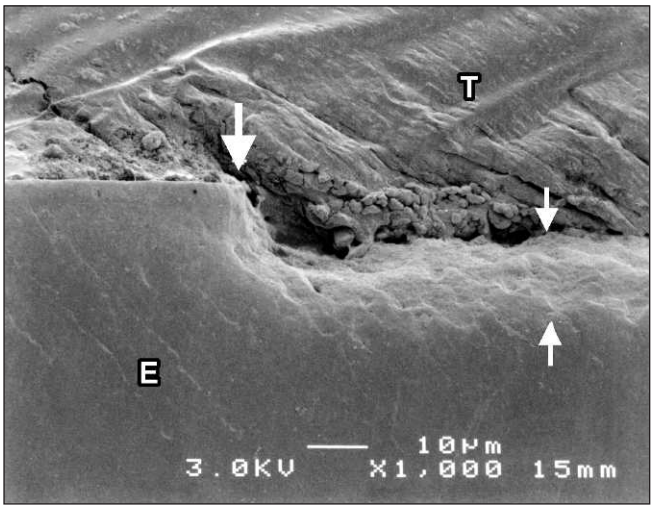

Figure 3. *Secondary electron image of superficial etched zone and subsurface etched zone.*
(E = enamel, T = tape, ↓ = border line, →← = rougher region)

electron detector (JSM-5300LV, JEOL, Tokyo, Japan) at 20 KV.

Statistics

Data were analyzed using the Welch and Student *t*-tests at $p<0.05$ level of significance.

RESULTS

Depth of Etching of Fissured Enamel

The etched depth with 35% phosphoric acid solution for 60 seconds is presented in Table 1. A microradiograph showing the loss of superficial enamel and a greater radioparency zone than underlying enamel is shown in Figure 1. Superficial etched depth was approximately 9-12µm (10.6±1.0µm, Mean±S.D.) and the radioparency depth was approximately 14-17µm (15.6±1.0µm, Mean±S.D.). From SEI, Figure 2 shows the loss of superficial enamel and the etching pattern from which the prism peripheries had been removed preferentially. Figure 3 shows the loss of superficial enamel and a rougher and whiter zone than underlying enamel. The superficial etched depth was approximately 8-13µm (11.4±1.5µm, Mean±S.D.) and the subsurface etched depth was approximately 12-18µm (15.1±1.8µm, Mean±S.D.).

The etched depths of microradiographic and SEM observations were found to be significantly different ($p<0.05$). However, both observation methods showed a similar state for etched enamel.

Resin-Infiltrated Enamel of the Enamel-Sealant Interface

Resin-infiltrated enamel or the so-called resin-impregnated layer and resin tags were found in the adhesive interface between the fissured enamel and the sealant. The resin-infiltrated enamel consisted of two layers;

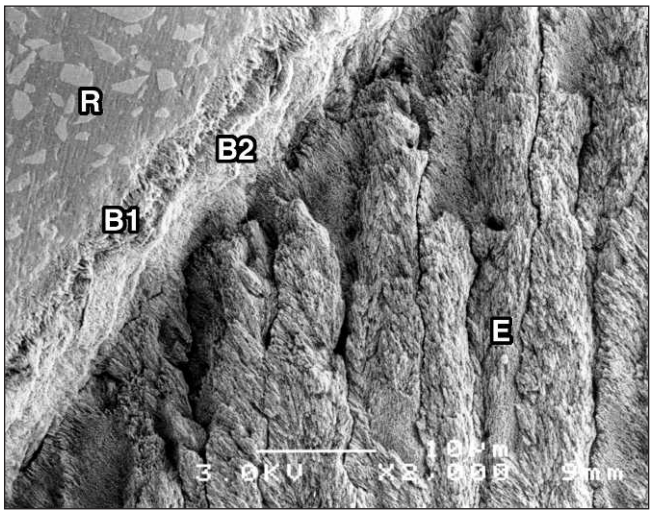

Figure 4. *Secondary electron image of the adhesive interface between the fissured enamel and Sealant A. A resin-infiltrated enamel layer, approximately 6 µm in width, is shown. Resin tags were not formed.*
(E = enamel, R = sealant, B1 = upper half layer, B2 = lower half layer)

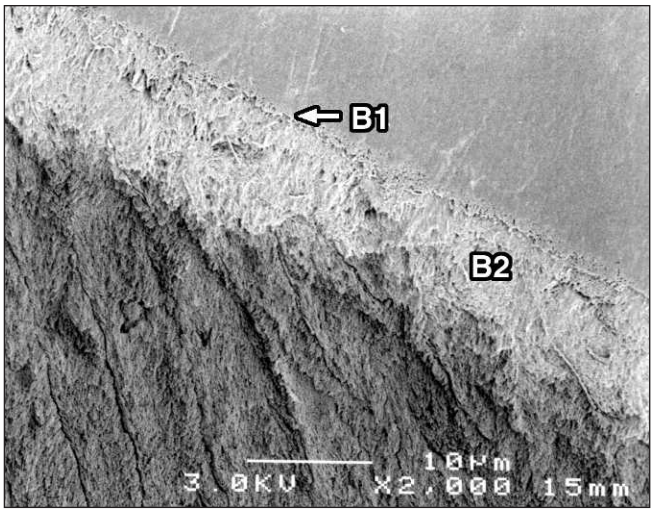

Figure 5. *Secondary electron image of the adhesive interface between the fissured enamel and Sealant B. A resin-infiltrated enamel layer, approximately 10 µm in width, is shown. Resin tags were not formed.*
(E = enamel, R = sealant, B1 = upper half layer, B2 = lower half layer)

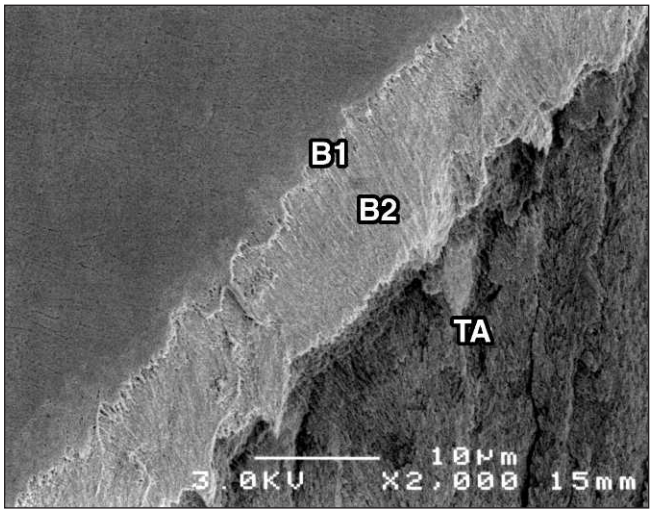

Figure 6. *Secondary electron image of the adhesive interface between the fissured enamel and Sealant C. A resin-infiltrated enamel layer, approximately 13 µm in width, and a 6 µm resin tag are shown.*
(B1 = upper half layer, B2 = lower half layer, TA = resin tag)

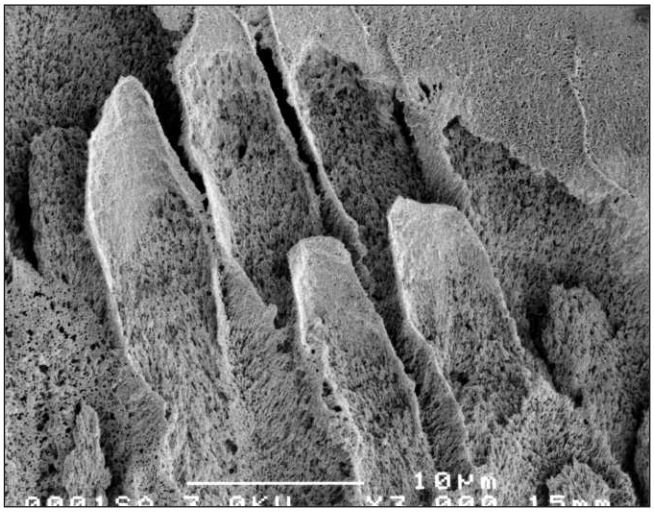

Figure 7. *Secondary electron image of the resin-infiltrated enamel and resin tags. Resin tags are difficult to measure when an oblique cutting pattern of the enamel rods is used.*

one situated on the upper half (B1), and the other situated on the lower half (B2). The resin tags (TA) projected into the enamel from B2.

There were differences in the appearance of sealant penetration in Sealant A, Sealant B and Sealant C. The mean viscosity of the three different sealants is shown in Table 2. Sealant A had the highest viscosity, Sealant B was intermediate and Sealant C exhibited the lowest viscosity.

Figure 4 shows the typical appearance of penetration by Sealant A. The resin-infiltrated enamel was formed approximately 6µm in width. Resin tags were not formed. Figure 5 shows the typical appearance of Sealant B penetration. The resin-infiltrated enamel was approximately 10µm in width. Resin tags were not formed. Figure 6 shows the typical appearance of sealant C penetration. The resin-infiltrated enamel was approximately 15µm in width. Resin tags were formed approximately 5-10µm in length.

There were several types of resin-infiltrated enamel. In the case of oblique or cross-cutting patterns of enamel rods, it was difficult to measure the penetration distance because the resin-infiltrated enamel and resin

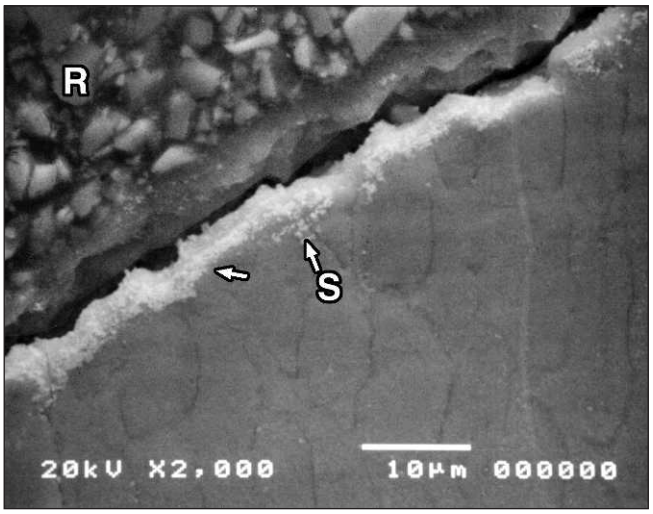

Figure 8. *Back-scatter electron image of the adhesive interface between the fissured enamel and Sealant A. Silver particles have penetrated under and/or within the resin-infiltrated enamel.*
(R = sealant, S = silver particles)

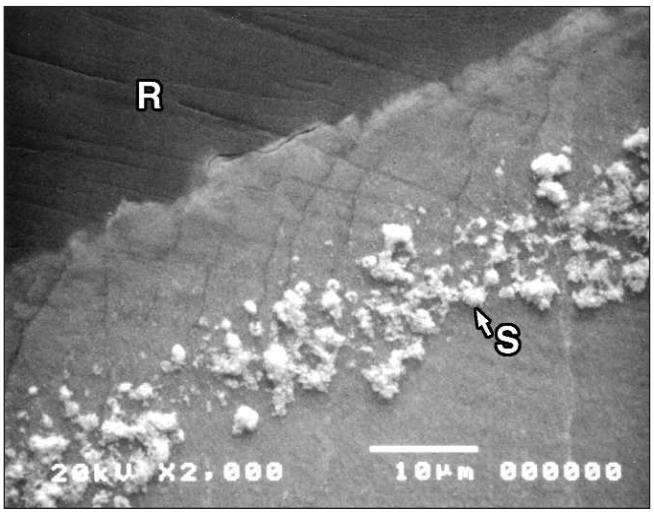

Figure 9. *Back-scatter electron image of the adhesive interface between the fissured enamel and Sealant B. Silver particles have penetrated under and/or within the resin-infiltrated enamel.*
(R = sealant, S = silver particles)

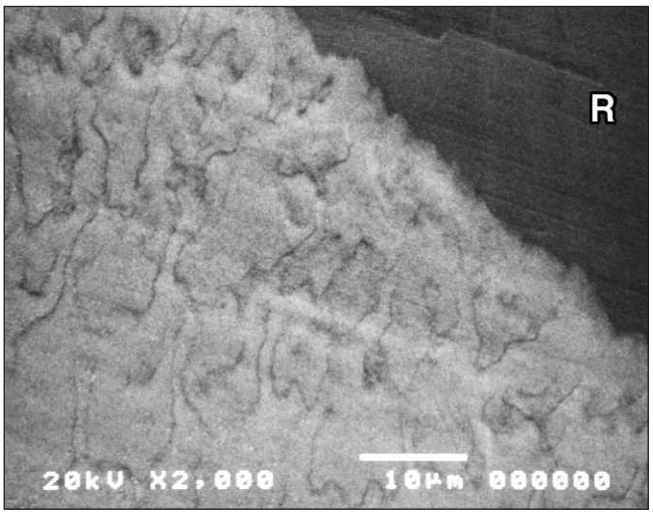

Figure 10. *Back-scatter electron image of the adhesive interface between the fissured enamel and Sealant C. There is no penetration of silver particles.*
(R = sealant)

tags were intricately entwined (Figure 7). On the other hand, the resin-infiltrated enamel and resin tags were straight when longitudinal enamel rods were involved (Figure 4-6). In this study, therefore, only the longitudinal resin-infiltrated enamel rods could be measured (Table 3). Penetration distance of Sealant A and B were shorter than the subsurface etched depth. The penetration distance of Sealant C was greater than the subsurface etched depth.

A pair-wise statistical comparison of penetration distance of all sealants and subsurface etched depth by SEM observation is shown in Table 4. Penetration distance of Sealant B was significantly longer ($p<0.01$) than Sealant A. Penetration distance of Sealant C was significantly longer ($p<0.01$) than Sealant A and B. Therefore, the subsurface etched depth and penetration distance of all sealants were statistically significantly different ($p<0.01$).

Enamel Beneath the Resin-Infiltrated Enamel

All samples of Sealant A (Figure 8) and B (Figure 9) showed penetration of silver particles (S) under or within the resin-infiltrated enamel. All samples of Sealant C (Figure 10) exhibited very little penetration of silver particles (Table 5).

Table 3: *Penetration Distance of Three Sealants into the Etched Enamel (µm)*

Sealant	Measurement Points	Resin-Infiltated Enamel			Resin Tag			Total Penetration Distance			Subsurface Etched Depth	
		Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.
A	150	5.4	1.2	3-8	0.7	1.0	0-3	6.0	1.7	3-11	< 15.1	1.8
B	150	10.1	1.2	8-12	1.3	1.3	0-4	11.3	1.8	8-16	< 15.1	1.8
C	150	13.6	1.8	10-17	8.0	1.6	5-10	21.6	2.1	15-26	> 15.1	1.8

Table 4: *A Pair-Wise Statistical Comparison of All Sealants and Subsurface Etched Depth*

	Sealant A	Sealant B	Sealant C	Subsurface Etched Depth
Sealant A		**	**	**
Sealant B			**	**
Sealant C				**

**: $p<0.01$, according to Student *t*-test.

Table 5: *Penetration of Silver Particle Under or Within the Resin-Infiltrated Enamel*

Sealant	Number of Specimens	Penetration of Silver Nitrate +	-
A	15	15	0
B	15	15	0
C	15	0	15

Because the polished surface was not immersed in 40% phosphoric acid gel before sputter coating with gold, the mineral enamel components were not dissolved, so the resin-infiltrated enamel and enamel rods were not visible, but the penetration of silver particles was very easily determined.

DISCUSSION

Use of fissure sealants with unfilled resin or resin composites after acid etching of the enamel has been advocated as a reliable method for the prevention of fissure caries (Ripa, 1993). Excellent retention and longivity of sealants depend upon three factors: 1) penetrability of the acid-etched enamel, 2) marginal sealing and 3) wear and abrasion resistance.

Silverstone (1975) suggested that etching enamel with phosphoric acid solution resulted in a superficial etched zone and subsurface qualitative and quantitative porous zones. The average loss of surface enamel etched with phosphoric acid solutions with concentrations ranging from 30% to 50% for 60 seconds is from 7µm to 12µm (Silverstone, 1974; Retief, 1975).

Shey & Brandt (1982) etched the unground facial surfaces of premolar teeth with three commercially available etching solutions for 60 seconds resulting in a mean depth of etch of 22.5µm. Legler & others (1990) reported that a stepwise decrease in the calculated depth of etch with decreasing acid concentration and duration of etching occurred. Etched depth ranged from 27.1µm when etching with 37% phosphoric acid solution for 60 seconds to 3.5µm when etching with 5% phosphoric acid solution for 15 seconds. Legler & others (1989) also reported that the concentration of phosphoric acid solution had no significant effect on shear bond strength, but the duration of etching affected shear bond strength significantly.

It has been proposed that the methacrylates with hydrophilic and hydrophobic groups promote the diffusion of monomers due to their good affinity for tissues (Nakabayashi & others, 1982; Wang & others, 1991). MDP (10-Methacryloyloxydecyl Dihydrogen Phosphate) (Kuraray, 1990) in Sealant C was essential in promoting penetration and bonding by the formation of a resin-infiltrated enamel and resin tags in the subsurface of enamel. In addition, self-etching effect of MDP (Sugizaki, 1991) improved the penetration, and Sealant C appeared to exceed the subsurface etched depth.

Percinoto & others (1995) mentioned that sealants with a low viscosity had a greater potential to penetrate into the fissures and the microporosities produced in the enamel by etching with phosphoric acid. The low viscosity of Sealant C seemed to facilitate the formation of a wider resin-infiltrated enamel than was produced by Sealant A and B.

In previous unpublished research, it was found that at least 60 seconds of sealant contact was necessary to facilitate adequate bonding even for low viscosity sealants such as Sealant C. Ten Cate & others (1975) also reported that penetration time was very important in obtaining good adhesion of polymers to enamel. In clinical practice, especially with young children, a 60-second application time is difficult to obtain, especially when the dentist is trying to keep a low viscosity sealant on the mesial aspect of occlusal pit and fissure when the patient is in a supine position. However, allowing a sealant to penetrate as long as possible prior to polymerization is also very important to obtain satisfactory sealant penetration.

Microleakage at resin-dentin interfaces corresponds to the porous dentin layer beneath or within the resin hybrid layer, which is formed by insufficient penetration of bonding monomers into decalcified dentin created by phosphoric acid etching (Sano & others, 1994a, 1994b).

In Sealant A, the size of the filler particles may have been larger than the microspaces of the enamel. Sealant B contained approximately 10% tinting agents. The presence of the filler of Sealant A and tinting agents in Sealant B increased the viscosity of these sealants, which lowered penetration into the etched enamel region, so that only narrow resin-infiltrated enamel zones were formed. Some etched enamel, not infiltrated by sealant, appeared to remain under or within the resin-infiltrated enamel. The clinical significance of this porous zone is unknown.

A previous unpublished *in vitro* study failed to confirm the presence of silver nitrate in the under-penetrated zone of etched enamel, for if silver nitrate had penetrated, it would have demonstrated a susceptible microleakage pathway. The presence of silver nitrate in the under-penetrated zone of etched enamel was observed in this study. Therefore, the results demonstrated that the remaining etched region may become a factor by allowing development of new dental caries by microleakage if the sealant was partially or completely lost.

Sealant C, which has low viscosity and good diffusibility of monomers, penetrated far beyond the etched depth. The SEI of the subsurface etched enamel showed delicate morphological changes, however the SEI of Sealant C showed a more delicate structure, which may have accounted for the excessive penetration depth of this sealant. The existence of resin-infiltrated enamel and resin tags might be able to offer adequate protection in the event of sealant loss. Further studies are needed to clarify this relationship.

CONCLUSIONS

The structural change of the etched enamel and the composition and viscosity of sealants are essential to the formation of a resin-infiltrated enamel. The lower viscosity sealant was effective in penetrating the total etched enamel compared with high viscosity sealants. The full penetration by Sealant C into the etched enamel may improve long-term retention, prevent microleakage and avoid subsurface porosity that may increase caries susceptibility in the event of sealant loss.

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Bond Strength of Compomers to Human Enamel

WH Tate • C You • JM Powers

Clinical Relevance

The highest tensile bond strengths for compomer restorative materials to enamel were attained using phosphoric acid etching, primers and moist bonding surfaces.

SUMMARY

The study evaluated the tensile bond strength between human enamel and seven compomer restorative systems under different bonding conditions. Seven compomers were bonded to human tooth structure with and without phosphoric acid etching of the bonding surface, with and without the use of their recommended combined primer and bonding agent and with both moist and wet bond interface environments. Overall, the highest bond strengths to human enamel were attained using phosphoric acid conditioning, primers and moist bonding surfaces.

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INTRODUCTION

Arising from the progressive development of materials that lie between true glass ionomer cement and true composite resin are the compomers (polyacid-modified composite resin) (McLean, Nicholson & Wilson, 1994). Relative to resin-modified glass ionomers (McLean & others, 1994), compomers exhibit good handling characteristics, have acceptable esthetics and release fluoride, the overall and complete significance of which has yet to be fully clarified (Burgess & others, 1996; Chung & others, 1998; Dionysopoulos & others, 1998; Friedl & others 1997; Hsu & others, 1998; Millar, Abiden & Nicholson, 1998; Tam, Chan & Yim, 1997; van Dijken & others, 1997; Vercruysse, de Maeyer & Verbeeck, 1998). Clinically, compomers bond to dentin and enamel through adhesive resins and, as a consequence of their limited dual-setting curing mechanism, require curing by photopolymerization (Christensen, 1997; Hse & Wei, 1997).

Overall, as a restorative and an orthodontic bracket adhesive material, compomer performance has been evaluated from mixed to promising (Christensen, 1997; Eberhard, Hirschfelder & Sidel, 1997; Eley, 1997; Hse & Wei, 1997; Lambrechts & others, 1996; Morabito & Defabianis, 1997; Rock & Abdullah, 1997; Roeters & others, 1998; Salama & el-Mallakh, 1997; Sjodin, Uusitalo & van Dijken, 1996; Swift & Vann, 1995; Tyas, 1998; Vaikuntam, 1997). Clinical wear (Christensen,

1997; Hse & Wei, 1997; Peters, Roeters & Frankenmolen, 1996), marginal sealing and marginal integrity possibly related to bond deterioration or technique sensitivity (Andersson-Wenckert, Folkesson & van Dijken, 1997; Peters & others, 1996; Tyas, 1998; Yap, Lim & Neo, 1995) are concerns with compomers.

Studies involving the clinical use of a compomer have noted good marginal sealing (Morabito & Defabianis, 1997; van Dijken & Horstedt, 1997). Furthermore, others have found no statistically significant loss of the marginal integrity of a compomer when compared clinically to that of a conventional composite; however, significantly more marginal staining was observed (Hse & Wei, 1997). Abate and others (1997) found that the use of phosphoric acid etching before primer and bonding agent placement allowed a better bond between a compomer and enamel, but was not particularly needed on dentin and cementum. Ferrari and others (1998) showed that treatment with phosphoric acid improved the sealing ability of compomers at cementum-enamel margins. In the same study, when two compomers were applied in combination with their corresponding enamel-dentin bonding systems using the total-etch wet bonding technique, they exhibited better sealing ability than when applied in combination with their respective primer-adhesive systems (Ferrari & others, 1998).

A contemporary approach to dentin and enamel adhesion involves the use of acidic or self-etching primers, which combines acid etching with the priming procedure (Gordan & others, 1998). By combining the acid etchant with the primer, an acidic monomer is formed (Chigira & others, 1989). Self-etching primers were developed to simplify the bonding procedure by serving simultaneously as a conditioner and primer, without being rinsed off (Perdigão & others, 1997). The idea was the formation of a continuum between the tooth surface and the adhesive material by superficially demineralizing dentin while simultaneously penetrating it with monomers, which can be polymerized *in situ* (Gordan & others, 1998; Schwartz, Summitt & Robbins, 1996; Watanabe, Nakabayashi & Pashley, 1994). With regard to enamel, early studies found that using acidic primers with composite resin did not alter enamel bond strengths (Nishida & others, 1993).

This study evaluated the bonding characteristics of five compomer and single-bottle self-etching primer systems (acidic primers) and two compomer and single-bottle primer systems requiring phosphoric acid etching (PRPA) under various bonding conditions. The tensile bond strengths between human enamel and the seven compomer-restorative systems, with and without phosphoric acid etching of the bonding surface, with and without the use of the combined primer and bonding agents and under both moist and wet bond interface environmental conditions were examined.

Table 1: *Products, Lot Numbers and Manufacturers*

Restorative Systems	**Lot #**
• F2000 Compomer Restorative System	19971018
◦ 3M Single Bond Dental Adhesive System	7AT
• F2000 Compomer Restorative System	19970821
◦ F2000 Compomer Primer/Adhesive in 3M Clicker Dispensing System (F2000C)	07AD
3M Dental Products *St Paul, MN 55144-1000*	
• Compoglass F Light-Curing Compomer-Based Restorative Material	6546978
◦ Syntac Single-Component Bonding Agent	912453
Ivoclar North America *Amherst, NY 14228*	
• Dyract Light Cured Compomer Restorative System	970116
◦ Prime&Bond 2.1 Bonding Agent	9611291
• Dyract AP Advanced Performance Compomer Restorative System	9705001319
◦ Prime&Bond 2.1 Bonding Agent	9611291
Dentsply/Caulk *Milford, DE 19963-0359*	
• Hytac Aplitip Light-Curing Compomer Filling Material	32491
◦ Hytac OSB Light-Curing, One-component Bonding Agent	030
ESPE America, Inc. *Plymouth Meeting, PA 19462*	
• Freedom Fluoride Releasing Lightcure Compomer	2229
◦ STAE Single Component Light Cured Dentin/Enamel Adhesive System	70812
Southern Dental Industries, LTD *Victoria, Australia*	
Acid-Conditioner	
• Etchant, 35% phosphoric acid (H3PO4)	7 HC
3M Dental Products *St Paul, MN 55144-1000*	

METHODS AND MATERIALS

Products, lot numbers and manufacturers are listed in Table 1. Materials, their composition and primer classification are listed in Table 2. One hundred and forty extracted human molars were collected and stored in a physiological saline solution containing 0.25% sodium azide, an antimicrobial agent (Block, 1991). These teeth were sectioned mesiodistally and embedded in resin with the buccal and lingual surfaces positioned for surface treatment and compomer bonding. The resin blocks were surfaced with 600-grit silicon carbide paper (3M Dental Products, St Paul, MN 55144) used on a polisher (Buehler Polimet I Polisher; Buehler Ltd, Lake Bluff, IL 60044). The embedded teeth were surfaced to enamel. Blocks were randomly assigned to a specimen group.

Seven compomer systems were bonded to human tooth structure with and without single-bottle primer

Table 2: *Composition and Classification of Compomers and Primer/Adhesive Systems Evaluated and Manufacturers' Etchant Recommendations*

Compomer	Etchant	Acidic Primer/Adhesive
F2000-FAS glass, colloidal silica, CDMA oligomer (dimethacrylate functional oligomer derived from citric acid), GDMA, hydrophilic polymer, camphoroquinone/amine	None	F2000 Compomer Primer/Adhesive (two parts)* A = HEMA, methacrylated polycarboxylic acids, photoinitiator, ethanol, water B = maleic acid (5%), water
Compoglass F-UDMA, TEG-DMA, CADCADMA, ytterbium trifluoride, Ba-Al-fluorosilicate glass, spheroid mixed oxide, inorganic fillers	Optional	**Syntac Single-Component**-HEMA, maleic acid, methacrylate, modified polyacrylic acid, initiators/stabilizers, water
Dyract-fluoro-silicate glass, acidic polymerizable monomers, light-curing polymers	Optional	**P&B 2.1**-dimethacrylate resins, PENTA, cetylamine hydrofluoride, initiators/stabilizers, acetone
Dyract AP-TCB resin, polymerizable resins, strontium-fluro-silicate glass, strontium fluoride, initiators/stabilizers	Optional	**P&B 2.1**-dimethacrylate resins, PENTA, cetylamine hydrofluoride, initiators/stabilizers, acetone
Hytac-Ca-Al-Zn-fluoroglass, yttrium trifluoride, silica, UDMA, methacrylated phosphoric acid, methacrylated oligomaleic acid, pigments, stabilizers, initiators	None	**OSB**-TEG-DMA, HEMA, methacrylated phosphoric acid, pigments, stabilizers, initiators, acetone
Compomer	**Etchant**	**Primer/Adhesive Requiring Phosphoric Acid Etching (PRPA)**
F2000-FAS glass, colloidal silica, CDMA oligomer (dimethacrylate functional oligomer derived from citric acid), GDMA, hydrophilic polymer, camphoroquinone/amine	Yes	**Single Bond**-HEMA, BisGMA, dimethacrylates, methacrylate functional copolymer (polyacrylic and polyitaconic acids = polyalkenoic acid copolymer), photoinitiator, ethanol, water
Freedom-modified dimethacrylates, silica, strontium glass, sodium fluoride, initiators	Yes	**STAE** - HEMA, TEG-DMA, initiators dimethacrylates, water, acetone

*F2000 Compomer Primer/Adhesive in 3M Clicker Dispensing System
BisGMA = biphenol glycidyl methacrylate
CADCADMA = cycloaliphatic dicarboxylic acid dimethacrylate
GDMA = hydroxypropylene dimethacrylate (glyceryl dimethacrylate)
HEMA = 2-hydroxyethylmethacrylate
PENTA = diphentaerythritol penta acrylate monophosphate
TEG-DMA = tetraethylene glycol dimethacrylate
UDMA = urethane dimethacrylate

Table 3: *Summary of the Experimental Design for Enamel Surface Treatment 24 Months**

Condition								
Restorative	compomer	compomer	compomer	compomer	compomer	compomer	compomer	compomer
H_3PO_4	yes	yes	yes	yes	none	none	none	none
Primer	none	none	yes	yes	none	none	yes	yes
Surface	moist	wet	moist	wet	moist	wet	moist	wet

*Five replications were performed for each of the seven compomer systems within the eight treatment groups, totaling 280 specimens. Acid-conditioning with phosphoric acid (H_3PO_4) for 15 seconds was followed by a 10 second dH2O rinse. Surfaces were either blotted dry (moist) or blotted dry and re-surfaced with 2µl dH_2O water (wet).

and bonding agent and with and without 35% phosphoric acid (H_3PO_4) etching for 15 seconds followed by a 10-second distilled water (dH_20) rinse (Table 3). The bonding surface interfaces for some specimens were blotted to a moist (hydrated) surface with a cotton pellet following appropriate initial surface treatment and before bonding agent treatment (if indicated) and compomer bonding (Table 3). The bonding surface interfaces for other specimens were blotted to a moist surface after appropriate initial surface treatment, they then received an additional surface application of 2 µl of dH_2O with a micropipette (P-10 Pipetman; Rainin Instrument Co, Inc, Woburn, MA 01888), before primer treatment (if indicated) and compomer bonding

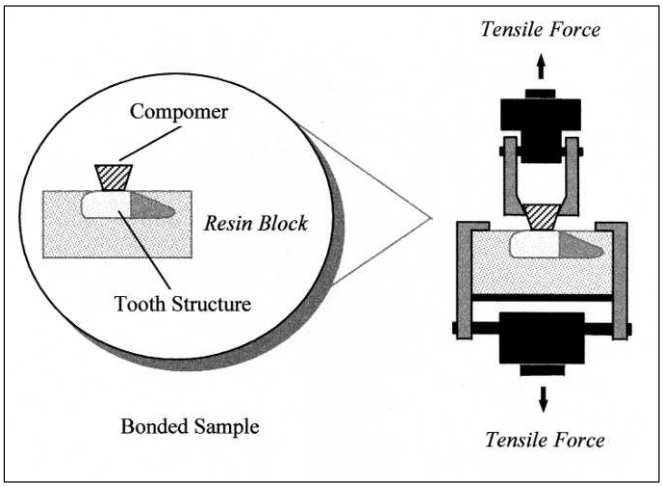

Figure 1. *Testing apparatus and sample configuration.*

(Table 3). This additional application of dH_2O was thinly spread over the surface and left the bonding interface with a visible excess of water.

A polytetrafluoroethylene mold in the shape of an inverted, truncated cone with a diameter of 5 mm tapering to a diameter of 3 mm at a height of 5 mm was positioned over the block in such a manner that the 3-mm in diameter hole coincided with the surfaced tooth structure (Barakat & Powers, 1986). A clamp was used to secure the block and mold in position. After appropriate surface treatment, corresponding compomer was incrementally placed into the mold and cured according to the manufacturers' recommendations using a curing light (Elipar II; ESPE America, Inc, Norristown, PA 19404) (Figure 1). Proper and consistent curing light intensity was assured by monitoring the curing light unit output using a light meter (Demetron/Kerr Corp, Danbury, CT 06810) (Tate, Porter & Dosch, 1999). Specimens were stored at 37ºC in 100% humidity for 24 hours.

After storage, the cone-shaped compomer-resin block was placed into a jig with an internal taper that corresponded to the shape of the specimen (Figure 1). The resin block and jig were loaded in tension using a testing machine (Model 8501; Instron Corp, Canton, MA 02021), at a cross-head speed of 0.5 mm/min until fracture. Bond strength was calculated in MegaPascals (MPa). Bond failure sites were visually observed under an X2 magnification and recorded.

Bond strength data were analyzed by four-way analysis of variance (SuperANOVA; Abacus Concepts, Berkeley, CA 94704). Means were compared with a Tukey-Kramer interval (SuperANOVA) calculated at the 0.05 significance level. Differences between two means that were greater than the appropriate Tukey-Kramer interval were considered statistically significant. Bond failure site data were not statistically analyzed.

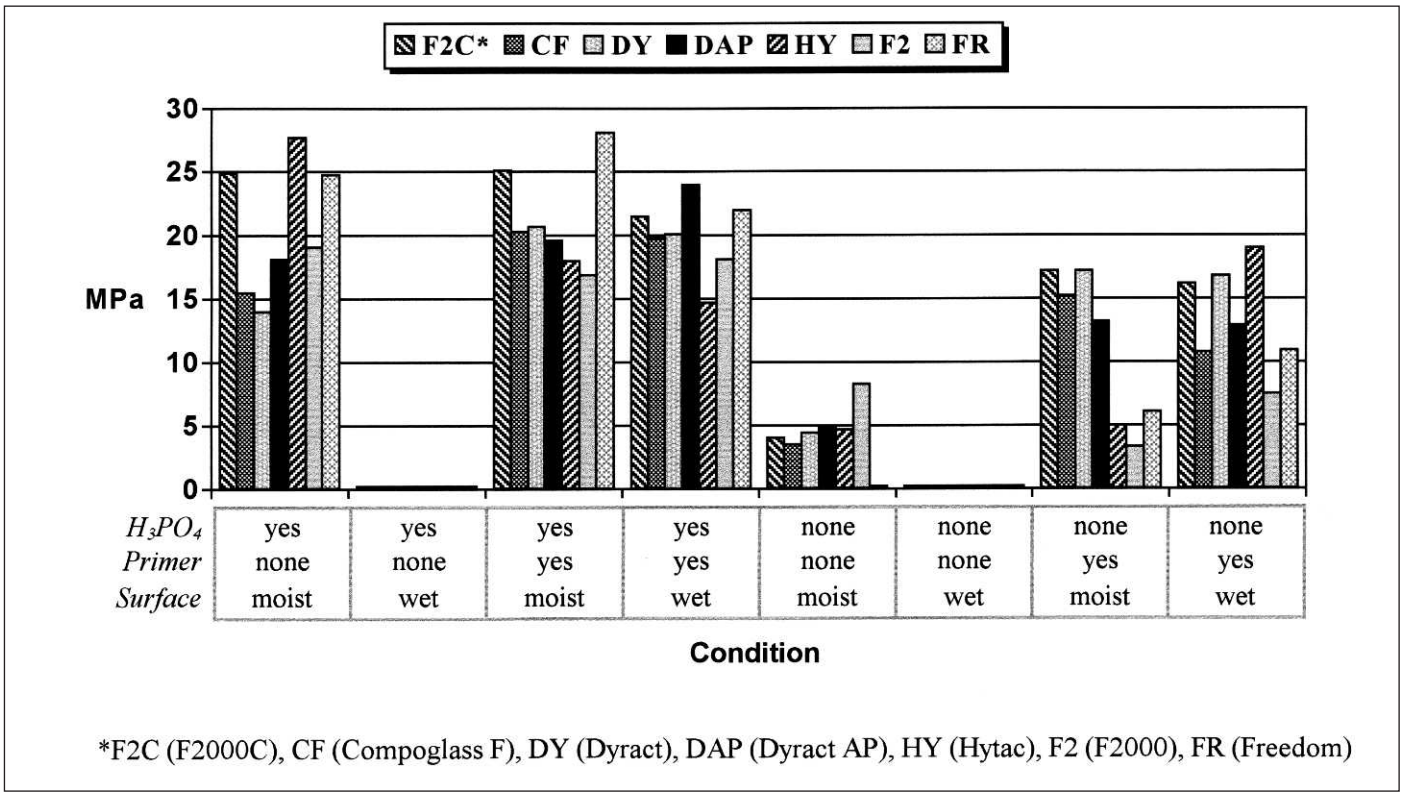

Figure 2. *Enamel-compomer bonding profile.*

Table 4: *Effect of Surface Treatment and Bonding Agent on the Tensile Bond Strength of Compomers to Human Enamel*

Condition								
H_3PO_4	yes	yes	yes	yes	none	none	none	none
Primer†	none	none	yes	yes	none	none	yes	yes
Surface	moist	wet	moist	wet	moist	wet	moist	wet
Compomers								
F2000C	24.9 (5.7)	0.0 (0.0)	25.1 (8.1)	21.5 (1.8)	4.0 (2.2)	0.0 (0.0)	17.2 (5.0)	16.2 (2.2)
Comp F‡	15.5 (3.3)	0.0 (0.0)	20.3 (4.8)	19.8 (5.0)	3.5 (2.8)	0.0 (0.0)	15.2 (5.3)	10.8 (3.4)
Dyract	14.0 (4.5)	0.0 (0.0)	20.7 (2.3)	20.1 (5.8)	4.4 (1.6)	0.0 (0.0)	17.2 (5.2)	16.8 (5.0)
Dyract AP	18.1 (7.6)	0.0 (0.0)	19.6 (3.0)	24.0 (10.0)	4.9 (1.0)	0.0 (0.0)	13.2 (3.3)	12.9 (2.9)
Hytac	27.7 (5.8)	0.0 (0.0)	18.0 (2.3)	14.7 (4.1)	4.7 (1.6)	0.0 (0.0)	5.0 (1.8)	19.0 (8.8)
F2000	19.1 (4.4)	0.0 (0.0)	16.9 (5.3)	18.1 (5.6)	8.3 (2.7)	0.0 (0.0)	3.3 (0.5)	7.5 (3.3)
Freedom	24.8 (3.5)	0.0 (0.0)	28.1 (6.4)	22.0 (13.0)	0.0 (0.0)	0.0 (0.0)	6.1 (2.5)	10.9 (3.1)

*Mean bond strengths with standard deviations in parentheses (n = 5) are listed in MPa. Tukey-Kramer intervals for comparisons of means at the 0.05 significance level among products, between etching with phosphoric acid (H_3PO_4) or not etching (none), between using adhesive and not using adhesive (none), and between moist and wet enamel were 2.8, 1.0, 1.0, and 1.0 MPa, respectively.

†F2000 Compomer Primer/Adhesive - Clicker Dispenser (F2000), Syntac Single-component (Compoglass F), Prime&Bond 2.1 (Dyract, Dyract AP), OSB Bonding Agent (Hytac), Single Bond (F2000), STAE (Freedom).

‡Compoglass F.

Table 5: *Analysis of Variance for Tensile Bond Strength*

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Product	6	431	71.8	3.93	0.0009
Etch PA†	1	4797	4797	262	0.0001
Primer	1	7326	7326	400	0.0001
Enamel	1	2443	2443	133	0.0001
Product * Etch PA	6	605	100	5.52	0.0001
Product * Primer	6	747	124	6.82	0.0001
Product * Enamel	6	90.2	15.03	0.82	0.5542
Etch PA * Primer	1	0.912	0.912	0.05	0.8235
Etch PA * Enamel	1	1746	1746	95.5	0.0001
Primer * Enamel	1	2969	2969	162	0.0001
Product * Etch PA * Primer	6	342	57.1	3.12	0.0059
Product * Primer * Enamel	6	662	110	6.04	0.0001
Etch * Primer * Enamel	6	347	58	3.17	0.0053
Product * Etch PA * Enamel	1	703	703	38.4	0.0001
Product * Etch PA * Primer * Enamel	6	95.7	16	0.87	0.5161
Residual	224	4096	18.3		

†Phosphoric acid (35%)

Dependent Variable: Bond Strength, MPa

RESULTS

Mean bond strengths and standard deviations are shown in Table 4 and graphically depicted in Figure 2. The analysis of variance showed that significant differences existed among the four independent variables and their interactions as shown in Table 5.

For specimens conditioned with phosphoric acid and blotted to a moist enamel bonding surface, Compoglass F, Dyract and Dyract AP produced higher tensile bond strengths using acidic primers, while Freedom produced higher bond strengths using a primer requiring phosphoric acid etching (PRPA). Hytac without use of an acidic primer and F2000 without the use of a PRPA produced higher bonds, while the F2000 Compomer Primer/Adhesive (F2000C) group was insensitive to the use of an acidic primer under these conditions.

Phosphoric acid etching and the use of acidic primers with a wet versus a moist bonding surface produced higher bonds with Dyract AP and lower bond strengths

Table 6: *Sites of Enamel-Compomer Bond Failures**

Condition								
H_3PO_4	yes	yes	yes	yes	none	none	none	none
Primer†	none	none	yes	yes	none	none	yes	yes
Surface	moist	wet	moist	wet	moist	wet	moist	wet
Compomers								
F2000C	100C	100A	29A/71C	24A/76C	100A	100A	86A/14C	60A/40C
Compoglass	8A/92C	100A	76A/24C	80A/20C	100A	100A	74A/26C	91A/9C
Dyract	28A/72C	100A	4A/96C	20A/80C	100A	100A	48A/52C	44A/56C
Dyract AP	11A/89C	100A	100C	100C	100A	100A	38A/62C	66A/34C
Hytac	4A/96C	100A	76A/24C	82A/18C	100A	100A	100A	86A/6C/8E
F2000	100C	100A	38A/62C	42A/38C/20E	100A	100A	100A	96A/4C
Freedom	48A/52C	100A	7A/93C	36A/64C	100A	100A	100A	85A/15C
Overall	14A/86C	100A	33A/67C	41A/57C/3E	100A	100A	78A/22C	75A/23C/1E

*Failure site description containing percent estimation of failure character of each, five replicate group. Percent adhesive (A), percent cohesive within the compomer (C), and percent cohesive within enamel (E) observations are listed.

with F2000C and Hytac. Phosphoric acid etching and the use of a PRPA with a wet bonding surface produced higher bonds with F2000 and lower bond strengths with Freedom. Compoglass F and Dyract bonding with acidic primers under these conditions remained unchanged.

Without phosphoric acid etching and with a moist bonding surface, F2000C, Compoglass F, Dyract and Dyract AP produced higher bonds using acidic primers. Without phosphoric acid etching and with a moist bonding surface, Freedom produced higher bonds using a PRPA. Lower bonds resulted from using a PRPA with F2000, while bonds for Hytac using an acidic primer remained unchanged.

Without phosphoric acid etching and with acidic primers, a moist bonding surface produced higher bond strengths with Compoglass F than did a wet bonding surface. Lower bonds under these conditions were produced with Hytac but were unchanged with F2000C, Dyract and Dyract AP. Lower bonds under these conditions using a PRPA were produced with F2000 and Freedom.

Phosphoric acid etching with a moist bonding surface produced higher bond strengths than without etching, regardless of the use of acidic or PRPA primers. With primers and a wet bonding surface, phosphoric acid etching increased bond strength with all compomers except for Hytac, whose bonds were higher without etching.

Measurable bond strengths did not occur with specimens fabricated without the use of acidic or PRPA primers and with a wet enamel bonding surface, regardless of the presence or absence of phosphoric acid conditioning. Overall, the highest bond strengths were attained using phosphoric acid conditioning, acidic or PRPA primers and moist bonding surfaces.

The character of each enamel-compomer bond failure is listed in Table 6. For specimens without the use of a primer, with a wet bonding surface and with and without phosphoric acid conditioning, all bond failures were adhesive (A) in nature. Similarly, adhesive bond failures occurred with specimens fabricated without the use of primers, with a moist bonding surface and without phosphoric acid conditioning.

Regardless of compomer, specimens prepared with phosphoric acid conditioning without the use of primers and with a moist bonding surface produced the highest percent of overall cohesive (C) failures. The use of phosphoric acid etching and primers with either a moist or wet bonding surface also produced mixed failures which were predominately cohesive in nature. Mixed bonding failures, predominately adhesive, were produced with specimens without phosphoric acid conditioning, using primers and with either a moist or wet bonding surface.

DISCUSSION

Tooth-conserving adhesive methods of retaining restorative materials are replacing traditional mechanical methods and procedures (Schwartz & others, 1996). Furthermore, bonded restorations can reduce clinical problems, such as postoperative sensitivity, marginal staining and recurrent caries by preventing microleakage at the restoration-tooth interface (Schwartz & others, 1996). Compomers and self-etching primers (acidic primers) are two of the most recent developments in adhesive dentistry. This study examined the bonding characteristics of seven compomer restorative systems to human dentin and enamel, some using acidic primers and others using primers requiring phosphoric acid etching (PRPA) under various bonding conditions.

Overall, bond strengths of the compomer material to enamel were improved by using phosphoric acid condi-

tioning and primers under moist bonding conditions. Only slightly lower bond strengths were observed using phosphoric acid conditioning and primers under wet bonding conditions and using phosphoric acid conditioning without using primers under moist surface conditions. Without phosphoric acid etching, low bond strengths were observed with compomers using PRPA, as would be expected. However, Hytac, using an acidic primer (OSB), also produced low bonds without phosphoric acid etching. The methacrylate group on OSB's phosphoric acid (Table 2) may limit its ability to adequately condition the surface.

Measurable bonding did not occur without the use of acidic or PRPA primers under wet bonding conditions, regardless of phosphoric acid etching. Without primers, readily evaporating azeotropic solutions were not formed (Gordan & others, 1998). The compomer resin, by itself, would appear unable to displace excessive surface moisture. Weak bond strengths were observed with a moist enamel surface without primers or phosphoric acid conditioning, suggesting a certain level of moisture displacement and subsequent adhesion to the untreated enamel surface by the restorative material. Syntac Single-Component Bonding Agent is a water-based adhesive system. The instructions for this system advise a little more air drying time of the primer to assure extraneous moisture evaporation than do the instructions for the ethanol- and acetone-based systems. The formulation of this water-based system appears to overcome surface tension forces to adequately interact with the enamel surface, producing similar bonding profiles to ethanol- and acetone-based counterparts.

In general, excessive surface moisture did not adversely affect enamel bond strengths when using primers without acid conditioning. Three systems, F2000 (Single Bond Dental Adhesive), Freedom (STAE Dentin/Enamel Adhesive) and Hytac (OSB Bonding Agent) produced significantly higher bond strengths under wet-bonding conditions, without acid etching when compared to moist conditions. The formulation of these systems allowed for successful displacement of the surface water, permitting resin to adequately penetrate the self-conditioned enamel surface. Perhaps the fact that Single Bond and STAE are PRPAs, and the aforementioned observation that OSB behaved more like a PRPA when used without phosphoric acid etching, contributed to these findings.

Under moist surface conditions, using acid etching alone produced higher compomer bond strengths to enamel than when using primers alone, without phosphoric acid etching. When bonding composite resin, others have found that using acid-etching agents resulted in statistically similar enamel shear bond strengths as compared to the sole use of a self-etching primer (Perdigão & others, 1997). Others have found improved shear bond strengths of compomer-to-enamel using phosphoric acid etching before the application of a primer/adhesive (Abate & others, 1997). Conditions created on the enamel by the acid appear to be beneficial for the adhesion of compomer material (Abate & others, 1997).

Acid etching of the highly-mineralized enamel enlarges the surface area for bonding (Buonocore, 1955). Acidic primers overall exhibit less demineralization of enamel than phosphoric acid and produce different, shallower etch patterns than conventional acid etchants (Ferrari, Goracci & García-Godoy F, 1997; Nikaido & others, 1997; Nishida & others, 1993; Perdigão & others, 1997; Schwartz & others, 1996). Shallow etching patterns observed with some acidic primers may result from either a deficient penetration of the self-etching primer into the enamel microporosities or as a result of the precipitation of calcium phosphates onto the enamel surface, interfering with resin penetration (Perdigão & others, 1997). As the acidic primer demineralizes the dentinal surface, the calcium phosphate concentration increases, thus neutralizing the primer and limiting further dissolution of apatite (Gordan & others, 1998). Phosphoric acid conditioning and water rinsing to remove dissolved calcium phosphates would prevent entrapment of this residue within the bonding resin layer, which might otherwise impair infiltration of the monomers into the etched enamel microporosities (Schwartz & others, 1996). Ethanol or acetone drying agents, while enhancing the resin monomers ability to penetrate surface irregularities by removing residual water, do not remove this calcium residue (Schwartz & others, 1996). Acidic primers, by the simultaneous demineralization and resin penetration of the enamel surface with acidic monomers (Schwartz & others, 1996), may provide optimal resin infiltration into the already acid-conditioned enamel surface. Additionally, mild demineralization by the acidic primer may also create an added enamel surface area, but not to the point of microtag decrement. Enamel is substantially more inorganic in composition than dentin and is, therefore, harder to etch (Ferrari & others, 1998).

A dye-penetration study found no significant difference in dentinal marginal sealing between a compomer, resin composite or resin-modified glass ionomer; however, for margins placed in enamel, composite restorations had significantly less leakage than did the compomer or resin-modified glass ionomer (Yap & others, 1995). All three materials were observed to have significantly poorer sealing ability with dentin compared to enamel (Yap & others, 1995). Another microleakage study that examined Dyract and Compoglass revealed improved sealing of Class V restorations at cervical or incisal margins using an enamel-dentin bonding sys-

tem in combination with the recommended compomer when compared to compomer application in combination with their respective primer-adhesive system (Ferrari & others, 1998). Total-etch wet-bonding treatment with phosphoric acid before the application of the enamel-dentin bonding systems was also shown to improve the sealing ability of these compomers (Ferrari & others, 1998). Others found improved compomer bond strengths to enamel using phosphoric acid conditioning before the application of the compomer's respective primer-adhesive (Abate & others, 1997). Conditions created on enamel by the acid appear to be beneficial for the adhesion of compomers (Abate & others, 1997), especially when used with acidic primers under moist surface conditions. Using phosphoric acid prior to the application of the supplied primer-adhesive resulted in higher shear bond strength of Dyract-to-enamel (Abate & others, 1997). In the same study, similar results were not found when bonding to dentin and root cementum. Mean shear-bond strengths were slightly lower for these structures when acid conditioning was used prior to primer-adhesive application (Abate & others, 1997).

Overall, this study found higher tensile bond strengths when using phosphoric acid etching with enamel-dentin acidic primers or PRPAs developed for use with composite resin under moist bonding surface conditions. Further, phosphoric acid etching with a moist enamel bonding surface without the use of an acidic primer or a PRPA produced significantly higher bond strengths for the F2000 group and the F2000C group, respectively, than without phosphoric acid. However, without their respective primers, bonding should have been similar between the materials within each etch or non-etch group relative to each other, since the compomer material was the same for both. Observed differences in bond strengths of the F2000 compomer in each group might be attributable to the restorative material being from different product lots. In addition, the two restorative systems had two different packaging systems for the restorative paste, syringe versus capsule. Perhaps technique differences between one system's dispensing method versus the other could affect the uniform, consistent application of the material onto the tooth surface enough to create the observed aberration in bond strengths.

CONCLUSION

Overall, the highest tensile bond strengths between human enamel and seven compomer restorative systems were attained using phosphoric acid etching, acidic primers or primers requiring phosphoric acid etching and moist bonding surfaces.

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Microleakage of Light-Cured Resin and Resin-Modified Glass-Ionomer Dentin Bonding Agents Applied with Co-Cure Vs Pre-Cure Technique

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Clinical Relevance

A significant decrease in microleakage was noted for Class V resin composite restorations where dentin bonding agents were used.

SUMMARY

This *in vitro* study evaluated the effect of dentin bonding agents in reducing microleakage after three months in Class V restorations restored with Z100 resin composite. Materials tested were three types of resin-based dentin bonding agents: a multi-step (Scotchbond Multi-Purpose); a one-step (Scotchbond One-Step); a self-etching, self-priming (Clearfil Liner Bond) and a resin-modified glass ionomer (GC Fuji Bond LC). Class V cavity preparations with occlusal margins in enamel and gingival margins in cementum were prepared both on labial and lingual surfaces of extracted premolar teeth. Restorations (two per tooth) were distributed randomly into nine test groups (n=10) consisting of the various DBAs applied with co-cure and pre-cure techniques, and no dentin bonding as a negative control group. Samples were stored in saline for three months, thermocycled, stained with silver nitrate, then sectioned through the middle of the preparation to facilitate the removal of the composite resin restoration.

For groups treated with the pre-cure technique, the differences between the enamel leakage values of SBMP-control, CFLB-control and SB1S-control subgroups were significant ($p<0.05$). For enamel leakage values of groups treated with the co-cure technique, the differences between the SBMP-control, SB1S-control, CFLB-control and Fuji LC-control subgroups were significant ($p<0.05$).

For cementum leakage values of groups treated with pre-cure technique, the difference between the CFLB-control and the Fuji, SBMP and SB1S groups was significant ($p<0.05$). No significant differences could be detected between the cementum leakage values of groups treated with the co-cure technique ($p>0.05$).

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The differences between the values obtained with application of CFLB with the pre-cure and co-cure techniques at the cementum margins were found to be statistically significant (p=0.02). No statistically significant differences could be detected between the pre-cure and co-cure values of the other test materials.

Generally for every group, cementum microleakage values were greater than enamel microleakage values (p<0.05). The use of Scotchbond Multi-Purpose, Scotchbond One-Step and Fuji Bond LC with the co-cure technique to decrease the application time did not cause any significant increase in microleakage. Only pre-curing using Clearfil Liner Bond provided better microleakage properties than the other pre-cured adhesives.

INTRODUCTION

Despite vast improvements that have expanded indications for their use, present-day resin composites still have shortcomings that limit their application. Inadequate resistance to wear under masticatory forces and marginal leakage due to polymerization shrinkage are often cited as primary problems (Peutzfeldt, 1997). Microleakage (the passage of bacteria, fluids, chemical substances, molecules and ions between the tooth and its restoration) is an intrinsic problem of traditional restorative materials and is clinically undetectable (Bauer & Henson, 1984). Nearly all microleakage studies suggest that most restorative materials are weak, that is, they permit dyes, radioisotopes or bacteria to enter a space between the cavosurface margins of the restoration and the wall of the cavity (Pashley, 1990).

Theoretically, a tight, non-leaking marginal seal could result from adhesion of the restorative material to tooth structure, but chemical adhesive bonding is rarely achieved and difficult to prove with restorative materials in the oral environment (Alperstein, Graver & Herold, 1983). Recent studies have shown that beveling of enamel cavosurface margins, acid etching and using dentin bonding agents are effective in reducing microleakage (Bauer & Henson, 1984). On enamel, the acid-etch technique has proven its durability. However, in contrast to enamel, dentin has a more complex structure. A successful dentin bond can only be obtained if an optimal interlocking of an adhesive-luting system (ie, a dentin bonding agent and a luting resin) can be achieved on the dentin surface (Bachman & others, 1997).

Modern dentin-bonding agents have evolved from the original concept of increasing dentin permeability and wettability and promoting bonding to the smear layer, to the use of stronger etchants to modify or remove the smear layer and obtain some form of micromechanical retention (McLean, 1996).

More recently, photocured resin bonding agents, coupled with glass-ionomer technology, have been developed, whereby carboxylic acid groups become available for attachment to dentin. These new bonding agents could be classified glass-ionomer bonding agents because they have a dual role in bonding to both dentin and glass ionomer cement (McLean, 1996).

New-generation bonding systems requiring fewer steps and less material could potentially be easier to use and more effective. Achieving this simplification involves creating materials having dual or multiple functions (Schumacher & others, 1997). Self-etching agents have been developed to eliminate the conditioning, rinsing and drying steps critical to normal bonding applications yet extremely difficult to standardize. These self-etching/self-priming systems are applied directly onto the dentin and enamel smear layers, followed by air drying (Prati & others, 1998).

McCabe and Rusby (1994) investigated the effects of pre-cure and co-cure techniques on the shear bond strength of Syntac and Art Bond bonding agents to dentin. They reported that, in contrast to some manufacturers' claims that bonding agents would provide similar bond strengths with both techniques, pre-curing the adhesive resin provided better bond strength to dentin.

Knight (1994) suggested that using glass ionomer cement under resin composite restorations placed with the co-cure technique would reduce marginal leakage and internal stresses. He postulated that during co-curing, as the resin activates before the glass ionomer cement, the uncured glass ionomer cement may take up the dimensional changes caused by polymerization shrinkage of the resin.

This investigation evaluated the three-month effectiveness of four dentin bonding systems: Scotchbond Multi-Purpose Plus (3M Dental Products, St Paul, MN 55144) (multi-step), Scotchbond One-Step (one-step) (3M Dental Products), Clearfil Liner Bond (Cavex Kuraray Co Ltd, Tokyo, Japan) (self-etching/priming) and Fuji Bond LC (GC Corp, Tokyo, Japan) (glass-ionomer dentin bonding agent) applied using pre-cure and co-cure techniques.

METHODS AND MATERIALS

Forty-five non-carious extracted permanent premolar teeth were cleaned, using a scalpel, and examined to ensure that there were no cracks or fractures, especially in the sites to be restored. They were stored in deionized water with a bactericidal agent, 0.2 % sodium azide, until ready for use.

Class V cavity preparations were placed in the premolar teeth on both facial and lingual surfaces. They were cut using a #33 inverted cone bur in a high-speed handpiece with air and water spray. Preparations were 1.5 mm deep, oblong in shape, measuring 2 x 3 mm. They were placed parallel to the cementoenamel junc-

tion (CEJ), with the gingival half of the preparations extended 0.5 mm below the CEJ. Cavosurface walls were finished to a butt joint with a #55 slow-speed bur. Cavity preparations were rinsed for 20 seconds with an air/water spray and gently air dried for 30 seconds. Ten restorations were evaluated for each of the pre-cure and co-cure techniques utilizing the four dentin bonding systems, as well as 10 restorations serving as the control.

The dentin bonding systems Scotchbond Multi-Purpose Plus, Scotchbond One-Step, Clearfil Liner Bond and GC Fuji Bond LC were applied following manufacturers' instructions. Polymerization was done using either pre-cure or co-cure techniques. Pre-cure means that the bonding agent was light cured prior to the application and polymerization of the resin composite. With co-cure, the bonding agent and resin composite restorative materials were polymerized at the same time. The hybrid-type composite resin (Z100; 3M Dental Products) was placed in 1 mm increments, the first placed occlusally, followed by the gingival increments (Feilzer, De Gee & Davidson, 1988). Each increment was light cured for 40 seconds. The negative control preparations were rinsed and air dried, and composite resin restorations were applied in the same manner, but without any bonding agents. Ten minutes after polymerization, the restorations were finished with a 12-fluted finishing bur, followed by polishing with abrasive disks (Sof-Lex; 3M Dental Products).

The teeth were stored for 90 days at 37°C, then thermocycled between 10°C and 50°C for 540 cycles using a 20-second dwell time in each bath. The apices of the specimens were sealed with Scotchbond Multi-Purpose/Silux Plus (Mfg). All tooth surfaces were covered with two coats of colorless (clear) nail polish to within approximately 1.0 mm of the tooth-restoration margin. The staining technique utilized was the same as that used in previous studies (Hilton, Swartz, Ferracane, 1997). The specimens were immersed in room temperature 3 mol/L silver nitrate in amber vials for 24 hours in a dark room. They were then removed, rinsed with tap water and placed in film developer (Film Developer; Eastman Kodak, Rochester, NY 14650) under fluorescent light for 24 hours. Once removed from the developer, the teeth were embedded in epoxy resin (Buehler Ltd, Lake Bluff, IL 60044) and allowed to set overnight before they were sectioned labiolingually in the approximate center of the restorations using a low-speed saw (Isomet; Buehler Ltd).

The composite restorative material was carefully removed from the cavity preparation with a #1/2 round bur in a high-speed handpiece (Hilton & others, 1997). Generally, removal of composite resin restorations was easy, and where it was not, composite material was left as a thin film, allowing a complete visualization of tracer penetration. Each section was evaluated with a stereoscopic microscope (Olympus SC 35; Olympus, Tokyo, Japan) at X10 magnification and blindly scored for microleakage by a second investigator. A visual scheme traced on paper was used to calibrate the investigators for scoring microleakage according to the scale used. Microleakage scores were based on the degree of dye penetration according to the following scale (Turner & others, 1995): 0 = no leakage; 1 = dye penetration less than halfway to the axial wall; 2 = dye penetration greater than halfway to the axial wall; and 3 = dye penetration along the axial wall.

The data were evaluated with Kruskall-Wallis analysis of variance, multiple Dunn tests, Mann-Whitney U test and Wilcoxon matched-pair signed rank test.

RESULTS

The mean microleakage values obtained from test groups are summarized in Figure 1.

Pre-cure Technique

At the enamel margin, the greatest mean microleakage values were obtained from the control group (2.0), followed in consecutive order by the Fuji LC (0.7), SB1S (0.4), CFLB (0.3) and SBMP (0.2) groups (Table 1).

At the cementum margin, the greatest mean microleakage values were obtained from the control group (2.6), followed by Fuji LC (1.80), SBlS (1.80), SBMP (1.50) and CFLB (0.90) groups (Table 2).

Co-cure Technique

At the enamel margin, the greatest mean microleakage values were obtained from the control group (2.0), followed by Fuji LC (0.7), CFLB (0.7), SB1S (0.60) and SBMP (0.2) groups (Table 1).

At the cementum margin, the greatest mean microleakage values were obtained from the control group (2.6), followed by Fuji LC (1.8), CFLB (1.8), SB1S (1.7) and SBMP (1.7) groups (Table 2).

Statistical Analysis

The results of the statistical analysis are summarized in Table 3. As the bonding agent groups were independent from each other and the number of samples in each group were lower than 30, they were compared with each other separately for each of the enamel margin or cementum margin subgroups of both pre-cure and co-cure groups with Kruskall-Wallis analysis of variance. Since the results of Kruskall-Wallis analysis of variance indicated significant differences ($p<0.05$), the groups were analyzed with Dunn tests to detect the groups causing differences. The results of this test revealed that for enamel values, groups treated with the pre-cure technique showed significant differences ($p<0.05$) between the SBMP-control, CFLB-control and SB1S-control subgroups. For the groups treated with the co-cure technique, the differences between the SBMP-control, SB1S-control, CFLB-control and Fuji LC-control

subgroups were also significant ($p<0.05$).

For cementum values of groups treated with the pre-cure technique, the difference between the CFLB-control and other DBAs was significant ($p<0.05$); and for cementum values of groups treated with the co-cure technique, there were no differences among all groups.

The differences between the values obtained with the pre-cure and co-cure techniques of enamel and cementum subgroups for each material were evaluated with Mann-Whitney U tests. Only the difference between the values obtained with application of CFLB with the pre-cure and co-cure techniques at cementum margins were found to be statistically significant (U = 20.0, and $p=0.02$). There were no significant differences between the enamel values of test groups applied with the pre-cure and co-cure techniques.

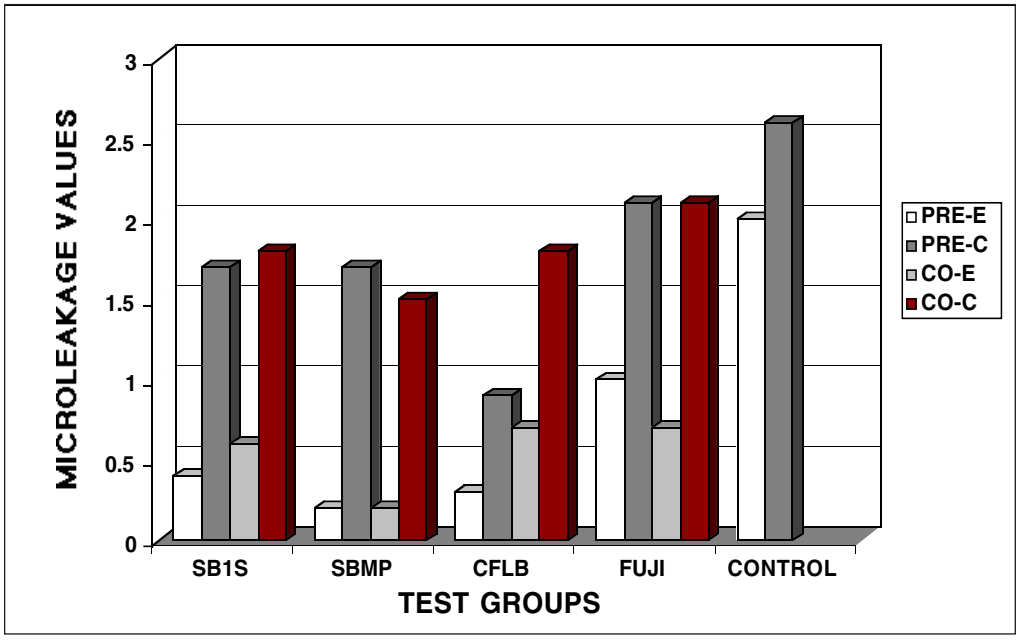

Figure 1. *Mean microleakage scores for different bonding systems. (PRE-E:The occlusal-enamel margins of teeth restored with pre-cure technique, PRE-C: The gingival-cementum margins of teeth restored with pre-cure technique, CO-E: The occlusal-enamel margins of teeth restored with co-cure technique, CO-C: The gingival-cementum margins of teeth restored with co-cure technique).*

Generally, cementum microleakage values were greater than enamel microleakage values for every group. Wilcoxon matched-pair tests revealed that the differences between the enamel and cementum scores were statistically significant for all groups ($p<0.05$).

DISCUSSION

This study evaluated the microleakage performance for four dentin adhesives (SB1S, SBMP, CFLB and Fuji LC), using pre-cure and co-cure techniques, against a non-bonded control. Leakage was evaluated at both enamel and cementum margins. The microleakage values obtained from the test groups were lower than the control groups, supporting the effectiveness of using dentin bonding agents to reduce microleakage.

Although in many investigations teeth are only cut once (Holtan & others, 1994), more detailed information on marginal integrity can be obtained by evaluating multiple sections prepared in one restoration (Friedl & others, 1997). Investigators have compared leakage of Class V composite restorations by using three techniques: (1) a single section through the middle of the preparation; (2) a demineralization and clearing protocol that allowed direct three-dimensional visualization of dye penetration; and (3) sequential grinding and computer image acquisition that allows a three-dimensional reconstruction of the leakage pattern. Both three-dimensional techniques revealed significantly greater leakage at the gingival margin than did the single-section technique (Hilton & others, 1997). The technique described in Hilton's study—removing the entire composite with a handpiece, thereby allowing complete visualization of the staining pattern within the cavity preparation—

Table 1: *Occlusal/Enamel Microleakage Values Obtained from Test Groups*

Dentin Bonding System	Application Technique	Microleakage Values 0	1	2	3	Mean
SB1S	PRE-CURE	6	4	0	0	0.4
	CO-CURE	5	4	1	0	0.6
SBMP	PRE-CURE	8	2	0	0	0.2
	CO-CURE	8	2	0	0	0.2
CFLB	PRE-CURE	7	3	0	0	0.3
	CO-CURE	3	7	0	0	0.7
FUJI	PRE-CURE	3	4	3	0	0.7
	CO-CURE	4	5	1	0	0.7
CONTROL		0	2	6	2	2

Table 2: *Cervical/Cement µm Values Obtained from Test Groups*

Dentin Bonding System	Application Technique	Microleakage Values 0	1	2	3	Mean
SB1S	PRE-CURE	0	5	3	2	1.8
	CO-CURE	0	5	2	3	1.7
SBMP	PRE-CURE	2	1	5	2	1.5
	CO-CURE	1	5	2	2	1.7
CFLB	PRE-CURE	2	7	1	0	0.9
	CO-CURE	0	4	4	2	1.8
FUJI	PRE-CURE	0	2	5	3	1.8
	CO-CURE	0	2	5	3	1.8
CONTROL		0	0	4	6	2.6

was chosen for use in this study. While this allowed an excellent three-dimensional assessment of the leakage pattern, it was time consuming and did not allow visualization of leakage that penetrated down the dentinal tubules in a pulpward direction.

Barnes and others (1994) performed an *in vitro* study that indicated there were no statistically significant differences in microleakage between facial and lingual enamel and cementum margins in Class V restorations when using both the rank order system and the measured data system to evaluate microleakage.

The results of this study demonstrated no significant differences in enamel margin sealing abilities among the four composite bonding systems using both techniques. Holtan and others (1994) reported dye penetration at one-third of the cavosurface margins of restorations bonded with Scotchbond Multi-Purpose Plus. In another dye penetration study (Ferrari & Davidson, 1996), nine specimens of Scotchbond Multi-Purpose Plus showed no microleakage at enamel margins, while one specimen showed penetration to half the distance to the axial wall. At the cementum margin, seven specimens showed no microleakage and three of the specimens showed penetration to one-half the distance to the axial wall.

Yap, Ho and Wong (1998) reported no significant difference in dye penetration either at enamel or dentin margins for Scotchbond Multi-Purpose, Prime&Bond 2.0 or Fuji Bond LC groups stored for one week in 37°C isotonic saline. However, they stated that after 500 thermal cycles between 5°C and 65°C for 20 seconds in each bath and a dwell time of 10 seconds in a resting bath at 34°C, Fuji Bond LC showed better sealing ability at the cervical margins than the other test groups. This study also indicated that thermocycling significantly decreased leakage at the dentin margins of restorations bonded with Fuji Bond LC in permanent teeth. These findings are not in accordance with this study where the Fuji Bond LC group exhibited greater microleakage values than Scotchbond Multi-Purpose or Clearfil Liner Bond groups. The differences in Fuji Bond LC results may be due to the effect of a longer storage time or the longer dwell time used in this study's thermocycle technique.

Bachmann and others (1997) stated that, in contrast to enamel, dentin has a much more complex structure that allows successful bonding to dentin only if an optimal interlocking of an adhesive system to dentin can be achieved. In accordance with their statements, greater microleakage values were observed at cementum margins for all material groups and techniques.

Friedl and others (1997) reported no significant differences in marginal gaps between enamel-composite and dentin-composite interfaces in permanent teeth, bonded with Scotchbond Multi-Purpose, following 5000 thermal cycles between 5°C and 55°C. In this study, the differences between enamel and cementum microleakage scores were statistically significant ($p<0.05$) for both technique groups.

Scotchbond One-Step is classified as a single-component or one-bottle system because the adhesive comonomer mixtures are stored in the same bottle. The functions previously accomplished by separate primers and bonding adhesives thus occur at the same time using the single-bottle systems. However, there is a possibility that the lack of a separate primer may reduce the infiltration depth or the wettability of the dentin bonding agent, thereby reducing adhesion and sealing capacity. Although this study obtained lower microleakage scores with a multi-step dentin bonding agent (SBMP) compared to one-step (SB1S) using both techniques, the differences were not statistically significant.

Other DBAs, the self-etching agents, were developed to eliminate the conditioning, rinsing and drying steps that may prove critical and difficult to standardize in operative conditions because of the instability of demineralized matrix. These self-etching/self-priming systems are applied directly onto the dentin and enamel smear layers for 30 seconds, followed by air-drying. Their adhesion mechanisms are different and should, at least in theory, eliminate certain problems related to collapse of the collagen fibrils after conditioning (Prati & others, 1998). These are in accordance with this study, where the lowest occlusal/enamel microleakage values were obtained from the SBMP and CFLB groups for the pre-cure technique, and SBMP for the co-cure technique and the lowest gingival-cementum

Table 3: *Table IV. Results of the Statistical Analysis*

		Pre-cure technique				Co-cure technique				
		SB1S	SBMP	CFLB	FUJI	SB1S	SBMP	CFLB	FUJI	CONTROL
Pre-cure Technique	SB1S		$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$				$p<0.05$
	SBMP	$p>0.05$		$p>0.05$	$p>0.05$		$p>0.05$			$p<0.05$
	CFLB	$p>0.05$	$p>0.05$		$p>0.05$			$p>0.05$		$p<0.05$
	FUJI	$p>0.05$	$p>0.05$	$p>0.05$					$p>0.05$	$p>0.05$
Co-cure Technique	SB1S	$p>0.05$					$p>0.05$	$p>0.05$	$p>0.05$	$p<0.05$
	SBMP		$p>0.05$			$p>0.05$		$p>0.05$	$p>0.05$	$p<005$
	CFLB			$p<0.05$		$p>0.05$	$p>0.05$		$p>0.05$	$p<0.05$
	FUJI				$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$		$p<0.05$
	CONTROL	$p>0.05$	$p>0.05$	$p<0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	

Statistically significant differences are bold typed
Light shaded areas indicates occlusal-enamel groups and dark shaded areas indicate gingival-cementum groups
SB1S: Scotchbond one-step, SBMP: Scotchbond Multi-Purpose Plus, CFLB: Clearfil Liner Bond II, FUJI: Fuji Bond LC

microleakage values were obtained from the CFLB group using the pre-cure technique.

Knowing that resin materials activate before glass-ionomer materials, it seems reasonable to expect that when co-curing such materials, the glass-ionomer would compensate for the polymerization shrinkage of the resin (Knight, 1994). However, the results of this study are not in accordance with this postulation, which could be due to the fact that Knight's study involved glass-ionomer cements under resin composite materials. In this case, the glass-ionomer base was much thicker than the glass-ionomer bonding agent layer, creating a higher potential for compensating the polymerization shrinkage of the overlying resin composite. Another possible explanation is that resin composite may not establish a good bond to a still unpolymerized glass-ionomer surface.

CONCLUSIONS

Using dentin bonding agents under Class V composite resin restorations caused statistically significant decreases in microleakage compared to restorations placed without using a bonding agent.

Cementum microleakage values were higher than enamel microleakage values for all groups using the newest dentin bonding agents.

Using the pre-cure technique, Scotchbond Multi-Purpose and Clearfil Linerbond provided the lowest microleakage values at both enamel and cementum margins.

While there were no significant differences between the applications of the pre-cure and co-cure techniques for Scotchbond Multi-Purpose, Scotchbond One-Step or Fuji Bond LC, a significant increase in microleakage occurred when the self-etching bonding agent Clearfil Liner Bond was used with the co-cure technique.

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Bond Strengths of a Porcelain Material to Different Abutment Substrates

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A Vichi • G Goracci

Clinical Relevance

The bond strength of a single-unit all-porcelain material to the substrates present on the surface of the abutments was evaluated. Amalgam and gold showed significantly lower bond strength values than enamel, dentin and composite resin.

SUMMARY

The study evaluated the bond strength values of a single-unit all-porcelain material luted with an adhesive-resin cement to different abutment substrates: amalgam, compomer, traditional glass ionomer cement, microhybrid resin composite, two resin composites for abutment build-up, gold, sandblasted gold, dentin and enamel. Syntac enamel-dentin bonding system, in combination with IPS-Empress porcelain material, was used. After thermal cycling, the samples were inserted into a Bencor jig device and sheared in a Controls testing machine. The statistical analysis of the differences between the bond strength values obtained was performed by ANOVA and the Student-Newman-Keuls multiple-comparison test. The type of failure at the interface was evaluated using scanning electron microscopy. The type of failure, such as adhesive, cohesive and adhesive-cohesive, was correlated with bond strength values. Enamel, dentin and the two resin composites for crown build-up showed the highest bond strength values, while amalgam and gold samples showed the lowest.

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INTRODUCTION

Metal-ceramic restorations have been used extensively in dentistry. Thanks to improvements in dental materials and procedures, it is now possible to reproduce the natural appearance of teeth in the anterior area with single-unit all-porcelain crowns (Pietrobon & Paul, 1997; Paul & Pietrobon, 1998). Increased patient demand for esthetics has resulted in the widespread application of single-unit all-porcelain crowns (Christensen, 1994). In order to satisfy patients' esthetic requirements, many new porcelain materials have been introduced. Most are luted with adhesive-resin cement systems. IPS-Empress system (Ivoclar, Schaan, Liecthenstein) is one of the more popular porcelain materials.

Candidates for receiving a single-unit all-porcelain restoration are: 1. vital teeth partially destroyed by trauma or decay; 2. endodontically-treated teeth; and 3. teeth needing the replacement of old, unaesthetic restorations, such as porcelain fused to metal crowns.

Vital teeth exhibiting extensive decay must be restored before being prepared for single-unit all-porcelain crowns. Endodontically-treated teeth can be built up using different restorative materials, such as metal posts, fiber posts or zirconium dioxide posts in combination with resin composites, compomers or glass ionomer cements (Ahmad, 1998). Removal of old porcelain to fused-metal crowns may expose a variety of substrates, including dentin and enamel. Therefore, adhesive-luting procedures for bond single-unit all-porcelain crowns should be effective on all substrates.

This study evaluated the bond-strength values of a single-unit all-porcelain material luted with adhesive-resin cement to the different substrates that may be part of the abutment's structure.

METHODS AND MATERIALS

The materials used in this study are listed in Table 1.

Preparation of Samples

The different substrates tested in this study were: 1. Amalgam (Amalcap-SAS-NG2 Vivadent, Ellwangen, Germany, Batch #457704); 2. Compomer (Dyract AP, De Trey Dentsply, Germany, A3, Batch #9707000413); 3. Traditional glass ionomer cement, (Fuji IX, GC, Tokyo, Japan, A3, Batch #280180); 4. Microhybrid resin composite (Spectrum TPH, DeTrey Dentsply, Konstanz, Germany, A3, Batch #980508); 5 and 6. Two resin composites for abutment build-up, (Photocore, Kuraray, Osaka, Japan, Batch #1412A and Bis Core Bisco, Itasca, IL, USA, 079018/079089); 7. Gold (Strator 3, Cendres & Metaux SA, Biel, Switzerland, Batch #0000005094); 8. Sandblasted gold; 9. Dentin and; 10. Enamel. Ten samples of each material were included in the experimental groups.

For the samples in Groups 1-6, 3 mm thick disks with a diameter of 5 mm were prepared using a prefabricated device.

The samples in Groups 7 and 8 were prepared by waxing disks of 5 mm thickness, then casting in the gold material. All samples were surfaced with a diamond bur where the porcelain was to be cemented. The bonding surfaces of Group 8 samples were sandblasted with AlO^3 particles (90 μm). All the materials were manipulated following manufacturers' instructions.

Samples in Groups 1-8 were then mounted in metallic rings 1 inch in diameter with cold-cure acrylic resin and clamped into a Bencor jig device for testing (Danville Engineering Inc, San Ramon, CA 94583).

Twenty sound human third molars, recently extracted for periodontal reasons, were used for preparing samples in Groups 9 and 10. The teeth were cleaned with scalers and flour of pumice and stored in distilled water for four weeks before being processed. They were mounted in rings 1 inch in diameter with cold-cure acrylic resin. The samples were randomly divided into two groups of 10 samples each. The buccal surfaces of Group 9 samples were ground flat to expose superficial dentin and polished on wet 240-, 400- and 600-grit SiC paper. The specimens were observed with a stereomicroscope (Zeiss OPM1, Munchen, Germany) to ensure that no enamel remained. The buccal surfaces of Group 10 samples were ground, as described for Group 9 specimens, in order to prepare a flat enamel surface.

Table 1: *Commercial Materials Used in the Study*

	Material	Product Name	Shade and Batch No.	Manufacturer
Abutment Materials	Amalgam	Amalcap-SAS-NG2	457704	Vivadent, Ellwangen, Germany
	Compomer	Dyract AP	A3, 9707000413	DeTrey, Kostanz, Germany
	GIC	Fuji IX	A3, 280180	GC, Tokyo, Japan
	Resin Composite	Spectrum TPH	A3, 980508	De Trey, Kostanz, Germany
	Resin Composite	PhotoCore	1412A	Kuraray, Osaka, Japan
	Resin Composite	Bis-Core	079018/079089	Bisco, Itasca, IL
	Gold	Strator 3	0000005094	Cendres & Metaux SA, Biel, Switzerland
	Sandblasted Gold	Strator 3	0000005094	Cendres & Metaux SA,Biel, Switzerland
Adhesives	Adhesive system	Syntac	907630	Vivadent, Schaan, Liechtenstein
	Resin cement	Variolink II	823116	Ivoclar, Schaan, Liechtenstein
Ceramic	Porcelain	IPS-Empress	Unknown	Ivoclar, Schaan, Lichtenstein

Table 2: *Shear Bond Values (MPa), Group Rankings and Failure Modes*

Group	Mean (SD)'	Group ranking*	Type of Failure"
1. (AMG)	6.90 (0.3)	C	10 A
2. (Dyract AP)	15.38 (1.2)	B	6 C / 2 A-C / 2 A
3. (Fuji IX)	15.12 (0.7)	B	10 C
4. (SpectrumTPH)	15.39 (1.1)	B	7 C / 2 A-C / 1 A
5. (PhotoCore)	18.06 (2.1)	A	5 C / 5 A-C
6. (Bis-Core)	19.26 (2.9)	A	8 C / 2 A-C
7. (Gold)	10.82 (1.3)	C	10 A
8. (Sandblasted Gold)	14.43 (1.2)	B	5 C / 3 A-C / 2 A
9. (Dentin)	17.0 (1.1)	AB	5 C / 3 A-C / 2 A
10. (Enamel)	19.9 (0.6)	A	6 C / 4 A-C

' (SD) = Standard Deviations
* Values marked by the same letter were not significantly different.
" A = Adhesive failure; C = Cohesive failure; A-C = Adhesive-Cohesive failure

One hundred porcelain cylinders, 3 mm in diameter and 5 mm in height were cast using IPS-Empress porcelain material, following the manufacturer's instructions.

Bonding Procedures

The bonding area was limited by the use of two-sided sticky tape containing a 3 mm diameter hole. The bonding area of dental substrates in the samples in Groups 1-10 were treated with Syntac enamel-dentin bonding system (Vivadent, Schaan, Lichtenstein, Batch #907630) strictly following the manufacturer's instructions. The bonding surfaces of the porcelain cylinders were etched with 10% hydrofluoric acid for two minutes, then washed, air-dried and silaneted (Syntac silane was applied for two-to-three minutes and air-dried). The porcelain cylinders were then luted to the different substrate samples with Variolink II resin cement (Vivadent, Batch #823116), following manufacturer's instructions. The samples were subsequently subjected to 500 thermal cycles between 5-55C°, keeping the specimens for 10 seconds at each temperature. The specimens were then stored for 7-10 days in distilled water at 23Cº.

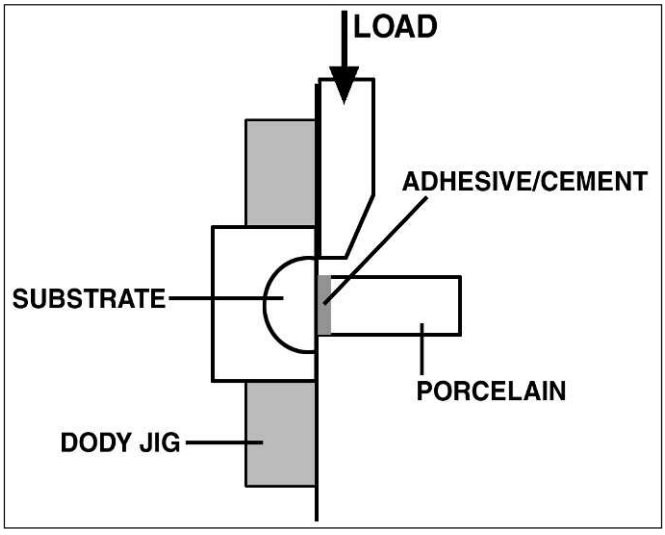

Figure 1. *The diagram shows how the specimens were mounted in the testing machine (from Sudsangiam & Van Noort 1999, modified).*

Bond Strength Testing

The samples were inserted into a Bencor jig device (Danville Engineering Inc, San Ramon, CA) and mounted in a Controls testing machine (Controls Testing Equipment Ltd, Hertforshire, England) (Figure 1). Shear loading was performed at a crosshead speed of 0.5 mm per minute. Samples were loaded until fracture occurred.

Statistical Analysis

A statistical analysis of the differences between measured values was performed using an analysis of variance (ANOVA) and the Student-Newmann-Keuls multiple comparisons test. The level of statistical significance was set at $p<0.05$. The statistical analysis was processed with the SPSS/PC+ software system (SPSS Inc, Chicago, IL).

Microscopic Evaluation

After fracturing, the samples were prepared for scanning electron microscopy to detect the type of failure at the interface. The samples were mounted on aluminum stubs with colloid silver paint and vacuum desiccated before being coated with gold-palladium at 15 mA for four minutes by sputtering (Edwards Sputter Coater S150B, London, UK).

Subsequently, the specimens were examined by a 515 Philips scanning electron microscope. (Philips Co, Amsterdam, The Netherlands) at a 10 kW accelerating voltage at different magnifications to detect the type of failure (adhesive, cohesive or combined adhesive-cohesive). Micrographs were taken to document the type of failure for each sample at different magnifications.

RESULTS

Shear bond strength values and group ranking are listed in Table 2. Groups 9 and 10, enamel and dentin respectively, and the two crown build-up composite resins (Groups 5 and 6), showed the highest bond strengths, in a range between 17.0 and 19.9 MPa. No statistically significant differences were found among these groups.

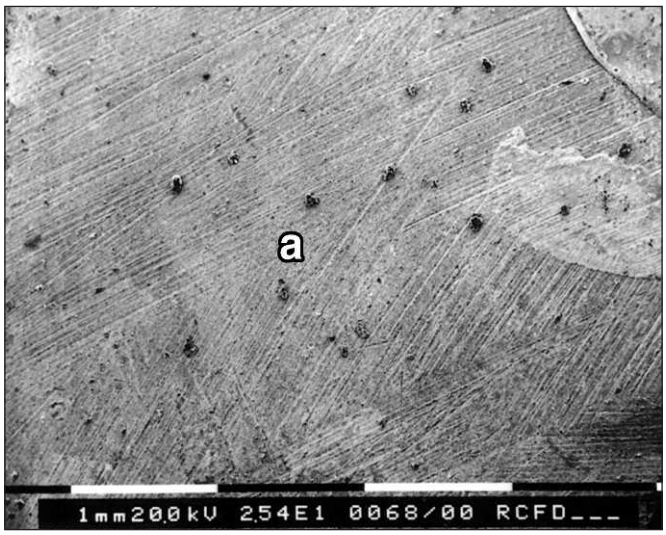

Figure 2. *Adhesive failure of a specimen of the amalgam group (Group 1). No resin remains on the surface. All amalgam samples showed adhesive failure and the lowest bond strength values (a: amalgam) (magnification x25).*

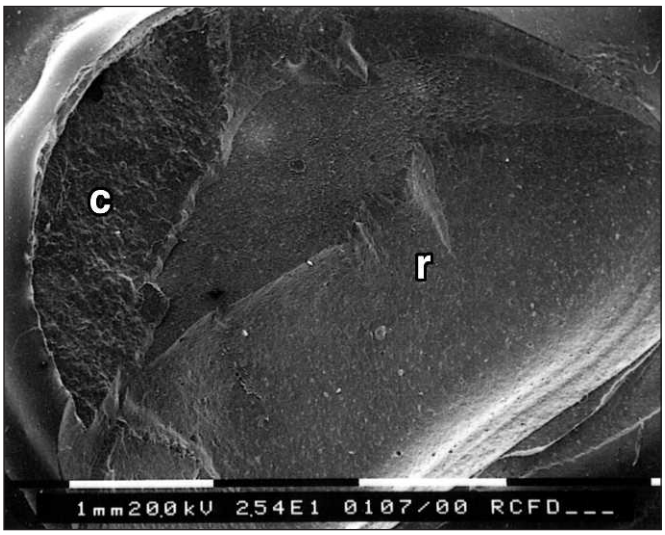

Figure 3. *Cohesive fracture of a specimen of resin composite for crown build up (Group 6) (r: resin composite, c: resin cement) (magnification x25).*

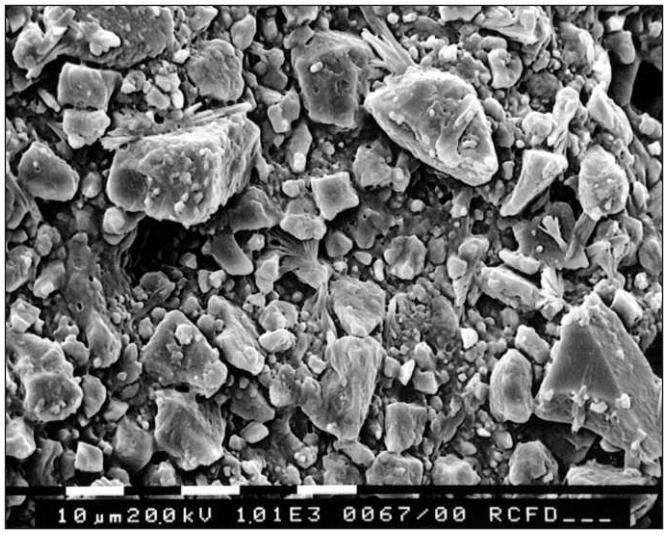

Figure 4. *High magnification of Figure 3. The resin composite structure is detectable (magnification x1010).*

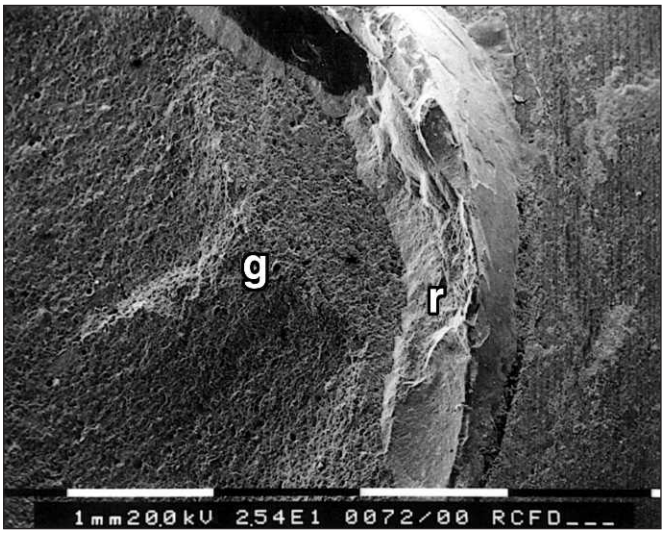

Figure 5. *Cohesive failure within the glass ionomer cement (Group 3). All samples of this group showed cohesive fracture (g: glass ionomer cement; r: resin cement) (magnification x25).*

Groups 2, 3, 4 and 8 samples showed mean bond strength values between 14-4 and 15.4 MPa. No statistically significant differences were found among these four groups. The lowest bond strength values were obtained when amalgam (Group 1) and gold (Group 7) samples were tested. The fracture patterns of the materials are given in Table 2. A differentiation has been made in adhesive, cohesive and combined adhesive-cohesive failure. Adhesive failure was the prevalent type of failure in Groups 1 and 7 (Figure 2). In fact, amalgam and gold were the substrates with the highest frequency of adhesive failure. Samples of Groups 5 and 6 frequently showed a cohesive type of failure (Figures 3 and 4). Only Group 3 samples showed 10 cohesive failures: all of them in the substrate (Figure 5). Groups 2, 4, 8, 9 and 10 samples showed more cohesive and/or adhesive-cohesive failure than adhesive types of failure (Figures 6-7). In these samples, the resin cement usually remained partially bonded to the substrate after testing procedures. In Groups 8 and 9, the type of failure was equally distributed among adhesive and combined-type of failure (adhesive-cohesive) (Figures 8 and 9). All the cohesive failures were placed in the substrate, not in the porcelain material.

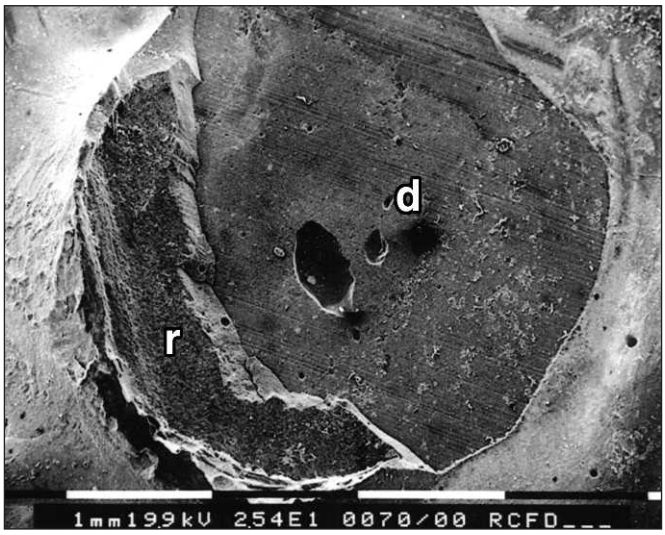

Figure 6. *Adhesive-cohesive fracture after testing a sample of Group 9. In this sample the type of failure was mainly adhesive. The picture reveals a type of peripheral fracture (cohesive) different from that observed in the central zone of the specimen (adhesive)(r: resin composite; d: dentin) (magnification x25).*

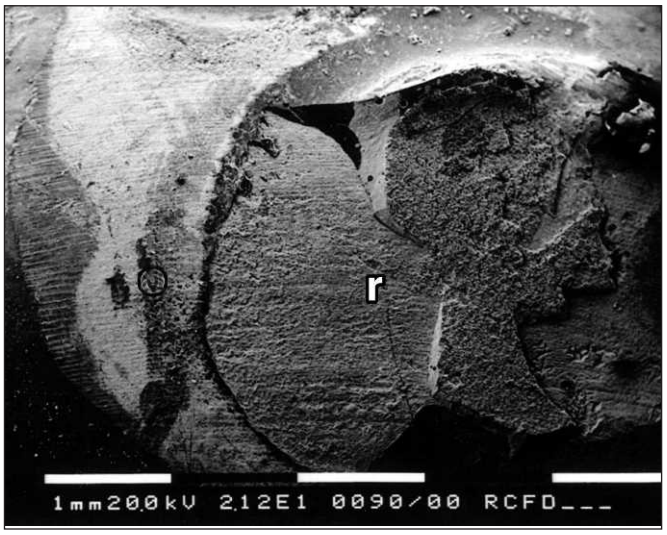

Figure 7. *Adhesive-cohesive failure after fracturing a sample of Group 10 (enamel) In this sample the type of fracture was mainly cohesive (r: resin cement) (magnification x25).*

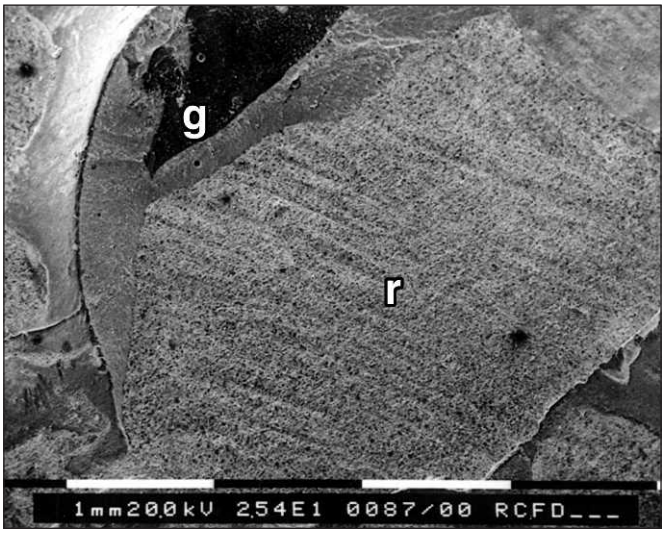

Figure 8. *When the abutment gold surface was sandblasted, cohesive-adhesive type of failure was prevalent. In this case the type of fracture was mainly cohesive (r: resin cement; g: gold) (magnification x25).*

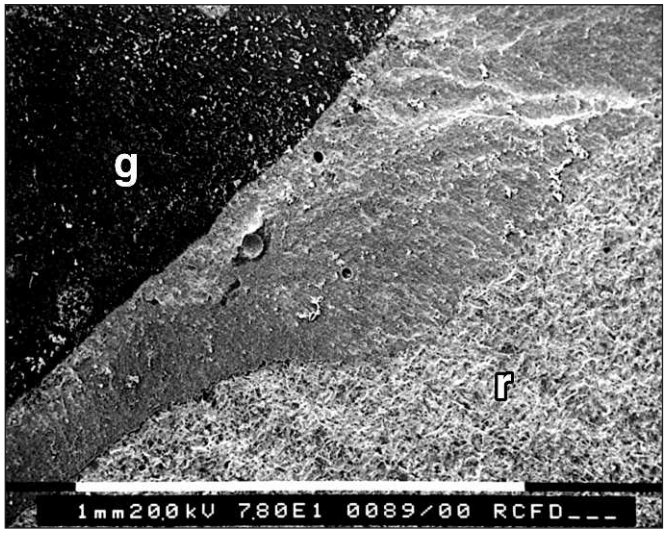

Figure 9. *High magnification of Figure 8. Two areas of adhesive and cohesive failures can be observed (r: resin cement; g: gold) (magnification x78).*

DISCUSSION

Successful cementation is key to the strength and longevity of this type of restoration. The cementation sequence has two distinct parts: treatment of the crown and treatment of the prepared tooth surface. Strong bond to both porcelain crown and tooth surfaces must be achieved. In order to enhance the micromechanical bond, the porcelain surface is etched with hydrofluoric acid, then silanated. The prepared tooth surface is etched for 15-30 seconds with phosphoric acid. When only dental substrates are present on the prepared tooth surface, the porcelain restoration is bonded mechanically by hybrid layer and resin tags and adhesive lateral branches formation (Nakabayashi & Pashley, 1998). Then the adhesive material and the resin cement are applied, respectively, on the abutment and in the internal surface of the crown, and finally the crown is seated and the resin cement light-cured. If, in addition to the enamel and the dentin, other substrates are present on the same abutment surface, the acidic treatment can determine different bond strength values in different areas of the same abutment. In this study, Syntac bonding system,

Variolink II resin cement and the IPS Empress porcelain system were selected because the combination of these materials was widely-tested in clinical studies (Haller, Klaiber & Hofmann, 1993; Brodbeck, 1996). The bonding procedure is usually the same on the entire abutment surface even though different substrates are present. For that reason, the different substrates tested in this study were treated with the same bonding procedure. Failure at the adhesive interface may be attributed to the incomplete wetting and infiltration of the resin into the conditioned substrates. The results of this investigation confirm the need for resin infiltration of the substrate in order to reach a high bond-strength value. The highest bond-strength values were obtained in those groups where the conditioned substrate was infiltrated by the resin, such as the enamel and dentin samples (Groups 9 and 10), or had a chemical/mechanical similarity with the bonding- luting system (such as resin composites and compomer).

The Group 7 samples (sandblasted gold) showed a relatively high bond-strength value, much higher than that scored when gold was not sandblasted (Group 8). The sandblasting procedure created a micromechanical retentive surface in which the resin can infiltrate, creating a strong micromechanical bonding: for that, this procedure might be clinically recommended.

The glass ionomer cement samples (Group 3) showed a relatively high bond-strength value. The bond-strength values between glass ionomer cement and dentin-enamel substrates are usually significantly lower than those obtained with composite resins (Davidson & Mjör, 1999). In this investigation, the mean bond strength value between the glass ionomer cement and the ceramic material was 15 MPa. The roughness of the surface of the abutment's material plays an important role in increasing the bond strength values, as shown for the sandblasted gold group compared to the group not sandblasted. Only cohesive failures in the glass-ionomer substrate were found. The frequency of this type of failure can be explained by the fact that the traditional glass ionomer cement may loose water during the shear-bond strength test, thus becoming brittle and less resistant to stress.

Finally, the amalgam samples showed low bond strength values, which suggests that this substrate should be removed and replaced by other restorative materials before the final impression for making the single-unit all-porcelain crown at least when the Syntac bonding system is the selected adhesive material. Sandblasting of gold substrate produced improved bonding. This procedure may have a similar effect on amalgam but was not tested in this study.

Microscopic examination of the fractured surfaces often revealed a peripheral type of fracture different from that observed in the central zone of the specimen. This observed pattern of fracture supported the theoretical findings by Van Noort & others (1991) and Sudsangiam & Van Noort (1999) of non-uniform interfacial stress during loading. Products which attain a high bond strength in the laboratory should show better clinical performances (Jamil, Aboush & Elderton, 1992; Abdalla & Davidson, 1993). If the shear test is accepted as an indication for bond strength and fracture pattern, cohesive failure may be considered as a superior property of the bonding system because it shows no further need for higher bond strength (Davidson, Abdalla & De Gee, 1993; Retief, Mandras & Russell, 1994).

If a vital abutment needs to be built-up before the final impression for making a single-unit all-porcelain crown and its carious lesion is located close to the pulp, using a traditional glass ionomer cement permits Fl-release into the dentin, reducing postoperative sensitivity and secondary decay (Davidson & Mjör, 1999). Recently, the use of Fuji IX glass ionomer cement and Dyract AP as build-up material for single-unit all-porcelain crowns was clinically evaluated. At the one-year recall, both restorative materials proved appropriate for the build-up of vital teeth (Ferrari & others, 1998).

Esthetic requirements for abutments became evident since the introduction of translucent, enamel-like all-porcelain restorations. These requirements are: 1. dentin-like core; 2. resistance to darkening of the crown and the root of the restored tooth and the surrounding gingival tissues; and 3. if the thickness of the buccal surface of the single-unit all-porcelain crown is not enough (1.5 mm or less), masking the darkness of the abutment surface. These requirements could only be fulfilled by non-metallic abutment materials. Only when the minimal thickness of the buccal surface of the porcelain crown is 2.0 mm, independent of the type of material by which the abutment was restored, the influence of the color abutment on the final appearance of the restoration is not clinically detectable (Vichi, Ferrari & Davidson, 1998). For that, a color-like tooth material should be preferred in order to build up abutments for single-unit all-porcelain crowns. In the case of endodontically-treated teeth, different types of esthetic posts, such as quartz fibers posts and Yttrium-partially stabilized Zirconium dioxide posts, can be used in order to allow transmission of light to the root of the tooth. These types of posts can be used in combination with a core build-up with resin composite material (Dietschi, Romelli & Goretti, 1997; Mannocci, Ferrari & Watson, 1998; Ahmad, 1998). The two resin-composite materials usually used for build-up of abutments in combination with esthetic fiber posts, which were tested in this study, showed high capability to bond to etched porcelain. In fact, the bond strength values recorded for both resin composites were very close to that observed for enamel and higher than that for dentin.

CONCLUSIONS

Within the scope of this study, the following conclusions can be drawn, which may assist the practitioner in selecting abutment materials for bonded porcelain crowns:

- Natural tooth structure (enamel and dentin) provided the best substrate for bonding with the adhesive and ceramic tested.
- Dyract AP, Fuji 1X, Spectrum TPH, Photocore and Bis-Core showed similar bond strengths to enamel and dentin. These restorative materials should be appropriate as core/abutment materials for the system tested.
- Cast gold and amalgam provided the lowest bond strengths and may not be appropriate abutment materials for the system tested. Sandblasting of gold produced a much better retentive surface and should be performed if a gold abutment is utilized.
- The sites and types of bond failure appear to correlate with the nature of the abutment substrate.

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Flow Characteristics and Sealing Ability of Fissure Sealants

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JA von Fraunhofer • A Elsabach

Clinical Relevance

Viscosity and flow properties of fissure sealants do not appear to affect their sealing ability.

SUMMARY

This study evaluated the relationship between fissure sealant viscosity, leakage prevention and the incidence of void formation of five commercially available pit-and-fissure sealants. Seventy-two intact, caries free human pre-molars and molars were divided into six test groups of 12 teeth each. All teeth were cleaned with a flour of pumice prophylaxis followed by etching for 60 seconds with 37% H_3PO_4, rinsing for 30 seconds and drying with oil-free air. Five commercial, light-cured fissure sealants and an unfilled version of one sealant were applied following manufacturers' instructions.

Teeth were thermal cycled for 5000 cycles from 5-50°C with a one-minute dwell time at each temperature. Silver nitrate staining followed by mesiodistal sectioning was performed. Leakage and void formation were evaluated at X50 optical magnification.

Viscosity was assessed by syringing the fissure sealants into short pipettes, allowing free flow for 30 seconds and then light curing for one minute. The length of unfilled capillary was measured with a Vernier gauge.

All experimental data was subjected to a one-way ANOVA, and where differences were detected, they were identified by a post hoc Tukey hsd test at *a priori* $\alpha = 0.05$.

Based on the conditions of the study, viscosity and flow characteristics had no effect on sealing ability or void formation.

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INTRODUCTION

Pit-and-fissure sealants, introduced in 1967 (Cueto & Buonocore, 1967), were recognized by the American Dental Association as effective in preventing pit and fissure caries in 1976 (ADA Council on Dental Materials and Devices and the Council on Dental Therapeutics, 1976). According to a report from the National Institutes of Health, this type of caries accounted for 88% of the total caries experienced by school children between 1986

and 1987 (Brown & others, 1996). Since then, much has been done to increase public and professional awareness of the importance of sealing pits and fissures as part of routine dental care as well as promoting the use of pit-and-fissure sealants (US Public Health Service, 1991; Cohen & Horowitz, 1993; Siegal, 1995; Selwitz, Colby & Rozier, 1992; Lang & others, 1988; NIH Consensus Development Conference, 1984; Frazier & Glasrud, 1986).

Over the past two decades, there have been numerous reports in the literature concerning the physical properties and clinical effectiveness of pit-and-fissure sealants. The consensus view on the clinical use of pit-and-fissure sealants is that they are safe, effective and economical in preventing caries (Simonsen, 1987, 1989, 1991; Wendt & Koch, 1988; Ripa, 1993; Ismail & Gagnon, 1995).

Sealant retention is generally equated to clinical effectiveness (Waggoner & Siegal, 1996) and sealant retention and maintenance of sealant integrity decreases caries initiation in surface pits and fissures. The influence of surface preparation on sealant retention has been studied by many; the recommended procedures for cleaning/preparation of the occlusal surface prior to sealant placement include treatment with H_2O_2, pumice and water, air polishing, air abrasion, incising with a sharp instrument tip or application of a bristle brush (Burrow & Makinson, 1990; Donnon & Ball, 1988; Bogert & García-Godoy, 1992; Goldstein & Parkins, 1994; García-Godoy & Gwinnett, 1987b). However, no differences appear in sealant retention following application of any of these methods, and all appear relatively equal in their clinical results (Waggoner & Siegal, 1996).

A review of the literature by Ripa (1993) found two communications reporting 41% and 57% complete retention 10 years postapplication of autopolymerizing sealants and five-year retention rates of almost 77% for autopolymerizing and visible-light-cured sealants. High partial retention rates have also been reported (Ripa, 1993). The clinical effectiveness of partially-retained sealants in preventing the onset of dental caries, however, is debatable. Simonsen (1991) reported no clinical evidence of caries in partially or completely sealed teeth after 15 years. Other workers, however, feel that the exposure of the sealed fissure due to occlusal wear, dissolution or other factors resulting in the loss of sealant material creates an environment conducive to caries initiation. The general consensus is that to ensure optimal sealant retention and caries prevention, sealants must be placed with meticulous care, and the treated pits and fissures should be evaluated at regular intervals for loss of material. In areas where there has been loss or disruption of the sealant, the treated surface should be reassessed for caries and resealed or restored as necessary.

Table 1: *Fissure Sealants Evaluated in the Study*

Code	Fissure Sealant	Manufacturer
A	Delton plus	Dentsply International York, PA 17404
B	D Helioseal	Vivadent, Liechenstein
C	Ultrashield XT	Ultradent Products, South Jordan, UT 84095
D	Seal-Rite	PulpDent, Watertown, MA 02471
E	Fluroshield	Dentsply International, Milford, DE 17404
F	Delton (unfilled)	Dentsply International, York, PA 84095

Another factor thought to be central to the clinical success of sealants that has received much attention in the literature is microleakage. Microleakage may support the caries process beneath the sealant (Burrow & Makinson, 1990; García-Godoy & Gwinnett, 1987a and b), so the ability of the sealant to adequately seal the pit or fissure and prevent microleakage is important. Studies of conventionally-placed sealants following acid etching of the enamel all showed some degree of microleakage (Rudolph, Phillips & Swartz, 1974; Flanagan & Pearson, 1988; Hicks & Silverstone, 1982; Park & others, 1993). More recent studies that utilized air-abrasion techniques for surface preparation or widened the fissures with rotary instrumentation prior to acid etching showed less microleakage than that found with the conventional acid-etch technique (Zyskind & others, 1998). These studies suggest that microleakage at the tooth/sealant interface is dependent upon the intimacy of contact between sealant and tooth, that is, adequate flow and permeation of the

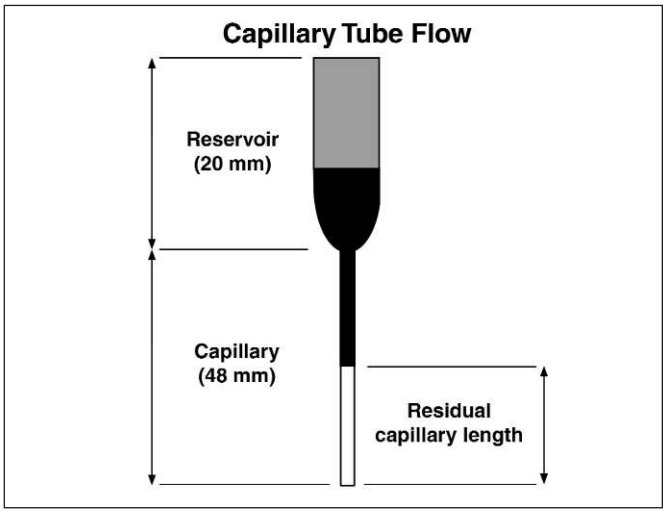

Figure 1. *Capillary flow tube.*

Table 2: *Leakage Behavior of the Experimental Sealant Groups*

Groups	A	B	C	D	E	F
Voids within material	5	4	3	3	2	4
Voids at interface	7	7	5	0	9	7
No. of leaking teeth	1	0	0	1	1	2
Leakage score*	3	0	0	2	4	2,3

*Leakage score: 0 = no leak; 1 = 25% penetration; 2 = 50% penetration; 3 = 75% penetration; 4 = 100% penetration.

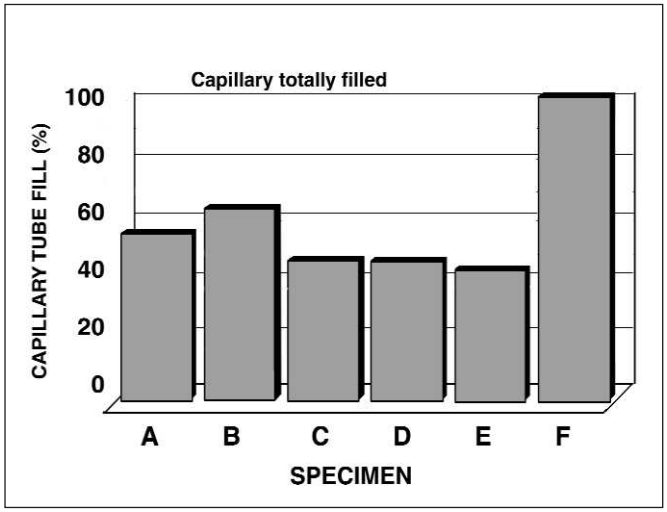

Figure 2.

sealant into the created etch pits in the treated surface.

Interestingly, however, one factor not reported in the literature is the effect of sealant viscosity and its flow behavior on the material's ability to successfully penetrate and seal a pit or fissure. Enhancing the penetration of the sealant into deep grooves and artificially-created pits and other surface topography should improve retention and decrease caries initiation in sealed teeth. Little information has been reported on this parameter for sealant success. This study evaluated the relationship between fissure sealant viscosity, leakage prevention and the incidence of void formation of five commercially available pit-and-fissure sealants.

METHODS AND MATERIALS

Five commercial fissure sealants, together with an unfilled version of one sealant, were used in the study (Table 1). The sealants were supplied in uniform volume capsules and ejected from the capsule by syringe. All materials were visible-light cured.

Six test groups (A-F) were established with 12 permanent teeth per group. All teeth were intact and caries-free, and there were equal numbers of human premolars and molars in each group. Prophylaxis was performed on the teeth with flour of pumice, then they were etched for 60 seconds with 37% H_3PO_4 solution, rinsed for 30 seconds and dried with oil-free air.

In the leakage study, sealant was placed in the fissures, light cured for 60 seconds and subjected to thermal cycling from 5–50°C, with a one-minute dwell time at each temperature for 5000 cycles. Thereafter, the teeth were stained using the silver nitrate technique described by Wu and others (1983) and modified by Hovland and Dumsha (1985), then sectioned vertically into mesiodistal portions before examination under X50 optical magnification. The number and location of voids within the sealant material and at the sealant/enamel interface, as well as the penetration of silver nitrate, were noted.

Sealant viscosity was assessed by syringing the fissure sealants into short Pasteur pipettes (48 mm capillary length, 20 mm reservoir length). The materials were allowed to free-flow for 30 seconds before being light cured for one minute. The length of unfilled capillary was measured with a Vernier gauge (Figure 1). Six pipettes were filled with each material.

All experimental data were subjected to a one-way ANOVA, and where differences were detected, they were identified by a post hoc Tukey hsd test at *a priori* $\alpha = 0.05$.

RESULTS

Data on void formation and marginal leakage are summarized in Table 2, while the viscosity behavior is summarized in Figure 2. No significant difference in viscosity was found among the filled sealants ($p>0.05$). Flow of the unfilled resin was significantly greater than that of the filled resins ($p<0.001$), and no residual capillary length was found with the unfilled sealant, that is, the unfilled material flowed completely out of the capillary in less than 30 seconds.

No differences among the six fissure sealants were detected in the number of voids within the sealant itself or at the sealant/tooth interface ($p>0.05$). In all cases, the void concentration at the sealant/tooth interface was greater than that within the material ($p<0.05$).

There was an overall low incidence of marginal leakage (0 or 1 affected teeth within each group) and no differences were detected in the leakage scores of the six sealants ($p>0.05$).

DISCUSSION

Extensive research has been undertaken to evaluate the safety, efficacy and economics of sealant placement as a preventative measure for pit-and-fissure caries. Much of the research about the efficacy and success of

sealants has addressed retention and microleakage, but few studies have evaluated the viscosity or flow behavior of the sealants, themselves. The question of sealant flow may not have been studied in any great depth because it seems intuitively obvious that less viscous materials should exhibit better flow and thus improve penetration into grooves.

This study showed no difference ($p>0.05$) in the flow properties of the five filled sealants, and all five materials exhibited markedly less flow ($p<0.001$) than the unfilled sealant. The coefficients of variation for the five filled sealants were 6% or less, indicating minimal scatter in the data.

Examination of the sealed teeth indicated no differences in sealant penetration, void formation or leakage for the six sealants despite the lower viscosity and attendant greater flow of the unfilled sealant. Theoretical considerations indicate that the flow of a liquid into a pore, that is, a wicking of a liquid into a semiporous surface, is determined by a number of factors. These factors include the pore diameter, the surface tension and density of the liquid and the viscosity of the liquid. In general, faster penetration rates are found with larger holes, denser liquids and those with a high surface tension, but slower rates are found with more viscous fluids. Thus poorer sealing, greater void formation and greater leakage might have been anticipated with the filled sealants. No such differences were found in this study.

It is well established that for liquid flow to occur over a solid, the surface energy of the solid must be greater than the surface tension of the liquid. The six sealants have similar base resins, and consequently, their surface tensions should be comparable. The filled sealants have greater densities than the unfilled resin, but no differences were noted among the five filled materials. Therefore, if the six sealants were applied to uniform substrates, greater flow should have occurred with the unfilled material. This was not observed and, therefore, the overriding factor in sealing efficacy would appear to be the nature of the substrate surface. Thus, sealing efficacy is determined by the pretreatment of the enamel, ie, prophylaxis, etching, washing and drying, and its effect on the enamel surface energy and not by the sealant material. It is possible that a larger sample size might have demonstrated differences among the six test materials, but this is unlikely since the data suggest that the greatest influence on sealing behavior is the substrate tooth, with all its inherent variability, and not the sealant material.

The findings of this study indicate that while a significant difference existed in the flow properties of the filled and unfilled fissure sealants tested, this difference had no effect on the formation of interfacial voids or those within the material itself. While all teeth that exhibited leakage also had voids at the tooth/sealant interface, not all teeth with such voids manifested leakage. Thus, no significant correlation could be established between the incidence (and extent) of leakage and the occurrence of voids at the tooth/sealant interface. Further, fissure sealant flow behavior had no effect on the sealing ability of the sealant, as denoted by the marginal leakage observed following thermocycling and silver nitrate staining.

This study supports the findings of previous studies (Waggoner & Siegal, 1996; Feldens & others, 1994; Park & others, 1993; Wright & Retief, 1984) that the presence of fillers has little effect on the clinical behavior of sealants. It follows from this study that further progress in enhancing the clinical success of pit-and-fissure sealants might be determined more by methods of enhancing the enamel surface energy rather than by modifications of the sealant materials.

CONCLUSIONS

Based on the conditions in our study, the following conclusions could be drawn regarding the flow behavior of the five sealant materials tested:

1. The viscosity and flow properties of the fissure sealants do not affect their sealing ability.

2. The differing flow properties of the filled and unfilled fissure sealants had no effect on the formation of interfacial voids or voids within the material itself.

3. Fissure sealant flow behavior was found to have no effect on the sealing ability of the sealant as denoted by the marginal leakage observed following thermocycling and silver nitrate staining.

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Three-Dimensional Optical Profilometry Analysis of Surface States Obtained After Finishing Sequences for Three Composite Resins

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Clinical Relevance

The clinical purpose of this study was to check the best finishing method on three composite resins.

SUMMARY

The operating protocols used for finishing composite resins are numerous and affect the success of filling from a mechanical, biological, and aesthetic point of view. The study determined the most favorable finishing for each of the composites considered. The three-dimensional optical profilometry examination was used to obtain qualitative and quantitative measurements of three hybrid composites. Tungsten carbide burs left irregularities harder to eliminate than those caused by diamond burs. Sof-Lex disks and the Enhance System gave good results for the three materials. Charisma presented a good surface regardless of polishing method used. Finishing Z100 and Prisma TPH required a special operating protocol as specified by the manufacturers.

This study demonstrated that the finishing procedure for composite materials must be strictly followed to obtain optimal results. Profilometry proved to be an excellent method to study the surface roughness of samples.

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INTRODUCTION

One of the parameters playing an important role in the reliability of a crown restoration with composite is the state of its surface. This surface state influences the amount of plaque retained and the appearance of discoloration. It also affects the patient's comfort, as irregularities of the order of 20 µm can be detected (van Noort & Davies, 1984).

Although a smooth surface can be obtained after simply polymerizing the material against a matrix, it is difficult to adjust the matrix correctly without removing excess material (Heath & Wilson, 1976). Moreover, the surface layer is essentially composed of organic matrix and is, thus, less dense than the underlying layer. Removing the superficial layer, therefore, increases the resistance of the surface (Wilson, Davies & von Fraunhofer, 1980). This layer can be eliminated and the tooth shaped with diamond or tungsten carbide burs in a high-speed handpiece.

In 1976, Heath and Wilson showed that after shaping, the surface of the restoration remained rough and required polishing. Lutz, Setcos and Philips (1983)

attributed this residual roughness to the hardness of the instruments. Their action needs to be completed. Different methods for polishing esthetic materials have been investigated. These methods include using aluminum oxide finishing disks, abrasive embedded in resin polishing points and polishing paste. Many authors have used the scanning electron microscope to study the results of various finishing sequences for composite restorations. More recently, mechanical profilometry has been used (Berastegui & others, 1992; Briand, 1990; Grimonster & others, 1994), allowing the results to be assessed quantitatively.

This study looked at the surfacing power of different finishing sequences and analyzed the suitability of various hybrid composites with microfine particles for polishing, using the three-dimensional optical profilometry method.

METHODS AND MATERIALS

Three hybrid composites with microfine particles were used for the study: Charisma (Heraeus Kulzer, Wehrheim, Germany), Prisma TPH (De Trey Dentsply, Weybridge, England) and Z100 (3M Dental Products, St Paul, MN 55144). Their compositions are given in Table 1.

These composites, chosen in the same shade range, were inserted into cylindrical molds 7 mm in diameter and 6 mm deep. They were polymerized in successive 2 mm layers for 40 seconds per layer using an Espe Elipar 2 lamp (ESPE, Seefeld/Oberbay, Germany) that generated a beam of light with a wavelength of 480 nm. Polishing was carried out immediately, since the surface state of hybrid composites is independent of the finishing time (Heath, Jordan & Watts, 1993).

Nine finishing sequences were performed (Table 2), which enabled testing and comparison of various instruments for shaping or polishing and lustring. For each sequence and composite, three specimens were done, and three different surfaces analyzed on each specimen. For shaping, the comparison was made between diamond burs and tungsten carbide burs. Polishing and lustring were conducted with either polishing disks (Sof-Lex; 3M Dental Products or Hawe-Neos Dental, Bioggio, Switzerland) or abrasive pastes (Enhance; De Trey Dentsply, KONSTANZ - Germany). For certain sequences, intermediate polishing was performed with silicon carbide disks (numbers 2, 3, 4 and 5); for others this step was suppressed (8 and 9). Sequence 1 was a control sequence consisting of simple polymerization of the material against a strip of Mylar. The samples were analyzed using a high-resolution optical profilometer to detect the microscopic variations in level at the surface of the material (Champion-Joniot, Gregoire & Roques, 1995). The profilometer used a technique of phase detection by interferometry. The light reflected by the surface to be analyzed was compared with that coming from a reference surface by means of a mini-interferometer. In the interferogram, the differences in height are proportional to the phase variations, and measuring the phase shift thus gave a direct determination of the relief. This method presented two advantages. First, it required no particular preparation of the sample and, second, the fact that the information was obtained by optical techniques meant that there was no deterioration of the sample. The dimensions of the surface to be analyzed were typically 70 mm by 30 mm. The profilometer (Nanosurf 488; SAS Technologies, Société HOLO-LASER, 6 rue de la Mission, Ecole 25480 MISEREY) gave a three-dimensional representation of the surface, allowing a search to be made for ridges and grooves (periodic or pseudo-periodic defects), and for torn pieces, instrument marks, prick marks and fissures (AFNOR, 1972).

The roughness of the surfaces can be expressed numerically by several parameters: Ra (arithmetical mean value of the movement of the profile above and below the center line of the surface); Rt (depth of the maximum roughness); Rp (roughness with maximum depth within the Rz); and Rmax (mean depth of roughness among five adjacent spaces). For this study, only the first two parameters, considered to be the most representative, were taken into account.

RESULTS

The composites were analyzed before and after each finishing sequence. The qualitative observation of the three-dimensional profiles revealed an excellent surface state

Table 1: *Composition of the Four Composites and Percentage of Mineral Filler*

	Charisma (Kulzer)	**Prisma TPH (De Trey)**	**Z 100 (3 M)**
Resin Matrix	isopropyl bis2 Hydroxy 3 (2) (4) Phénoxy) Propylméthacrylate) 3-6 Dioxaocta méthyl diméthacrylate	Bis GMA T E G D M A	Bis G M A T E G D M A
FILLER TYPE SIZE (µm)	barium aluminium borosilicate (0,7µm) silicium dioxyde	barium aluminium borosilicate <1µm) silicium dioxyde (0,02 µm à 0.07 µm)	zirconium silicate (0,6 µm)
WEIGHT % of mineral filler	77%	77%	84,5%
VOL % of mineral filler	60%	58%	69%

Table 2: *Clinical Protocols Chosen for Finishing the Composites*

Sequence No 1	Polymerization against a strip of mylar
Sequence No 2	1°) Tungsten carbide burs (Komet) 12 blades H 135 30 blades H 135 EF 2°) Silicon carbide disks (Vivadent) 3°) Sof Lex disks (3M)
Sequence No 3	1°) Tungsten carbide burs (Komet) 2 blades 30 blades 2°) Silicon carbide disks (Vivadent) 3°) Hawe Neos disks (Hawe Neos Dental)
Sequence No 4	1°) Diamond burs (Komet) 8858 858 EF 2°) Silicon carbide disks (Vivadent) 3°) Sof Lex disks (3M)
Sequence No 5	1°) Diamond burs (Komet) 8858 858 EF 2°) Silicon carbide disks (Vivadent) 3°) Hawe Neos disks (Hawe Neos Dental)
Sequence No 6	1°) Diamond burs (Komet) 8858 858 EF 2°) Enhance Finishing system (De Trey Dentsply)
Sequence No 7 3°)	1°) Diamond burs (Komet) 2°) tungsten carbide burs (Komet) Enhance finishing system (De Trey Dentsply)
Sequence No 8	1°) Diamond burs (Komet) 8858 858 EF 2°) Sof Lex disks (3M)
Sequence No 9	1°) Diamond burs (Komet) 8858 858 EF 2°) Hawe neos disks (Hawe Neos Dental)

Table 3: *ANOVA Table for Ra, Showing the Significance When the Finishing Sequences, Composites and Sequence-Composite Combinations are Analyzed*

	DF	F value	P value
sequence	8	5.884	<0.0001
composite	2	6.689	0.0026
sequence + composite	16	2.436	0.0079

DF degree of freedom

for the controls, which were simply polymerized on a Mylar matrix. For example, it was noted that the surface was almost perfectly plain for Z100. In the other cases, more or less marked surface irregularities could be seen.

The qualitative assessment of the results was confirmed by quantitative data obtained by calculating the total roughness (Rt) and mean value of roughness (Ra).

Rt values of less than 0.56 mm were the wavelength of visible light for all measurements. This expressed the reflective nature of fillings made with such materials.

Moreover, the Ra values were extremely low, in the order of 1/100 mm. The best results were obtained from the control group, showing that all the finishing sequences increase the roughness of the surface.

The results were analyzed statistically. The ANOVA test showed a significant difference concerning the comparison of sequences, the comparison of the composites (Table 3) and also the sequence-composite interactions. After calculation of the averages (Table 4), it can be seen from the graph in Figure 1 that, apart from the control samples, the best sequences were 4 and 6, with Ra values of 0.022 and 0.023 mm, respectively. So, it appeared that diamond burs plus silicon carbide disks as intermediate polishing and then Sof-Lex disks produced the least surface roughness. The same conclusions could be accomplished with diamond burs plus Enhance finishing system, and the sequences giving the worst results were sequences 3, 7 and 8. It was found that sequences 3 and 7 used tungsten carbide burs, and sequence 8 omitted the use of silicon carbide disks as intermediate polishing. Fisher's PLSD calculation, highlighting a significant difference among sequences 3-4, 3-6, 4-7, 4-8 and also sequences 6-7 and 6-8 confirmed the previous results.

It thus appeared that using tungsten carbide burs for shaping caused surface irregularities that were difficult to eliminate afterwards (sequences 2, 3, 7). Intermediate polishing improved the roughness (sequences 4 and 8) and lustring gave good results with the Enhance system or Sof-Lex disks.

There were significant differences between Charisma and the other two composites. The average of the Ra values was 0.021 mm for Charisma; whereas it was 0.031 mm for Z100 and 0.027 for Prisma TPH (Figure 2). Charisma showed a smaller difference between extreme values than the other two composites, which meant that it had a more constant surface state whatever the type of finishing was applied.

DISCUSSION

There are two advantages to the optical profilometry method used in this study. First, optical profilometry gave a quantitative aspect through the calculation of Ra and Rt, which cannot be obtained with the SEM. Then,

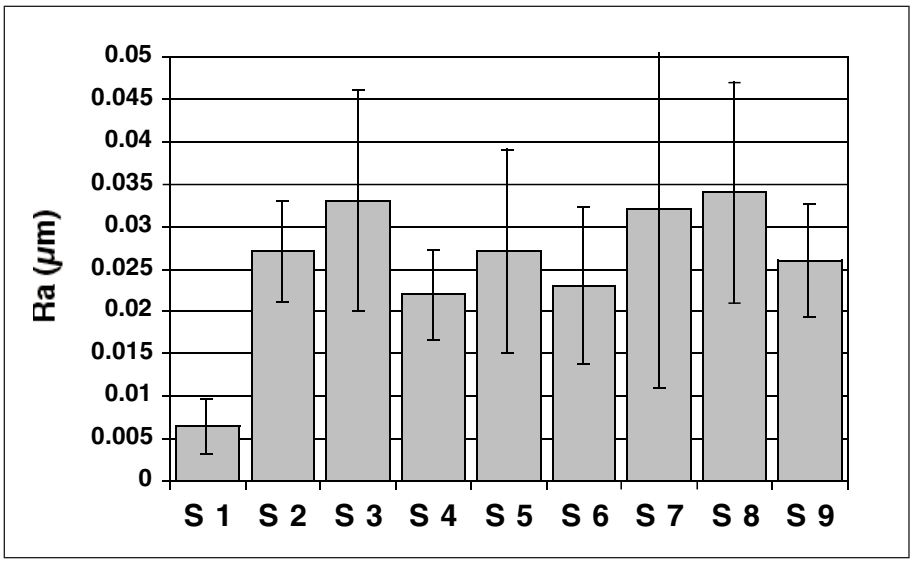

Figure 1. *Graph of mean values of Ra parameter (mm) for the nine sequences studied: sequences 4 and 6 have the lowest mean values.*

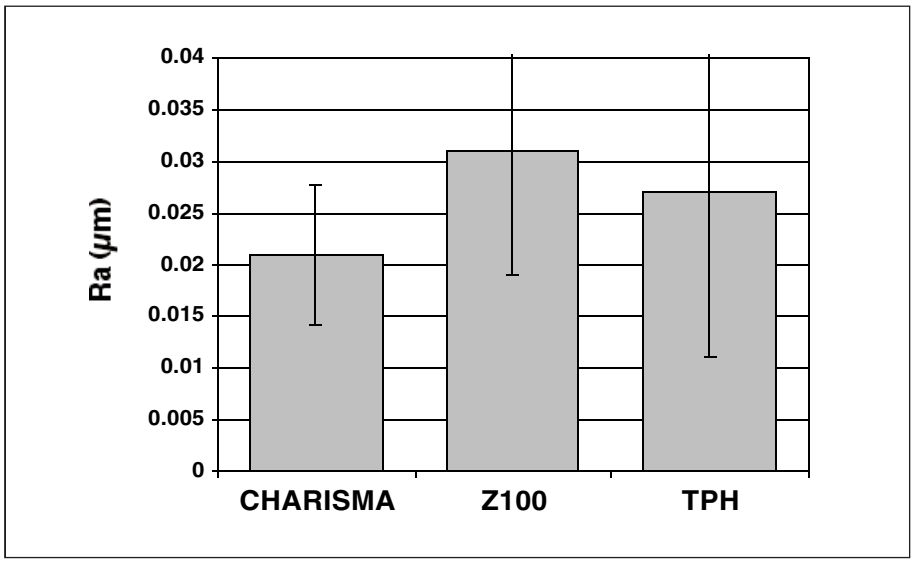

Figure 2. *Graph of mean values of Ra parameter (mm) for the three composites studied: the Charisma shows the best surface states.*

with respect to mechanical profilometry, it enabled the sample surface to be studied more precisely, as the optical beam was less limiting than the recording head, which, because of its size, cannot penetrate certain micro-irregularities, as pointed out by Wassell, McCabe, and Walls (1994).

From the results, it was clear that the smoothest surface was obtained when the sample was simply polymerized against a Mylar matrix. Nevertheless, as certain authors have shown (Berastegui & others, 1992; Wassell & others, 1994), the surface layer, rich in resin, needs to be eliminated. Finishing is thus indispensable.

For shaping, our study showed that using 30-micron and 15-micron diamond burs gave a better surface state. Raskin and Vreven (1996) came to the same conclusion, finding that tungsten carbide burs caused more surface damage. Berastegui and others (1992) preferred tungsten carbide burs. However, these authors used a mechanical profilometer, and the roughness values they obtained cannot be compared with our results. This is not because of the technique, which is identical, but because of the way the surface of the sample is read. A mechanical profilometer has a recording stylus that moves over the surface, following its imperfections. The optical profilometer uses a beam of light that sweeps the sample surface, detecting tiny variations that the stylus would not be able to penetrate.

Wilson and others (1980) have demonstrated that using tungsten carbide burs alone cannot give a satisfactory finish. Tate and Powers (1996) have recommended the use of aluminum oxide disks following finishing burs. We agree with these authors that intermediate polishing is necessary to improve the quality of the surface. Sequence 8 showed higher values for the parameters studied than sequence 4, in which intermediate polishing was done with siliconed points, whereas sequences 5 and 9 seem to present nearly the same values when all the composites are confounded. Charisma and Z100 showed lower values for sequence 5, and it was the opposite for Prisma TPH. According to van Noort and Davies (1984), polishing pastes leave a better surface state than abrasive disks. Wilson and others (1980) prefer to use Sof-Lex disks. Hoelscher and others (1998) found no significant difference in the method of finish with hybrid composites. In this study a very good finish was obtained with the Enhance system, although Z100 seemed to give better results with the Sof-Lex disks. The authors agree with Jefferies, Barkmeier and Gwinnett (1992), who concluded that the best finishes are obtained when the composites are polished with the systems recommended by the manufacturer.

If we look at the materials themselves and their composition, Charisma has the smallest difference in the mean values, followed by Z100 and Prisma TPH.

Table 4: *Mean Values of Ra Parameter (mm) for the Nine Sequences Studied*

	Mean	Std Dev	Std Err
Sequence No 1	0.0065	0.0032	0.0014
Sequence No 2	0.027	0.0059	0.0018
Sequence No 3	0.033	0.013	0.0041
Sequence No 4	0.022	0.0053	0.0016
Sequence No 5	0.027	0.012	0.0047
Sequence No 6	0.023	0.0092	0.0027
Sequence No 7	0.032	0.021	0.0070
Sequence No 8	0.034	0.013	0.0042
Sequence No 9	0.026	0.0066	0.0022

Table 5: *Mean Values of Ra Parameter (mm) for the Three Composites Studied*

	Mean	Std Dev	Std Err
CHARISMA	0.0021	0.0068	0.0012
Z100	0.031	0.012	0.0021
TPH	0.027	0.016	0.0035

Ferracane, Condon and Mitchem (1992) tried to find explanations for the greater or lesser resistance of the composites to abrasion during finishing. In their opinion, it depended on several factors, including the degree of polymerization of the matrix, the size, composition and volume of the particles, and the adhesive quality of the particles on the matrix. Similarly, Johnson, Dhuru and Brantley (1993) demonstrated the existence of a relationship between the percentage of filler in the hybrid composites and the mechanical properties.

In this study, the duration and depth of polymerization were checked for each composite. As far as the mineral filling was concerned, it was identical for Charisma and Prisma TPH, but only the overall percentage of filler is known. For the organic matrix, its composition is similar for Prisma TPH and Z100; it was slightly different for Charisma. Because the way the filler is attached to the matrix is unknown, this could also be a factor explaining the difference of suitability for polishing of these three composites.

CONCLUSIONS

This study determined the finishing sequence best suited for available composites from a clinical viewpoint. Finishing burs left a rough surface. Therefore, intermediate polishing with siliconed points appeared to be necessary. Aluminum oxide disks and polishing paste with impregnated disks both provided a good finish. Concerning the materials, the presence of microfine particles composed of mineral filler and strongly bound to the organic matrix produced the appearance of an excellently polished surface.

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Microleakage of Bonded Amalgam Restorations: Effect of Thermal Cycling

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Clinical Relevance

In vitro data indicate that universal adhesive dentin systems, when used to bond amalgam restorations, reduce microleakage only when the restorations do not undergo thermal cycling.

SUMMARY

This study examined the effect of thermal cycling on the microleakage of bonded amalgam restorations. Three dental amalgam alloys and a gallium alloy were tested with two adhesive resin systems and copal varnish as a control.

Class V cavity preparations were prepared on 168 freshly extracted premolars or molars. The preparations were placed parallel to and 1.0 mm occlusal to the cementoenamel junction (CEJ). Four groups of 42 teeth each were treated with one of the following adhesive dentin systems: Bond-It, All-Bond 2/Resinomer or a copal varnish (Copalite). The four groups of 42 teeth each were then restored with one of three dental amalgams: Orosphere Plus, Indiloy, Oralloy or a Gallium alloy (Galloy), resulting in 12 test groups of 14 teeth each. The specimens were stored in double distilled water at 37°C for 24 hours. Final contouring and polishing of the restorations were performed under water spray. Half of the restorations in each group were thermocycled for 3000 cycles (5°C-37°C-55°C-37°C) with a dwell time of 15 sec at each temperature. The other half were stored in double distilled water at 37°C for 24 hours. Then all 168 restorations were stained with dye, sectioned and scored for microleakage. Results showed that the adhesive dentin systems reduced microleakage in amalgam restorations compared to copal varnish only in non-thermocycled specimens.

Statistical analysis of the results showed that there was an extremely significant difference ($p<0.001$) in microleakage between the non-thermocycled and the thermocycled specimens in all test groups, whereas, there was no significant difference ($p>0.05$) among thermocycled specimens. The reduction of microleakage was not significantly different between Bond-It and All-Bond 2/Resinomer in non-thermocycled specimens. Oralloy showed the most microleakage in the non-thermocycled groups when compared to the other alloys using the same adhesive liner.

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INTRODUCTION

Silver amalgam has been in use as a restorative material since the beginning of the 19th Century. Throughout its long history, numerous improvements have been made to the material, its manipulation and its safety and efficacy. Perhaps the most important advance was the introduction of "high copper" alloys, patented by Youdelis in 1967 but not widely available until after 1975. These alloys exhibit reduced corrosion, retention of the polished surface, improved marginal integrity, lower creep, higher one hour compressive strength than conventional alloys resulting in superior clinical performance that has been confirmed in controlled studies (Leinfelder, 1981; Leinfelder, 1983). In addition, high copper alloy restorations release less mercury in the mouth (Reinhart, Boyer, Svare, 1983).

Dental amalgam has been the subject of intense criticism due to concerns about the effect of Hg from amalgam restorations on human health. Large-scale literature reviews (Eley and Cox, 1987) have debated the problem in recent years, reflecting both public and professional concern. The US Public Health Service has endorsed the continued use of amalgam (January 1993). The latter document includes the conclusions and previous endorsements of the Canadian Dental Association (1986), the US National Board of Health and Welfare (1988), WHO (1989), the American Dental Association (1990), the NIH Technology Assessment Conference, USA (1991), the Swedish Medical Research Council and the Federal Public Health Office of Germany, 1992 (Dunne, Gainsford and Wilson, 1997). Throughout these investigations, no specific disease has been linked to chronic mercury exposure from dental amalgam fillings (Vimy, 1995).

Despite the "anti-amalgam" campaigns and the increasing demand for tooth-colored restorations, dental amalgam still remains the most commonly used restorative material for moderate to large restorations in posterior teeth. In the USA, approximately 100 million amalgam restorations are made annually (Nash and Bentley, 1991). In a recent survey (Product Use Survey 1995), 76.3% of American dentists most commonly used amalgam for posterior Class II restorations.

However, amalgam has disadvantages, such as its color and lack of adhesion to tooth structure (Johnson, Gordon and Bales, 1988). The lack of adhesiveness of amalgam requires cavity design with mechanical retention at the expense of healthy tooth structure (Pashley and others, 1991). Marginal leakage and its potential pathologic consequences are serious clinical problems (Birtcil, Pelrner and Stark, 1981, Gotlieb, Retief and Bradley, 1985, Varga, Matsumura and Masuhara, 1986, Staninec and Holt, 1988, Lacy and Staninec, 1989, Charlton, Moore and Swartz, 1992). Adhesive systems, designed to bond amalgam to enamel and dentin, have been introduced in an effort to compensate for microleakage concerns and the need for additional retentive devices (Varga, Matsumura and Masuhara, 1986, Staninec and Holt, 1988, Lacy and Staninec, 1989, Charlton, Moore and Swartz, 1992). These systems may obviate the need for protective bases and strengthen remaining tooth tissues weakened by caries and cavity preparation (Trushkowsky, 1991, Bakland & others, 1992).

There is an obvious advantage for the clinician if one of the universal adhesive systems utilized for bonding resin and ceramic could also be used to bond amalgam to tooth structure. However, this bond must withstand the stresses in the oral environment such as thermal changes, and provide a long-term seal against microleakage.

This study examined the effect of thermal cycling on the microleakage of bonded amalgam restorations. Three dental amalgam alloys and a gallium alloy were tested with two universal adhesive resin systems and copal varnish as a control.

METHODS AND MATERIALS

One hundred and sixty-eight freshly extracted premolars and molars were divided into 12 groups of 14 teeth each, representing the different alloy/adhesive systems tested (Table 1). After removing residual tissue tags, the teeth were cleaned with phosphate-buffered saline and examined under a microscope to eliminate those with cracks.

Standardized Class V cavities were prepared on the buccal surface of each tooth using a #57 tungsten car-

Table 1: *Test Groups: Adhesive Dentin Systems and Amalgam Alloy Combinations*

Group*	Adhesive Dentin System	Restorative Amalgam
1	All bond 2/Resinomer	Orosphere Plus (Orores, Ororesth**)
2	Bond-it	Orosphere Plus (Orobond, Orobondth**)
3	Copalite	Orosphere Plus (Orovarn, Orovarnth**)
4	All bond 2/Resinomer	Indiloy (Indires, Indiresth**)
5	Bond-it	Indiloy (Indibond, Indibondth**)
6	Copalite	Indiloy (Indivarn, Indivarnth**)
7	All bond 2/Resinomer	Oralloy (Orres, Orresth**)
8	Bond-it	Oralloy (Orbond, Orbondth**)
9	Copalite	Oralloy (Orvarn, Orvarnth**)
10	All bond 2/Resinomer	Galloy (Galres, Galresth**)
11	Bond-it	Galloy (Galbond, Galbondth**)
12	Copalite	Galloy (Galvarn, Galvarnth**)

* Each group consisted of 7 specimens non-thermocycled and 7 specimens thermocycled
** Thermocycled specimens

bide bur in a high-speed handpiece with air and water spray. The preparations were placed parallel to and 1.0 mm occlusal to the cementoenamel junction (CEJ). Preparations were 1.5 mm deep, oblong in shape, measuring 3 x 4 mm. Cavosurface walls were finished to a butt joint with a #55 slow-speed bur under water spray. Cavity preparations were rinsed for 20 seconds with an air/water spray and gently air dried for 30 seconds.

Application of the adhesive systems was performed according to their respective manufacturers' instructions. Bond-It represented the resin dentin adhesive systems that include total etching (enamel-dentin). All-Bond 2/Resinomer represented the resin adhesive systems that include total etching used in combination with a viscous resin in order to create a chemical and mechanical bond with the amalgam. Copalite was applied in two thin layers, allowing the first layer to air dry for 30 seconds prior to applying the second layer.

Teeth were then restored with one of three amalgams (Orosphere Plus, Indiloy, Oralloy) or the gallium alloy (Galloy). The manufacturers and components of the materials are listed in Table 2. Restorations were overfilled and carved back to proper contour.

Specimens were then placed in double distilled water at 37°C for 24 hours. Final contouring and polishing of the restorations was performed using flexible disks (Soflex Pop-on, 3M Dental Products St Paul, MN, USA) under water spray. Eighty-four restorations (half of the specimens in each test group) were thermocycled 3000 times (5°C-37°C-55°C-37°C) with a dwell time of 15 seconds at each temperature. This procedure was carried out over a 24 hour period. The other restorations were placed in double distilled water at 37°C for 24 hours. After that, nail varnish was applied to the entire surface of the tooth except for the restorations and approximately 0.5mm of tooth surface adjacent to the restoration. The tooth apices, also, were sealed to avoid dye penetration from the root canal.

The teeth were immersed in a 0.5% solution of basic fuchsin for 24 hours at 37°C. They were then rinsed in tap water, dried, embedded in Epoxy Resin (Epon, Fluca Chemica AG, Buchs, Switzerland) and sectioned in a bucco-lingual plane with a water-cooled diamond saw (Saw DDM P216 RVA Histo, Torcy, France). Three parallel sections (300µm apart) with a thickness of 300µm were cut. This procedure created six interfaces that were examined under a microscope with a measuring ocular at 100 x magnification.

The degree of microleakage at both the enamel and dentin margins was rated on a scale from 0-4 (Eakle

Table 2

MATERIALS	COMPONENTS	MANUFACTURER
Bond-it	Conditioner: 37 % phosphoric acid Dentin 15 sec, Enamel 30 sec). Primer: part A (NTG-GMA, Mg, Acetone), part B (PMGDM, Pyromellitic Dianhydrate, Acetone). Bonding resin: Unfilled resin.	Jeneric/Pentron Inc 53 North Plains Industrial Road, Wallingford CT 06492
All bond 2	Conditioner: 32% Phosphoric acid (Dentin 15 sec, Enamel 30 sec). Primer: part A (NTG-GMA, Na, Acetone, Ethanol), part B (Biphenyl Dimethacrylate, Acetone, Ethanol). Bonding resin: Bis-GMA, HEMA, Urethane Dimethacrylate, Dihydroxyethyl-P-toluidine, Dimethylamine ethylmethacrylate.	Bisco Inc, 1100 W Irving Park Rd, Schaumburg IL 1-800 BIS-DENT
Resinomer	Base: Bis-GMA, Methacrylate monomer, Tetriary amine, Photo Initiator, Glass ionomer powder (54% by weight), Silica. Catalyst: Diazysulphone Dimethacrylate, Polymeric dimethacrylate, Peroxide catalyst, Alumina, Strontium glass, Silica.	Bisco Inc, 1100 W Irving Park Rd, Schaumburg, IL 1-800 BIS-DENT
Copalite	Natural copal gum, ethyl ether anhydrous, chloroform.	HJ Bosworth Co, Skokie, IL 60076
Orosphere Plus	Admixed blend, caps. Ag 69%, Cu 12%, Sn 18%, Zn 1%.	Jeneric/Pentron Inc, 53 North Plains Industrial Road, Wallingford, CT 06492
Indiloy	Spherical blend, caps. Ag 60%, Cu 13%, Sn 22%, In 5%.	Shofu Dental Corporation, 4025 Bohannon Drive, Menlo Park, California 94025
Oralloy	Spherical blend, caps. Ag 59%, Cu 13%, Sn 28%.	Coltene/ Whaledent Dentalvertriebs GmbH, Fischenzstrasse 39, D-78462, Konstanz/Germany
Galloy	Spherical blend, caps. Powder. Ag 60.10%, Cu 11.8%, Sn 28.05%, Pt 0.05% (net wt 35 g). Liquid: Gal 61.98%, In 24.99%, Sn 12.98%, Bi 0.05% (net wt 17g). Per capsule 700 mg powder, 343 liquid (1:0.49).	Southern Dental Industries, Bayswater Victoria, Australia 3153

*NTG-GMA: N-p-tolylglycine-glycidyl methacrylate; PMGDM: Pyromellitic methacrylate-glycidyl dimethacrylate; Bis-GMA; Bisphenol-glycidyl methacrylate; HEMA; 2-hydroxyethyl methacrylate.

and Nakamoto, 1989; Mandras, Retief and Russel, 1991). 0 = No dye penetration (DP), 1 = DP≤ 0.25 mm, 2 = DP> 0.25 mm to ≤ 0.5 mm, 3 = DP > 0.5 mm to ≤ 1 mm, 4=DP>1 mm. The reason for converting the depths of dye penetration into scores was that in many of the restorations, the dye penetration extended beyond the length of the gingival wall, ie, towards the pulp or along the pulpal wall, where exact readings of the penetration depth proved to be critical. For the same reason, all dye penetration extending beyond the length of the gingival wall, ie, >1 mm, was recorded as score 4.

The means of the six dye penetration data (six interface sections) of each tooth were recorded and a One Way Analysis of Variance (ANOVA) was performed to determine the effect of the sealing ability of the three different liners on the different amalgam restorations.

RESULTS

The results of this study showed that the adhesive dentin systems reduced microleakage in amalgam restorations compared to copal varnish only in non-thermocycled specimens. However, none of the materials used to bond amalgam restorations completely eliminated microleakage in all specimens. In many cases microleakage did not occur at the occlusal/enamel restoration interface, but did occur at the gingival/dentin restoration interface. This has been taken into account since, in clinical practice, the existence of microleakage at the gingival margin of an amalgam restoration will eventually lead to failure even if the other margins are sound.

Microleakage results of all the examined groups are presented in Figures 1, 2, 3 and 4. Comparison and One-Way Analysis of Variance (ANOVA) were performed to examine the differences in microleakage among the test groups. Analysis indicated that there was extremely significant difference ($p<0.001$) in microleakage of non-thermocycled vs thermocycled specimen groups, except in the case of Oralloy specimens lined with copalite, where there was no significant difference ($p>0.05$) in any of the groups.

There was no significant difference ($p>0.05$) among thermocycled specimen groups.

The Orosphere Plus specimens in the non-thermocycled groups showed no significant difference ($p>0.05$) in Orores vs Orobond and in Orobond vs Orovarn, whereas the difference was extremely significant ($p<0.001$) in Orores vs Orovarn (Figure 1).

The microleakage of specimens filled with Indiloy was not significantly different ($p>0.05$) in Indires vs Indibond, whereas the microleakage was significantly different ($p<0.05$) in Indibond vs Indivarn and extremely significantly different ($p<0.001$) in Indires vs Indivarn (Figure 2).

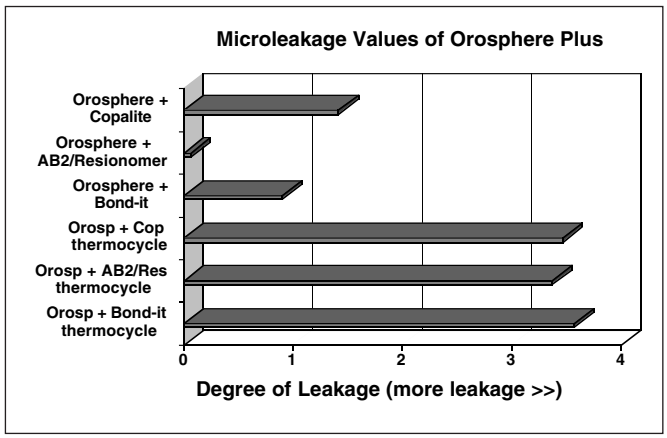

Figure 1.

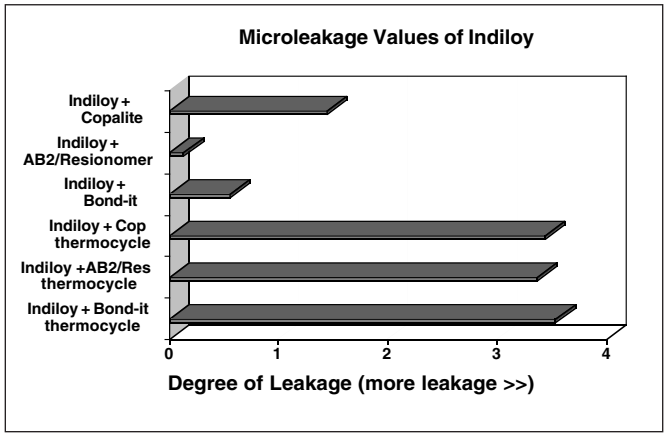

Figure 2.

The microleakage of Oralloy specimens showed an extremely significant difference ($p<0.001$) in Orres vs Orvarn, very significant difference ($p<0.01$) in Orbond vs Orvarn and no significant difference ($p>0.05$) in Orres vs Orbond (Figure 3).

The Galloy specimens showed no significant difference ($p>0.05$) in Galres vs Galbond, whereas the difference was extremely significant ($p<0.001$) in Galres and Galbond vs Galvarn (Figure 4).

Comparing the microleakage of non-thermocycled specimen groups filled with different type of amalgam and but with the same liner, there was no significant difference between Orosphere, Indiloy and Galloy, whereas the difference was extremely significant among those groups compared with Oralloy.

DISCUSSION

The results of the present study indicate that using an adhesive dentin system or a combination of an adhesive dentin system with an intermediate viscous resin under amalgam restorations reduces microleakage when compared with a copal varnish liner. However,

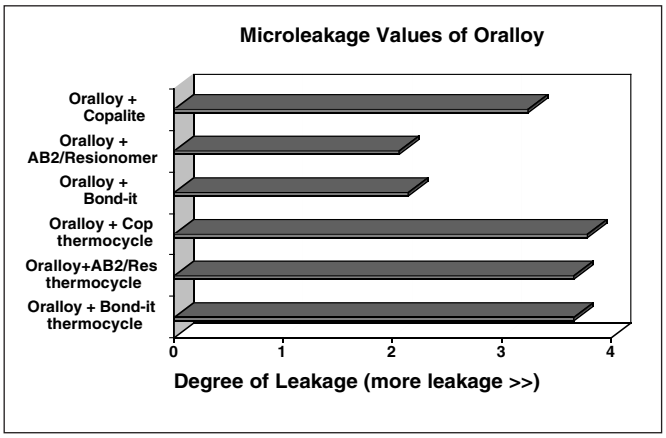

Figure 3.

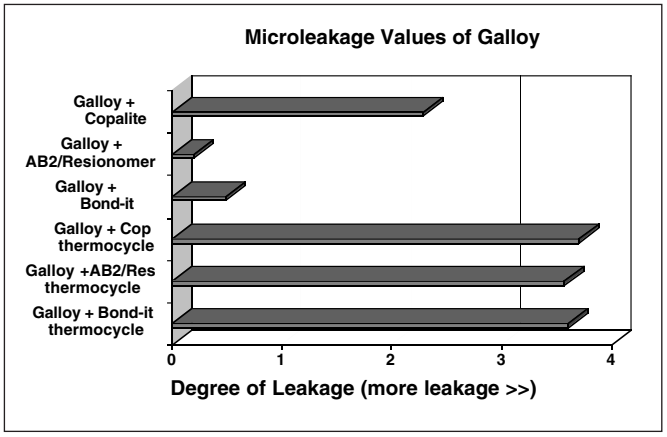

Figure 4.

this is only true when the restorations do not undergo thermal cycling. After thermal cycling, there was no significant difference in microleakage between bonded amalgam restorations and those lined with varnish.

These results are in contrast to a number of previous studies that evaluated bonded amalgam restorations and found significant improvement in the reduction of microleakage (Staninec and Holt, 1988; Cooley, Tseng and Barkmeier, 1991; Charlton, Moore and Swartz, 1992; Edgren and Denehy, 1992; Saiku, St Germain and Meiers, 1993; Berry and Tjan, 1994; Turner, St Germain and Meiers, 1995; Meiers and Turner, 1998; Tangsgoolwatana and others, 1997).

A major problem associated with microleakage studies is the poor standardization of the method. Comparing the results of different studies is critical since there are no generally accepted standards for experimental parameters, such as type and concentration of the storage solution, time of storage, temperature during storage, type and duration of thermal cycling and/or mechanical cycling, and the scoring criterion (Soderholm, 1991; Taylor and Lynch, 1992; Haller and others, 1993; Dejou, Sindres and Camp, 1996). The age of extracted teeth is also of great importance when examining the current dentin bonding systems, since the quality of the hybrid layer differs in sclerotic dentin (Retief and others, 1990; Soderholm, 1995).

It must also be pointed out that, in most cases, microleakage did not occur at the occlusal margin of the restoration but did begin from the gingival margin (and extended towards the axial wall), where the enamel is thinner. In extended complex cavities where amalgam is most frequently used as a restorative material, the gingival wall most frequently reaches the cementoenamel junction. Torii and others (1989) examined the caries inhibition in bonded amalgam restorations and found few caries lesions in dentin on the occlusal side of the restorations, whereas on the gingival side, the lesions reached dentin in almost all specimens.

Adhesion to enamel with the current adhesive systems has become a routine and reliable aspect of modern restorative dentistry, but dentinal adhesion has proved to be more difficult and less predictable. The adhesive dentin systems Bond-It and All-Bond 2, used in this study, are fourth-generation bonding systems that utilize total etching technique. These dentinal adhesives are based on hydrophilic primers and the penetration of resin monomers into the tubules and onto the demineralized dentinal surface, forming a hybrid layer (Nakayabashi, Nakamura and Yasuda, 1991; Van Meerbeck, 1993). All-Bond 2 was used in combination with a viscous resin, Resinomer. Manufacturers claim that condensation of amalgam into the uncured Resinomer film creates a chemical and mechanical bond with the amalgam and provides an immediate and effective seal against microleakage. A study conducted by Gwinnett and others (1994) offered morphologic evidence of the mechanical entrapment of resin in the amalgam. It is pointed out in the same study that this may provide the primary mechanism, but other mechanisms, such as sulphone-amalgam interactions, could not be discounted. Although Tangsgoolwatana and others (1997) found the least microleakage in bonded amalgam restorations with All-Bond 2/Resinomer, among the lining materials they tested, they detected (using fluorescent markers in conjunction with confocal microscopy) microleakage at the liner-amalgam interface in 62.96% of the specimens. They inferred that this appeared to contradict the manufacturer's claim that diazysulfone dimethacrylate, an active monomer in Resinomer, can form chemical adhesion to amalgam. The above researchers also showed that the pathway of microleakage occurred at the liner-tooth interface in 83.33% of specimens with All-Bond 2/Resinomer.

The quality of the hybrid layer formed by the present generation of dentin bonding systems has come under question by several investigators. Studies by Sano and

others (1995) have shown that although specimens with All-Bond 2 demonstrated the absence of gap formation, silver nitrate could migrate along the porous zone at the base of the hybrid layer. This phenomenon is called "nanoleakage," indicating diffusion of small ions and molecules throughout the hybrid layer in the absence of gap formations (Sano and others, 1994). This is caused by an imperfect diffusion of the adhesive monomers throughout demineralized collagen fibers, leaving a porous zone as a microleakage pathway beneath the resin-impregnated layer. The formation of these nanometer-sized porosities may cause the hydrolysis of collagen fibers and degradation of adhesive monomers (Sano and others, 1994).

According to Van Meerbeck and others (1993), in dentin bonding agents which remove the smear layer and expose collagen fibers by decalcification, microleakage may progress within the decalcified dentin layer if resin impregnation of the collagen network is incomplete.

The heterogeneous structure of dentin also affects the quality of bonding of the current dentin bonding systems. The tubules may branch, particularly near the amelodentinal and cementodentinal junctions. Generally, branching of tubules are smaller and more numerous in root dentin than in crown dentin (Mjör and Ferjeskov (1986). Acid etching of the heterogeneous dentin structure results in different surface chemistries and morphologies. Since both chemistry and morphology will affect adhesion, large variations in bond strength values must be expected (Soderholm, 1995).

Haller and others (1993) reported that all the dentin bonding agents they tested failed to prevent microleakage at the gingival margin of Class V cavities. It has also been shown in recent studies examining superficial dentin close to the cervical area (Class V and proximal boxes of Class II cavities), that adhesion and sealing are only partially achieved by current dentin bonding systems (Perdigão and others, 1996; Ferrari and Davidson, 1996).

The results of this study show that bonded amalgam restorations are susceptible to thermal changes. Thermocycling is the *in vitro* process of subjecting the restoration and the tooth to temperature extremes compatible with the oral cavity. This simulates the introduction of hot and cold transient extremes in the oral cavity and shows the relationship of the linear coefficient of thermal expansion between tooth and restorative material. If the value of the linear coefficient of thermal expansion for the material is significantly greater than that for tooth substance, a small gap will develop through which fluids containing bacteria can penetrate. In practice, however, the situation is not so clear-cut. The coefficient of thermal expansion is an equilibrium property, and the expansion or contraction due to transient stimuli is a function of both coefficient of thermal expansion and thermal diffusivity. For filling materials, the ideal combination of properties would be a low value of diffusivity combined with a coefficient of thermal expansion value similar to that of tooth substance (McCabe, 1990).

In the case of bonded amalgam restorations, these parameters must be taken into account for tooth, bonding agent and amalgam. Harper and others (1980) suggested that there are very slow rates of thermal diffusion through composites, silicates and unfilled resin materials. The conductivity of amalgam, however, is significantly higher than that of tooth structure and other restorative materials (with the exception of gold) due to its metallic nature. The coefficient of thermal expansion is also quite different between enamel (11.4ppm°C-1), dentin (8ppm °C–1), amalgam (25ppm°C-1) and composite resins (25-60ppm°C-1) (McCabe, 1990). Perhaps this leads to the creation of gaps and subsequent microleakage in thermocycled specimens. Iwase and others (1989) found gradually increased microleakage with the duration of the thermal cycle stress in Class V cavities restored with Clearfil Posterior. They suggested that this was due to the gradual increase in the marginal gap dimensions at the tooth/restoration interfaces produced by the differences in the coefficients of thermal expansion of the restorative resin and tooth structure.

Santos and Meiers (1994) evaluated the effect of both aging and thermocycling on the ability of Amalgam Bond (Parkell) to increase the fracture resistance of teeth restored with amalgam, and found that after being thermally stressed, specimens show no evidence of sustained adhesion between the amalgam-bond and amalgam. A similar study by Bonilla and White (1996) reported that resin bonding initially improves the fracture resistance of bonded amalgam restored teeth, but the strengthening effect is transient. Mahler and others (1996) using Panavia-21, reported no difference between bonded and non-bonded amalgam restorations for postoperative sensitivity after one or two weeks, nor for marginal fracture after one year. Phrukkanon, Burrow and Tyas (1998) reported very weak bond strengths when bonded Permit C and Galloy using four different bonding systems to bovine dentin.

In this study, comparing the results of microleakage in non-thermocycled specimens among the amalgams, Oralloy showed significantly higher microleakage than Orosphere Plus, Indiloy and Galloy. This might be attributed to the higher content of tin in Oralloy (Sn 28% compared to 22% in Indiloy and 18% in Orosphere Plus), which affects the dimensional stability during setting of amalgams. Although Galloy contains 28.05% Sn, the development of different phases upon setting

(mainly Ga-Cu and Ag-In) may produce a slightly positive dimensional change during setting (manufacturer's claim). In addition, the use of the recommended resin sealant to protect it from moisture, might contribute to less microleakage than Oralloy.

Finally, it must be pointed out that currently, there is no possibility of correlating the results of these *in vitro* tests with clinical findings. This relates to the lack of reliable evaluation criteria *in vitro*, a lack of diagnostic skills *in vivo* and lack of *in vivo* validation of simulation procedures (Roulet, 1994). Results of *in vivo* studies are often less negative than *in vitro* studies. Nevertheless, *in vitro* testing is essential for developmental purposes. *In vitro* results should be viewed as a theoretical level of maximum leakage, which may be expected *in vivo* (Pashley, 1990).

The results of this study have to be considered as a comparison between several adhesive dentin restorative systems with amalgam, and not as an absolute conclusion about the adhesive amalgam restorative system efficiency. Further long-term clinical evaluations are needed to clarify the potential of bonded amalgam restorations.

CONCLUSIONS

The universal adhesive dentin systems Bond-It and All-Bond 2/Resinomer when used to bond amalgam restorations with Orosphere Plus, Indiloy, Oralloy and Galloy, reduced microleakage only when the restorations did not undergo thermal cycling. After thermal cycling, microleakage was not significantly different between the bonded and non-bonded amalgam restorations. In bonded amalgam restorations, microleakage was less at the occlusal than at the gingival wall.

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Technique Sensitivity of Dentin Bonding: Effect of Application Mistakes on Bond Strength and Marginal Adaptation

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Clinical Relevance

Strict accordance to recommended application protocols is essential for successful bonding to dentin. Application mistakes when using dentin adhesive systems resulted in dramatically lower bond strengths and percentages of gap-free margins.

SUMMARY

This *in vitro* study evaluated dentin bond strength and marginal adaptation of direct resin composites according to the manufacturers' instructions and with simulated application errors. One hundred and forty cavities were prepared into disks of freshly extracted human third molars and filled with one resin composite. Dentin adhesives of the third (with self-etching primer: Syntac Classic), fourth (with total etching: Scotchbond Multi-Purpose Plus) and fifth generation (one-bottle adhesive: Prime&Bond 2.1) were used for bonding. Simulated application mistakes were as follows: 1) prolonged etching; 2) excessive drying after conditioning; 3) drying primers immediately after application and 4) drying primers excessively. After 21 days of storage and 24 hours thermocycling (1150 cycles), replicas were made and push-out testing was performed. Replicas were examined for marginal adaptation using SEM (X200 magnification).

Compared with values of the control groups, application errors resulted in dramatically decreased bond strengths and reduced percentages of gap-free margins for all products tested ($p<0.05$). Excessive drying after conditioning exhibited significantly less effect for the third generation adhesive than for products requiring total etching/wet bonding.

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INTRODUCTION

The growing demand for esthetic restorations and the alleged toxicity of silver amalgam have stimulated intensive research focused on amalgam alternatives (Opdam & others, 1998; Wilson, Dunne & Gainsford, 1998). Successful adhesion to hard-tooth tissues is mandatory for the restoration of teeth with tooth-colored materials, such as direct or indirect resin composites, ceramic inlays and veneers (Walshaw & McComb, 1996; Van Meerbeek & others, 1998). The polymerization shrinkage of resin composites generates stress between bonded restoration and tooth; therefore, shrinkage still remains the major antagonist to durable adhesion of resin composites (Van Meerbeek & others, 1998). A good marginal seal guarantees gap-free margins and prevents microleakage, recurrent caries and pulpal irritation (Swift, Perdigão & Heymann, 1995).

Since its introduction, the enamel etch technique (Buonocore, 1955) has provided an ideal surface for reliable bonding performance using adhesive resins. Success with approaches of bonding to dentin, however, have been less reliable due to the characteristics of the dentin substrate, including high organic content, tubular structure variations and the presence of outward fluid movement (Eick & others, 1991; Eliades, 1994; Perdigão, 1995). Despite these difficulties, dentin bonding has become more successful with the development of new dentin adhesive systems (DAS) over the last 10 years (Watanabe & Nakabayashi, 1994; Finger & Fritz, 1996; Miyazaki & others, 1998; Pallesen & Qvist, 1998).

In the beginning, separate chemical components and several application steps were needed for priming and bonding. The procedures became even more complicated with the advent of "wet-bonding" techniques (Triolo, Swift & Barkmeier, 1995; Kanca, 1997; Blunck & Roulet, 1998). Today, fifth-generation adhesives are promising an equal adhesive performance with less time-consuming application protocols (Finger & Fritz, 1996; Mason, Calabrese & Graif, 1997; Wilder & others, 1998). These so-called one-component dentin adhesive systems combine the chemical properties of primer and bonding resin within one bottle (Vargas, Fortin & Meckes, 1995; Finger & Fritz, 1996; Van Meerbeek & others, 1998; Barkmeier, Hammesfahr & Latta, 1999). Although the effectiveness of multi-step DAS has been good, the easy handling properties of self-priming resins have made them very popular with dental practitioners (Swift & others, 1997).

Virtually all data published in the field of dentin bonding have been reported with manipulation of materials in strict accordance with manufacturers' instructions. In daily practice, however, errors or variations in application protocol may occur frequently. A recent study dealing with simulated mistakes reported poor marginal adaptation (Peschke, Blunck & Roulet, 1998).

This study evaluated the effect of simulated errors during application of different types of DAS on dentin bonding performance as measured by push-out bond strength and marginal adaptation. The selected testing design was a conically modified extrusion model (Haller & others, 1991; Frankenberger & others, 1999), first documented by Roydhouse (Roydhouse, 1970) and Kimura (Watanabe & Nakabayashi, 1994). The conical modification enables circular lengthways-cut dentinal tubules for the simulation of severe clinical conditions (Schüpbach & Krejci, 1997; Frankenberger, Krämer & Petschelt, 1999).

METHODS AND MATERIALS

Specimen Preparation and Bonding Procedures

One hundred and forty caries-free human third molars were used in this investigation. The teeth were stored in 0.1% thymol solution, at ambient temperature, for less than four weeks after extraction. They were then debrided and examined to ensure that they were free of defects. Disks of 2 mm thickness were cut from the mid-coronal level of the tooth, perpendicular to the tooth axis. One central conic cavity was prepared into each dentin disk, using standardized conic burs (Cerafil bur, Komet Inc, D-32657 Lemgo, Germany). After preparation, the dentin disks were embedded in a temporary restoration material (Provipont, Vivadent Inc, FL-9494 Schaan, Liechtenstein), and ground flat to eliminate embedding resin on the dentin surfaces. The specimens were randomly assigned to 14 groups (n=10).

The disks were filled with one direct-resin composite (Tetric, Vivadent, batch-number 618465, shade A 2). The cavity surfaces were treated with DAS of different generations according to the manufacturers' instructions (dentin pre-treatment steps are displayed in Table 1) or with specific application mistakes (Table 2). For SY, no group with prolonged drying of the primer was carried out due to the self-etching characteristic, this situation was already simulated with intensive drying after (self-) conditioning.

During the application of the resin composite, the specimens were placed on a glass sheet. The resin composite was inserted in one increment and packed with a plugger. Excess resin composite was carefully removed with an explorer. The composite was cured for 60 seconds from 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 a curing intensity of at least 400 mW/cm^2.

After finishing of the specimens, the disks were stored in distilled water at 37°C for 21 days.

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 with a transport time between the water baths of 15 seconds. The water temperature was checked continuously to ensure a reliable thermocycling effect. Following the thermocycling, impressions were taken using a polysiloxane impression material (Permagum, Espe Germany, D-82229 Seefeld, Germany) and replicas (Epoxy Die, Vivadent) were produced for analyzing marginal adaptation.

Table 1: *Brand Names, Chemical Compositions, Bonding Procedures, Dentin Pretreatment and Manufacturers of the Products Tested*

Bonding System (Code)	Bonding Steps	Batch Number	Composition	Dentin Pre-Treatment	Manufacturer
Syntac Classic (SY)	Primer	614334	4% maleic acid, 25% triethylene glycol dimethacrylate, water/acetone	Apply Primer for 30 seconds, dry. Apply Adhesive for 30 seconds, dry. Apply bond, air thin. Light cure for 20 seconds.	Vivadent Ets FL-Schaan Liechtenstein
	Adhesive	614377	35% polyethylene glycol dimethacrylate 5% glutaraldehyde, water		
	Bond	611589	60% bisphenol glycidyl methacrylate, 40% triethylene glycol dimethacrylate, photoinitiator		
Scotchbond Multi-Purpose Plus (SB)	Etchant	3 DK 3 CL	35% orthophosphoric acid	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, USA
	Primer	3 CL	40% 2-hydroxyethyl methacrylate, 10% polyalkeonic acid copolymer, water		
	Adhesive	3 CB	40% 2-hydroxyethyl methacrylate, 60% bisphenol glycidyl methacrylate, photoinitiator		
Prime&Bond 2.1 (PB)	Etchant	950148	36% orthophosphoric acid	Apply Etchant for 15 seconds, rinse, dry gently. Apply primer/ adhesive for 30 seconds, air-thin and light cure for 10 seconds. Apply second coat, air-thin and light cure for 10 seconds.	DeTrey/Dentsply, D-Konstanz, Germany
	Primer/ Bond	950366	elastomeric dimethacrylate resins, dipentaerythritolpentacrylate phosphoric acid ester, cetylamine hydrofluoride, acetone		

Push-Out Testing

Specimens were positioned into the extrusion device and mounted in a universal testing machine (Zwick Corp, D-89075 Ulm, Germany). A cylinder-shaped rod (Ø1.8 mm) was attached to a compression load cell, traveling at a crosshead speed of 0.5 mm/min and was applied to each restoration until failure occurred. Failure was defined as the loss of 30% of the maximal push-out force. Push-out bond strength was determined by computing the quotient of maximum load (N) and adhesion area (truncated cone; mm^2).

Scanning Electron Microscopic (SEM) Evaluation

The replicas were sputtered with gold (Sputter device: Balzers SCD 40, Balzers, FL-9494 Vaduz, Liechtenstein) and the interfaces analyzed under 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, D-91054, Germany). Marginal quality was calculated as 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 100x magnification to determine the fracture modes.

Statistical Analysis

The statistical analysis was performed using SPSS for Windows 95/V 7.5 (SPSS Inc, Chicago, IL 60611). The values

Table 2: *Codes of Simulated Application Errors*

Mode of Application/Application Error	Code
According to the manufacturers' instructions (control)	CON
Etching of the complete dentin surface for 60 seconds (overetching)	TE60
Intensive drying of the correctly etched dentin surface for 60 seconds (overdrying)	DRY
Drying of the primer for 60 seconds	PR60
Application of primer and immediate drying, subsequently application of adhesive or second coat	PR0

of bond strength and margin analysis were non-normally distributed (Kolmogorov-Smirnov test), therefore, a non-parametric test (Mann-Whitney-U test) for pairwise comparisons at the 0.05 level of significance (α) was performed.

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

RESULTS

Push-out Bond Strength (PBS)

The PBS results for the control and error groups are displayed in Figures 1a, 2a, and 3a. In the control groups, the adhesives of the third (SY) and fourth generation (SB) achieved significantly higher bond strengths than the one-bottle adhesive (PB) ($p<0.05$).

For each adhesive system tested, the mistake groups showed significantly lower PBS than the control groups ($p<0.05$).

For SY, missing primer penetration time (PR0) resulted in significantly lower PBS than the other errors ($p<0.05$). The mistake groups TE60 and DRY showed no statistically significant difference ($p<0.05$).

Within the SB groups, TE60, DRY and PR60 obtained better PBS than PR0 ($p<0.05$).

Also for PB, the mistake groups ranked significantly below the control group ($p>0.05$). The errors TE60 and PR60 exhibited significantly higher bond strengths than DRY and PR0 ($p<0.05$). The observed fracture mode was generally adhesive.

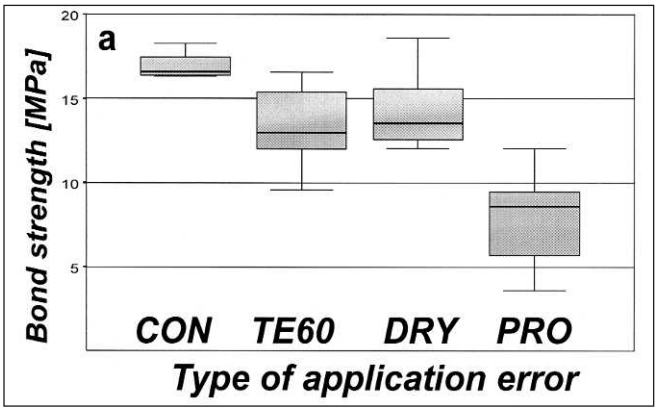

Figure 1a*: Boxplot of mean push-out bond strength (MPa) for Syntac Classic. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

Marginal Adaptation (MA)

The means of gap-free margins are displayed in Figure 1b, 2b and 3b. The control groups SY and SB achieved significantly higher percentages of gap-free margins than the one-bottle adhesive PB ($p<0.05$).

For all adhesive systems under investigation, incorrect use produced significantly less percentages of gap-free margins than the control groups ($p<0.05$).

For SY, overdrying after (self-) etching (DRY) resulted in significantly better MA than the errors TE60 and PR0 ($p<0.05$).

Within the SB groups, drying the primer immediately after application exhibited significantly inferior MA than the other mistakes ($p<0.05$).

For PB, the mistake groups ranged significantly below the control group ($p>0.05$), revealing percentages of gap-free margins between 51 and 68%.

DISCUSSION

This *in vitro* study should clarify the effect of application mistakes with dentin adhesive systems on bond strength and marginal adaptation. The mode of investigation was a simulated cavity design for testing bond strength and marginal adaptation, simultaneously. Compared to other studies utilizing shear bond-strength tests, the push-out procedure was selected, allowing bond-strength testing and margin analysis in

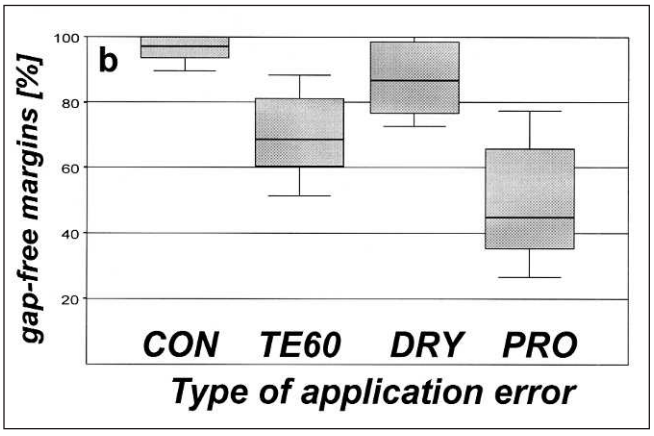

Figure 1b*: Percentages of gap-free margins (%) at the dentin-composite interface of the Syntac Classic groups. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

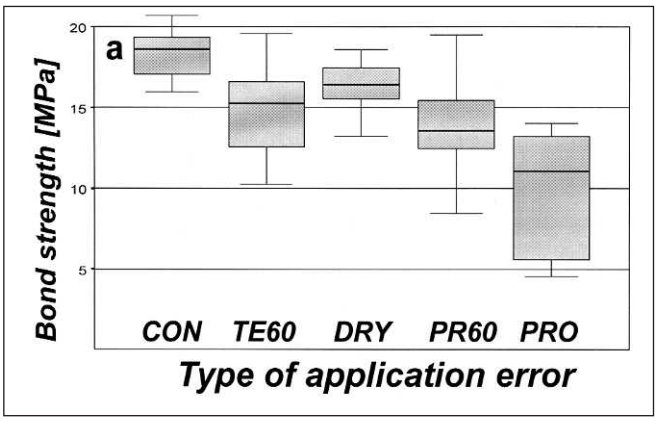

Figure 2a*: Boxplot of mean push-out bond strength (MPa) for Scotchbond Multi-Purpose Plus. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

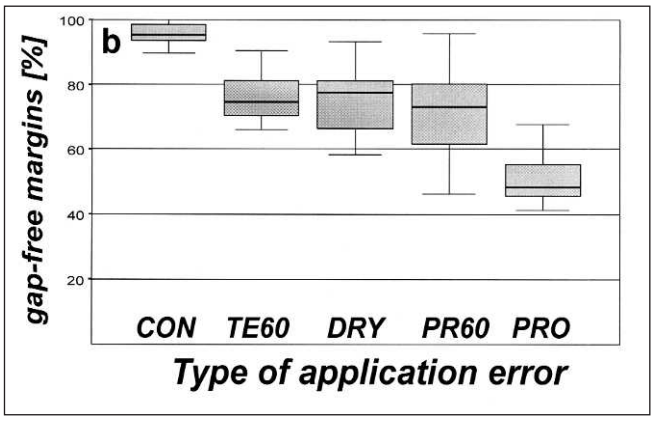

Figure 2b*: Percentages of gap-free margins (%) at the dentin-composite interface of the Scotchbond Multi-Purpose Plus groups. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

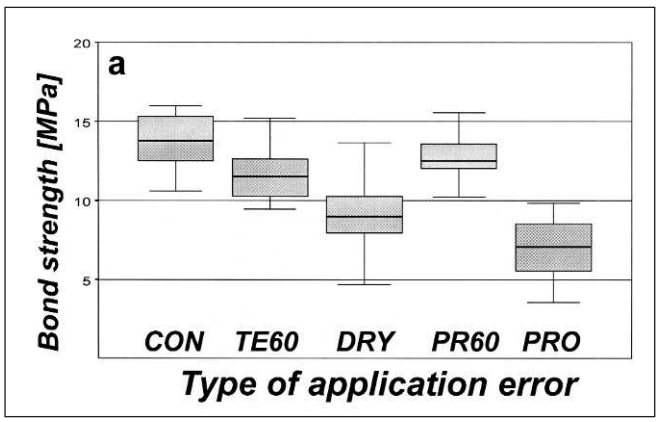

Figure 3a*: Boxplot of mean push-out bond strength (MPa) for Prime& Bond 2.1. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

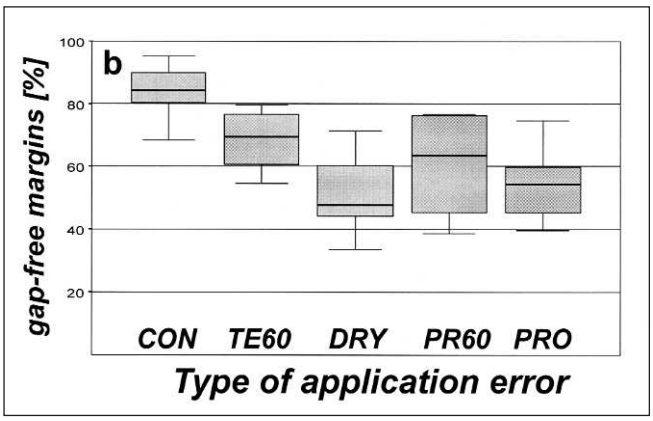

Figure 3b*: Percentages of gap-free margins (%) at the dentin-composite interface of the Prime&Bond 2.1 groups. The bars represent median values with 25/75% quartiles, vertical lines represent the complete range of values.*

one specimen (Haller & others, 1991). The extrusion design simulates polymerization stress as it occurs in cavities. Results showed a configuration factor (relation of bonded to unbonded resin composite surface) of ~1.7 in this study, compared to a factor of ~0.2 in shear or tensile procedures using bonded composite cylinders (Feilzer, De Gee & Davidson, 1987; Frankenberger & others, 1999; Patierno & others, 1996; Mason, Calabrese & Graif, 1997). Since the cavity design exhibited wall-to-wall shrinkage stresses, an evaluation of the stress-bearing capacity of the adhesive systems was possible by testing both bond strength and margin analysis (Haller & others, 1991; Frankenberger & others, 1999). Stressing the interface prior to bond strength testing may be advantageous (da Cunha Mello & others, 1997) and has reproducibly demonstrated a clear distinction regarding the bonding efficacy of simplified vs more time-consuming adhesives in a previous investigation (Frankenberger, Krämer & Petschelt, 1999).

Almost all data concerning *in vitro* dentin bonding performance has been reported while adhering strictly to the manufacturers´ recommendations for use. Ciucchi demonstrated that different general dental practitioners achieved rather inconstant dentin shear bond strengths using identical adhesive systems for bonding (Ciucchi, Bouillaguet & Russell, 1997). Therefore, it is an obvious assumption that incorrect application procedures may affect dentin bonding behavior, such as reported by Peschke for the particular adhesive system Optibond FL (Peschke, Blunck & Roulet, 1998).

Producing clinically relevant application mistakes was a central question in the course of this investigation. Prolonged etching of the dentinal surface probably occurs frequently in the daily practice of adhesive dentistry. Total etching by use of phosphoric acid gel is generally recommended for a 30 second period for the enamel margins of the cavity while 15 seconds is sug-

gested for dentin conditioning. This would imply separate etching of the two substrates which is not easily accomplished. Phosphoric acid application syringes tend to distribute rather large splashes, so the dentist has to put up with either prolonged etching of dentin or with a time-consuming repetition of the complete etching protocol.

Excessive drying after total etching may also occur frequently because the dentist wants to visualize the frosty appearance of the etched enamel. Therefore, the cavity is dried until this opaque zone indicates that enamel is etched successfully for bonding of the adhesive resin. However, dentinal parts of the cavity may be over-dried in the course of this particular procedure. The presence of a matrix band hindering water evaporation from proximal boxes may additionally complicate this problem by requiring more compressed air to visualize the enamel etch pattern.

The third possibility for an application mistake is prolonged drying of primers. This is easily explainable by the apprehension regarding residual primer solvent when the adhesive resin is applied. Primarily, water as primer solvent exhibits a hydrolytic potential when the primer solvent is not evaporated completely.

In the course of "time efficient" dentistry, a major problem might be the waiting period for sufficient primer penetration. A supposed short cut in dentin bonding application could imply primer application without waiting, enabling the application of the adhesive resin immediately after evaporation of the primer solvent to give considerably shorter treatment times.

The results of the different adhesive systems used according to manufacturers' instructions support the results of previous studies using the push-out design, demonstrating higher bond strengths for multi-step adhesive systems, such as Scotchbond Multi-Purpose Plus or Syntac Classic (Frankenberger & others; Haller & others, 1991). This study also revealed worse marginal adaptation when using the single-bottle adhesive system. The results might indicate that separate steps of dentin treatment using chemically different solutions offer improved bonding efficacy due to different viscosities and consecutively cohesive strengths.

For all the adhesive systems tested, performing the simulated application mistakes, as described, resulted in decreased dentin bonding performance represented by PBS and MA. Within the SY groups, the worst bond-strength resulted from shorter primer penetration time compared with overetching and excessive drying. Because of the self-etching nature of the SY primer, this would be due to insufficient smear layer removal and reduced demineralization by the 4% maleic acid. In the SY groups, the over-dried specimens revealed superior marginal adaptation to the other error groups. This suggests that self-etching adhesive systems are less sensitive to prolonged drying of the primer. Furthermore, this may also suggest that the SY "adhesive" actually acts as a second primer. This particular overdried group of SY showed statistically better results for PBS and MA than the "overdry" group of PB. This may indicate that SY shows a greater tolerance for this type of application mistake due to the lack of need for wet-bonding procedures and an increased "window of opportunity" when prolonged drying occurs. Nevertheless, focusing on the controls, the SY group with prolonged drying showed unacceptable bond strength and marginal adaptation.

Within the SB groups, PBS and MA revealed the worst performance when primer penetration was omitted (PR0). PBS findings indicate that the relatively high water content of the SB primer seems to achieve good rewetting of the collapsed collagen network after overdrying (DRY). This hypothesis is supported by the fact that the SB group performed better than the acetone-based PB after over-drying.

The main reason for the commercial success of simplified adhesives is the easy handling, convenience and lack of confusion (only one bottle) with these products rather than improved bonding. The results shown by PB tend to confirm this assumption demonstrating less difference between the control and the mistake groups. The prolonged drying of the primer seems to be partially compensated by the application of a second coat. Thus, it can be concluded for this investigation that the one-bottle system (PB) did not show less technique sensitivity than the multi-step products.

Not only the absolute values for PBS and MA decreased after application errors, but also standard deviations showed an increase, demonstrating less reliability of the dentin bonding behavior of each system applied. Despite several remarks on significantly superior results within the mistake groups, the predominant fact for this investigation remains that only strict adherence to the manufacturers' instructions can offer predictable and reproducible dentin bonding performances with the products tested.

CONCLUSIONS

- Strict adherence to the manufacturers' protocol for use offers reasonable results when using the tested dentin bonding agents.
- Application errors caused dramatic decreases in adhesive performance (determined by PBS and MA) with all systems tested.
- The investigated third-generation adhesive with a self-etching primer revealed less technique sensitivity to excessive drying due to the absence of wet-bonding procedures and requirements.

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Physical Properties of Three Packable Resin-Composite Restorative Materials

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RS Shaddy • CM Stanislav

Clinical Relevance

The results of fracture toughness, transverse strength and elastic modulus revealed significant differences among high-performance packable resin composites and conventional hybrid composites.

SUMMARY

This study evaluated selected physical properties of three packable resin composites (Alert, SureFil and Solitaire) and compared them to two conventional hybrid materials (Prodigy and Z-100). The specific properties investigated were diametral tensile strength, transverse strength, elastic modulus and fracture toughness. Following photopolymerization, specimens for each composite material were stored in deionized water at 37°C for 35 days. A one-way ANOVA and Tukey's post-hoc test were employed for each property to determine whether significant differences occurred with respect to specific restorative materials.

All materials had statistically similar diametral tensile strengths. Alert had the highest mean fracture toughness and elastic modulus but had a low mean transverse-strength value. SureFil exhibited good mean physical property values compared to both the conventional and packable materials. Solitaire had low mean fracture toughness, transverse strength and elastic modulus values, which could cause concern regarding use in posterior restorations. The packable resin composites tested had a wide range of mean values for the physical properties investigated. Generally, Alert and SureFil were superior to Solitaire and comparable to the hybrid materials Prodigy and Z-100, but clear discrimination among performance of these materials requires clinical testing.

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INTRODUCTION

Resin composites have been used in the posterior segments as an esthetic alternative to metallic restorations for more than two decades. Early problems of excessive wear, postoperative sensitivity and secondary caries have been encountered, and this has resulted, initially, in a diminished acceptance of these materials as suitable alternatives for the restoration of molar and premolar teeth (Phillips & others, 1973; Eames & others, 1974; Leinfelder & others, 1980). Considerable research toward solving these problems has been conducted, and as a result, today's materials are superior to their predecessors in several respects. For example,

the average annual wear of several recent-generation posterior resin composites has been shown in laboratory and clinical studies to be equivalent to silver amalgam (Mazer & Leinfelder, 1992; Dickinson, Gerbo & Leinfelder, 1993; Leinfelder & Broome, 1994). Consequently, wear resistance is not as significant a concern as in the past. Unfortunately, other problems, such as microleakage, secondary caries and difficulties in establishing proper approximal contour and contact continue to discourage clinicians from using these materials. Improved dental adhesives have contributed to the reduction of microleakage and its attendant sequelae, but the semi-solid nature of the restorative material continues to challenge the clinician with respect to establishing approximal contact.

The principal difference with handling properties between the commonly used, directly-placed posterior restorative materials, amalgam and resin composite, is that amalgam is condensable and packable. During amalgam condensation, the operator physically compresses the solid phase of the mixed alloy, which brings the liquid-mercury phase to the surface and reduces the space between the solid-phase particles. During manipulation, resin composites behave more like viscous liquids. When force is placed on the resin, instead of compressing or packing the mass, the force leads to displacement. As a result, achieving adequate interproximal contact with resin composites has been a significant clinical challenge (Leinfelder & Prasad, 1998). Clinical techniques, such as prewedging, have been suggested to overcome this difficulty. Success, however, has not been universal and appears to be greatly influenced by the degree of separation between the teeth that need to be restored in order to achieve contact. Being packable or placed under pressure without undue displacement seems to be a significant factor in establishing proper approximal contact. Because of their liquid nature, developing posterior resin composites that demonstrate condensability is probably not a reality; however, imparting the property of packability to these materials could significantly improve this clinical deficiency.

Several new products have been marketed as high-density or condensable resin-composite restorative materials. Essentially, manufacturers of these products have made them packable, so that their handling characteristics during placement will not contribute to clinical deficiencies associated with improper approximal contact. This laboratory study evaluated the diametral tensile strength, transverse strength, elastic modulus and fracture toughness of three packable materials and compared them to two conventional hybrid resin composites.

METHODS AND MATERIALS

Mean values and standard deviations for diametral tensile strength, transverse strength, elastic modulus and fracture toughness were determined for packable resin composites Alert (Jeneric/Pentron, Wallingford, CT 06492), SureFil (L D Caulk/Dentsply, Milford, DE 19963) and Solitaire (Hereaus Kulzer Dental Products, South Bend, IN 46614), as well as conventional hybrid resin composites Prodigy (Sybron Kerr Dental Specialties, Orange, CA 92867) and Z-100 (3M Dental Products, St Paul, MN 55144).

Diametral tensile strength was determined by placing the resins in a circular mold 5.5 mm in diameter and 2.5 mm deep. Each specimen was polymerized with an Optilux visible-light source (Demetron Research Corp, Danbury, CT 06810) and directed for 40 seconds from the top and bottom sides of each disk. Following polymerization, the specimens were stored in deionized water at 37°C for 35 days, and the peak force-to-failure was determined with a Model 1123 Instron Testing Machine (Instron Corp, Canton, MA 02021) operating at a crosshead speed of 10 mm/minute. Diametral tensile strength (DTS) was determined according to the following equation:

$$\text{DTS (MPa)} = \frac{\text{Failure Load(Kg)} \times 9.087\ \text{N/Kg} \times 2}{\pi \times \text{diameter} \times \text{length}}$$

Transverse strength and elastic modulus testing was conducted according to modified ISO Specification 4049, a three-point bending method. The resins were placed in a mold measuring 25 mm long, 2 mm wide and 2 mm deep. Each specimen was polymerized with an Optilux visible-light source by directing the beam for 40 seconds from each of five overlapping positions along the length of the mold. This was accomplished for both the top and bottom sides of each specimen. Following storage in deionized water at 37°C for 35 days, each specimen was placed on a pedestal with a span of 21 mm. A force was placed at the middle of the span, with the Instron Testing Machine operating at a crosshead speed of 0.75 mm/minute. Transverse strength (TS) was determined according to the following equation:

$$\text{TS (MPa)} = \frac{3 \times \text{Failure Load (Kg)} \times 9.087\ \text{N/Kg} \times 21.0}{\text{mm } 2 \times \text{width} \times \text{depth}^2}$$

The elastic modulus was determined from the slope of the stress strain curve generated from the three-point bending test.

Fracture toughness testing used single-notched specimens as described by Ferracane, Antonio and Matsumoto (1987). This involved placing the resins in a rectangular mold 24 mm long, 5 mm wide and 3 mm deep. The mold had a razor blade insert placed at midspan to create a pre-crack within the polymerized composite. Each specimen was polymerized with an Optilux visible-light source by directing the beam for 40 seconds from each of five overlapping positions along the length of the mold. This was accomplished for the top and bottom sides of each specimen. Following polymerization, the

specimens were stored in deionized water at 37°C for 35 days and placed on a pedestal with a span distance of 21 mm. The specimens were loaded to failure with an Instron Testing Machine operating at a crosshead speed of 0.5 mm/minute. Fracture toughness (K_{Ic}) was determined according to the following equation:

$$K_{Ic}\ (MPa.m^{0.5}) = [\frac{\text{Peak Load (N) x Span}}{\text{Thickness (m)} \bullet \text{Width}^{1.5}}] \text{ x fa/w}$$

where fa/w is a factor calculated from ASTM Method E399.

Twelve specimens of each resin composite were made for the diametral tensile strength, transverse strength and elastic modulus tests. Eight specimens of each resin were made for fracture-toughness determination. Data generated for each property were subjected to one-way ANOVA and Tukey's post-hoc test to determine whether differences occurred among the resin composite products tested.

RESULTS

Results of the diametral tensile strength testing are presented in Table 1. Mean values and standard deviations ranged from a high of 45.3 ± 6.8 MPa for SureFil, to a low of 40.1 ± 2.2 MPa for Alert. No statistically significant differences were detected among the five products tested ($p>0.05$). The results of transverse strength testing are presented in Table 2. Mean values and standard deviations ranged from a high of 109.5 ± 16.9 MPa for Prodigy, to a low of 53.6 ± 10.1 MPa for Solitaire. No statistically significant differences were noted between the mean values for Prodigy, SureFil and Z-100 ($p>0.05$). These products exhibited significantly greater mean transverse strength values than Alert or Solitaire ($p<0.05$). Test results for elastic modulus are presented in Table 3. Mean values and standard deviations ranged from a high of 22,647 ± 4854 MPa for Alert, to a low of 5165 ± 656 MPa for Solitaire. The mean value for Alert was significantly greater than all other products tested ($p<0.05$). Only SureFil and Z-100 demonstrated statistically similar results ($p>0.05$). Fracture toughness test results are presented in Table 4. Mean values and standard deviations ranged from a high of 1.87 ± 0.11 $MPa.m^{0.5}$ for Alert, to a low of 0.77 ± 0.03 $MPa.m^{0.5}$ for Solitaire. All reported values were statistically different from each other ($p<0.05$).

Table 1: *Mean Diametral Tensile Strength (MPa)*

Product	Diametral Tensile Strength
SureFil	45.3 ± 6.8
Solitaire	42.9 ± 18.3
Prodigy	40.8 ± 4.0
Z-100	40.2 ± 5.3
Alert	40.1 ± 2.2

Note: Groups connected by a vertical bar are statistically similar.

Table 2: *Mean Transverse Strength (MPa)*

Product	Transverse Strength
Prodigy	109.5 ± 16.9
SureFil	95.3 ± 10.8
Z-100	94.6 ± 8.7
Alert	69.9 ± 11.9
Solitaire	53.6 ± 10.1

Note: Groups connected by a vertical bar are statistically similar.

Table 3: *Mean Elastic Modulus (MPa)*

Product	Elastic Modulus
Alert	22,647 ± 4,854
Z-100	18,948 ± 1,316
Surefil	16,823 ± 839
Prodigy	12,675 ± 1,738
Solitaire	5,165 ± 656

Note: Groups connected by a vertical bar are statistically similar.

Table 4: *Mean Fracture Toughness ($MPa.m^{0.5}$)*

Product	Fracture Toughness
Alert	1.87 ± 0.11
SureFil	1.47 ± 0.09
Prodigy	1.22 ± 0.08
Z-100	1.04 ± 0.07
Solitaire	0.77 ± 0.03

Note: Groups connected by a vertical bar are statistically similar.

DISCUSSION

All packable restorative resin composites were developed to create a handling characteristic of the material that would mimic amalgam, particularly with respect to manipulation that produces a restoration with appropriate interproximal contact. According to the manufacturers, the technical approach by which this was accomplished was through modifications in the filler of each system. With Alert, packability is achieved using an irregularly shaped microfilamentous glass filler in conjunction with ground barium borosilicate and a silanated microfine silica to establish a high level of filler particle loading (Leinfelder & Prasad, 1998). Surefil employs a patented "Interlocking Particle Technology™," which the manufacturer claims is a blend of different sized particles (Caulk/Dentsply, 1998). When compressed mechanically, the larger fillers interlock with the smaller fillers to achieve packability. Solitaire employs porous, rough-edged fillers ranging in size from 2 to 20 microns. The manufacturer claims that, when used in conjunction with the so-

called vitroid Polyglas resin matrix, the composite exhibits solid mass behavior (Hereaus Kulzer, 1998).

Establishing packability and eliminating slump of resin composites is a favorable development with respect to the proper restoration of approximal contact. However, it does not ensure that the restorative material can function adequately in the oral environment. Results of the physical property testing conducted during this study, when compared to the values of currently used and accepted resin products, should provide some insight in this regard. This study used two hybrid resins with well-known and generally successful clinical performance as a comparison for physical properties.

Loads that stretch or elongate cause tensile stresses. The diametral tensile strength test is applied to those materials exhibiting a very limited plastic deformation for which information regarding stretching or elongation resistance is desired. It represents the minimal stress a structure will withstand before rupture when tensile loads are applied (Phillips, 1991). This test is very applicable for materials placed intraorally, since masticating forces are often obliquely applied and tend to create tensile stresses. The results of this study indicate that all three condensable composite products were statistically similar to each other and to the currently used products with respect to this property. It appears, therefore, that SureFil, Alert and Solitaire should withstand the tensile loading present in the oral cavity.

Transverse strength is a strength test of a beam supported at each end and subjected to a static load. This test, in a sense, is a collective measurement of all types of stresses administered simultaneously. The stresses on the upper surface of the beam tend to be compressive, while those on the lower surface are tensile (Phillips, 1991). The values reported for SureFil compared favorably with those of currently used products. Alert and Solitaire were found to have significantly lower transverse strength values than SureFil and the controls. The mean value for Solitaire was determined to be significantly less than that for Alert.

The modulus of elasticity, or measure of a material's stiffness, is important with respect to anticipated restoration longevity. Materials with a low elastic modulus may experience momentary displacements when masticatory stresses are applied. In Class II situations, this may cause the approximal portion of the restoration to be torqued away from the axial wall. Release of the stress allows the restoration to return to its original position. This back-and-forth motion will tax the enamel and dentin bonding system, which could result in leakage and secondary caries (Leinfelder & Prasad, 1998). It could also result in restoration fracture in the isthmus area. The relatively high mean elastic modulus of Alert and the mean value for SureFil, which approximates that of currently used posterior resin materials, are favorable for these two products in this regard. The low mean value reported for Solitaire is a concern.

Fracture toughness is a measure of stress intensity at the tip of a crack or flaw from which a crack propagates through a material. This property has been related to a dental material resisting both crack propagation and wear in the oral environment (Fujishima & Ferracane, 1996). Although there is general agreement that fracture toughness improves as filler particle volume is increased, concern has been raised that the values reported may vary widely and are dependent upon the method of testing. Because of difficulties associated with the double-torsion test and the short-rod test (Fujishima & Ferracane, 1996), the single-edge notch test was selected for this study. The relatively high mean-fracture toughness values obtained for Alert and SureFil, and the fact that these values were statistically superior to those of currently used resin products, implies that these materials should resist crack propagation and demonstrate adequate wear resistance in the oral environment. The low mean fracture toughness value demonstrated by Solitaire, which was significantly less than the conventional hybrid restoratives, may indicate that Solitaire might not be suitable for posterior use when strong mastication forces are possible.

It was noted that during the preparation of specimens, all three high-density resin composites exhibited packability and little, if any, slumping. This may favorably address concerns that have arisen with respect to the restoration of approximal contact when traditional hybrid resins were compared to silver amalgam; however, actual clinical testing is needed to confirm this observation. Results of the physical property testing conducted in this study suggest that all products can resit diametrically applied tensile stresses. SureFil presented favorable values for modulus of elasticity, fracture toughness and transverse strength, while Alert performed favorably with respect to elastic modulus and fracture toughness.

CONCLUSIONS

The high-density resin composites tested in this study demonstrated a wide range of physical property values. Overall, Alert and Surefil were at least comparable, if not better in mechanical properties than conventional materials. Solitaire's significantly lower transverse strength, elastic modulus and fracture toughness may be a cause for concern clinically. Clear and adequate discrimination of these materials will require clinical testing.

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Cumulative Assessment of Factors Leading to Restorative Decisions in an Educational Environment A Graphical Demonstration Using an *In Vitro* Case

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Clinical Relevance

The more abundant the shortcomings of restorations and signs denoting caries, the more frequent and sooner restorative interventions were proposed in a series of *in vitro* evaluations.

SUMMARY

Even though accuracy and inter-examiner variation assessments of borderline restorative items have been previously reported, no attempt has been made to replicate the effect of cumulative, sequential diagnostic and treatment planning decisions.

This study assesses the cumulative effect of factors indicating restorative needs by evaluating how readily tooth restoration was proposed on the basis of restoration quality and presence of caries (compared to gold standards).

Ninety-one senior dental students in Mexico City (79% female; mean age 22.8 years) assembled in 19 teams of five students each. They sequentially evaluated 56 restored and unrestored posterior teeth in an *in vitro* model. Each student examined the set, removed those teeth needing restorative intervention and returned the remaining set for examination by a second student. When the second assessment was completed, the remaining teeth were turned over to the third teammate and so on. Teeth were subsequently assessed for restoration quality and enamel and dentinal caries.

When a tooth showed a carious lesion, a dentinal lesion or a defective restoration, the likelihood of it being selected for restorative treatment increased. When more than one feature was present, the chances of the tooth being selected more frequently and earlier increased, accordingly. The specificity of restorative treatment needs was not excellent.

A strong graphical association between the presence of caries and/or defects in restorations with proposed restorative treatment was demonstrated using a non-quantitative research model. The more abundant these features were, the higher the probability appeared for a tooth to fit the clinical picture suitable for restorative intervention.

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INTRODUCTION

Several studies have found substantial inter-examiner variation in the appraisal of carious lesions and subsequent treatment planning, whether using (Kay & others, 1988; Merrett & Elderton, 1984) or using no objective measures of inter-examiner agreement (Cleaton-Jones & others, 1989; Elderton & Nuttall, 1983;

Maryniuk, 1990; Noar & Smith, 1990; Nutall & Elderton, 1983; Rytömaa & others, 1979; Foster, 1994), and under either *in vivo* (Elderton & Nuttall, 1983; Nutall & Elderton, 1983; Rytömaa & others, 1979; Foster, 1994) or *in vitro* research conditions (Kay & others, 1988; Merrett & Elderton, 1984; Noar & Smith, 1990). In general, various degrees of over-treatment patterns have been reported. When an objective criterion was used to appraise diagnostic performance (Kay & others, 1988; Merrett & Elderton, 1984), accuracy and inter-examiner agreement tended to be poorer than in study designs not using one (Cleaton-Jones & others, 1989). Inter-examiner agreement is affected even more when the spectrum of restorative needs is limited to cases with "borderline" treatment needs (Cleaton-Jones & others, 1989; Maryniuk, 1990). The variation in diagnostic and treatment decisions is apparently due to idiosyncratic decision-making in the diagnostic processes of dentists (Kay & others, 1988; Elderton & Nuttall, 1983). How this affects the overall success of treatment is not well known, but it is a familiar, yet not well-understood scenario—that dentists believe many restorations they evaluate can be improved (Maryniuk, 1985; Maryniuk & Kaplan, 1986). Dentists planning more treatment on new patients support these reports, compared to patients who have been under a dentist's care for some time (Elderton & others, 1985). Generally, clinicians are more comfortable with restorations they are familiar with (often because they have placed those restorations) than with restorations that have just come under their scrutiny. In the latter context it would be easier for a tooth to fit the description of a caries script (or restorative script). Bader & Shugars (1997) described caries scripts as highly summarized versions of a clinician's experience with similar presentations of clinical pictures suitable for restorative intervention. The main practical problem of such caries scripts guiding restorative intervention is that those distinguishing characteristics, as an expression of treatment need (on account of caries or surrogate indicators of caries likelihood), are very common. As Bader & Shugars (1997) suggested, caries scripts are not necessarily associated with the unequivocal presence of decay, but rather the probability that it is present. Where the need for intervention is uncertain, more often than not clinicians will choose to intervene. While it has been shown that the diagnostic performance of clinicians benefits from training in probabilistic reasoning (Choi & others, 1998), most clinicians base their decisions on more subjective processes. They rely on their own personal restorative scripts, developed over an extended period of time in training and clinical practice. Bader & Shugars (1997) postulated that the subjective appraisal of evidence in this context seems to reinforce decision models that lead to early and frequent intervention in the face of uncertainty.

Two overlapping questions were investigated in this study: (i) would an earlier intervention or a higher likelihood of intervention result from more tooth/restoration factors comprised in the script? Furthermore, (ii) when restorations are sequentially appraised by more than one clinician, is there a cumulative effect of those factors indicating restorative needs?

METHODS AND MATERIALS

A random sub-sample was drawn from a stratified random sample of final-year Mexico City dental students who were surveyed for other investigations (Maupomé & Sheiham, 1997a; 1997b; 1998). The size of the sub-sample was arbitrarily set at 95 participants divided into 19 teams. Students participating in this study did not take part in a parallel trial (Maupomé, 1998).

The standard clinical procedure for detecting dental decay taught to students endorsed the probing of carious lesions using a sharp explorer. In practical terms, the array of clinical strategies employed in the curriculum emphasized the acquisition of diagnostic skills to detect individual lesions over a more holistic management of caries risk, as it has been separately established for the same study population (Maupomé & Sheiham, 1997a; 1997b; 1998).

In Vitro Set of Teeth

A large set of teeth were examined with a stereomicroscope (Nippon Kogaku KK, Japan) at 20X magnification; if restored, the tooth-restoration interface was examined. The teeth had been cleaned of debris upon extraction, fixed in 10% neutral-buffered formalin with pH indicator for several weeks and rinsed in tap water. The teeth were selected for having controversial areas on occlusal surfaces that suggested the need to restore or re-restore (deep or stained pits and fissures, marginal defects or surface defects), showing a clinically-common presentation with minor features placing them between two broad areas of the restorative continuum: programmed for, and non-programmed for, a course of restorative treatment. Fifty-six permanent molars (n=47) and premolars (n=9), restored (n=28) and non-restored (n=28), were thus chosen for this study. All restorations were amalgams. Teeth were placed in ice-cube trays filled with dental stone (series A1 to A8; B1 to B8; C1 to C8; D1 to D8; E1 to E12; and F1 to F12) and individually photographed (10X, B&W). Only the crown was visible, thus using the stone as a simulated gingiva. Each tooth could be taken out of the tray individually.

Trial Procedure

Students assessed the teeth in isolation, one person at a time. Illumination was obtained from a dental unit lamp. Students were provided with the teeth, a Maillefer No 6 probe and a mirror. They did not use

magnification to examine the teeth nor was magnification generally employed in clinical practice. There were no time limits for the examination. The students were asked to assume that these teeth were in "acceptable" occlusion in an "average" patient who was attending his or her first dental check-up and treatment, if needed, and that the patient was a young adult in good general health, with reasonably good oral hygiene, low caries experience (DMFT=6), with no symptoms. Radiographs were not supplied since this aspect had been separately investigated (Maupomé & Sheiham, 1997a; 1997b) using other research instruments, but, most importantly, because the teeth were not in approximal contact and, therefore, the entire crown was easily visible (Maupomé, 1998). The value of radiographic information was not as crucial in these circumstances, particularly since the teeth had been selected because of their borderline status. This design limitation was identified as an idiosyncratic feature of the study and excused in view of its research objectives.

Students were randomly allocated to teams of five each. The first student in a team assessed each tooth and removed those teeth needing restoration. These teeth were eliminated from the trial on that team; the remaining teeth, presumably sound according to the first student, were submitted for review by the team's second student. Once the second student completed his or her assessment, the remaining teeth were submitted to a third, and so on. After five examinations or depletion of teeth on the trays, that team's trial was finished. Students did not give reasons for their decisions.

Students who previously participated in the study did not communicate with participants who were just starting their assessments. Each participant was encouraged to use the same criteria and rationale for assessment that they would normally employ in their clinical activities.

Cumulative Assessment: Restorative Assessment Score

A score was designed to determine (i) the frequency of a tooth being allocated to treatment and (ii) how promptly this occurred in a team. The Restorative Assessment Score (RAS) was calculated by adding five points every time a given tooth was selected for treatment by the first student of a team, four points if selected by the second student and three points if selected by the third student. Accordingly, when the fourth student selected it, two points were added to the RAS of the tooth and only one point was added if the fifth student selected it. If the tooth survived five examinations without being selected, the score was nought. RAS could range from 0 to 95 (5 points 19 times if a tooth was chosen by every first student).

Gold or Normative Standards (NS)

A first-normative standard (NS A) concerning the quality of the restorations was obtained following the criteria of Ryge and Snyder (1973): the quality designation "satisfactory" has two categories: (a) meets all standards and (b) observe at next visit. The designation "not acceptable" has two categories: (c) replace for prevention and (d) replace immediately. For each category the examiner must consider three characteristics of the restoration: surface and color, anatomic form and marginal integrity. Assessments of the restorations according to these criteria were done by two calibrated examiners. A consensus on every tooth's operational category was reached by discussing the differences found.

A second normative standard (NS C) involved the histological determination of carious lesions in the most controversial areas within the crowns that could invite a clinician to focus his/her attention on deciding whether or not restorative intervention was warranted. While the response to these controversial areas was separately established in a parallel trial (Maupomé, 1998), participants in the current investigation could consider features anywhere on the teeth. For the histological determination, restorations were carefully removed using an air-rotor handpiece and intra-coronal burs. First, restorations were weakened by carving a ditch along the longest axis of the amalgam, then its fragments were forced out by means of an excavator. These cavities were cleaned of debris using a pressurized air stream. Great care was taken not to damage the walls of the cavity. Both restored and unrestored teeth were sectioned using a diamond wafering disc blade (0.15 mm thickness) (Buehler Ltd, USA) mounted in an electric motor (2850 rpm). A stream of tap water was used as the cooling agent. A first-cut was made through the center of the area highlighted as nearly perpendicular as possible to the cavo-surface line angle when one was involved. A second cut was then made at approximately 90° to the first, to enable a piece of tooth to be removed, thereby exposing the region of interest or the area deep to the region of interest. The sections were examined with a stereomicroscope at 15X and 20X magnification by one examiner who determined the presence or absence of caries at or deep to the relevant regions of each tooth. Lesion depth was also recorded. No attempt was made to distinguish between residual or recurrent carious lesions.

A third normative standard (NS D) was also involved in determining the lesions within the controversial areas. It differed from NS C in that it used dye as an objective way to identify dentinal lesions. The demineralized tooth structure (roughly equivalent to infected dentin) stains positive, whereas non-demineralized dentin does not take up the dye (Fusayama & Terachima, 1972; Wirthlin, 1970; Sato & Fusayama, 1976; Kuboki & others, 1977; Kidd & others, 1989). No distinction can be made between affected dentin left behind during cavity preparation or a recurrent lesion developing in dentin. The sectioned teeth used in NS C

were submitted to a caries-detector dye test (1% acid red in propylene glycol wt/wt) (Kidd & others, 1989). Tooth sections had the dye applied on a pledget of cotton wool for 10 s. They were washed with tap water, dried and examined on a stereomicroscope (20X) for any dentin stained by the dye.

Statistical Analyses

Data were analyzed using descriptive statistics to design a graphic portrayal of the decisions made, together with the decay/restoration features established by means of the normative standards.

RESULTS

Basic Results

After the trial, teeth were compared under a stereomicroscope (10X) with their photographs. Since some were damaged while being probed, they were eliminated, leaving 50 teeth for analysis.

Nineteen teams comprising 91 students participated in the study (79% female; mean age 22.8 years). Gender and age distributions were reasonably representative of the class, with slight over-representation of female students.

Assessments of Restorative Needs

Most teeth were allocated to treatment by the first two students of each team. Three first-students chose between 40 and 50% of the teeth; six chose between 51 and 60%; eight chose between 61 and 70%; and two chose between 71 and 80%. Most students believed that some teeth did not require restoring. There were three instances when the third or fourth students depleted the trays, making these teams smaller. Only in 20 instances did a subsequent student not propose a tooth for restoration from those left by his/her predecessor (27.7% of 72 sequential examinations, considering 91 teams of students minus 19 first-students whose assessments did not follow another).

RAS scores were plotted along the score scale (Figure 1). Thus, the further down the axis of the graph, the higher the score. It was observed that only three teeth (RAS 7, 50 and 55, respectively) were located towards the lower end of the scale. All remaining teeth had a RAS score from 71 to 95, and the largest proportion (64%) scored above 82. Unrestored teeth (n=24) were more frequently below the RAS 82 threshold, compared to restored teeth (n=26). Restored teeth seemed programmed for restoration more frequently and readily than unrestored teeth.

By plotting positions derived from the normative standards (NS A, C and D) with the actual positions that teeth had along the RAS scale in Figure 1, shows how closely students' assessments fitted normative standards. For example, Figure 1's legend indicates tooth C7 had a restoration that was due for replacement, according to NS A [ ]; had histologic evidence of caries in enamel and dentin, according to NS C (:); and had a positive result for collagen changes in dentin, according to NS D < >. Tooth C7 had a RAS score of 92. This was the same score for tooth F3, which had no need for a restoration, had no signs of enamel or dentinal decay and stained negative to acid red (Figure 1).

According to the Ryge and Snyder (1973) criteria (NS A), six teeth out of 26 restored teeth needed restoration replacement (Figure 1). RAS scores ranged from 81 to 93. According to the histologic assessment (NS C), 10 teeth presented lesions in enamel and seven presented lesions in enamel and dentin. RAS scores ranged from 76 to 92. According to the dye technique (NS D), 10 teeth stained positive to collagen changes in dentin. RAS scores ranged from 77 to 92.

Only one tooth positive to the dye technique and another needing a restoration replacement were below the RAS 82 mark. Using normative standards as a validation measure, it was observed that students correctly planned to restore 22 teeth. Their RAS score tended to increase on teeth that showed a carious lesion, a dentinal lesion and/or a defective restoration. Seven unrestored and 15 restored teeth had some degree of caries (NS C and D) or a defective restoration (NS A). Furthermore, when teeth had a defective restoration and a lesion, the chances of being selected for treatment more frequently and earlier increased accordingly. However, it was observed that teeth deemed sound by NS A, C or D were also programmed for restoration: 25 were at or above the RAS 71 level; 15 were above the RAS 82 level, thus being included in the main group of teeth which actually needed treatment. Indeed, some were not only at the same level of assessment (eg, A2, B4 and F3, RAS 89, 89 and 92, respectively) as decayed teeth, and/or teeth with defective restorations, but above them (eg, F9 and F6, RAS 95 and 94) (Figure 1).

DISCUSSION

As stated elsewhere for the same study population (Maupomé, 1998), a survey of practicing dentists was not included in the design for technical reasons, although it would have been desirable as a research approach. There is no reliable professional register of practicing dentists in Mexico (Maupomé & others, 1998). There was no obvious advantage in drawing a convenience sample of dental practitioners if a reliable sampling framework of dental students in the last eight months of their final clinical residency program was available, together with relevant research information (Maupomé, 1998; Maupomé & Sheiham, 1997a; 1997b; 1998). Direct extrapolation of results to fully-qualified dentists may not be warranted, even though the different features that can be attributed to restorative decisions specific to the dental school environment seem to reflect the general lack of clinical

agreement between dentists (Bader & others, 1995) rather than suggesting obviously different criteria and decision-making mechanisms (in the United States).

There are three methodological considerations that warrant discussion in the context of the research design. Since the teeth left in the trays diminished in number as they were allocated to treatment, only the first students from each team had access to identical sets of teeth to appraise. While it would be statistically untenable to make a direct comparison of treatment patterns from any one examiner to another, such direct contrast has been quantitatively investigated beforehand (Maupomé, 1998). An alternative approach would be life-table analysis (Anderson & others, 1980). This was rejected since its primary application is the evaluation of survival over time, when the subjects under longitudinal follow-up last in one category (eg, a patient suffering from advanced neoplastic disorder) a certain amount of time before being shifted to another category (ie, the patient dies from that disease). In our study design, however, time intervals were unimportant: evaluations of teeth succeeded one another, not allowing for actual changes to occur in the teeth, neither bearing any obvious impact on the outcome. In the current situation, discrepancies cannot be ascribed to changes in the teeth but rather to idiosyncratic restorative decisions. Such discrepancies may have significant clinical implications (Brantley & others, 1995).

The second consideration concerns the relevance of normative standards C and D to establishing whether teeth were carious or not. Students may have looked at other part(s) of the tooth and not only the specific areas that were appraised in NS C and D. While these are not unequivocal evaluations, they seemed to be reliable: the areas asessed were selected as those areas where controversy may have arisen. No evident signs of caries were apparent elsewhere, and the set was chosen on the premise of depicting a borderline status between the programmed for and non-programmed for restoration.

Finally, it can be argued that the very design of the trial encouraged students to excel in their diagnostic "sharpness," therefore, making them more prone to over-diagnosis or over-treatment than they would normally have been. This is unlikely. On one hand, care was taken to make each participant confident enough of the respect and seriousness with which his/her clinical judgement was received. This aspect was emphasized to every participant. No feedback or suggestions from fellow students was permitted. On the other hand, ample variation in caries diagnostic criteria or treatment plans has been previously reported in clinical studies (Elderton & Nuttall, 1983; Rytömaa & others, 1979), *in vitro* trials (Merrett & Elderton, 1984; Maryniuk, 1990; Noar & Smith, 1990) or radiographic trials (Mileman & others, 1985). Findings in this population regarding inter-examiner agreement, expectations for restoration longevity and decay progression, and the overall orientation of clinical customs (Maupomé, 1998; Maupomé & Sheiham, 1997a; 1997b; 1998) also suggest that the appropriateness of restorative treatment decisions was open to controversy. It is interesting to note that the first mention of this research design in a peer-reviewed journal more than 50 years ago (Bakwin, 1945) was also concerned with the appropriateness of clinical measures.

First students planned most treatment. Apart from the obvious fact that more teeth were present to be restored, first students probably selected most teeth which actually needed restorative treatment, as indicated by their RAS scores and the results of the normative standards in Figure 1. Nevertheless, students either showed poor specificity in their assessments of restorative needs or they preferred to restore if in doubt as to caries status. While this feature could be specific to the educational setting where they were trained, it is likely that this scenario is shared with other professional settings. On the one hand, the relatively high level of decay activity and severity present in the environment where these students have come in contact with patients should prime their clinical behavior in general. This has been discussed elsewhere (Maupomé, 1998). However, the ubiquity of features constituting the caries scripts (as described by Bader and Shugars (1998)) suggest that these patterns of clinical behavior are not solely applicable to student populations. There is substantial evidence that agreement on diagnostic and management decisions among clinicians is, on the whole, somewhat poor (Grembowski & others, 1997; Bader & Shugars, 1993) probably because many of those decisions deal with borderline cases.

Overall, the RAS score increased when teeth showed a carious lesion, a dentinal lesion and/or a defective restoration; when more than one feature was present, the chances of the tooth being selected for treatment more frequently and earlier increased accordingly. This goes along the interpretation that clinicians are "doers" rather than "observers": apparently, many of them seem to make a decision for an intervention first, then support it with a diagnosis (Bader & Shugars, 1993). Since the components of a restorative script are highly visual and tactile, the introspection of the clinical image of a tooth may closely match the restorative script when examined, and then the clinician will "automatically" recommend intervention (Bader & Shugars, 1997). It is more difficult to establish how this information is processed by the individual clinician to build up a case for restorative intervention because they are not verbal, nor explicit statements in the form of laboratory values. This field has not been

extensively investigated. From the scant research information available (Maupomé, 1991), it has been determined that restorative criteria relied on concepts mainly derived from indicators physically present in teeth. Those concepts were broadly characterised by (i) failure to establish the serviceability of restorations. The practical objective pursued was to assess the morphologic appearance considered against a paradigm of restoration beauty/adequacy, which few restorations seemed to fulfil in real life. (ii) Also, they were separated from an adequate appraisal of the potential for lesions to go beyond a remineralizable status—the practical objective pursued was the instant assessment of lesions and lesion proxies. For example, tooth discoloration, marginal defects and debris-retention points. Within the framework of previous reports which proposed that the availability of relevant knowledge in memory and the ability to retrieve pieces of information relevant to the current case are fundamental requirements of clinical reasoning (Bordage & Zacks, 1984), students seemed to use well-defined strategies to identify those concepts that signaled the need to restore. Their major diagnostic deficiency was that many indicators were either irrelevant to the adequate evaluation of treatment needs or were an inaccurate portrayal of them. The laxity, itself, of some restorative criteria may force clinicians to make up for shortcomings in their clinical application by devising benchmarks, attaching examples to concepts and designing rules to be applied to the current cases.

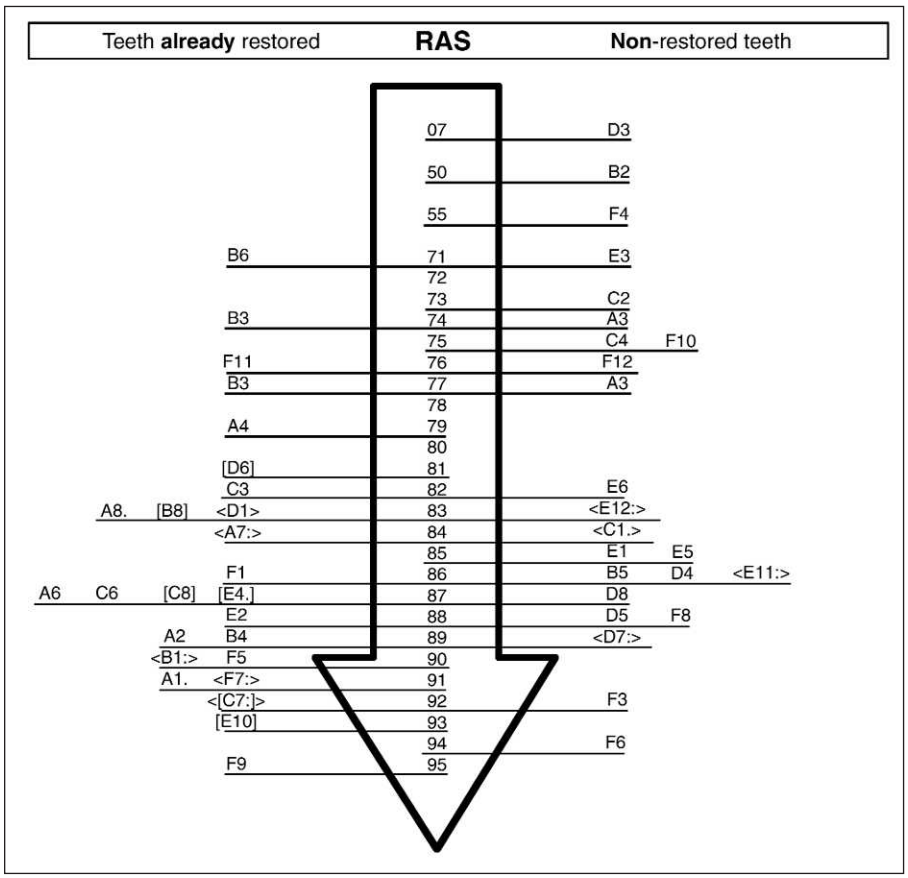

Figure 1. *Restorative Assessment Scores (RAS) plotted with the results of the Normative Standards (NS A, C AND D).*

Taking these results not at the individual decision level but also as an exploration into decisions made by a group, the sequential evaluation of a case by several clinicians can be seen as leading to an increased risk of a false-positive decision (Nuttall, 1983) occurring at some point along that sequence, unless diagnostic accuracy is improved. If a parallel is to be drawn between a system of regular dental recalls and that of sequential appraisals, such as the one depicted in this investigation, a false negative error should be self-correcting and of little consequence. A false positive error, however, would have its probability of occurrence compounded with each recall examination, the probabilities being additive (Dowell & others, 1983).

CONCLUSIONS

This investigation in an educational setting demonstrated graphically that cumulative assessments of treatment needs may lead to an earlier intervention or a higher likelihood of intervention when more tooth/restoration shortcomings are present. Treatment plans in such settings (in the United States) have been reported to recommend restorative treatment more frequently than do practicing dentists (Bader & others, 1995). While fears of inexorable, rapid progression of dental decay prevalent in the setting where this research took place (Maupomé, 1998; Maupomé & Sheiham, 1997a; 1997b; 1998) may have strengthened the tendency to intervene restoratively earlier and more frequently throughout these cumulative appraisals, the results emphasize the need to evaluate new educational and professional approaches to objectively consider restorative treatment needs (Shugars & Bader, 1992). This evaluation should take place in terms of the appropriateness (the positive balance between the expected health benefit versus negative consequences by a sufficiently wide margin to make the procedure worth doing (Park & others, 1986) and effectiveness of restorative treatment needs (a measure of the procedure achieving in the real world what

it was aimed to attain (Last, 1988). Efforts to develop clinical guidelines should support the adoption of restorative scripts more relevant to current practice recommendations and to the actual epidemiological profile of dental decay. The design of more reliable diagnostic assessment tests to detect various stages of caries penetration would be particularly useful tools.

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Clinical Techniques/Case Reports

Foreign Body Gingivitis Associated with a New Crown: EDX Analysis and Review of the Literature

S Gordon

Clinical Relevance

Abrasive tools and materials used in or near the gingival margin may drive microscopic foreign particles into the gingival connective tissue, causing chronic inflammation known as foreign body gingivitis.

SUMMARY

Gingival inflammation associated with foreign bodies in connective tissue is termed Foreign Body Gingivitis (FBG). It is not commonly recognized by clinicians and has recently been described fully in the literature. It is more common in females, and the incidence by age follows a normal distribution, unlike bacterially-induced gingivitis. Most frequently, a red or red-and-white painful, chronic lesion, it has usually been present for less than one year and does not resolve with optimization of oral hygiene. It may be clinically confused with lichen planus. There is no gingival site predilection. Microscopically, foreign bodies are associated with the gingival inflammation, and elemental analysis suggests that they are usually derived from abrasives, and less commonly from restorative materials. Treatment of FBG is still unclear and its prevention is discussed. A case is presented in which a patient developed localized foreign body gingivitis after placement of a crown. Elemental analysis using energy dispersive X-ray microanalysis (EDX) of the foreign particles was most consistent with an abrasive material.

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INTRODUCTION

From time to time, a dentist will encounter a patient with an area of gingival inflammation that eludes resolution through conventional means. Most diseases of the periodontal tissues are inflammations caused by accumulations of microbial plaque (Genco, Goldman & Cohen, 1990). Plaque control is usually our first instinct, but when oral hygiene is excellent and plaque is not present, we are forced to think of less likely processes. Such lesions may be attributed to a number of other systemic and local causes. Until recently, this differential diagnosis has not included foreign bodies in the connective tissues.

Daley and Wysocki (1990) were the first to describe foreign-body gingivitis. Energy-dispersive x-ray microanalysis (EDX) of the lesional tissue, together with the clinical histories, suggested a possible iatrogenic source for the foreign material in eight cases. They also demonstrated that foreign material is not a normal finding in the gingival connective tissues.

Gordon and Daley (1997a) analyzed 61 cases of foreign-body gingivitis using electron microscopy and EDX, and noted that the composition of the foreign material matched that of a dental material in most of the cases. They concluded that in most cases, the foreign material consisted of dental materials, including abrasives and restorative materials. They speculated that the materials were introduced into the gingiva during prophylaxis, home hygiene and restorative procedures. The inflammation did not appear to be caused by any specific material. There was no correlation between the degree or type of inflammation and the presence of allergenic elements, such as nickel. Neither was the character of the inflammation correlated with the cytotoxicity of the elements composing the foreign bodies. Rather, the mere presence of foreign particles was correlated with the presence of inflammation (Gordon, 1996; Gordon & Daley, 1997a).

This is consistent with other known foreign-body reactions. Silicosis, a fibrotic pulmonary disease (Cotran Kumar & Robbins, 1984; Rubin & Farber, 1994; Kales & Mark, 1995), has been found in workers in dentistry and the ceramics industry who have been exposed to dust containing silica (silicon dioxide) (Mackert, 1992). The closely related disease, silicatosis, is caused by silicate particles which are less fibrogenic (Kales & Mark, 1995). Silicone augmentation is a well-recognized cause of granulomas (Amemiya & Dake, 1994; Chun & Cho, 1991). Beryllium particles can cause acute or chronic respiratory disease (Cotran & others, 1984; Rubin & Farber, 1994). Iron oxide, tin oxide and barium sulfate also cause non-collagenous chronic pulmonary disease. Byssinosis is a chronic interstitial pneumonia caused by a hypersensitivity reaction to organic dusts, including cotton, flax and hemp (Cotran & others, 1984; Rubin & Farber, 1994). Chronic foreign body reactions that have been described in the oral region include silicone granulomas, suture granulomas, giant cell hyaline angiopathy (pulse granuloma), myospherulosis and reactions to temporomandibular joint prostheses (Peters, 1984; Weinberg, Kryshtalskyj, Tocchio & McCann, 1995). Even amalgam tattoos are frequently inflamed when examined microscopically (Buchner & Hansen, 1980).

Suggested criteria for the microscopic diagnosis of foreign body gingivitis include unequivocal identification of foreign bodies in the gingival connective tissues in an area of chronic inflammation, and the consistent localization of these foreign bodies in at least two sequential tissue sections (Gordon, 1996; Gordon & Daley, 1997a).

When these diagnostic criteria are applied, foreign body gingivitis is most common in middle-aged female patients and may present as red or red-and-white lesions. It may be painful, and its clinical appearance may mimic gingivitis, lichen planus, benign mucous membrane pemphigoid or other inflammatory conditions including dysplasia (Figure 1). It may occur on either jaw, anterior or posterior and it may be focal or generalized. Often, there is excellent oral hygiene and sometimes a history of a recent dental procedure in the area. It has a distinctive microscopic appearance (Gordon, 1996; Gordon & Daley, 1997b).

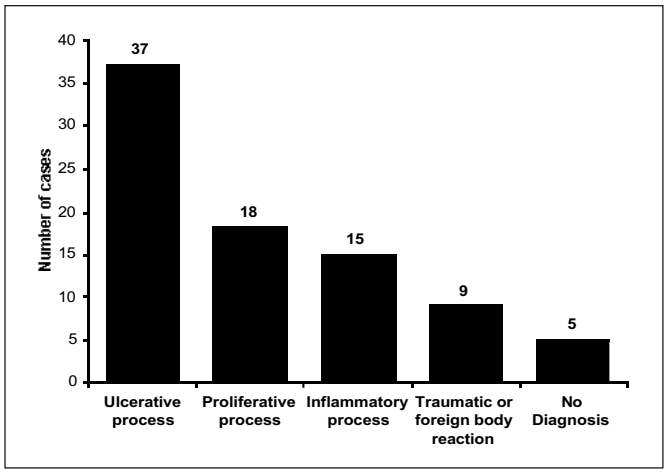

Figure 1. *Clinical diagnosis at time of biopsy in microscopically-diagnosed cases of foreign body gingivitis.*

The age distribution of foreign body gingivitis follows a normal curve with the most common age interval being 41 to 50 years appearance (Gordon, 1996; Gordon & Daley, 1997b). In contrast, the incidence of gingival disease rises cumulatively with increasing age (Carranza, 1979). Foreign-body gingivitis is uncommon before age 20.

Foreign-body gingivitis related to placement of a crown is illustrated in the following case report.

CASE REPORT

The patient, a 42-year-old female, was referred to a periodontist because of an area of persistent gingival inflammation around tooth #3-6 (#19). The gingival lesion had arisen shortly after her previous dentist placed a porcelain-fused-to-metal crown on this tooth two years earlier. The lesion was red in color. Localized plaque accumulations were minimal and did not correlate with the degree of inflammation observed. Because of the persistent gingival inflammation, the general dentist had performed exploratory flap surgery one year earlier, but the inflammation persisted. The crown was clinically acceptable and its margins were close to, but not touching the gingival margin. The metal was a non-gold alloy that contained some nickel.

The periodontist formulated a working diagnosis of granulomatous inflammation and performed an incisional biopsy of the area. He submitted the lesional tissue to the Oral Pathology Diagnostic Service of the University of Western Ontario.

Microscopic examination of the biopsy showed severe mucosal inflammation. The epithelium was hyperplastic and exhibited a thickened layer of parakeratin on its surface, and elongation of the rete pegs. The underlying inflammatory cell infiltrate consisted primarily of lymphocytes, plasma cells and neutrophils, indicating a mixture of chronic and acute inflammation. There was focal granulomatous inflammation with collections of histiocytes and foreign body giant cells, some of which contained fragments of crystalline foreign material.

Energy-dispersive x-ray microanalysis of the particles revealed statistically significant quantities of aluminum, silicon, magnesium, manganese and zirconium (Figure 3). Elemental analysis did not reveal nickel in any particles.

The lesion was diagnosed as foreign-body gingivitis, using the criteria proposed by Gordon and Daley.

DISCUSSION

During dental procedures, there are a number of opportunities for foreign particles to be embedded in the connective tissues. The dentist must ensure that restorations are smooth and will not cause physical trauma, trap food fragments or harbor plaque. Restorations must also be esthetically pleasing and not feel rough to the patient's tongue. Many dental restorative materials are malleable at the time of insertion and may be carved or shaped while still pliable, but others are hard and must be trimmed with abrasive or steel tools. Even materials that are malleable at the time of insertion may need to be trimmed later with more force. These procedures frequently result in the abrasion or frank cutting of the gingiva. This may introduce both abrasive and restorative particles into the gingival connective tissue. A common example of this is the amalgam tattoo.

Subgingival finishing procedures are especially common when esthetics are important and margins are extended into the sulcus, although subgingival margins should be avoided, if possible (Wilder, May & Strickland, 1995; Heymann, Sockwell & Strickland, 1995). Finishing tools can easily abrade the sulcular epithelium and hurl tiny particles of restorative material and/or abrasives into the lamina propria.

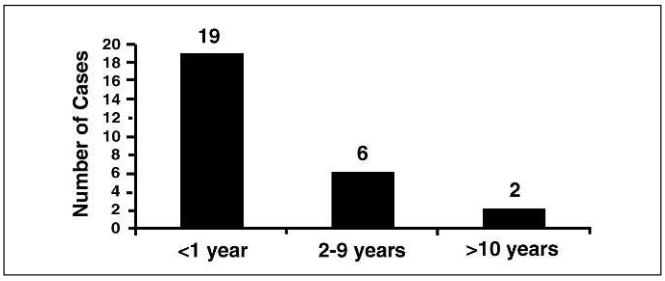

Figure 2. *Duration of symptoms in cases of foreign body gingivitis before biopsy was performed.*

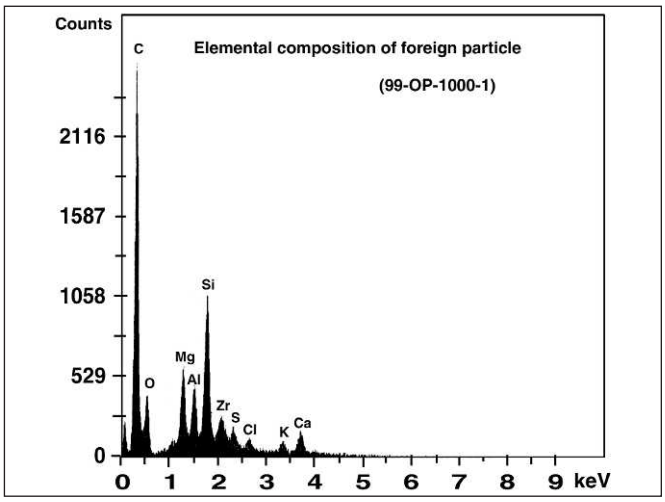

Figure 3. *Typical elemental analysis of a foreign particle. In this instance, it detected calcium, chlorine, potassium and oxygen, which are ubiquitous tissue elements, as well as magnesium, aluminum, silicon, and zirconium.*

In 75% of the reported cases of foreign body gingivitis, the foreign particles have been abrasives (predominantly silicon) either alone or in combination with another material. Several cases have arisen shortly after an aggressive prophylaxis. However, a subset of the cases has apparently been related to restorative procedures; EDX analysis has revealed particles of amalgam, gold, titanium and vanadium in some cases (Gordon, 1996; Gordon & Daley, 1997a).

EDX elemental analysis of this specimen revealed particles containing aluminum, iron, magnesium, manganese, silicon and zirconium, which are not normally found in these levels in the human body (Daley & Wysocki, 1990). This combination of material was most consistent with previously reported EDX analyses of abrasive dental materials, including toothpaste, polishing paste, dental prophylaxis paste and abrasive tools. On previous elemental analysis (Gordon and Daley, 1997a), members of this group contained variable amounts of aluminum, chromium, cobalt, iron, manganese, molybdenum, nickel, silicon, tin, titanium, tungsten, zinc and/or zirconium. Porcelain was a less likely source of the foreign material in this case; previously published EDX analysis of porcelain revealed aluminum, chromium, silicon and titanium. Crown alloy was an unlikely source; the elemental match was poor. Unfortunately, the nature of EDX elemental analysis does not lead to a direct identification of compounds (Ghadially, 1979, Goldstein et al, 1992).

Although dentists do not ordinarily think of foreign bodies as a cause of gingival inflammation near restorations, this may not be a rare condition. In one study, foreign body gingivitis had an incidence of 0.3% of biopsies, compared to the incidence of amalgam tattoo in 1.4% of biopsies (Gordon & Daley, 1997b). Cases have been associated with adjacent crowns, partial

dentures, amalgams, orthodontic treatment and periodontal surgery (Gordon, 1996). Patients with preexisting conditions such as lichen planus that make them susceptible to ulceration may be particularly prone to this.

Clinicians and oral pathologists, alike, must be aware of foreign bodies in the differential diagnosis of gingival inflammation, particularly where there has been opportunity for foreign particles to be embedded, or where the patient is predisposed to mucosal ulceration. Diagnosis may require a biopsy. Because the particles are usually less than 5 microns in diameter (Gordon & Daley, 1997b), they may be overlooked unless the pathologist is alert to the possibility that they may be present (Neville, Damm, Allen & Bouquot, 1995).

If identification of the specific material present in the tissues is necessary for clinical or medico-legal reasons, EDX analysis may yield the answer (Chun & Cho, 1991; Daley & Gibson, 1990; Sumner, 1983; Ghadially, 1979; Harrison, Rowley & Peters, 1977). However, the composition of the foreign material does not appear to affect the clinical presentation or prognosis (Gordon & Daley, 1997b), so EDX analysis, while desirable, is not required in the majority of cases.

What is the treatment of foreign body gingivitis? This question remains largely unanswered because it is a recently recognized disease. Most cases have been diagnosed within two years of onset (Figure 2) (Gordon, 1996; Gordon & Daley, 1997b). This may indicate that the condition resolves on its own, given time, much as an amalgam tattoo dissipates over the years (Buchner & Hansen, 1980; Harrison, Rowley & Peters, 1977). Dentists should be cautious about deciding to strip these lesions out, as it may not be necessary. Topical steroid application does not appear to cause any lasting relief of symptoms (Gordon, 1996; Gordon & Daley, 1997b). More study is required in this area.

CONCLUSIONS

Foreign materials may inadvertently be ejected into the gingival connective tissues during dental procedures, including crown preparation, placement and polishing, and can cause persistent and sometimes painful gingival inflammation.

Dentists need to be sensitive to this possibility in order to properly diagnose and manage these cases when they occur, and more importantly, to prevent them from happening.

Acknowledgement

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The traditional, surgical model for managing dental decay includes excavation of the carious tooth structure followed by restoration with various dental materials. Recently, alternative models have been proposed. Caries is now viewed as an infectious disease process, and a medical model of treatment has been advocated. Non-restorative approaches, such as biomimetics, remineralization, vaccines, and gene replacement therapy are being explored. In the restorative area, minimal intervention has become the watch-word, and non-metallic materials, such as composite resin, glass ionomers, and ceramics are being used in combination with advanced adhesives to provide a conservative, restorative approach.

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Symposium Agenda

Friday, September 15, 2000

7:00-10:00	Registration
7:45-8:00	Introduction and Welcome *W Dan Sneed*
Theme 1:	**Non-Restorative Approaches**
8:00-8:50	Current concepts of dental caries and its prevention: The role of third party insurers *Maxwell H Anderson*
8:55-9:45	Risk assessment *Kenneth J Anusavice*
9:45-10:00	Break
10:00-10:50	Remineralization *Lawrence C Chow*
10:55-11:45	Gene replacement therapy *Jeffrey D Hillman*
11:50-12:40	Potential for vaccines in the prevention of carious lesions *Michael W Russell*
12:40-1:00	Panel Discussion – (Research, Treatment Decisions, Caries Risk, Probiotics)
1:00-2:00	Lunch
2:00-2:50	Ways to remove roadblocks to advancement and implementation of knowledge in the field of biomimetics *Norman S Braveman*
2:55-3:45	Assessment of current approaches to dental education *Mark A Latta*
3:50-4:40	Ways underserved populations could benefit from new approaches *Charles R Hook*
4:45-5:00	Panel Discussion – (Barriers to Changing Practice and Education Related to Non-restorative Techniques)

Saturday, September 16, 2000

Theme 2:	**Metallic Restorative Materials and Historical Standards**
8:00-8:50	Performance standards for competitive dental materials *E Steven Duke*
8:55-9:45	Mercury, its impact on the environment and its biocompatibility *John Osborne*
9:45-10:00	Break
10:00-10:50	Gold as a historic standard & role for the future *Cleveland T Smith*
10:55-11:45	Research into non-Hg containing metallic alternatives *Frederick Eichmiller*
11:45-12 noon	Panel Discussion – (Amalgam vs. Non-Hg Containing Alternatives)
12 noon -1:00	Lunch
Theme 3:	**Conservation Dentistry Through Adhesion and Non-Metallic Materials**
1:00-1:50	Adhesives & cements to promote preservation dentistry *Bart Van Meerbeek*
1:55-2:45	Recent commercial composite formulations *M Mike Suzuk*i
2:45-3:00	Break
3:00-3:50	Indirect resin & ceramic systems *Anne Peutzfeldt*
3:55-4:45	Various forms of inonomers *Reinhard A Hickel*
4:45-5:00	Panel Discussion – *Ed Swift* (Are Non-metallic Restoratives Viable as Amalgam Replacements?)

Sunday, September 17, 2000

Theme 4:	**Future Materials and Biocompatibility:**
8:00-8:50	Direct posterior composite restorations *Didier Dietschi*
8:55-9:45	Future polymers *Jack L Ferracane*
9:45-10:00	Break
10:00-10:50	Future ceramic systems *Jean-Francois Roulet*
10:55-11:45	Biocompatibility of restorative materials *Arne Hensten Pettersen*
11:45-12 noon	Panel discussion – *Dorothy McComb* (Future Materials Development to Promote Conservation and Prevention)
12:00-12:30	Directions for future research/Summary *Ivar A Mjör*

The organizers of this symposium would like to acknowledge and express their appreciation for:

- The Sponsorship of Dentsply/Caulk, Espe, Hereaus Kulzer, The Medical University of South Carolina, The Founders Fund of the Academy of Operative Dentistry and Procter & Gamble.
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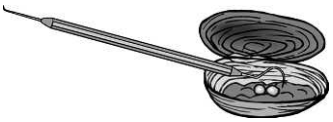

Please submit your own clinical tips and techniques to share with your colleagues. Send "pearls" and/or comments on this section via Fax (317) 278-4900 or e-mail to **editor@jopdent.org**.

SHADE SELECTION FOR COMPOSITE REPAIR OF LOST VENEER FACINGS

Contributed by:
James S Knight, DDS
MUSC College of Dental Medicine
Department of General Dentistry
Charleston, SC

Introduction

Many patients still have cast crowns with mechanically-retained resin facings. When these facings must be replaced or repaired, it is a simple procedure using visible light cured composite resin. Shade selection for the composite is a very important step in this clinical procedure and is not so simple when opaquers must be used to mask out the underlying metal. A technique is presented to help determine an appropriate resultant shade in these cases.

Armamentarium

Dental mouth mirror
Shade guide for the composite to be used
Composite material
Resin opaquers/tints
Small piece of clear plastic or cellophane
Curing light

Procedure

1) Using the shade guide, select the composite shade which most closely matches the adjacent teeth or represents the desired shade.

2) Select the appropriate opaquer shade to correspond with the chosen composite shade.

3) Place a layer of the opaquer on the back of a dental mirror to cover an area of approximately 6 mm by 6 mm. Any smooth surface will suffice, but a dental mirror is usually handy. The opaquer thickness should approximate the thickness required in the mouth to block out the underlying crown metal.

4) Light-cure the opaquer.

5) Apply a layer of the selected shade of composite over the opaquer. The thickness of the composite should approximate that of the finished facing.

6) Place a piece of clear cellophane or thin plastic over the composite with light finger pressure, being careful not to create voids or air bubbles on the composite surface. Then polymerize the composite through the plastic using the curing light.

7) Remove the cellophane from the composite and pry the composite sample off of the mirror back. The composite will have a polished appearance and will indicate the resultant shade from the combination of the opaquer with the overlying composite.

8) Use this sample as a shade tab in the mouth to compare the resultant shade to the adjacent teeth. If a different shade combination is required, repeat the previous steps using different shades of opaquer and/or composite.

Discussion

Selection of a proper shade of composite can be a difficult task and the use of an opaquer under the composite can further complicate this process. This technique creates a sample of composite and opaquer polymerized together which has a reflective "polished" surface to better evaluate the combined final shade. Composite tints could also be incorporated if required to achieve the desired shade.

The composite can be easily pried off of the metal back of a dental mirror to form a shade tab to compare in the mouth. Any smooth surface should suffice in place of a dental mirror. Several different combinations of opaquer and composite may be used to make different shade tabs for comparison. The clinician can also use this technique to compare the effects of different layer thickness.

Conclusions

This simple and quick technique is particularly useful when determining a shade for a composite repair of a resin-veneered crown. It may have application in other clinical situations and can provide a guide for the clinician to use to achieve predictable resultant shades when combining composites over opaquers.

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