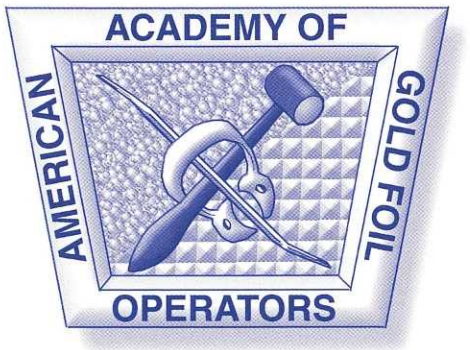
OPERATIVE DENTISTRY



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

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Guest Editorial

Operative Dentistry—The Past, Present and Future

When the organized profession of Dentistry was first established in the 19th century, the discipline of Operative Dentistry was considered to be the entire clinical practice. As scientific information increased in the 20th century and the need for more complex patient treatment was recognized, separate disciplines evolved from Operative Dentistry, such as Endodontics, Periodontics, Prosthodontics, Oral Pathology and Orthodontics and they continue to exist today as specialties in dentistry. The scope of Operative Dentistry today involves the restoration of teeth to proper form, function and esthetics, while maintaining the integrity of the adjacent soft and hard tissues of the oral cavity. This includes both direct and indirect restorations, including full coronal coverage. The value of Operative Dentistry to the profession of Dentistry is still reinforced by the extensive amount of time this discipline occupies in the overall clinical science curriculum of dental schools. In the last decade, surveys of the general practice of dentistry indicate that at least 30% of clinical treatment time is spent providing Operative Dentistry procedures for their patients.

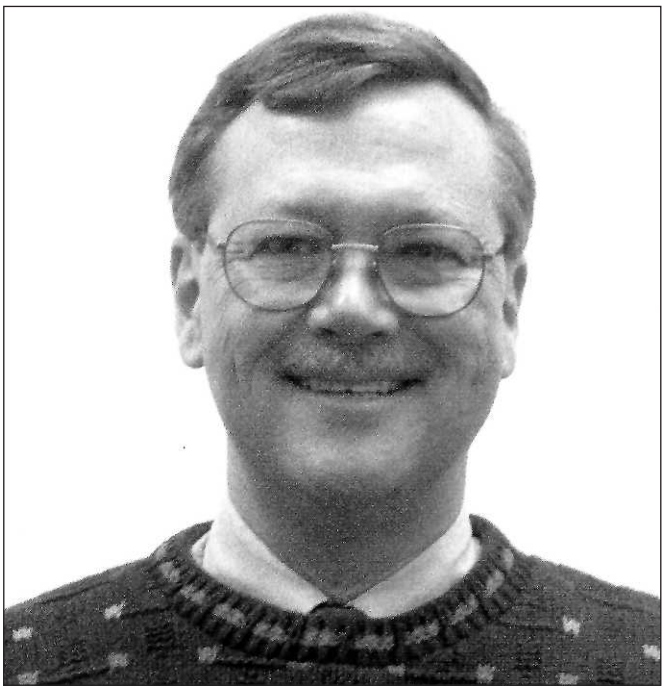
Significant advancements in Operative Dentistry have been realized. Before the 20th century, gold foil filling materials were the major restorative materials used for Operative Dentistry procedures. Some of the major developments in the last 100 years include the standardization of dental amalgam alloy in the early 1900s, the "lost-wax" gold casting procedure introduced in the early 1900s and scientifically refined in the 1930s, the ability to create a micromechanical bond to tooth structure by acid-etching procedures developed in the 1950s and the development of a stable tooth-colored material (resin composite) in the 1960s. Dental amalgam alloy was further improved by the addition of increased amounts of copper in the 1960s, and resin composite materials have been further refined by the development of sub-micron sized filler particles. In the 1980s, the ability to etch and bond porcelain to tooth structure provided another dimension to our restorative armamentarium. Today, Operative Dentistry procedures routinely include bonding to both enamel and dentin in conjunction with resin composite, glass-ionomer cement, fired feldspathic and cast/pressed ceramics and metallic restorative materials. Manufacturers, in cooperation with dental researchers and clinical practitioners, have continually introduced new materials and clinical procedures for the restoration of teeth for the benefit of the practicing restorative dentists and their patients.

Although the 21st century dentist can do incredible procedures for patients today with the restorative materials available, it is critically important that we continue to investigate these products and further refine our clinical skills. Often, materials are developed without the clinical research and proven clinical manipulative techniques that either refute or support the clinical success of these new materials. It is exciting to be involved with the development of new materials but disheartening if we are unable to meet the expectations of our patients. Restorative dental materials will not perform adequately if they are placed incorrectly. This reality must be remembered in the discipline of Operative Dentistry and other specialties as we continually strive to meet the needs of our patients in an efficient and cost-effective manner while providing restorations with the best possible durability. Knowledge of the physical, chemical and mechanical requirements for restorations, as well as an intimate knowledge of the requirements of occlusion, go "hand-in-hand" with the proper clinical manipulation and selection of dental materials. Development of the skills necessary to practice restorative dentistry requires clinical practice willingness to be a "continual learner." Education begins in earnest when a dentist graduates from dental school.

As we move ahead to the 21st century, it is imperative that Operative Dentistry not only embraces the best restorative materials and techniques available, but that we also become experts in the management of dental caries. Since the 1950s the success of fluoridation in preventing caries has demonstrated the dental profession's commitment to preventive dentistry, but unfortunately we have not yet completed the job. Dental caries is still a significant disease for our patients, either man-

ifesting as new caries or recurrent caries around defective dental restorations. We know today that dental caries is a multifactorial disease dependent mainly on a specific bacterial plaque composition and a diet of refined carbohydrates. It is not enough to tell our patients that they need to brush and floss their teeth better to avoid dental caries. A customized caries management program, which includes therapies such as providing therapeutic exposures to accepted fluoride modalities, prescribing antimicrobial rinses to reduce specific bacteria when appropriate and recommending other preventive treatments designed to raise the bacterial plaque pH to a level where remineralization instead of demineralization of tooth structure is favored, should be provided to our patients. Finally and most importantly, we need to work together with our patients to modify "caries-promoting" dietary habits which focus on reducing the intake of refined carbohydrates. We will truly make progress in the discipline of Operative Dentistry in controlling dental caries if we embrace the concept of caries management for our identified "caries-risk" patients, with the ultimate goal of preventing future restorative treatment.

One way that dentists can demonstrate a commitment to the pursuit of quality restorative dentistry and more specifically to our discipline of Operative Dentistry is by challenging and completing the Board Certification in Operative Dentistry program administered by the American Board of Operative Dentistry, Inc. (ABOD). The ABOD certification program is a three-part program involving written, clinical and oral examinations. The ultimate goal of the certification program is to enhance the quality of Operative Dentistry in practice, education and research. Attaining certification status recognizes significant disciplined study as well as excellence in clinical achievement. Since 1985 our board-certified members now total 37. We also have 16-founding members of the ABOD. Eighteen of our 50 states are represented by our membership, and we also have three certified members from the country of Thailand. As of October 2000, we have 23 board-eligible candidates at various stages of the certification program. I encourage you to join these dedicated individuals to begin the process of challenging our certification program and to actively contribute in helping us maintain the high esteem of our Operative Dentistry discipline within the profession of Dentistry!



Henry A St Germain, Jr, DMD, MSD, MEd

Henry A St Germain, Jr, DMD, MSD, MEd
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Commentary

It is a pleasure to feature this guest editorial from Dr Henry St Germain, particularly in promoting the activities of the American Board of Operative Dentistry. Dr St Germain received his DMD degree from Tufts University in 1975, an MSD in Operative Dentistry from Indiana University in 1983 and an MEd from George Washington University in 1992. He completed a distinguished career in the US Navy Dental Corps in 1995, finishing a tour as Chairman of Operative Dentistry at the Naval Postgraduate Dental School in Bethesda, MD. He currently serves as Chairman of Adult Restorative Dentistry at the University of Nebraska Medical Center College of Dentistry.

Dr St Germain was board-certified as the 22nd member by the American Board of Operative Dentistry in 1990. He has actively supported this organization, serving as Chairman of the Examination and Certification Committee from 1994-2000 and as the current President of the ABOD (2000-2002). I would like to join Dr St Germain in strongly encouraging our Academy membership to consider the professional challenges and rewards of seeking certification by the American Board of Operative Dentistry.

Michael A Cochran
Editor

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Clinical Research

Clinical Evaluation of a Polyacid-Modified Resin Composite in Class III Cavities: One Year Results

M Demirci • M Üçok

Clinical Relevance

Dyract's clinical performance in Class III cavities at one year recall is promising.

SUMMARY

This study evaluates the one-year clinical performance of a polyacid-modified resin composite material, Dyract (DeTrey Dentsply, Konstanz, Germany), in Class III cavities.

Sixty-two Class III cavities in 30 patients were restored with Dyract. Restorations were evaluated at baseline and one-year recall according to modified Ryge criteria by two experienced, calibrated examiners.

At one-year recall the rate of retention was 98.4%. None of the restorations were clinically unacceptable in regard to color match, wear or loss of anatomical form, marginal discoloration, caries, marginal adaptation and surface texture. After one year, color change and marginal discoloration in restorations were statistically significant (p=0.031) but did not require the replacement of any of the restorations. At baseline, only one patient reported postoperative sensitivity and two months later, endodontic treatment was performed.

Dyract's clinical performance in Class III cavities at one year recall is promising but further long-term clinical research on color change and marginal discoloration is needed.

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INTRODUCTION

Since the introduction of glass ionomer cements in 1972, some developmental changes in the liquid and powder components of the material have occurred. These changes were to obtain physical properties similar to amalgam and esthetic properties similar to composite resin. Recently, these changes have focused on the liquid part of glass-ionomer cements (Hammesfahr, 1994). By using different chemical approaches, such as combining methacrylate technology with glass

ionomer chemistry, a new group of materials were introduced as hybrid materials (Hammesfahr, 1994). Chemically, hybrid materials are between glass ionomer cements and composite resins (Burgess, Norling & Summit, 1994). The new materials are grouped into two categories: resin-modified glass ionomer cements and polyacid-modified resin composites (Gladys & others, 1997; Hammesfahr, 1994; McLean, Nicholson & Wilson, 1994).

Polyacid-modified resin composites are also known as compomers. This term refers to a derivative of glass-ionomer cements and composite resins (Berg, 1998; García-Godoy, 2000). Although compomers are similar to resin-based composites in their chemical structure, differences include reactive, ion-leachable glass particles and polymerizable monomers. Compomers contain no water in their formulation and are one-component materials, which do not need mixing, in contrast to glass ionomer and resin-modified glass-ionomer cements. An acid-base reaction does not occur during the setting process of compomers, as in the typical setting of glass-ionomer cements (García-Godoy, 2000). Dyract, found in this group, is a single component material. The resin matrix in Dyract is TCB, the reaction product of butanetetracarboxylic acid and 2-hydroxyethyl methacrylate. This material contains two acidic, carboxylate groups and two polymerizable methacrylate groups within the same molecule. The filler is a reactive silicate glass (72%) containing fluoride. Following the light-curing phase, an acid-base reaction occurs only after the restoration is placed and water is absorbed from saliva into the surface. In the presence of water from the tooth and oral environment, the active carboxylate group on the TCB, which is now part of the polymerized material, can react with glass to initiate an acid-base reaction. As a result of this reaction, fluoride can be released (Berg, 1998; Hammesfahr, 1994; Tyas, 1998), but the amount of total fluoride released is significantly less than that released by glass ionomer or resin-modified glass-ionomer cements (Rothwell, Anstice & Pearson, 1998; Shaw, Carrick & McCabe, 1998; Yip & Smales, 2000; Yip, Lam & Smales, 1999).

The bonding of Dyract to tooth structure is achieved by means of Primer/Adhesive (Tyas, 1998). This system uses an acetone solvent with PENTA (dipentaerythritolpentacrylate phosphoric acid ester) as the primary adhesion promoter (Barkmeier, Hammesfahr & Latta, 1999). The multi-step application of dentin bonding agents for composites has been seen by the practitioner as a clinical inconvenience. Although Dyract is similar to composite resins, its PSA Primer/Adhesive is a self-etching system (Berg, 1998). It replaces the conditioner, primer and adhesive resin, thus providing great ease of application (Roeters & others, 1998).

In primary molar restorations, it was reported that Dyract provided satisfactory results and low failure rates after three years (Marks & others, 1999; Roeters & others, 1998). In another study, this material showed significant color change and was far less satisfactory in esthetic performance than conventional resin composites after 18 months (Gladys & others, 1999). However, other studies have reported low levels of failure in Class III cavities after three and five years (van Dijken, 1996; van Dijken 1999).

This paper evaluated the clinical performance of Dyract restorations in Class III cavities at baseline and at one-year recall in regard to color match, wear or loss of anatomical form, marginal discoloration, caries, marginal adaptation and surface texture.

METHODS AND MATERIALS

This clinical study was performed at the Department of Conservative Dentistry, Istanbul University. Sixty-two Class III carious lesions in 30 patients were selected. The average age of patients was 29.9 years (range 13-78 years). All cavities were prepared and restorations placed by the same operator. Cavity preparation was limited to the removal of caries. The incisal margins of the cavities were cervical to the incisal edge of the teeth and the cervical margins were at/or incisal to the cemento-enamel junction. After the cavities were prepared, the manufacturer's instructions were closely adhered to regarding cavity treatment and placement of the restorative material. Isolation was achieved with cotton rolls and saliva ejectors. After air drying the cavities, the PSA Primer/Adhesive was applied in two coats. The first coat was left on for 30 seconds, gently air dried and cured for 10 seconds. The second coat was immediately placed, air dried and cured for 10 seconds. Color matching was done with a Vita shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) and the material, delivered in compules, was injected into the cavities. In deep cavities the first material layer was applied on the pulpal walls and light cured for 40 seconds. Then a second layer was applied and light cured for an additional 40 seconds. In shallow cavities, the material was placed in a single increment and light cured for 40 seconds from both the buccal and palatal sides. The intensity of the curing light (XL3000, 3M Dental Products, St Paul, MN, USA) was measured before and after application and the light output was never below 450 Mw/cm^2. Following the removal of excess material with fine diamond burs and strips, the restorations were finished and polished with Sof-Lex abrasive disks (3M Dental Products, St Paul, MN, USA).

The restorations were evaluated by two experienced, calibrated examiners according to the modified Ryge criteria (Ryge, 1980) (Table 1). At baseline and one year recall, color match, wear or loss of anatomical form, marginal discoloration, caries, marginal adaptation and surface texture were evaluated.

Table 1: *Direct Clinical Evaluation Criteria (Modified Ryge Criteria)*

Rating	Aspect	Method
	Color Match	
Alpha (A)	There is no a mismatch in color, shade and/or translucency between the restoration and the adjacent tooth structure.	Visual inspection
Bravo (B)	There is a mismatch in color, shade and/or translucency between the restoration and the adjacent tooth structure, but the mismatch is within the normal range of tooth color, shade and/or tranclucency.	Visual inspection
Charlie (C)	The mismatch is between restoration and adjacent tooth structure outside the normal range of tooth color,shade and/or translucency.	Visual inspection
	Cavosurface Marginal Discoloration	
Alpha (A)	There is no discoloration anywhere on the margin between the restoration and the tooth structure.	Visual inspection
Bravo (B)	There is discoloration anywhere on the margin between the restoration and the tooth structure, but the discoloration has not penetrated along the margin of the restorative material in a pulpal direction.	Visual inspection
Charlie (C)	The discoloration has penetrated along the margin of the restorative material in a pulpal direction.	Visual inspection
	Wear/Anatomic Form	
Alpha (A)	The restoration is not under-contoured,that is, the restorative material is not discontinuous with existing anatomic form.	Visual inspection and explorer
Bravo (B)	The restoration is under-contoured, that is, the restorative material is discontinuous with existing anatomic form, but sufficient restorative material is not missing so as to expose the dentin or base.	Visual inspection and explorer
Charlie (C)	Sufficient restorative material is missing so as to expose the dentin or base.	Visual inspection
	Caries	
Alpha (A)	There is no evidence of caries contiguous with the margin of the restoration.	Visual inspection
Bravo (B)	There is evidence of caries contiguous with the margin of the restoration.	Visual inspection
	Marginal Adaptation	
Alpha (A)	There is no visible evidence of a crevice along the margin into which the explorer will penetrate.	Visual inspection and explorer
Bravo (B)	There is visible evidence of a crevice along the margin into which the explorer will penetrate. The dentin or base is not exposed.	Visual inspection and explorer
Charlie (C)	There is visible evidence of a crevice along the margin into which the explorer will penetrate. The dentin or base is exposed.	Visual inspection and explorer
Delta (D)	The restoration is fractured or missing in part or in toto.	Visual inspection and explorer
	Surface Texture	
Alpha (A)	Surface of restoration is smooth.	Explorer
Bravo (B)	Surface of restoration is slightly rough or pitted, can be refinished.	Explorer
Charlie (C)	Surface deeply pitted, irregular grooves (not related to anatomy), cannot be refinished.	Explorer
Delta (D)	Surface is fractured or flaking.	Explorer

According to the modified Ryge criteria, Alpha (A) indicates the clinically ideal situation, Bravo (B) indicates a clinically acceptable situation, Charlie (C) is a clinically unacceptable situation where the replacement of the restoration is required and Delta (D) indicates a situation where the restoration is unacceptable due to fracture, mobility or loss and has to be replaced. Conflict in scoring was resolved with consensus. Data were analyzed statistically using the McNemar test.

RESULTS

Sixty-two Class III restorations in 30 patients were evaluated at baseline. At one-year recall, 61 restorations were evaluated and the rate of retention was 98.4%. Direct clinical evaluation rates are shown in Table 2. None of the restorations were clinically unacceptable in regard to color match, wear or loss of anatomical form, marginal discoloration, caries, marginal adaptation or surface texture. However, after one year, color change and marginal discoloration in restorations were statistically significant (p=0.031) (Table 2), but the changes were to Bravo values and did not require the replacement of any of the restorations.

At baseline, only one patient reported a moderate sensitivity which resolved within one week. The sensitivity was thought to be from the depth of the cavity. Two

Table 2: *Results of Clinical Evaluation of Dyract Restorations (Observation are in %). O: Oscar, A: Alpha, B: Bravo, C: Charlie, D: Delta*

	Color Match			Marginal Discoloration			Wear/Anatomic Form			Caries		Marginal Adaptation				Surface Texture			
	A	B	C	A	B	C	A	B	C	A	B	A	B	C	D	A	B	C	D
Baseline *n=62*	952	4.8	0	100	0	0	100	100	0	100	0	96.7	3.3	0	0	100	0	0	0
1 year *n=61*	85.2	14.8	0	90.2	9.8	0	91.8	8.2	0	100	0	91.8	8.2	0	0	95.1	4.9	0	0
p	***p*=0.031 (S)**			***p*=0.031 (S)**			***p*=0.063 (NS)**					***p*=0.250 (NS)**				***p*=0.250 (NS)**			

S=significant ($p<0.05$)
NS=not significant

months later, the patient returned with an acute apical abscess. Endodontic treatment was performed and the restoration replaced. At baseline and one-year recall, no other cases of sensitivity were reported.

DISCUSSION

At one year recall, the retention was 98.4%. The authors found the results of Dyract's one-year retention rate to be consistent with the rates reported by others: >97% (van Dijken, 1996) and 100% (Prati & others, 1998). Such a retention rate is remarkably high, given that Dyract's adhesive agent (PSA Prime/Adhesive) is an acid primer and HEMA-like resin monomer (Ferrari & others, 1998) which contains acetone. Acetone wets the enamel surface, penetrates the dentin, and by diffusing into the dentinal tubules, forms a layer of interdiffusion between the surface treated dentin and the adhesive system (Abate & others, 1997; Dentsply DeTrey-DeDent, 1994; Ferrari & others, 1998). Furthermore, the authors also claim that the hydrophilic phosphate groups in the PENTA molecule, which is in the formulation of PSA Primer/Adhesive, reacts with the tooth surface and forms an ionic bond with the calcium ions of the hydroxyapatite (Abate & others, 1997; Çehreli & Altay, 2000; Dentsply DeTrey-DeDent, 1994; Toledano & others, 1999; Tyas, 1998; Yap, Lim & Neo, 1995). In addition to the ionic bonding of the material to the tooth structure, macromechanical retention obtained from the cavity preparation might be a factor contributing to this high retention rate.

At baseline, 95.2% of the restorations had ideal color match (Alpha) and only 4.8% had clinically acceptable color match (Bravo). At one-year recall the rates were as follows: ideal color match–85.2%; clinically acceptable color match–14.8%. While at the end of one year the tendency ranged from ideal color match group to the clinically acceptable color match group with a 10% increase in the latter, all values were observed to still be within the clinically acceptable color match range. These results are consistent with those of van Dijken (1995). van Dijken (1996) reported that the hybrid materials' high content of hydrophilic monomer causes a high rate of water sorption, which results in a color change. This assumption might explain the color change found in this study. However, Gladys & others (1999) demonstrated that the color changes of Dyract occurred in the first six months and were less pronounced in the following 12 months of their study. Color changes were observed to range from "excellent color match" to "slight color mismatch" by the end of the first 12 months. Compared with their observations, the color changes ranged from "ideal color match (Alpha)" to "clinically acceptable color match (Bravo)" and were more pronounced. This difference might be due to the different cavity types selected in the two studies. Roeters & others (1998), in contrast to these results, observed an improvement in the color match of Dyract in primary Class I and Class II restorations after one year. However, after three years they reported a pronounced color change from "ideal color match (Alpha)" towards "clinically acceptable color match (Bravo)." The extent of color change over time remains in question and further evaluation with long-term clinical studies is needed.

At one-year recall, marginal discoloration was observed only in 9.8% of the restorations and was only located on an unspecific point on the enamel surrounding the restoration and did not progress towards the pulp. This was a clinically acceptable situation.

At baseline, 96.7% of the restorations had ideal marginal adaptation (Alpha). Only 3.3% of the restorations had a crevice along the margins (Bravo). At one year recall 91.8% of restorations had clinically ideal marginal adaptation (Alpha) and 8.2% of the restorations had a crevice (Bravo). But in the restorations with a crevice, neither dentin nor base was exposed, and this was a clinically acceptable situation.

Marginal alterations and marginal discoloration were frequently observed in the same cases after one year. Marginal discoloration was related to a crevice at Bravo along the margins in 66.7% of the cases. Furthermore, a crevice was found in 80% of the cases where marginal discoloration at Bravo was present at the one-year recall.

The manufacturer claimed that Dyract's bond strength to dentin (14.5 MPa) is higher than its bond strength to enamel (9.6 MPa) (Dentsply DeTrey-DeDent, 1994). Tyas reported (1998) that this difference in bonding strengths may be the factor which causes discoloration at the enamel level. The manufacturer does not recommend the application of the material on acid treated surfaces. However, many researchers thought that since Dyract is a composite-like material, its bonding strength to etched enamel should be higher (Cortes & others, 1993; Desai & Tyas, 1996; Tyas, 1998). When tooth surface is acid etched, the bonding strength is found to be approximately three times higher than that of unetched surfaces (Cortes, García-Godoy & Boj, 1993; Cortes & others, 1998; Desai & Tyas, 1996). When acid is applied, El-Kalla and García-Godoy (2000) reported the formation of a hybrid layer between the material and enamel into which resin tags penetrate and showed that an improved adaptation was achieved. Some microleakage studies also showed an improved marginal seal when enamel etching is performed (Brackett & others, 1998; Owens, Halter & Brown, 1998). Çehreli and Altay (2000) have proposed using Dyract with acid etching procedures on enamel to prevent marginal discoloration. However, although van Dijken (1995) has not performed acid etching in enamel, he has found marginal discoloration in only 3.6% of the restorations after six months. This study agrees with his results; the authors also observed marginal discoloration at the enamel level in only 9.8% of the restorations at one-year recall, which showed that the clinical performance of the material was satisfactory.

At one-year recall, 91.8% of the restorations were clinically ideal (Alpha) in regard to wear and loss of anatomical form, while only 8.2% had a rating of Bravo. That is, they were still clinically acceptable. Wear was limited to the restorative material and did not extend to the sound tooth structure.

At one-year recall secondary caries was not detected. In regard to surface texture, 4.9% of the restorations were slightly pitted and had rough surfaces (Bravo) which could be restored by repolishing.

At baseline and one-year recall, only one case of sensitivity was reported. This patient complained of a moderate level of sensitivity, which was resolved in a week. Two months later the patient returned with an acute apical abscess. Endodontic treatment was performed and the restoration was replaced. The reason for the failure was thought to be the non-healing pulpal response to the cavity preparation and the material application.

CONCLUSIONS

1. At baseline only one patient reported postoperative sensitivity and two months later endodontic treatment had to be performed.
2. After one year, the rate of retention was 98.4% and all the restorations were clinically acceptable (Alpha and Bravo) in regard to color match, wear or loss of anatomical form, marginal discoloration, caries, marginal adaptation and surface texture.
3. After one year, color change and marginal discoloration in restorations were statistically significant (p=0.031). However, the values were at Bravo and did not require the replacement of any of the restorations.
4. Dyract's clinical performance in Class III cavities at one-year recall was found to be promising but further long-term clinical researches on color change and marginal discoloration are needed.

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Laboratory Research

Microleakage of Packable Composite Resins

JC Meiers • R Kazemi •CD Meier

Clinical Relevance

Packable composite resins, when placed in bulk, demonstrated significantly more enamel crazing in butt joint cavity preparations when compared to a conventional anterior/posterior hybrid composite resin.

SUMMARY

This study evaluated the microleakage performance of a new generation of composites known as "packable" composites within a high C-factor preparation. Class V cavity preparations with occlusal margins in enamel and gingival margins in dentin were prepared on extracted human molar teeth. Prepared teeth were randomly distributed into four treatment groups (n=18) consisting of three "packable" composites—Alert, Solitaire, and SureFil—and a traditional anterior/posterior small particle hybrid composite Z-100. Prime & Bond NT bonding agent was used with each composite. Samples were stored in tap water for 24 hours, thermocycled, stained with dye, sectioned into halves and scored for microleakage. All test groups showed a significant increase in both linear and penetrating dentinal microleakage when compared to enamel microleakage. Z-100 had significantly less dentinal marginal microleakage than SureFil. There was no significant difference in the enamel microleakage values between groups. However, the "packable" composites exhibited significantly higher percentages of enamel crazing adjacent to the cavity walls when compared to Z-100. The enamel crazing within the "packable" composite groups warrants further investigation to determine if this is a characteristic related to the composition of this class of composites, the mode of light curing used in this study or the result of the cavity/marginal design.

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INTRODUCTION

Dental amalgam has been widely used as the primary restorative material in posterior teeth for more than 100 years. However, the use of composite resins to restore posterior teeth has expanded in recent years due not only to the increased demand for esthetics, but also concern over mercury toxicity in amalgam restorations. Despite many improvements in the properties of composites, a number of problems still exist related to their clinical use. These include postoperative sensitivity, technique-sensitivity and microleakage (Eick & Welch, 1986; Browne & Tobias, 1986; Prati, 1989; Rykke, 1992). In the past, composites traditionally possessed poor wear resistance (Leinfelder & others, 1980). However, more recent clinical studies suggest

that the wear rates of numerous posterior composites may approach those of amalgam (Johnson & others, 1992; Willems & others, 1993; Taylor & others, 1994) and the ADA Council on Scientific Affairs has recently supported their use in initial and moderate size Class I and II restorations (Association Report, 1998).

Although considerable research has led to improved composite resins, their clinical handling characteristics continue to discourage and challenge many clinicians when placing composite restorations in posterior teeth. Most traditional composites are sticky and will not hold their shape, which leads to difficulty in manipulation, making it difficult to establish proper proximal contour and contact in Class II cavity preparations (Williams, 1996). Recently, a new generation of composites has been introduced to the market with new filler designs that permit them to be packed with more force into cavity preparations. This allows for a more consistent achievement of proximal contacts. Manufacturers of these new materials have classified them "condensable" or "packable" posterior composites. These composite formulations are designed to hold their shape and not slump on placement. The difference in the plasticity of the "condensable/packable" posterior composites may make close contact and adaptation to the dentin bonding agent and walls of the cavity preparation more difficult and less consistent when compared to the current, more plastic anterior/posterior composite resin restorative materials. This may present a greater challenge to preventing microleakage with these types of materials.

This study investigated and compared the microleakage within a high C-factor cavity preparation of three "packable" composite resins, Alert, Solitaire and SureFil and a conventional anterior/posterior composite resin Z-100.

METHODS AND MATERIALS

Thirty-six non-carious extracted teeth stored in deionized water containing 0.2% sodium azide bactericidal agent were selected for this study. For teeth to be selected, they had to be examined to ensure the absence of any enamel crazing or cracks using a binocular microscope at 20X magnification (Olympus Co, Lake Success, NY 12422). Residual tissue tags were removed from the teeth and were thoroughly rinsed under running tap water for 15 minutes to remove the sodium azide solution. Class V cavity preparations were made on the buccal and lingual surfaces of each tooth using a high-speed handpiece and a #330 bur (Brassler, USA, Savannah, GA 31419). Oblong preparations, measuring approximately 2 x 6 x 1.5 mm, were made parallel to the cementoenamel junction (CEJ), with the gingival half of the preparations extending 0.5mm apical to the CEJ. Cavosurface walls were finished to a butt joint. The buccal and lingual surfaces of the teeth being studied were randomly assigned a number from 1 to 72. The treatment scheme for each surface was determined using a random number generation.

Three "packable" composites and one conventional anterior/posterior composite (Table 1) were investigated, with 18 preparations included in each group. The preparations were restored as follows:

The entire preparation was etched with 37% phosphoric acid. The enamel was etched for 20 seconds with the dentin etched for 15 seconds. The gel etch was rinsed thoroughly for 15 seconds, and dried to remove excess water, leaving the dentin visibly moist. Prime & Bond NT (Caulk/Dentsply, Milford, DE 19963) was then applied to the preparation for 20 seconds using a disposable brush tip. Excess solvent was removed with mild air flow, then light cured with a visible light unit that produced 600 mW/cm^2 (Caulk/Dentsply, Milford, DE 19963) of light output for 20 seconds. The visible light-curing unit was checked for light output by using a radiometer (Demetron Research Corp, Danbury, CT 06810) before each curing session. If the dentin did not appear shiny, then Prime & Bond NT was reapplied to the dentin, gently dried and light cured again for 20 seconds. Either Solitaire (Heraeus Kulzer, Inc, South Bend, IN 46614), Alert (Jeneric/Pentron Inc, Wallingford, CT 06492), SureFil (Caulk/Dentsply, Milford, DE 19963) or Z-100 (3M Corp, St Paul, MN 55144) composite was then condensed in bulk into the preparation and light cured for 60 seconds following the randomized treatment sequence.

All restorations were finished flush to the margins using Sof-lex (3M Corp, St Paul, MN 55144) disks within five minutes after light curing. The restorations were stored in room temperature water for 24 hours, then thermocycled for 1,000 cycles between 5°C and 55°C

Table 1: *Compositional Values, Physical and Mechanical Properties**

Product	Filler Volume %	Average Filler Particle Size µm	Linear Polymerization Shrinkage %	Volumetric Polymerization Shrinkage %	Flexural Modulus MPa
Alert	70	0.7 with Filamentous glass 20-50 µm in length	0.8	2.3	15,840
Solitaire	66	2-20	1.2	3.5	3,960
SureFil	60	0.8	0.8	2.2	11,440
Z-100	66	0.6	1.0	2.8	14,362

Data obtained from Manufacturer's Data Files and *Dental Advisor*, Vol 15, No 7, 1998

using a dwell time of 30 seconds. The root apices were then sealed with Vitrebond (3M Corp, St Paul, MN 55144) glass-ionomer cement, and the entire tooth was painted with two coats of acid-resistant varnish (Revlon, Inc NY, NY 12401) to within 1 mm of the restorations' margins. The teeth were placed in a 0.5% basic fucshin dye for 24 hours at room temperature, embedded in orthodontic acrylic, cut at the midpoint of the restoration (including both buccal and lingual sections in each cut) generating two sections per restoration using an Isomet Slow Speed Saw (Buehler, Inc, Lake Bluff, IL 60044). To remove any smear layer created by the sectioning, the sectioned teeth were treated with 0.5% citric acid for 15 seconds and rinsed with distilled water. Each section was viewed under an Olympus SC 35 (Olympus Co, Lake Success, NY 12422) stereo microscope at 20X and blindly scored by an independent examiner. Microleakage was scored on the degree of dye penetration as follows (Figure 1):

0= no dye penetration

1= dye penetration up to, but not beyond 1/2 the occlusal or gingival wall

2= dye penetration up to, but not contacting the axial wall

3= dye penetration along the axial wall

Both sections of each restoration were scored and the section with the greatest amount of microleakage was recorded as the score for that restoration. Microleakage scores were recorded for both the enamel (occlusal) and dentin (gingival) margins. In addition, microleakage was separated into penetrating and non-penetrating (linear) types. Penetrating microleakage was defined as dye penetration radiating along the dentin tubules toward the pulp. Non-penetrating (linear) microleakage was defined as dye penetration confined to the area along the composite/dentin interface. Both sections of the restoration were read, and if one of the sections had penetrating microleakage, it was recorded for the restoration. Additionally, the enamel margins were examined for "crazing." This was defined as dye penetration in the enamel, not at the margin interface, closely situated to it but definitely separate from the fracture plane. Figure 2 shows a typical pattern of enamel crazing found in this study.

The linear microleakage scores for the groups were analyzed using a Kruskal-Wallis test (non-parametric ANOVA) and then a Dunn multiple comparison test at a significance level of $p<0.05$. Penetrating microleakage data and enamel crazing (nominal) was subjected to Chi-Square analysis at a significance level of $p<0.05$.

RESULTS

Tables 2 and 3 display the microleakage data for the four restorative materials being tested. For each treatment group, gingival microleakage was significantly greater when compared with

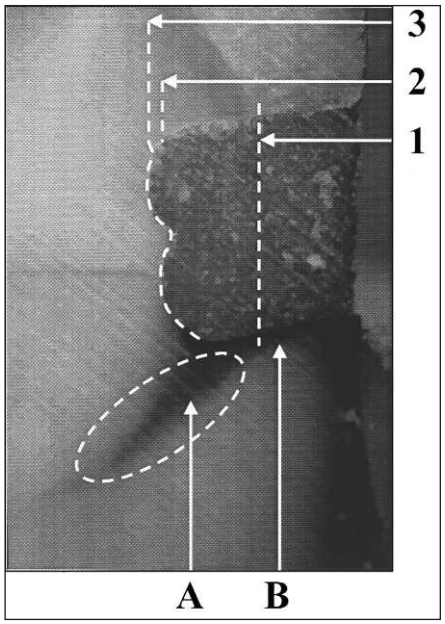

Figure 1. *Diagram of Microleakage Scoring System:*
0 = No microleakage
1 = Leakage ≤ 1/2 length of occlusal/gingival walls
2 = Leakage ≥ 1/2 length of occlusal/ginigival walls
3 = Leakage that covers entire length of occlusal/ginigval walls and also involves the axial wall
A = Example of Penetrating Microleakage—dye radiating along dentinal tubules toward the pulp
B = Example of Linear Microleakage—dye that is not radiating and follows the walls of the preparation.

Table 2: *Summary Table for Microleakage at Enamel/Occlusal Margins*

	Microleakage Scores					
Material	**0**	**1**	**2**	**3**	**Median**	**%P***
Solitaire	9	9	0	0	0.5	0
Alert	9	9	0	0	0.5	0
SureFil	11	7	0	0	0	0
Z-100	12	6	0	0	0	0

* %P = Percent Penetrating Microleakage:
Number of samples showing penetrating microleakage / Total Number of samples having microleakage (linear + penetrating) X10

Table 3: *Summary Table of Microleakage at Dentin/Gingival Margins*

	Microleakage Scores					
Material	**0**	**1**	**2**	**3**	**Median**	**%P***
Solitaire	0	6	7	5	2	44
Alert	0	4	9	5	2	72
SureFil	0	4	5	9	2.5♣	72
Z-100	0	10	5	3	1♣	38

* %P = Percent of Penetrating Microleakage:
Number of samples showing penetrating microleakage / Total number of samples having microleakage (linear + penetrating) X100
♣ = Significant difference, $p<0.05$, between groups for linear Microleakage

Table 4: *Enamel Crazing**

Material	Crazed	Not Crazed	% Crazed
Solitaire	6	3	66
Alert	8	1	89
SureFil	6	1	86
Z-100	1	5	17♣

* These values are calculated from those samples that had enamel microleakage as indicated in Table 2
♣ = Signicant difference, $p<0.05$, in enamel crazing versus other groups

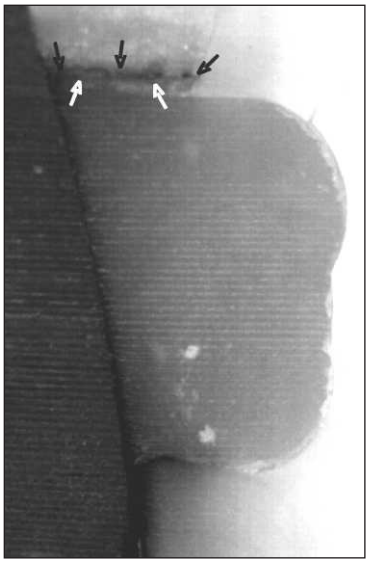

Figure 2. *Example of enamel crazing—highlighted by the arrows—that is representative of what is tabulated in Table 3. This particular specimen was from the SureFil group.*

enamel microleakage. There were no significant differences between any of the restorative materials regarding linear or penetrating enamel micro-leakage (Table 2.) Linear microleakage was found to be minimal and no penetrating microleakage was exhibited at the enamel margin. However, the linear enamel microleakage demonstrated two distinct patterns—either interfacial—between the restorative material and the cavity preparation, or cohesive—within the enamel (Table 4 and Figure 2.) Z-100 showed significantly less enamel crazing/fracture than the three "packable" composite resins.

Table 3 illustrates dentin/gingival microleakage for each of the four restorative materials being tested. There were no significant differences when comparing the linear or penetrating gingival microleakage scores between the three "packable" composites. However, Z-100 had statistically significant less linear gingival microleakage when compared to SureFil.

DISCUSSION

The results of this study indicated that all four composite resins performed similarly in a high C-factor cavity preparation with respect to total microleakage scores (both penetrating and linear). The only significant difference in the study occurred between SureFil and Z-100, where SureFil had significantly more linear gingival microleakage than Z-100. The compositional changes that impart various physical and mechanical properties (Table 1) and create the handling characteristics called "packability" found in Alert, Solitaire and SureFil did not significantly differentiate them from a conventional anterior/posterior hybrid formulation regarding microleakage within this study design.

A Class V preparation was used with margins ending on both enamel and dentin, even though the "packable" composite resin materials are not marketed to be used in this type of preparation, to study the behavior of these materials in a high C-factor situation (Feilzer, deGee & Davidson, 1987). This design also allowed the authors to continue to compile their database of other materials tested in previous studies. A butt joint enamel margin was selected to follow the usual enamel margin designs advocated on most preparations for posterior composite resin restorations.

The extent of enamel crazing associated with our samples was not totally unanticipated. However, the significant difference found between the packable composites compared to the conventional anterior/posterior hybrid material was surprising, Figure 2 and Table 3. This type of enamel crazing has been reported in other studies (Hembree, 1984, Porte & others, 1984, Fusayama, 1992, Applequist & Meiers, 1996, Kanca, 1999, Kanca & Suh, 1999). Postulated reasons for this phenomenon have included the use of enamel butt joint margins with the acid etch-technique (Hembree, 1984, Porte & others, 1984, Applequist & Meiers, 1996), the use of visible light versus chemical cure composites (Fusayama, 1992) and the use of a bulk packing technique followed by a non-incremental pulse light curing technique (Kanca, 1999 and Kanca & Suh, 1999). This study design incorporated all of these features, which would favor some degree of enamel crazing.

The high number of crazed enamel samples within the "packable" composite group compared to Z-100 may be a reason for concern. Versluis, Sakaguchi & Douglas (1992) found that Z-100 had the highest post-gel linear shrinkage values in a group of 10 anterior/posterior composite resin formulations. Versluis postulated that these post-gel shrinkage values would translate into strains and stresses on the margins of restorations when these composites were undergoing their polymerization contraction. Kanca (1999) found significant enamel crazing in Class I preparations restored with Z-100 when using a bulk fill, non-incremental pulse light cured protocol. Kanca stated that this was seen clinically as a white line around the enamel margins of the restoration that would later translate into a "ditching" around the composite margins.

The high percentage of enamel crazing found within Alert, Solitaire and SureFil, when compared to Z-100, may indicate that the filler particle technology which reportedly enables these "packable" composite resins to resist slumping and provide some resistance to condensation (Nash & Leinfelder, 1998, *Dental Advisor*, 1998, *SureFil High Density Posterior Restoration*

Manual, 1998) may also translate into increased post-gel linear shrinkage stresses direct toward margins—especially where these materials are firmly attached, that is, etched enamel margins. It may also indicate that the interlocking particle technology inherent to the "packable" composites decreases the capacity for flow for these composites in helping to compensate for the shrinkage stressed placed on the walls of the restoration. Table 1 shows percent of linear polymerization shrinkage for the four tested composites. These values are rather similar, with Solitaire having the highest and Surefil and Alert the lowest numerical values. Unfortunately, these are not the same as post-gel linear shrinkage values, so the way they would translate into the type stresses induced at margins as suggested by Versluis is unknown.

The modulus of elasticity has also been related to stressed induction at a margin from a composite resin (Braem et al, 1987, Kemp-Scholte & Davidson, 1990). Materials with a higher modulus of elasticity are stiffer, and as a result have a greater susceptibility to internal stress. Consequently, materials with a lower modulus are said to be more flowable and undergo plastic deformation. This inherent flow, which allows the molecules to slip into new positions and orientations, compensates for any stresses caused by contraction shrinkage, thereby allowing for the maintenance of the adhesive bond (Feilzer, DeGee & Davidson, 1990). However, Solitaire had the lowest flexural modulus of this group of composites but still displayed high percentages of enamel crazing when compared to Z-100, which has a significantly higher flexural modulus (Table 4.) Therefore, for some materials, this property alone cannot be relied on to be a predictor of craze-free marginal performance.

CONCLUSIONS

The "packable" composite formulations Alert, Solitaire and SureFil, performed similarly to the anterior/posterior hybrid formulation Z-100 with respect to enamel and gingival/dentin linear and penetrating microleakage with the exception of SureFil demonstrating significantly greater linear dentinal microleakage than Z-100. However, the "packable" composite formulations demonstrated a significantly higher percentage of enamel crazing than Z-100. This phenomenon may have been due to the margin design of the preparation, the composition of the materials, the bulk filling technique and the mode of visible light activation or a combination of these factors. While this data cannot be transferred directly to the clinical situation, clinicians may want to be aware of this phenomenon and monitor if further *in vitro* or *in vivo* research confirms or refutes this relationship associated with this class of composite.

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Bond Strength of Polyacid-Modified Resins Using a New One-Step Adhesive System

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Clinical Relevance

The tested "universal" adhesive system provides equal or higher bond strengths of the tested polyacid-modified resins to enamel and dentin compared to the adhesive systems provided by the manufacturers.

SUMMARY

During the last few years a number of one-bottle adhesive systems have been developed. However, no "universal" adhesive system recommended for use with different polyacid-modified resins (PMR) is currently available. This study compared the shear bond strengths of four PMR Dyract AP (D), Compoglass F (C), F 2000 (F) and Hytac (H)) to enamel and dentin using (1) the adhesive system provided by the manufacturer and (2) a new one-step "universal" adhesive system (Prompt L-Pop).

Seventy enamel and 70 dentin-surfaces were prepared for 10 replications of each bonding combination (C1, C2, D1, D2, F1, F2, H1/2). After the bonding procedure and subsequent storage of the specimens in distilled water at 37°C for 24 hours, shear bond strengths were determined using a Universal Testing Machine at a cross-head speed of 0.75 mm min-1 until failure occurred. Fracture modes were examined at 25x magnification under a light microscope.

The median shear bond strength values (MPa) to enamel were 13.2 (C1), 16.5 (C2), 17.7 (D1), 41.2 (D2), 12.7 (F1), 41.2 (F2), 33.9 (H1/2); to dentin, values of 3.3 (C1), 3.7 (C2), 7.4 (D1), 12.2 (D2), 11.4 (F1), 8.6 (F2) and 4.6 (H1/2) were measured. In both enamel and dentin, bond strengths of the tested PMR were either not significantly different or significantly higher using the universal adhesive system compared to the adhesive systems provided by the manufacturers. Bond strengths to enamel and dentin were not significantly different from each other in D and F with their corresponding adhesive system. In all other groups, bond strengths to enamel were significantly higher compared to dentin. Failure modes were mostly adhesive in dentin and mixed adhesive/ cohesive in enamel. SEM observations revealed similar hybrid layer and tag formation in dentin for the four adhesive systems. On enamel, a clearly visible etch pattern was detected only for the universal adhesive system.

In conclusion, the universal adhesive system achieved equal or higher bond strengths of the tested PMR to enamel and dentin compared to the adhesive systems provided by the manufacturers.

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INTRODUCTION

Most dental adhesive systems still require several time consuming procedural steps resulting in practitioners' demands for simplification of use. For enamel, conditioning by acid etching (Buonocore, 1955) is a simple method to achieve high bond strengths and reliable marginal sealing of composite resin restorations based on microretention.

In dentin, moisture presents a major problem for bonding of the mainly hydrophobic composite resins. Many adhesive systems consist of several components to prepare the dentin surface for resin infiltration. An acid is used to penetrate the smear layer and to demineralize the superficial dentin, thus opening and exposing the collagen network. A priming agent containing solvents and hydrophilic monomers infiltrates the conditioned surface and stabilizes the collagen fibers (Nakabayashi & Pashley, 1998). These bi-functional monomers provide the link for incorporating an adhesive resin, thus forming a hybrid layer (Nakabayashi, Kojima & Masuhara, 1982), which enables micro-retentive bonding of the restorative material to dentin.

The recently introduced polyacid-modified resins have become quite popular for Class V restorations in adults and multiple applications in deciduous teeth because of their fluoride release and good handling and esthetic properties (Attin, Vataschki & Hellwig, 1996; van Dijken, 1996). The adhesive systems for these materials are designed to work on both enamel and dentin. However, the bond strengths to enamel are inferior to those achievable with conventional acid etching. A simplified adhesive system which produces good dentin bond strength without compromising enamel bonding would, therefore, be highly desirable.

This study tested the shear bond strength to enamel and dentin of a recently introduced one-step adhesive system which provides simple handling properties and which is claimed to be compatible with any polyacid-modified resin.

METHODS AND MATERIALS

Preparation of Specimens

One hundred and forty caries-free, unrestored human third molars which had been stored in a 0.5% chloramine solution immediately after extraction were selected for the study. After cleaning, the teeth were kept in distilled water at 4°C for no longer than two months, then mounted in a holder using an acrylic resin (Sampl Kwick, Buehler, Lake Bluff, IL 60044, USA). Wet grinding of the buccal surfaces was performed with up to 600 grit silicon carbide abrasive paper until a flat enamel or superficial dentin area of at least 3 mm in diameter was exposed. Prior to the bonding procedures, the specimens were stored in distilled water at a temperature of 23°C for 24 hours.

Bonding Procedures

The adhesive systems were applied precisely according to the manufacturers' instructions (Table 1). A split teflon mold was used to prepare cylindrical specimens 3 mm in height and 3 mm in diameter. The mold was firmly clamped to the tooth surface to define the bonding area. After application of the adhesive system, the mold was filled with the restorative material in two increments of 1.5 mm each to allow adequate light curing. The curing light unit (Elipar Highlight, ESPE, 82229 Seefeld, Germany) was set to the conventional curing mode at 800 mW/cm^2. Output intensities were monitored with a light meter (Cure Rite, Caulk/ Dentsply, Milford, DE 19963, USA). Immediately after the bonding procedure, the mold was removed and specimens were stored in distilled water at 37°C for 24 hours. The polyacid-modified resins were bonded to enamel and dentin using either the corresponding adhesive system provided by the manufacturer or the "universal" one-step adhesive system, Prompt L-Pop (ESPE, 82229 Seefeld, Germany) (Table 2).

Shear Bond Strength

The prepared specimens were secured in a mounting jig. The shear force was transmitted by a 0.5 mm blunt-edge chisel with a standardized distance of 200 µm between blade and tooth surface using a Zwick Materials Testing Machine (model #1446, Zwick, 89079 Ulm, Germany) at a cross-head speed of 0.75 mm min^{-1} until failure occurred. Shear bond force was recorded in Newtons and bond strength was calculated in MPa. The failure modes were examined visually under a light microscope (M5A, Wild, 9435 Heerbrugg, Switzerland) at 25x magnification.

Scanning Electron Microscope (SEM)- Examination Enamel

Following the same storage and preparation methods as described for the shear bond strength tests, additional enamel specimens were prepared to examine the enamel surface patterns produced by application of the four tested adhesive systems. One layer of each adhesive system was applied to the enamel surface according to the manufacturers' instructions with respect to application mode (active or inactive) and time. Without light curing, the specimens were rinsed in acetone for 30 seconds to dissolve and remove the adhesive layer from the enamel surface. After the drying procedure the specimens were gold sputtered and the treated surfaces were examined under a scanning electron microscope (Stereoscan 240, LEO Elektronenmikroskopie, 73446 Oberkochen, Germany) at 2800x magnification.

Dentin

Superficial dentin specimens bonded to each material using its corresponding adhesive system according to the manufacturers' instructions (Table 1) were prepared

Table1: *Bonding Procedures, Batch Numbers and Manufacturers of Products Tested*

Adhesive System (Batch-No)	Enamel and Dentin Pretreatment	Restoration Material (Batch-No)	Manufacturer
Syntac Single Component (812599)	1) Apply Syntac Single Component with a brush 2) Wait for 20 seconds, air thin and light cure for 20 seconds 3) Repeat step 1), air thin and light cure for 20 seconds	Compoglass F (924919)	Vivadent, 9494 Schaan, Liechtenstein
Prime & Bond 2.1 (9802000643)	1) Apply Prime & Bond with applicator tip 2) Wait for 30 seconds, air thin and light cure for 10 seconds 3) Repeat step 1), air thin and light cure for 10 seconds	Dyract AP (9801001235)	DeTrey/Dentsply, 78467 Konstanz, Germany
F 2000 Primer/Adhesive (19970902)	1) Apply F 2000 Primer/Adhesive with a brush 2) Wait for 30 seconds, air thin for 5-10 seconds and light cure for 10 seconds	F 2000 (702)	3M Dental Products, St Paul, MN 55144-1000, USA)
Prompt L-Pop (001)	1) Apply Prompt L-Pop with applicator tip 2) Agitate for 15 seconds and air thin	Hytac (032)	ESPE, 82229 Seefeld, Germany

Table 2: *Codes for Bonding Combinations*

	Compoglass F	Dyract AP	F 2000	Hytac
Manufacturer's adhesive system	C1	D1	F1	H1/2
Prompt L-Pop	C2	D2	F2	

to examine the formation of a hybrid layer and resin tags. The bonded specimens were cross-sectioned perpendicular to the long tooth axis using a water-cooled low-speed saw (Leitz, Microtome 1600, 64625 Bensheim, Germany). The resulting slices were polished using 600-grit silicon carbide abrasive paper. For clearer visualization of the resin-infiltrated dentin layer and resin tags, the specimens were treated according to a method proposed by Nakabayashi and Takarada (1992). The specimens were immersed in 6 mol/L HCl for 30 seconds to superficially dissolve any mineral dentin components which were not protected by resin. The specimens were rinsed with water, treated by immersion in 1 wt% NaOCl for one hour and again rinsed with water. By NaOCl-treatment, the HCl-demineralized dentin matrix is removed and clearer SEM-examination of the resin-infiltrated bonding interface is permitted (Nakabayashi & Saimi, 1996).

Statistical Analysis

Medians and 25%- and 75%-percentiles were determined from 10 replications of each bonding combination. The Mann-Whitney-Wilcoxon rank sum test (SPSS/PC+, Vers 5.01, SPSS Inc, Chicago, IL 60611, USA) was used for pair-wise comparisons between groups (α=0.05). In order to assess the influence of material, substrate and adhesive system on shear bond strength in general, the levels of significance were adjusted to $\alpha^* = 1-(1-\alpha)^{1/k}$ (k = number of performed pair-wise tests) using the error rates method (Miller, 1981).

RESULTS

The median shear bond strengths (MPa) to enamel and dentin with the corresponding 25%- and 75%-quartiles are shown in Figure 1. Pair-wise testing showed that in both enamel and dentin, bond strengths of the tested PMR were either not significantly different or significantly higher using the universal adhesive system compared to the adhesive systems provided by the manufacturers. For Dyract AP and F 2000 with their corresponding adhesive systems, bond strengths to enamel and dentin were not significantly different from each other. In all other groups, significantly higher bond strengths to enamel compared to dentin were found. The error rates method showed an influence of material, substrate and adhesive system on shear bond strength in general.

The determination of failure modes revealed mostly adhesive failures in dentin and mixed adhesive/cohesive failures in enamel (Table 3). In the cases where mixed adhesive/cohesive failures were observed, the cohesive part of the fractures occurred exclusively within the restorative material and in no case within dental hard tissue.

SEM observations of the enamel surfaces revealed a clearly visible micro-retentive etching pattern only after treatment with the "universal" one-step adhesive system (Figure 2).

Scanning electron microscopic examination of the cross-sectioned specimens detected very similar hybrid

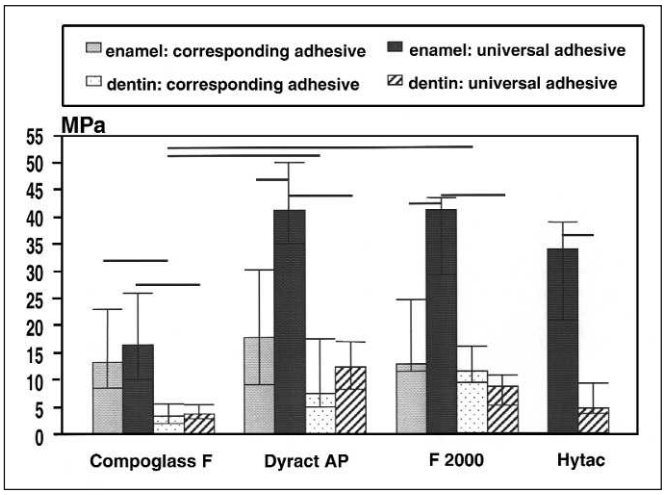

Figure 1. *Median shear bond strengths (MPa). Histograms represent median values and vertical lines represent 25%/75%-quantiles of 10 replications. Significant differences (α=0.05) are labeled with horizontal bars.*

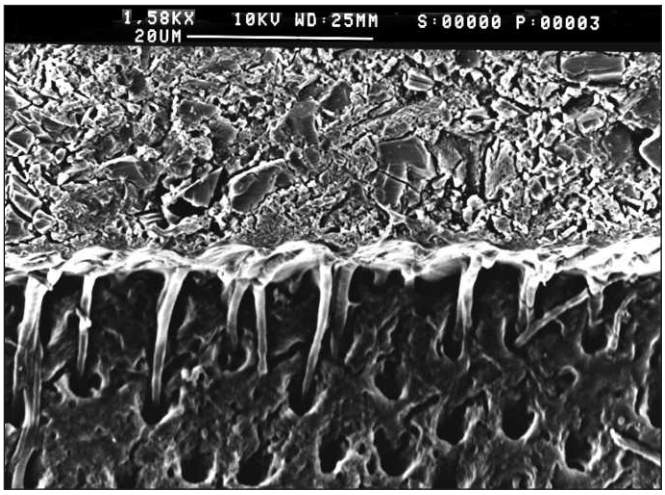

Figure 3. *Typical hybrid layer and resin tag formation as produced by F 2000 Primer/Adhesive on superficial dentin (1580x magnification).*

layers and tag formation (Figure 3) for any of the tested adhesive systems.

DISCUSSION

Unlike many conventional composite resin restorative materials, separate conditioning and bonding procedures for enamel and dentin are not recommended for polyacid-modified resins. Their adhesive systems are designed to work on both substrates.

Multi-step bonding procedure to dentin may increase potential risks that could endanger successful clinical performance of the restoration. After application of an acidic conditioner, inadequate rinsing may leave residual acid, which can over-etch the dentin or block the interfibrillar space with residual reaction products

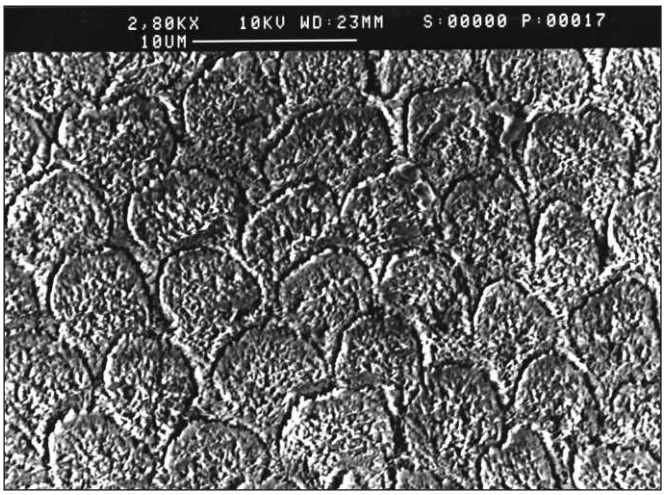

Figure 2. *Etch pattern as produced by Prompt L-Pop on enamel (2800x magnification).*

(Nakabayashi & Pashley, 1998). Insufficient air drying may leave the surface too wet. Either problem may hinder adequate penetration of the priming agent and adhesive resin (Jacobsen & Söderholm, 1995; Tay, Gwinnett & Wei, 1996). Overdrying, on the other hand, may lead to a collapse of the collagen network, resulting in dramatically worse bonding properties (Tay & others, 1996). If the adhesive resin does not completely infiltrate the collagen network and leaves unprotected, decalcified collagen fibers at the base of the hybrid layer (Nakabayashi & Takarada, 1992; Kato, Watanabe & Nakabayashi, 1994), hydrolytic degradation and degradation from acids and enzymes released by bacteria may occur by nanoleakage (Sano & others, 1995) in this gap (Burrow, Satoh & Tagamo, 1996).

Based on these potential problems, the reduction of procedural steps in adhesive systems is not only for time saving reasons, but also for elimination of possible risks that may lead to deterioration of the bond. Major improvements have been observed with bonding systems incorporating self-etching primers (Chigira & others, 1994; Watanabe, Nakabayashi & Pashley, 1994; Ikemura, Kouro & Endo, 1996). These products avoid the rinsing and drying steps which may be critical for the demineralized matrix (Pashley & others, 1995) and resin infiltration. If the acidic monomers penetrate the demineralized zone to its full depth, nanoleakage should be eliminated or greatly reduced.

However, achievement of perfectly hybridized dentin without losing optimum bonding properties to enamel is a problem. In a recent SEM investigation of several one-bottle systems, a traditional pattern of etched enamel could only be achieved after treatment with phosphoric acid, whereas direct application of the adhesive systems resulted in no characteristic etch

Table 3: *Failure Modes in Enamel and Dentin*

		ENAMEL		DENTIN	
Bonding Combination	**n**	**Adhesive**	**Mixed Adhesive/ Cohesive**	**Adhesive**	**Mixed Adhesive/ Cohesive**
C1	10	3	7	9	1
C2	10	2	8	10	0
D1	10	5	5	9	1
D2	10	3	7	10	0
F1	10	5	5	10	0
F2	10	2	8	9	1
H1/2	10	3	7	10	0

pattern (Ferrari, Goracci & García-Godoy, 1997). Although good immediate bond strengths are produced, the degree of etching of enamel seems to be minimal (Shono, 1995). These shallow bonds might limit the longevity of enamel-resin bonding under cyclic thermal and masticatory stress in the clinical situation (Nakabayashi & Pashley, 1998).

Despite recent improvements in the hybridization of dentin, the challenge in the development of adhesive systems still is providing a conditioner which avoids over-etching of dentin without compromising optimum enamel adhesion.

In this study the adhesion of four current adhesive systems was compared by determination of the shear bond strength to human enamel and dentin, which is a widely used method to initially evaluate new adhesive systems (Rueggeberg, 1991; Fowler & others, 1992). The results of recent studies indicate that *in vitro* application of the new hydrophilic bonding systems leads to results similar to *in vivo* application with respect to shear bond strength testing (Mason & others, 1996) and SEM morphology of the hybrid layer (Ferrari & others, 1996).

With the introduction of a microtensile bond strength testing method, it has been proposed that relatively large bonded areas, as used in shear bond strength tests, may contain small flaws or defects in the bonded interfaces (for example, water blisters, air bubbles), which may lead to crack propagation and catastrophic failure (Sano & others, 1994). Other test methods are claimed to apply force more specific to the bonded interface, for example, fracture toughness test (Tam & Pilliar, 1994; Ruse & others, 1996).

However, the determination of failure modes in this investigation revealed mostly adhesive failures in dentin and mixed adhesive/cohesive failures in enamel. If mixed adhesive/cohesive failures were observed, the cohesive part of the fractures occurred exclusively within the restorative material and in no case within enamel or dentin. It has been suggested by Nakabayashi and Pashley (1998) that if high bond strengths can be measured without inducing cohesive failure of dental hard tissue, the stress distributions were adequate to uniformly stress the bonding interface allowing for valid comparisons between adhesive systems.

With the universal adhesive system, significantly higher shear bond strengths to enamel were recorded compared to dentin, which was also found for other self-etching systems in recent studies (Gordan, Boyer & Söderholm, 1998; Barkmeier, Hammesfahr & Latta, 1999). Recent findings confirm similarly high values of 31.1 MPa (Issa & Watts, 1999) and 39.4 MPa (Li & Powers, 1999) for Prompt L-Pop/Hytac to human enamel. With the universal adhesive system, bond strengths to dentin ranged from 3.7 MPa for Compoglass F to 12.2 MPa for Dyract AP and were either not significantly different or significantly higher compared to the manufacturers' adhesive systems. Several studies investigating Prompt L-Pop found good marginal sealing (Nunes, Perdigão & Rosa, 1999), etched enamel morphology (Breschi & others, 1999) and dentin interaction (Lopes, Perdigão & Ambrose, 1999) similar to conventional adhesives. Findings of Miyazaki & others (1996) indicate that active application may result in higher bond strengths to dentin compared to inactive application. This could explain why agitating only one layer of Prompt L-Pop by brush for 15 seconds is sufficient to form a 3.0-4.8 µm thick hybrid layer in dentin (Lopes & others, 1999).

SEM examination revealed similar hybrid layer and resin tag formation to superficial dentin for all tested adhesive systems. Due to the low PH-value of the involved methacrylated phosphates, only the "universal" one-step adhesive system produced a clearly visible etching pattern on enamel surfaces, which could be the reason for the outstanding enamel shear bond strength values of up to 41.2 MPa measured in this investigation.

As a significant decrease in shear bond strength with increased storage time could be observed for other systems (Lucena-Martin & others, 1999), long-term *in vitro* testing will be helpful to gain further knowledge. Though the "universal" one-step adhesive system, due

to its simple handling properties and good bonding to both enamel and dentin, seems to be a promising approach for future development of adhesive systems, clinical data are needed to confirm the *in vitro* findings

CONCLUSIONS

The tested one-step "universal" adhesive system achieved equal or higher bond strengths of the tested polyacid-modified resins to enamel and dentin compared to the adhesive systems provided by the manufacturers.

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Influence of Contact Stress on OCA Wear of Composite Restoratives

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Clinical Relevance

Increase in contact stress significantly enhances the wear of composites. Contact stress on occlusal contact areas should be quantified on restorations analyzed for clinical trials in order to make clinical wear assessment more discriminating and to avoid misinterpretations. Composite usage in patients with large biting forces and parafunctional behavior should be avoided in large restorations.

SUMMARY

Occlusal contact area (OCA) wear has been shown to exceed contact-free area wear by three-to-five times in clinical studies. A reciprocal compression sliding wear device was used to investigate the influence of contact stress on OCA wear of four resin composite restoratives (Silux, Z100, Ariston and Surefil). A dental amalgam (Dispersalloy) was used for comparison. The pattern and mechanisms of wear, and the relationship between wear and composite surface hardness were also studied. Thirty wear specimens and six hardness specimens were made for each material. Wear specimens were tested at 20 to 60 MPa contact stresses against SS304 counter-bodies with artificial saliva as lubricant up to 20,000 cycles. Wear depth (μm; n=6) was measured using profilometry. Hardness testing (KHN) was done with a digital microhardness tester (load=500 gf, dwell time=15 seconds). Results were analyzed using ANOVA/Scheffe's test ($p<0.05$). At all contact stresses Dispersalloy had significantly better OCA wear resistance than the composites. The wear of Z100 was significantly greater than Silux, Ariston and Surefil. The influence of stress on wear and counter-body loss was material dependent. Correlation between contact stress and wear was significant for all materials with correlation coefficient (r) ranging from 0.96 for Z100 to 0.88 for Ariston. The wear mechanisms for the different composites varied depending on their microstructure and the contact stress. There was

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no significant correlation between material hardness and wear/counter-body loss.

INTRODUCTION

Wear is a natural process that occurs whenever two or more surfaces move in contact with one another (Zum-Gahr, 1987). Wear can be defined as the ultimate consequence of interaction between surfaces, manifested in the gradual removal of materials. Since teeth, together with any restorations, move in contact with one another, wear is inevitable. Composite resins ('Composites') have been available to the dental profession for about four decades. Composite resins may be defined as three-dimensional combinations of a least two chemically different materials with a distinct interface (Phillips, 1981).

The first generation composites contained fillers with a mean diameter of 30 to 50 μm. Although there were variations of filler types, most consisted of quartz. Based on a number of clinical studies which indicated that the wear resistance of these materials was not substantially different from amalgams, recommendations were made for their use in posterior teeth. While early research suggested that composites could possibly serve as amalgam substitutes (Phillips & others, 1971), subsequent long-term investigations were less optimistic (Phillips & others, 1973; Leinfelder & others, 1980). After 12-18 months of service, the degree of wear and loss of anatomical form was found to be extensive.

All modern-day composites are basically the product of evolution and refinement of previously developed composites. Their tooth-color matching ability and lack of metallic mercury have caused them to be promoted as an amalgam substitute for the restoration of posterior teeth. The use of dental amalgam is expected to decrease because of increasing emphasis on alternative materials and environmental/health concerns causing changes in government regulations (Roulet, 1997). The wear of many current composites in conservative restorations is nearly equivalent to that of amalgam (10 to 20 μm a year) (Leinfelder & others, 1986). However as clinical studies (Lutz & others, 1984) showed that occlusal contact area (OCA) or sliding contact wear can exceed that of contact free abrasive (slurry) wear by three to five times, wear continues to be an important consideration for large restorations. If OCA wear is of sufficient magnitude, appreciable changes may develop in functional occlusion.

The objectives of this investigation include: (1) evaluating the effects of contact stress on wear behavior of four different composites, (2) comparing the OCA wear performance, (3) determining the pattern and mechanisms of wear and (4) studying the relationship between wear and composite surface hardness.

METHODS AND MATERIALS

Specimen Preparation

Four different visible-light cured composites were investigated (Table 1). They include a microfilled (Silux Plus), two minifilled (Z100 and Surefil) and a midifilled (Ariston pHc) composite. Table 1 shows the polymers and fillers used for the different composites. An amalgam alloy (Disperalloy, Dentsply Inc, Milford, DE 19963) was used for comparison. The composites were placed in the rectangular recesses (8 mm long x 4 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental,

Table 1: *Description of Composite Materials*

Material	Manufacturer	Type	Polymer	Fillers	Filler size (μm)	Filler content (% by volume)	Lot No
Silux Plus	3M Dental Products, St Paul, MN 55144	Microfill	BisGMA TEGDMA	Silica	0.04 (mean)	40	19980106
Z100	3M Dental Products, St Paul, MN 55144	Minifill	BisGMA TEGDMA	Zirconia Silica	0.5–0.7) (mean)	66	19980203
Ariston pHc	Vivadent Schaan, Liechtenstein	Midifill	BisGMA UDMA Dimeth-acrylate	Ba-Al-Fluorosilicate glass Alkaline glass Silica Ytterbium Trifluoride	1.3 (mean)	59	A06719
Surefil	Dentsply-Caulk Milford, DE 19963	Minifill	Urethane-modified BisGMA	Ba-Boron-Fluorosilicate glass Silica	0.8 (mean)	65	980709

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

Composite classification based upon that reported by Ferracane (1995)

Bioggio, Switzerland). A glass slide was placed over the acetate strip and pressure was applied to extrude the excess material. The composites were light-polymerized according to the manufacturers' cure-times through the glass slide with a curing light (Spectrum; Dentsply Inc, Milford, DE 19963). The intensity of the light-source was checked with a radiometer (Cure Rite, EFOS Inc, Ontario, Canada) before starting each experimental session. The mean output was 421±1.5 mW/cm^2 and the output was not affected by illumination through the glass slide and acetate strip. Immediately after light polymerization, the acetate strips were discarded and the composites stored in artificial saliva (Artificial Saliva, NUH Pharmacy Laboratory, Singapore) for 24 hours at 37°C. The amalgam alloy was condensed into the customized molds and carved flat using a plastic instrument. It was allowed to set for 24 hours at 37°C in artificial saliva and "wet" finished with silicone abrasives (PN 308, Shofu, Kyoto, Japan) with a slow-speed handpiece at 40,000 rpm.

The materials for hardness testing were also prepared as mentioned above. The dimensions of the recesses in the acrylic molds were 3 mm long x 4 mm wide x 2mm deep. A total of 30 wear and 6 hardness specimens were made for each restorative material.

Hardness Testing

After 24 hours storage, the specimens were blotted dry and positioned centrally beneath the indentor of a digital microhardness tester (FM7, Future-Tech Corp, Tokyo, Japan). A 500 gf load was applied through the indentor with a dwell time of 15 seconds. The Knoop Hardness Number (KHN) of each specimen was recorded and the mean for each material was computed.

Wear Apparatus and Testing

The wear apparatus used was a reciprocating compression-sliding system in which the material specimens were moved back and forth against a loaded counter-body. The apparatus utilized a crank-and-slider mechanism, whereby rotary action from an induction motor was translated to the linear motion of the sliding platform. One complete circle of radius 1.5 mm drawn by the crank directly translated to a complete horizontal motion of the platform, comprising a forward and backward stroke of 3 mm each. Resolving the circular motion on a plane-to-motion in a line, this circular motion at constant speed gave a line motion with sinusoidal speed. An induction motor with a synchronous speed of 1500 rpm at 230 V and 50 Hz was used with a reduction gear ratio of 15. The resultant speed of the crank was 100 rpm, which gave an angular velocity of $\omega=(10/3)\pi$. Together with the crank offset of 1.5 mm, the resultant sinusoidal horizontal platform velocity was $V=5\pi\sin[(10/3)\pi t]$. Thus, the platform had a speed of 0 mm/s at each end of the 3 mm stroke and smoothly reached a maximum speed of about 16 mm/s at the center of the stroke.

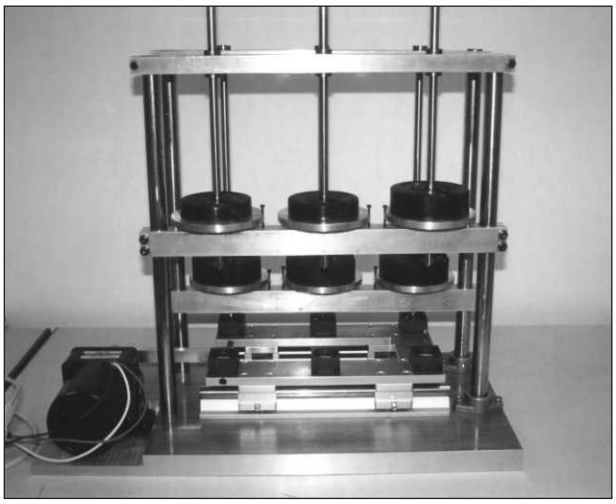


Figure 1. *The wear instrumentation.*

Table 2: *Mean Wear in µm (standard deviation) After Wear Testing and Wear Factor for the Various Contact Stresses*

Materials	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa
Wear in µm					
Silux Plus	31.5 (1.0)	42.3 (0.7)	46.7 (4.2)	53.2 (2.9)	64.0 (7.1)
Z100	59.6 (19.5)	117.4 (13.0)	175.4 (30.8)	253.7 (28.3)	378.0 (32.9)
Ariston pHc	24.4 (2.7)	30.5 (4.8)	48.0 (6.6)	56.3 (9.8)	55.2 (3.8)
Surefil	24.8 (6.9)	34.5 (5.8)	48.0 (7.2)	56.0 (8.4)	81.4 (9.1)
Dispersalloy	5.9 (0.6)	7.4 (1.8)	8.1 (1.4)	9.5 (1.6)	11.8 (5.8)
Wear Factor					
Silux Plus	5.3	5.7	5.8	5.6	5.4
Z100	10.1	15.9	21.8	26.7	31.9
Ariston pHc	4.1	4.1	6.0	5.9	4.6
Surefil	4.2	4.7	6.0	5.9	6.9

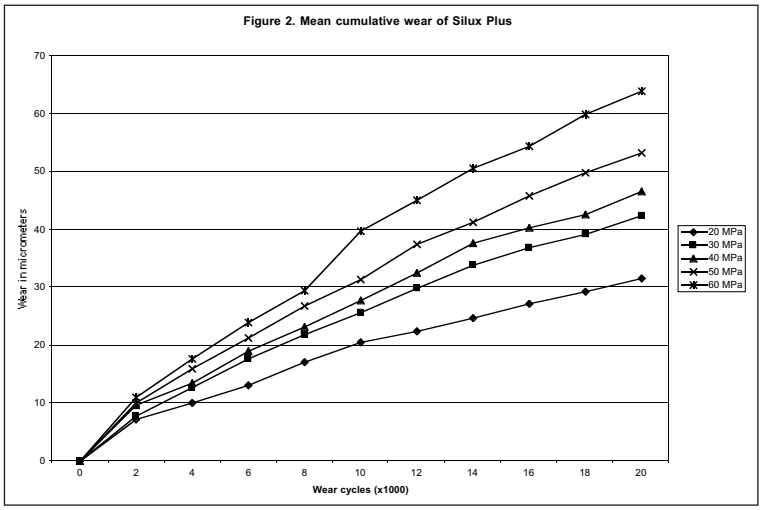


Figure 2. *Mean cumulative wear of Silux Plus.*

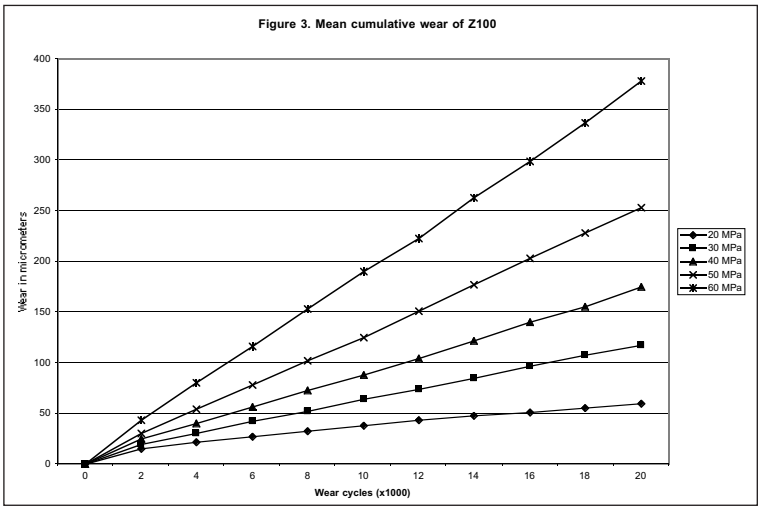


Figure 3. *Mean cumulative wear of Z100.*

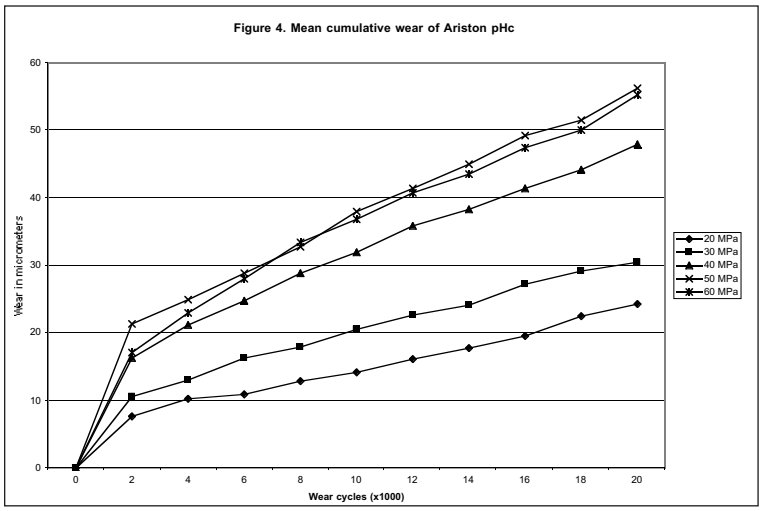


Figure 4. *Mean cumulative wear of Ariston pHc.*

The specimens were placed on the sliding platform in holders that could be filled with lubricating medium. Six holders were arranged symmetrically on the platform, and over each specimen was a load assembly comprising a vertical shaft with an attached load pan (Figure 1). Discrete dead weights were placed on the pan for creating the desired compressive load on the specimen. At the bottom end of the load shaft was a cylindrical recess into which the abrading counter-body was inserted and fastened by means of an M3-sized screw. The complete load assembly was held over the specimen by two supporting bearing blocks at each end of the vertical shaft. These bearing blocks were mounted on rigid columns beside the sliding platform. One block was positioned just over the specimen to minimize the movement arm acting on the supports, and the other was positioned above the weights to prevent rocking and ploughing actions on the specimens due to frictional forces arising from the wear test.

Although the bearings in these support blocks prevented any horizontal motion of the load assembly, they allowed the load assembly to move freely in the vertical direction. Gravity acting on the load assembly ensured a constant contact and compressive force of the counter-bodies against the specimens throughout the entire wear test. The fixed horizontal position of the load assemblies resulted in wear tracks of 3 mm on the specimens when they were moved back and forth under contact with the counter-bodies.

The restorative materials were subjected to wear testing against flat-ended AISI SS304 stainless steel abrading counter-bodies with circular cross-sections of 1 mm diameter at 100 cycles/min with artificial saliva as a lubricant. This gave a nominal contact area of 0.785 mm^2 (πr^2) with the specimens. To standardize the contact surfaces, the contacting surfaces of the stainless steel abrading counter-bodies were finished with sandpaper ranging from 600 to 1200 grit before beginning each wear test. The contact stress (σ) was varied by adjustment of the load. The load (P) to be used was determined by the following equation according to the stress (σ) being investigated:

$$P=(\sigma \times A)/a$$

where "A" is the nominal circular contact area of 0.785 mm^2 and "a" is the gravitational acceleration (9.81 mm/s^2) of the load.

Contact stresses investigated were 20 MPa, 30 MPa, 40 MPa, 50 MPa and 60 MPa. Six specimens were made for each material-stress combination. Material wear was measured using profilometry (Talycontor, Rank Taylor Hobson, Leicester, UK).

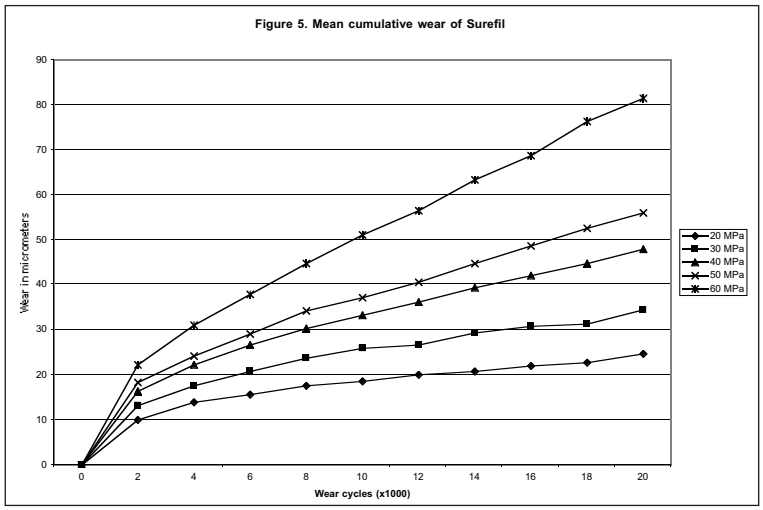


Figure 5. *Mean cumulative wear of Surefil.*

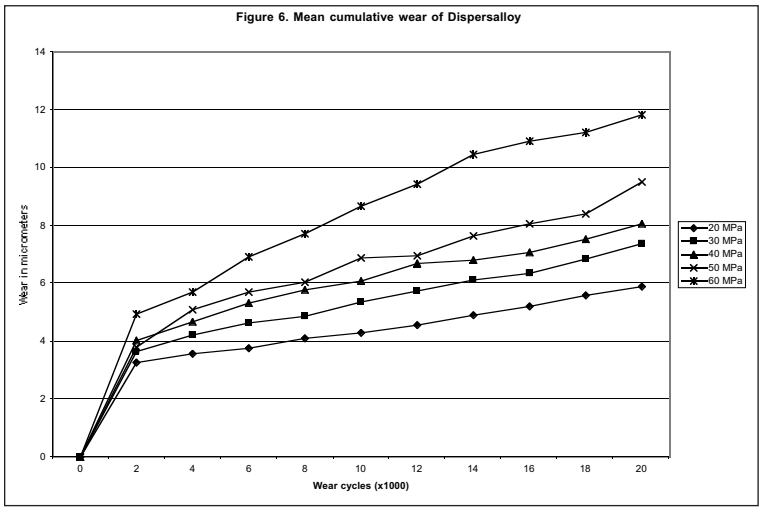


Figure 6. *Mean cumulative wear of Dispersalloy.*

Wear measurements were taken at the center of the wear track at every 2000 cycles up to 20,000 cycles. The wear factor for the composites at the various contact stresses was calculated using the equation:

Wear Factor=Wear of composite/Wear of comparison (Dispersalloy)

Counter-body height loss (μm) was measured by weighing the specimens after each 2000 cycles interval using the following formula:

$$\text{Abrader height lost } (h) = w/(d \times \pi r^2)$$

where "w" is the weight loss and "d" is the density of SS304 (8.03 g/cm^3).

SEM Evaluation

Specimens wear tested at 20, 40 and 60 MPa contact stress were examined with scanning electron microscopy (SEM) after 20,000 cycles to compare wear patterns and evaluate the wear mechanisms. Representative specimens were mounted and examined with a JSM-5800 LV SEM (Joel Ltd, Tokyo, Japan) at an accelerating voltage of 15 keV and a working distance of 10 mm.

Statistical Evaluation

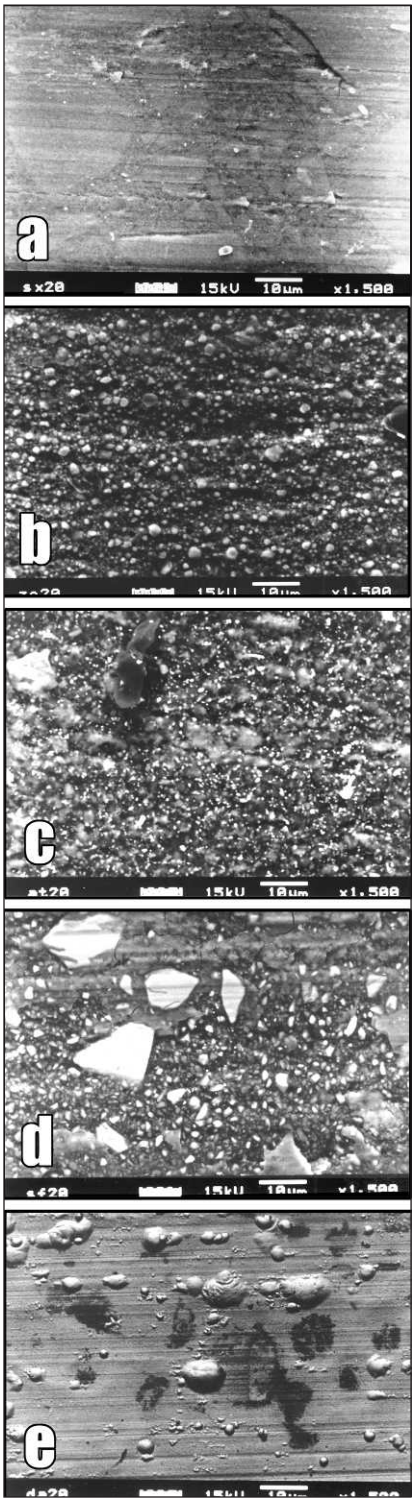
With the exception of correlation, a confidence level of 0.05 was used for all statistical analysis. Two-way analysis of variance (ANOVA) was performed on wear test and counter-body loss data, with restorative material and contact stresses as main effects, and all possible combinations of these variables as interaction effects in the ANOVA model. Post-hoc Scheffe's test was used to test for differences among means (SPSS Inc, Chicago, IL 60611). For each contact stress, a one-way ANOVA was performed on wear and counter-body loss data, with materials as the independent variable and wear and counter-body loss as dependent variables. One-way ANOVA was also performed for each material to determine the effects of contact stress on wear and counter-body loss. In addition, significant differences in surface hardness between restoratives were evaluated. Correlation between hardness and wear, hardness and counter-body loss, stress and wear, and stress and counter-body loss were conducted using Pearson's product-moment correlation coefficient at 0.01 significance level.

RESULTS

The mean material wear, wear factor and mean counter-body loss after wear testing with the various contact stresses are shown in Tables 2 and 3. The mean KHN of the various composites are shown in Table 4. Figures 2 to 6 show the cumulative wear of the various materials. The SEMs of the worn surfaces after wear testing for 20,000 cycles at 20 and 40 MPa contact stress are shown in Figures 7 to 8. Results of statistical analyses are displayed in Tables 5 to 7.

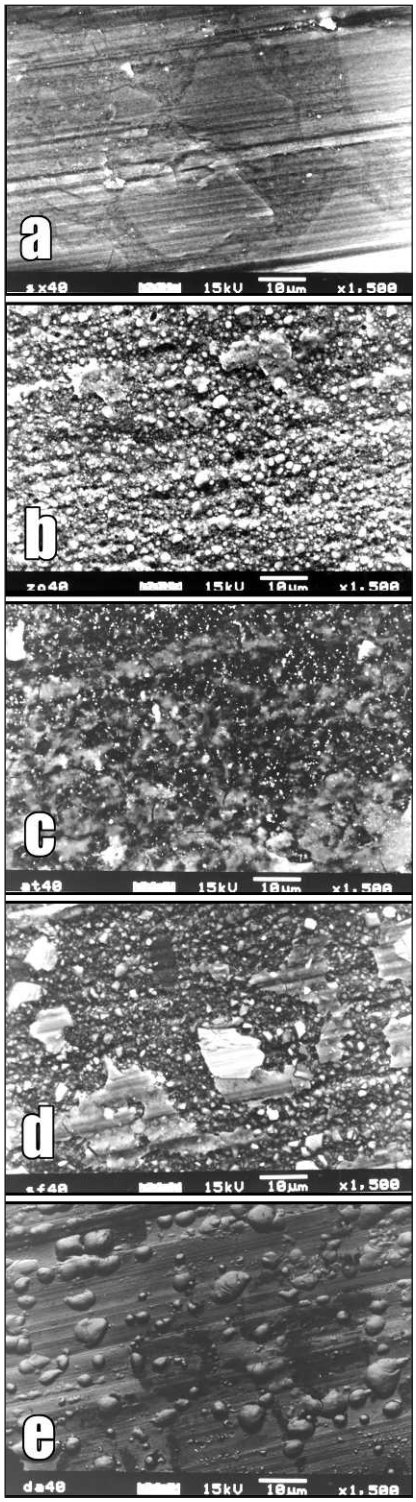
For all contact stresses evaluated, Z100 had the highest wear and Dispersalloy the lowest. Dispersalloy had significantly lower wear than all the composites evaluated. The wear of Z100 was significantly greater than Silux, Ariston and Surefil. No significant difference in wear performance was noted between the latter three composites. With the exception of Z100, OCA wear factor ranged from 4 to 7 for the various composite-contact stress combinations. Wear factor for Z100 was higher, ranging from 10 for 20 MPa to 32 for 60 MPa contact stresses. The greatest counter-body loss was also observed with Z100. For all contact stresses, wear against Z100 resulted in significantly greater counter-body loss compared to the all composites evaluated. In

Figure 7. *SEMs of the worn surfaces after wear testing for 20,000 cycles at 20 MPa contact stress. Magnification x1500.*



(7a) Silux Plus, (7b) Z100, (7c) Ariston pHc, (7d) Surefil and (7e) Dispersalloy

Figure 8. *SEMs of the worn surfaces after wear testing for 20,000 cycles at 40 MPa contact stress. Magnification x1500.*



(8a) Silux Plus, (8b) Z100, (8c) Ariston pHc, (8d) Surefil and (8e) Dispersalloy

addition, wear testing with Surefil also resulted in significantly greater counter-body wear compared to Dispersalloy for contact stress of 20 MPa.

Two-way ANOVA of wear and counter-body loss showed significant interaction between contact stress and materials. In other words, the influence of stress on wear and counter-body loss was material-dependent. The influences of contact stress on wear of individual restoratives are reflected in Table 5. For all restoratives, wear at contact stress of 60 MPa was significantly greater than that at 20 MPa. Correlation between stress and wear was significant for all restoratives. No significant difference in counter-body loss was observed between the different contact stresses for all restoratives with the exception of Z100. For Z100, counter-body loss at 60 MPa was significantly greater than at other contact stresses. With the exception of Z100, no significant correlation was observed between stress and counter-body loss.

Ranking of surface hardness from smallest to largest KHN was as follows: Silux<Ariston<Surefil<Z100<Dispersalloy. Silux was significantly softer than all the other restoratives. Dispersalloy was significantly harder than Z100, Ariston and Surefil. Z100 and Surefil was significantly harder than Ariston. There was no significant correlation between restorative hardness and wear/counter-body loss.

DISCUSSION

The use of composite resins as amalgam substitutes in posterior restorations had been limited by their ability to withstand the physical and mechanical rigors of service in the oral environment. Although the wear resistance of composites has been substantially improved, it is still lower than amalgam (Chadwick & others, 1991). To develop more wear-resistant restorative materials, it is necessary to acquire a deeper understanding of the fundamental mechanisms that drive the intra-oral wear process. Clinical wear of composites occurs at both the occlusal contact (OCA) and contact-free areas (CFA). Until recently, much of the published clinical data on composite wear had concentrated on generalized (CFA) loss of material. Although this type of wear pattern is important, localized (OCA)

Table 3: *Mean Counter-Body Loss in µm (standard deviation) After Wear Testing with the Various Contact Stresses*

Materials	Counter-Body Loss (µm)				
	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa
Silux Plus	13.2 (6.5	10.6(8.2	15.9 (0.00)	13.2 (6.5)	13.2 (11.9)
Z100	39.6 (8.7	52.9(12.9)	87.2 (6.1)	87.2 (26.1)	142.7 (48.1)
Ariston pHc	10.6 (8.2	15.9(0.0)	10.6 (8.2)	10.6 (8.2)	10.6 (8.2)
Surefil	18.5 (11.9)	15.9(10.0)	21.1 (8.2)	15.9 (14.2)	31.7 (14.2)
Dispersalloy	0 (0.0)	7.9 (8.7	2.6 (6.5)	7.9 (8.7)	5.6 (8.2)

Table 4: *Mean Knoop Hardness Number (KHN) of the Different Restoratives*

Materials	Hardness
Silux Plus	22.5 (2.4)
Z100	66.2 (9.1)
Ariston pHc	37.7 (4.5)
Surefil	55.2 (9.2)
Dispersalloy	111.7 (3.6)

loss of substance may be of greater concern, as it is of much greater magnitude (Lutz & others, 1984). OCA wear may be attributed to direct opposing tooth contact during bruxism and thegosis and indirect contact through trapped food particles during the closed phase of mastication (Mair & others, 1996). Direct tooth contact may also occur during mastication (Anderson & Picton, 1957), especially in the final stages just prior to swallowing, where contacts can occur in every stroke (Adams & Zander, 1964).

Clinical findings suggest that contact stress (chewing pressure) during mastication and parafunction is an important factor influencing the wear of both composites and opposing tooth structure (Chapman & Nathanson, 1983). Clinical contact stress levels vary considerably since stress depends not only on the biting force but also on the actual area of contact between two surfaces. As biting forces differ between males and females and between different teeth (Rugh & Solberg, 1972), contact stresses are difficult to clinically standardize. Values from 3.9 to 17.3 MPa during mastication have been reported (Anderson, 1956). Clarke, Townsend & Carey (1984) demonstrated that an average bruxing event involved 60% of the maximum clench power before a person went to sleep. This far exceeds the normal force used during mastication or any functional activity. A range of contact stresses from normal mastication to parafunction was thus investigated.

For the same test conditions and duration, the wear of ultra-high molecular weight polymers sliding against stainless steel in a reciprocating test was much higher than in a unidirectional pin-on-plate test (Dowson, Atkinson & Brown, 1975). As the reciprocating wear test system was also more clinically relevant (for example, during bruxism), it was selected instead of a simple pin-on-plate test for this experiment. A stainless steel counter-body was used for the reason given by McKinney and Wu (1982). Briefly, enamel or enamel-like antagonists tend to polish composite surfaces, producing little wear. Softer counter-body materials such as stainless steel are abraded by the inorganic matrix,

Table 5: *Results of Statistical Analysis*

Subject		Differences (Wear)	Differences (Counter-Body Loss)
Contact Stress	**20 MPa**	Dispersalloy<all composites Z100>Silux, Ariston, Surefil	Z100>Silux, Ariston & Surefil & Dispersalloy Surefil>Dispersalloy
	30 MPa	As above	Z100>Silux, Ariston, Surefil & Dispersalloy
	40 MPa	As above	As above
	50 MPa	As above	As above
	60 MPa	As above	As above
Materials	**Silux Plus**	20<30, 40, 50, 60 MPa; 60>50, 40, 30 MPa and 50>30 MPa	NS
	Z100	20<30, 40, 50, 60 MPa; 60>50, 40, 30 MPa; 50>40, 30 MPa and 40>30 MPa	60>20, 30, 40, 50 MPa
	Ariston pHc	20, 30<40, 50, 60 MPa	NS
	Surefil	20<40, 50, 60 MPa, 60>50, 40, 30 MPa and 50>30 MPa	NS
	Dispersalloy	20<60 MPa	NS

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

Table 6: *Comparison of Surface Hardness Between Materials*
Differences
Z100, Ariston, Surefil & Dispersalloy > Silux
Dispersalloy > Z100, Ariston & Surefil
Z100 & Surefil > Ariston
Results of one-way ANOVA and Scheffe's test ($p<0.05$). > indicates statistical significance and NS indicates no statistical significance.

producing a rough contact surface which theoretically wears the composite matrix preferentially. This results in a "plucking" effect in which the unworn filler particles are removed in their entirety. The "plucking" wear pattern has been observed clinically on posterior composite restorations (Abell, Leinfelder & Turner, 1983). As OCA wear is also caused by indirect contact through trapped food particles, a more relevant counter-body should be softer than enamel, having the hardness closer to that of hard foods. In addition, the OCA wear observed with bruxism is the sum result of slurry wear during mastication and sliding wear during the bruxing event.

For all contact stresses, the amalgam alloy (Dispersalloy) had significantly less wear than composite resins. This agrees with the findings of various clinical studies (Chadwick & others, 1991; Lambrechts, Braem & Vanherle, 1987) which compared the clinical wear of Dispersalloy with composites. Figure 8e shows the wear site on a Dispersalloy restoration after wear testing for 20,000 cycles at 40 MPa. At the OCA wear facet, zones of smearing, pitting, scratching and destructive creep can be observed. The resulting surface, however, remains relatively smooth. At 60 MPa contact stress, the surface topography remained relatively similar, although wear grooves caused by the stainless steel counter-body and smearing were more prominent.

Clinical studies showed that wear was less severe with microfilled composites than with minifilled and midifilled composite resins (Dietschi & Holz, 1990; Lundin & others, 1990). The better OCA or attrition wear of microfills was also generally observed in laboratory tests (Condon & Ferracane, 1997; Yap & others, 1999) using enamel and cobalt-chromium antagonists. At contact stresses of 40 to 50 MPa, the microfilled composite (Silux) in this study also had less wear than minifilled and midifilled composites. However at lower stresses of 20 and 30 MPa, the minifilled (Surefil) and midifilled (Ariston) composites had lower wear than the microfilled composite. At 60 MPa, Ariston had the least wear, followed second by Silux. Contact stresses must, therefore, be taken into consideration when ranking wear performance of composite resins.

Although the OCA wear resistance of a microfilled composite was reported to be similar to Dispersalloy (143 μm in four years) in the clinical study by Lambrechts & others (1987), about 20% of the microfilled restorations suffered catastrophic failure after four years. Silux, used in this experiment, has also shown excellent clinical CFA wear resistance after five years but experienced a higher incidence of fracture than more heavily filled materials (Tyas & Wassenaar, 1991). The clinical failure of microfilled composites often comes as a surprise to clinicians since the amount of wear prior to fracture is negligible. Other clinical studies have demonstrated that microfilled composites undergo greater marginal degradation and localized wear in contact sites than do more heavily filled composites with larger particles (Bryant, Marzbani & Hodge, 1992; Mazer & Leinfelder, 1992). A current hypothesis is that inadequate fatigue resistance is responsible for the accelerated OCA wear and marginal degradation observed in composites with filler particles that average less than 1.0 μm in size (Mazer, Leinfelder & Russell, 1992; Braem, Lambrechts & Vanherle, 1994a). Microfilled composites have been shown to have fracture resistance, stiffness and fatigue strength lower than those of more heavily filled composites (Drummond, 1989; Willems & others, 1992, Braem &

Table 7: *Results of Pearson Correlation (correlation coefficient)*			
Correlations	**Contact Stress**	**Hardness and Wear**	**Hardness and Counter-Body Loss**
	20 MPa	-0.34 (NS)	-0.20 (NS)
	30 MPa	-0.16 (NS)	0.05 (NS)
	40 MPa	-0.12 (NS)	-0.00 (NS)
	50 MPa	-0.06 (NS)	0.09 (NS)
	60 MPa	-0.10 (NS)	0.07 (NS)
Correlations	**Materials**	**Stress and Wear**	**Stress and Counter-Body Loss**
	Silux Plus	0.93 (S)	0.52 (NS)
	Z100	0.96 (S)	0.75 (S)
	Ariston pHc	0.88 (S)	-0.11 (NS)
	Surefil	0.92 (S)	0.30 (NS)
	Dispersalloy	0.60 (S)	0.21 (NS)
S indicates correlation is significant at the 0.01 level. NS indicates no statistical significance.			

others, 1994b). In stress-bearing situations, microfilled composites with their low modulus will undergo more deformation, resulting in possible crack formation and increased strain on the resin matrix. An additional factor contributing to their degradation is the fact that the pre-polymerized resin fillers (Figure 7a and 8a) are not well bonded to the polymer matrix. The resin fillers are heat-cured and do not form covalent chemical bonds with the resin matrix due to the lack of available methacrylate groups on their surfaces. They may, therefore, become debonded and dislodged under high stresses. This was, however, not observed for Silux wear tested at both 40 and 60 MPa. This reinforces the importance of fatigue in the failure of microfilled composites. The composites in this study may not be subjected to sufficient fatigue to cause catastrophic failure. From Figures 2 to 6, it can be seen that no wear rate discontinuity was observed. Rate discontinuity results from a possible change in wear mode for which wear is enhanced by the generation of subsurface damage resulting from fatigue. The number of cycles (20,000) was limited by fracture of the stainless steel counterbodies when wear tested with Z100 at high stresses in the pilot study. The use of microfilled composites for posterior restorations is therefore not advised despite the low wear found in this study.

The ideal OCA wear factor for the composite restoratives should be one, but this was not achieved by any composites evaluated. Excluding Z100, the OCA wear of composites were generally four to seven times greater than amalgam for the various contact stresses. For Z100, OCA wear resistance was 10 to 32 times poorer than amalgam. The clinical use of composites as amalgam substitutes in larger and more posterior restorations is therefore not recommended, especially in patients with parafunctional habits where contact stresses can be very high. Differences in contact stresses experienced in molars and pre-molars (Rugh & Solberg, 1972) may account for the markedly different clinical OCA wear rates. Over a period of four years, steady-wear rates on occlusal contact areas of 29 μm for molars and 15 μm for premolars were reported by Lambretchs & others (1989). The wear factor of the microfilled composite, Silux, remained fairly constant with increased contact stresses, while the minifilled and midifilled composites (Z100, Surefil and Ariston) generally showed an increase in wear factor with increase contact stress.

The wear performance of the various composites can be partially explained by their microstructures. Composites can be considered biphasic, with one phase (fillers) embedded in the other (resin/polymer matrix). From the SEM micrographs of the microfilled composite Silux (Figures 7a and 8a), it can be observed that the main mechanism of material loss is abrasive wear. The simultaneous loss of both phases does not cause surface protrusions after wear testing. They therefore maintain a relatively smooth surface which minimizes surface friction and wear. As the contact stress is increased, the wear grooves left by the stainless steel counter-body becomes deeper and more distinct (Figure 8a). For the minifilled composite Z100, preferential wear of the resin matrix occurred, followed by displacement or "plucking" of the filler particles as a result of filler-matrix adhesive failure. This was observed as spherical black spaces in Figures 7b and 8b. At contact stresses of 40 and 60 MPa, these black spaces appeared to increase in both size and quantity (Figure 8b). The former suggests possible cohesive failure of the polymer matrix, which occurs subsequent to microcrack formation as the protruding intact fillers transmit shear forces to the surrounding matrix. Filler displacement and microcracking were also observed with Surefil and Ariston at higher contact stresses (Figures 8c and 8d, respectively). These microcracks were more obvious around the large fluorosilicate glass fillers (observed as gray to white opaque masses) used in both composites. In addition to wear resulting from filler-matrix adhesive failure and cohesive failure through the matrix, shearing of the fluorosilicate glass fillers was also observed (Figures 8c and 8d), as evidenced by their flat surfaces after wear testing. As with Z100, preferential wear of the matrix, followed by filler particle displacement, was the major perceptible wear mode at 20 MPa contact stress.

In this study the influence of contact stress on wear and counter-body loss was found to be material dependent. For the composites, a significant positive correlation was observed between stress and wear, that is, greater contact stress results in more wear. The correlation coefficient (r) ranged from 0.96 for Z100 to 0.88 for Ariston. This is in agreement with past studies (Harrison & Moores, 1985; Lutz, Krejci & Barbakow, 1992) conducted on earlier composites which showed that increases in contact stress significantly enhanced wear. The contact stress on occlusal contact areas should, therefore, be quantified on restorations analyzed for clinical trials in order to make clinical wear assessment more discriminative and to avoid misinterpretations. For more conclusive results, it was suggested that an adequate number of large, uniformly-sized stress-bearing MOD restorations be placed in molars of fully dentate patients (Lutz & others, 1992). This would help reduce standard deviations and justify the costs of clinical wear tests. No correlation was observed between surface hardness and wear of the materials.

Counter-body loss was generally less than material loss and can be attributed to abrasive wear. Abrasive wear occurs when hard asperites plough into softer surfaces. In this case the asperites are an integral part of the composite surface (that is, the inorganic filler particles). The roughened contact surfaces of the stainless

steel antagonists, in turn, may cause "plucking" wear, leading to loss of composite material. Harder filler particles may theoretically lead to greater counter-body loss. However, surface hardness is dependent, not only on the hardness of the filler particles, but also on the percentage of filler by volume. Chung and Greener (1990) found a positive correlation between the percentage of filler by volume and Knoop hardness of composite resins, that is, higher filler volume results in increased hardness. Hence, Silux, with its lowest filler volume (40%), had significantly lower surface hardness compared to the other composites. The significantly higher KHN of Z100 and Surefil, compared to Ariston, can also be attributed to their higher filler volumes (Table 1). In addition to filler hardness and volume, the bond of the filler particles to the polymer matrix must be considered. If frictional or other forces are higher than the filler–matrix bond, the filler particles may be dislodged instead. No correlation between composite surface hardness and counter-body loss was thus observed.

For counter-body loss, significant differences between the various contact stresses was only observed for Z100. Wear testing at 60 MPa resulted in significantly greater counter-body loss than wear testing at 20 to 50 MPa. Only Z100 had a significant correlation (r=0.75) between contact stress and counter-body loss. When wear tested specimens were visually inspected, "graying" of the composite wear tracks was noted for Z100 for all contact stresses. This was not observed for the other composites evaluated. The graying of Z100 may be attributed to adhesive wear which occurs when surfaces slide against one another. The effects of friction causes the asperites on the stainless steel surface to become cold-welded to the composite surface. The transfer of material from the stainless counter-body, in addition to abrasive wear, could have resulted in significantly greater counter-body loss at all stresses compared to the other materials evaluated. The bond of this adherent layer to the composite surface was weak and could be easily removed by steam-cleaning.

CONCLUSIONS

For all contact stresses, the amalgam alloy (Dispersalloy) had significantly better OCA wear resistance than the composites evaluated. Amongst the composites, the wear of Z100 was significantly greater than that of Silux, Ariston and Surefil. OCA wear factor ranged from four to seven for the various composite-contact stress combinations, with the exception of Z100, which ranged from 10 to 32. For all contact stresses, wear against Z100 resulted in significantly greater counter-body loss compared to the other restoratives. The influence of stress on wear and counter-body loss was material dependent. Correlation between contact stress and wear was significant for all restoratives, with correlation coefficient (r) ranging from 0.96 for Z100 to 0.88 for Ariston. The wear mechanisms for the different composites varied depending on the contact stress and their microstructure. With the exception of Z100, no significant correlation was observed between stress and counter-body loss. There was no significant correlation between restorative hardness and wear/counter-body loss.

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Three-Body Abrasive Wear of Composite Restoratives

AUJ Yap • SH Teoh • KB Tan

Clinical Relevance

The use of composites as an amalgam substitute in low stress, contact-free areas exposed to three-body abrasive wear is feasible. Choice of composite material is, however, an important consideration.

SUMMARY

This investigation studied the three-body abrasive wear resistance and wear patterns of five composite restoratives. The possible relation between three-body wear and surface hardness was also investigated. A three-body wear instrumentation was used to investigate the wear resistance of five composite restoratives [Silux Plus (SX), Z100 (ZO), Ariston pHc (AR), Surefil (SF) and Tetric Ceram (TC)]. An amalgam alloy [Dispersalloy (DA)] was used as control. The amalgam alloy (DA) had the lowest three-body wear (0.3±0.27 µm) and the highest surface hardness (KHN 131.5±27.87). TC had the most wear (2.14±0.58 µm) and SX was the softest restorative (KHN 34.04±2.73). Ranking was as follows: Wear resistance—DA>ZO>SF>AR>SX>TC; Hardness—DA>SF>ZO>TC>AR>SX. With the exception of ZO, DA was significantly more wear resistant than all the composites evaluated. ZO was significantly more wear resistant than SX and TC. DA was significantly harder than all the composites evaluated. SF was significantly harder than AR and SX. For the composite restoratives, correlation between hardness and wear was significant, with a correlation coefficient of *r*=-0.45. A significant negative but weak correlation exists between hardness and three-body wear of composite restoratives.

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INTRODUCTION

Wear is a natural process that occurs whenever two or more surfaces contact one another (Zum-Gahr, 1987). With patients keeping their natural dentition longer, the potential for tooth and restoration wear is greater and is increasingly becoming a clinical problem. Traditionally, three terms—attrition, abrasion and erosion—have described the wear of teeth and dental materials. Erosion has been used in dental literature to describe the surface loss attributed to chemical effects. Attrition describes the surface loss at sites of occlusal contact and abrasion describes wear at non-contact or contact-free areas together with a number of other situations which cannot be ascribed to erosion or attrition (Smith, 1989). According to Mair & others (1996), there

are two stages in the mastication process from the wear point of view. Initially, the teeth are brought from an open position to one of near contact (open phase). During the second or closed phase force is applied to the food bolus and shredding takes place by lateral movements of the teeth. It is in these two phases that the effect of any abrasive particles in the diet differs. During the open phase the abrasive particles are free to move within the food suspension and therefore act as a slurry. During the closed phase the abrasive particles become trapped between the tooth surfaces and are no longer free to act as a slurry. They are dragged between surfaces, resulting in three-body abrasive wear.

This investigation studied the three-body abrasive wear resistance and wear patterns of four composite restoratives and the possible relation between three-body wear and surface hardness.

METHODS AND MATERIALS

Specimen Preparation and Hardness Testing

Table 1 lists the composite restoratives tested and their composition. An amalgam alloy (Disperalloy, Dentsply Inc, Milford, DE 19963) was used both as a control and for purposes of comparison. The composite restoratives were placed in the rectangular recesses (8 mm long x 4 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over them and pressure applied to extrude excess material. The restoratives were light polymerized through the glass slide with a Spectrum Curing Light (Dentsply Inc, Milford, DE 19963) according to manufacturers' cure times. Immediately after light polymerization, the acetate strips were discarded and the composites stored in artificial saliva (Artificial Saliva, NUH Pharmacy Laboratory, Singapore) for 24 hours at 37°C. The amalgam alloy was condensed into the customized molds and carved flat using a plastic instrument. It was then allowed to set for 24 hours at 37°C in artificial saliva before 'wet' finishing with silicone abrasives (PN 308, Shofu, Kyoto, Japan) with a slow speed handpiece at 40,000 rpm. Five specimens were made for each restorative material. After being stored for 24 hours (necessary for setting the amalgam prior to polishing and composite post-cure), the specimens were blotted dry and subjected to hardness testing with a digital microhardness tester (FM7, Future-Tech Corp, Tokyo, Japan) at a site adjacent to the planned wear track. A 500gf load was applied through the indentor with a dwell time of 15 seconds. The Knoop Hardness Number (KHN) of each specimen was recorded and the mean KHN of each material computed.

Wear Instrumentations and Testing

The wear instrumentation was designed to provide three-body abrasive wear. Using a central rotating main shaft that rotates a specimen holder (Figure 1), the specimens were abraded against block-shaped stainless steel (AISI SS304) abraders with a layer of millet seed slurry in-between. A sun gear located on the main rotating shaft was joined to six other planetary gears that were part of the six shafts fixed with cams. The cam profile controlled the movement of the abraders that were synchronized to produce wear only when the specimens were facing the abraders. This prevented unnecessary wear of the abraders and specimen holders and reduced the formation of wear debris. In order for the abraders to ensure a constant force of 15 N on the specimens, they were pressed against the specimens at regular intervals using varying compression of the spring force within the abrader housing. The spring (stiffness of 10 N/mm) inside the abrader housing was preloaded with a compressive force of 10 N. The cam profile (Figure 2) was designed so that the abraders would contact the specimens with a force of 15 N when the specimens came into the range of the abrader surface, that is, the spring would be further compressed by 0.5 mm.

Table 1: *Technical Profiles of the Composites Evaluated*

Product	Composition
Silux Plus (3M Dental Products St Paul, MN 55144) Batch: 19980106 Shade: Yellow	Resins: BisGMA, TEGDMA Fillers: Silica Mean Filler Size: 0.04 µm` Filler Volume: 40%
Z100 3M Dental Products St Paul, MN 55144) Batch: 19980203 Shade: A2	Resins: BisGMA, TEGDMA Fillers: Zirconia Silica Mean Filler Size: 0.7µm Filler Volume: 66%
Ariston pHc Vivadent, Schaan Liechtenstien Batch: A06719 Shade: NA	Resins: BisGMA, UDMA, TEGDMA Fillers: Ba-Al-Fluorosilicate glass, Alkaline glass, Silica, Ytterbium Trifluoride Mean Filler Size: 1.3 Filler Volume: 59%
Surefil Dentsply-Caulk Milford, DE 199653 Batch: 980709 Shade: A	Resins: Urethane-modified BisGMA Fillers: Ba-Boron-Fluorosilicate glass, Silica Mean Filler Size: 0.8µm Filler Volume: 65%
Tetric Ceram Vivadent, Schaan, Liechtenstien Batch: A10962 Shade: A2	Resins: BisGMA, UDMA, TEGDMA Fillers: Barium glass, Ytterbium Trifluoride, Ba-Al-Fluorosilicate, Silica Mean Filler Size: 0.7µm Filler Volume: 60%

BisGMA = Bisphenol A-glycidyl methacrylate
TEDGMA = Triethylene glycol dimethacrylate
UDMA = Urethane dimethacrylate

Figure 1. *The wear instrumentation.*

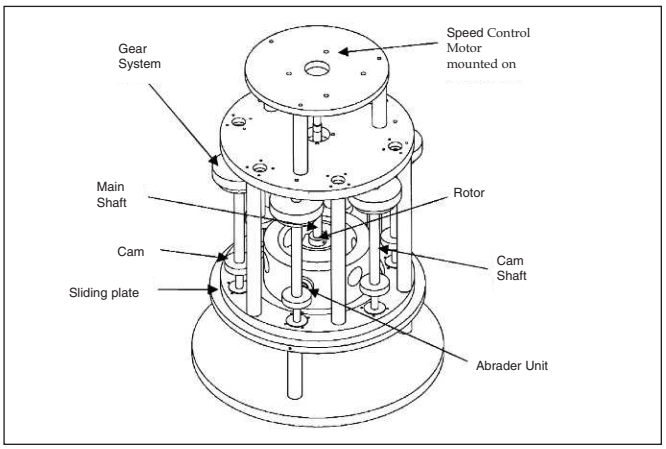

Figure 1A.

Figure 1B.

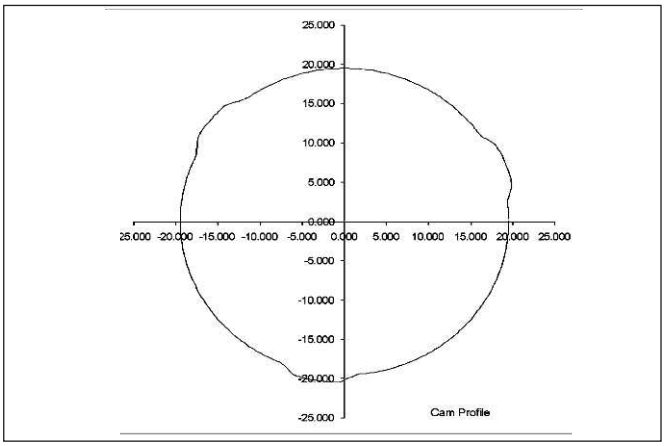

Figure 2. *The cam profile.*

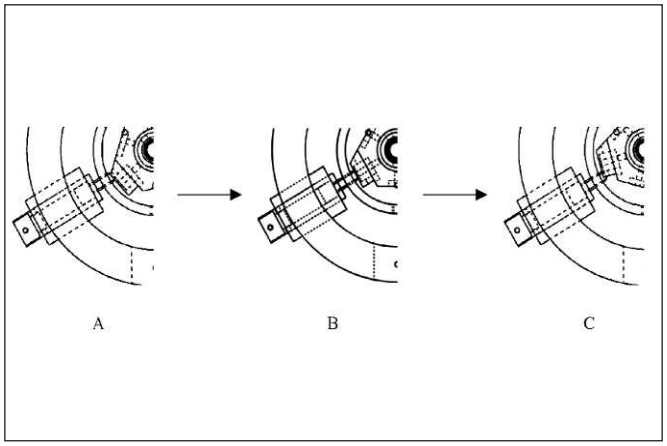

Figure 3. *Relative motion of the abrader with respect to the specimen.*

The cam assembly consisted of six bakelite cams that rotated on their axis. The camshafts were driven by their respective planetary gears which were connected to the sun gear on the main rotating shaft. The ratio of the number of teeth of the sun gear to the planetary gear was 2:1. Hence, rotation speed of the planetary gear was twice that of the sun gear. Each degree of the rotator's rotation corresponded to two degrees of the cam's rotation so that when the cam turned 120 degrees, the rotator rotated the specimen by 60 degrees, moving it to the next abrader. Figure 3 shows the relative motion of the abrader with respect to the specimen holder as the main shaft rotates. At position A the cam pushes the abrader forward, contacting the specimen holder. At point B the specimen is subjected to a force of 15 N. At point C the abrader is returned to its pre-stressed condition of 10 N. The specimens were subjected to 20,000 cycles of wear with a rotation speed of 10 rpm. Material wear (maximum depth of wear track) was measured along the length of the specimens at the midpoint of width using profilometry (Talycontor, Rank Taylor Hobson, Leicester, UK). A vertical magnification of X100 and a horizontal magnification of X20 was employed for profilometry. The travel length of the stylus was set at 10 mm and the adjacent unworn areas were used as references.

SEM Evaluation

Representative specimens of the different restoratives after wear testing were mounted and examined with a JSM-5800 LV SEM (Joel Ltd, Tokyo, Japan) at an accelerating voltage of 15 keV and a working distance of 10 mm.

Statistical Evaluation

Wear and hardness test data were subjected to statistical analysis using the one-way ANOVA and Scheffe's post-hoc test at a significance level of 0.05 using a computer software (SPSS 9.0, SPSS Inc, Chicago, IL 60611). Correlation between wear and hardness was determined using Person's product-moment correlation at a significance level of 0.05.

Table 2: *Mean KHN and Three-Body Wear*

Material	Hardness [KHN]	Three-body Wear [µm]
Silux Plus	34.04 (2.73)	1.88 (0.63)
Z100	62.90 (12.41)	0.66 (0.23)
Ariston pHc	41.50 (3.84)	1.74 (0.25)
Surefil	73.70 (4.83)	1.44 (0.65)
Tetric Ceram	48.18 (2.06)	2.14 (0.58)
Dispersalloy	131.50 (27.87)	0.30 (0.27)

Figures in brackets are standard deviations.

Table 3: *Results of Statistical Analysis*

Subject	Differences
Hardness	Dispersalloy > all composites Surefil > Silux, Ariston
Three-body Wear	Silux, Ariston, Surefil, Tetric > Dispersalloy Silux, Tetric > Z100

Results of one-way ANOVA and post-hoc Scheffe's tests ($p < 0.05$); > indicates statistical significance

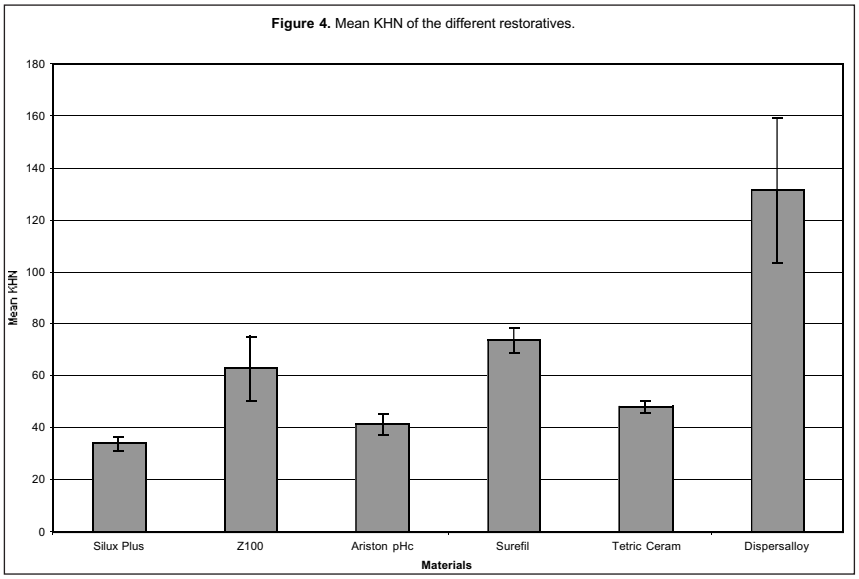

Figure 4. *Mean KHN of the different restoratives.*

RESULTS

The mean hardness values (KHN) and three-body wear (µm) are shown in Table 2 and Figures 4 and 5. Table 3 reflects the results of statistical analysis for inter-material comparison.

Dispersalloy was significantly harder than all the composite resins evaluated. For the composite restoratives, ranking of hardness values from largest to smallest were as follows: Surefil>Z100>Tetric>Ariston>Silux. Surefil was significantly harder than Ariston and Silux. No other significant difference in hardness was observed among the different composites.

Dispersalloy had the least three-body wear. With the exception of Z100, the amalgam alloy was significantly more wear resistant than all the composites evaluated. No significant difference in wear was observed between Z100 and Dispersalloy. The ranking for composite wear from least to most three-body abrasive wear was: Z100<Surefil<Ariston<Silux<Tetric. Z100 had significantly less three-body wear than Silux and Tetric. No other significant differences in three-body wear were observed between the different composites.

Correlation between hardness and wear was significant at the 0.05 level with a correlation coefficient (r) of -0.45. Thus, higher surface hardness was associated with less three-body abrasive wear. The SEM micrographs of the wear tracks and adjacent unworn areas of the different restoratives are shown in Figures 6 to 11. The SEM of the unworn areas of all composites showed a predominance of microfillers. All composites demonstrated exfoliation of filler particles after three-body abrasive wear testing. Abrasive wear on the amalgam produced a roughened, scratched surface (Figure 11).

DISCUSSION

Wear, as a micromechanical surface interaction, cannot be observed directly. Scientific knowledge about wear has been deducted from indirect evidence, such as wear rates, microstructural changes or wear debris type (Sarkar, 1980). Deductions were made in this study from the wear measurements and the microstructural features of the worn composite specimens. Three-body abrasive wear has been considered the main wear mechanism active in contact-free areas, resulting in generalized loss of form (Lutz & others, 1984). The forces produced during the closed phase of mastication have been modeled in the range of 10 to 20 N (de Gee, Pallav & Davidson, 1986; Sakaguchi & others, 1986). A 15 N force was applied on the specimens in the three-body wear instrumentation used in this study. The abraders were made of stainless steel as recommended by McKinney and Wu (1982). Enamel or enamel-like abraders are very hard and tend to polish composite surfaces, producing little wear. Softer abraders, such as stainless steel, are abraded by the hard inorganic fillers, producing a rough contact surface which theoretically wears the resin matrix preferentially.

The wear of modern composite restoratives is substantially better than the first generation composite

resins. Wear resistance has been improved primarily by the reduction of filler particle size and increase filler loading. Despite this, the occlusal contact attrition wear of composites is still higher than amalgam (Chadwick & others, 1991), limiting their clinical use in posterior teeth. In the current view of dental composite abrasive wear, three-body action gradually removes the soft resin matrix between the hard filler particles. Eventually, the particles are left unsupported and are easily exfoliated, leaving a layer of unprotected resin. This layer of unprotected resin wears away rapidly and the process continues. This view had been substantiated by the dependence of the abrasive wear rate on the degree of cure of the polymer resin (Ferracane & others, 1997) and the relationship between the level of filler loading and wear rate (Condon & Ferracane, 1997). SEM evaluation of the composite specimens in this study also support the current view of abrasive wear.

The microstructure of the unworn areas of all composites showed a predominance of microfillers (Figures 6a to 10a). This results from using acetate strips and applying pressure during specimen preparation. Exfoliation of filler particles was observed with all composites after three-body abrasive wear. Comparing the SEM micrographs of wear tracks and unworn areas of the different composites showed a greater occurrence of black voids on the surface microstructure. Such exfoliation or "plucking" wear patterns has been noted clinically on posterior composite restorations (Abell, Leinfelder & Turner, 1983). The microstructure of the wear track of Silux was particularly different from that observed at the unworn areas. This can be attributed to the exposure of the prepolymerized filler complexes after wear testing (Figure 6b). Exfoliation of the silica microfillers was also observed with Silux as with all other composites. Large voids were observed, especially with Surefil (Figure 9b), and this is associated with the exfoliation of the large barium fluoroalumino borosilicate glass particles that have a mean diameter of 5.2 μm and the largest diameter of 9 μm.

The amalgam alloy had the lowest three-body wear. With the exception of Z100, the amalgam alloy experienced significantly less wear than all the composites evaluated. No significant difference in three-body wear was observed between Dispersalloy and Z100. The wear resistance of Silux and Tetric was significantly lower than that of Z100. The choice of composite in non-stress bearing, contact-free areas exposed to abrasive wear is therefore important. Composites with small particles are believed to resist abrasion by a protection mechanism in which thin expanses of resin are protected from abrasive forces by the presence of more closely spaced filler particles (Bayne, Taylor & Heymann, 1992). Silux,

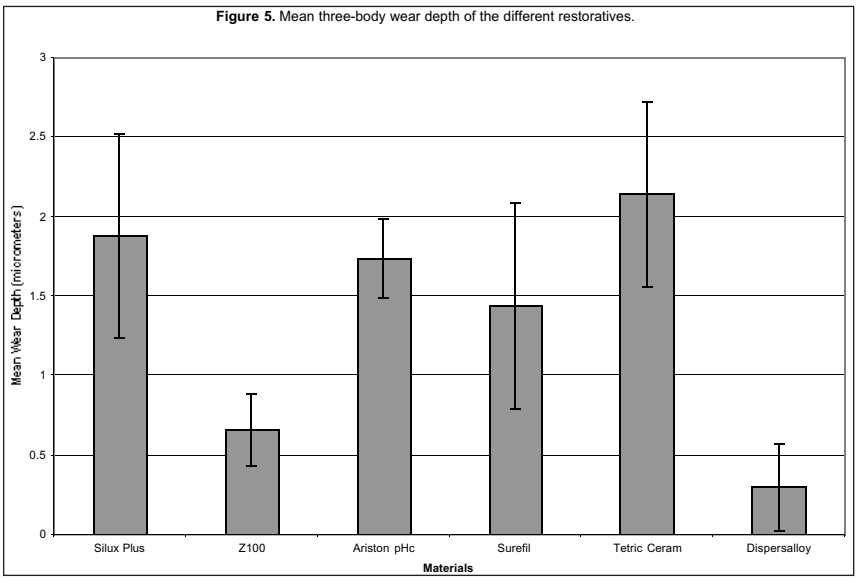

Figure 5. *Mean three-body wear depth (microns) of the different restoratives.*

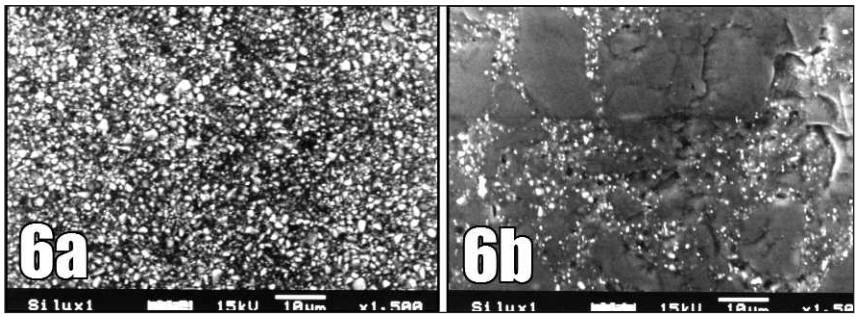

Figure 6. *SEM micrograph of Silux: (a) unworn area, (b) wear track. Magnification x1500.*

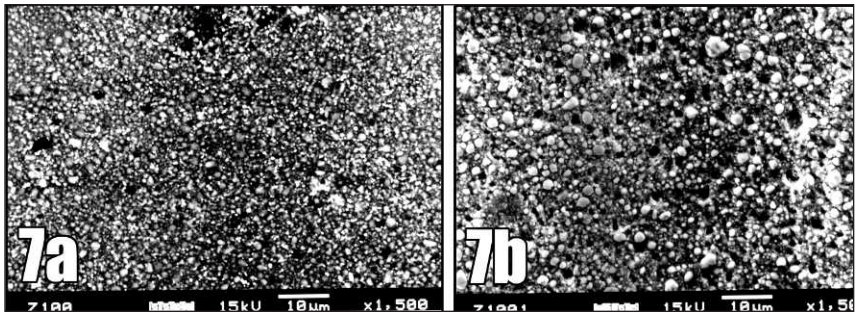

Figure 7. *SEM micrograph of Z100: (a) unworn area, (b) wear track. Magnification x1500.*

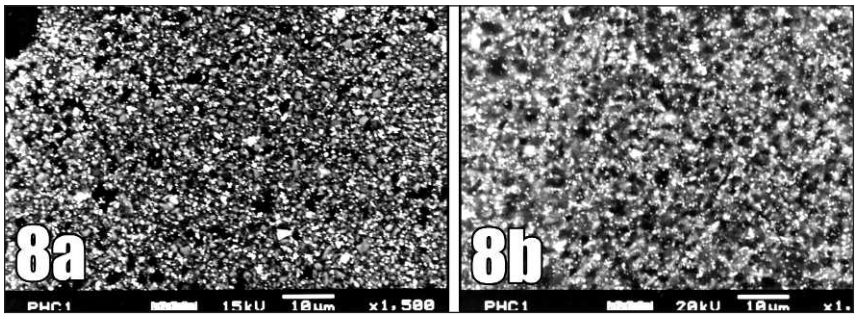

Figure 8. *SEM micrograph of Ariston pHc: (a) unworn area, (b) wear track. Magnification x1500.*

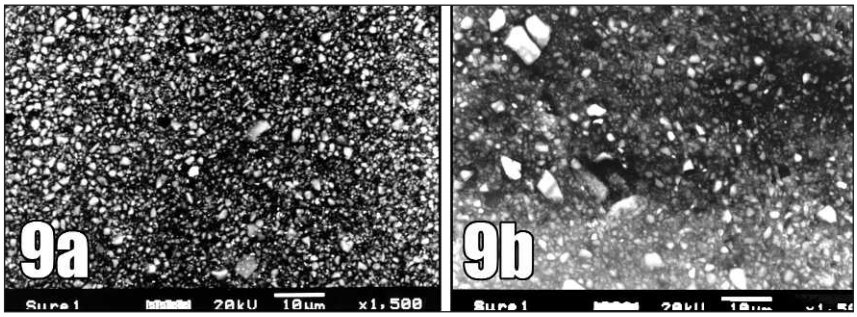

Figure 9. *SEM micrograph of Surefil: (a) unworn area, (b) wear track. Magnification x1500.*

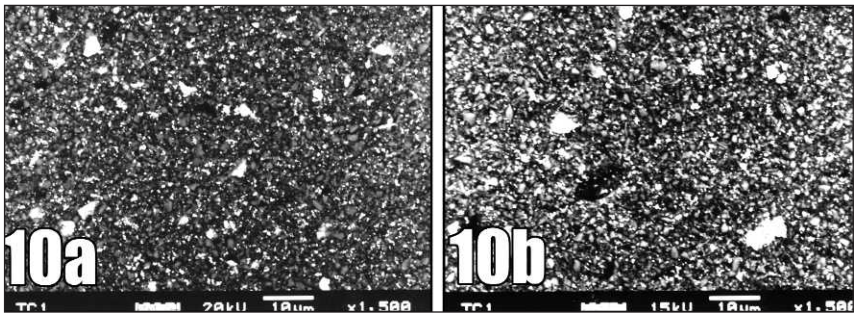

Figure 10. *SEM micrograph of Tetric Ceram: (a) unworn area, (b) wear track. Magnification x1500.*

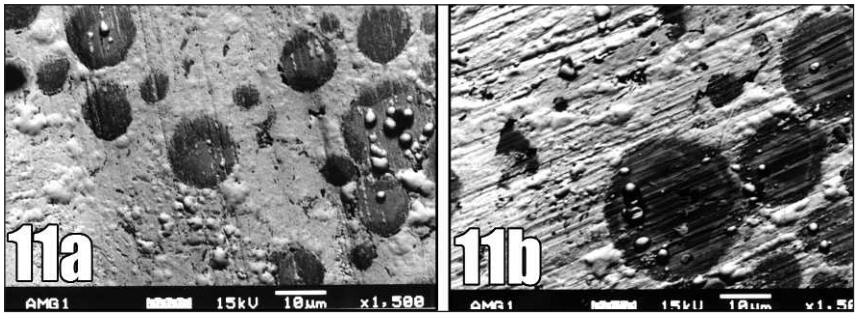

Figure 11. *SEM micrograph of Disperalloy: (a) unworn area, (b) wear track. Magnification x1500.*

being a microfilled composite, should theoretically be the most resistant to abrasive wear. The wear resistance provided by the microfillers may be mitigated by the low filler volume (40%). The significantly better three-body wear resistance of Z100, as compared to Tetric, could also be explained in part by filler volume, as the mean filler size was similar. Z100 had a filler volume of 66% while Tetric had a lower filler volume of 60%. Other factors, including filler type, filler shape and resin type may also play a part in three-body wear but this could not be determined due to the unsystemic nature of the differences in composition between materials.

Composite with higher filler volumes, such as Surefil and Z100, exhibited higher surface hardness when compared with composites with lower filler volumes. Silux Plus, with the lowest filler volume, also had the lowest surface hardness. For the composite restoratives, a significant negative correlation (correlation coefficient r=-0.45) was observed between hardness and abrasive wear. This means that materials with higher surface hardness are less prone to three-body abrasive wear (that is, more wear resistant). Attempts had been made to relate simple mechanical properties to the abrasion resistance of restorative materials. If such a relationship exists, it would satisfy the requirements of a test method for research, quality control and standard specification tests. Resistance to indentation has been studied by many workers using either hardness (McCabe & Smith, 1981; Jørgensen, 1980) or scratch tests (Roberts, Powers & Craig, 1977). This parameter would be expected to have a considerable influence if abrasive wear forms an important part of the wear process. Relatively good agreement was demonstrated between hardness and *in-vitro* abrasion resistance (McCabe & Smith, 1981; Jørgensen, 1980). This was also found in this study. However, the correlation was not strong and more research must be conducted on a wide variety of composite types to further validate this. Whether this relationship can be extended into *in-vivo* abrasive wear is yet to be confirmed as there is a general lack of correlation between *in vivo* and *in vitro* wear studies (Mair & others, 1996). It is important to note that the results apply specifically to three-body abrasive wear and cannot be translated to two-body attrition or occlusal contact area wear (Yap & others, 1999).

CONCLUSIONS

The amalgam alloy Dispersalloy had the lowest three-body wear and the highest surface hardness. With the exception of Z100, the amalgam alloy was significantly more wear resistant than all the composites evaluated. Z100 had significantly better three-body wear resistance than Silux and Tetric Ceram. A significant but weak correlation exists between three-body abrasive wear resistance and surface hardness. The use of composites as an amalgam substitute in low stress, contact-free areas exposed to three-body abrasive wear is feasible. However, choice of composite material is an important consideration.

Acknowledgments

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Wear Assessment of High Viscosity and Conventional Composite Restorative Materials

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Clinical Relevance

Relative wear rates of composite restoratives are important in the selection of materials for the placement of posterior resin restorations. The results of this study indicate that there is a significant difference in *in-vitro* wear rates of resin restorative materials.

SUMMARY

Newer composite restoratives used in the posterior dentition are marketed as high viscosity, condensable or packable materials. The *in-vitro* wear characteristics of three newer generation materials were compared to three conventional hybrid composites. Specimens were subjected to wear in a Leinfelder wear simulator equipped with a conical stylus tip to simulate localized wear. Using surface profilometry, computer generated surface maps were analyzed to determine both volumetric loss and maximum depth of wear facets for the materials tested. Volume loss (mm^3) was as follows: Z100 – 0.010 ± 0.003; SureFil – 0.014 ± 0.004; Alert 0.016 ± 0.005; Spectrum TPH – 0.042 ± 0.003; Prodigy – 0.055 ± 0.005; Solitaire – 0.062 ± 0.008. Maximum depth of the wear facets (mm) was as follows: Z100 – 69.2 ± 8.8; Alert 80.9 ± 15.4; SureFil – 82.6 ± 11.4; Spectrum TPH – 125.2 ± 15.4; Solitaire – 159.2 ± 14.9; Prodigy – 162.9 ± 22.2. The results of this study indicate that there are significant differences in the wear rates of composite materials. However, there was no clear trend that the newer high viscosity composites exhibited superior wear characteristics when compared to conventional composites.

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INTRODUCTION

Wear resistance of composite resin restorative materials is a major concern in clinical practice for restorations involving posterior occlusion (Swift 1987; Wilson, Mandradjieff & Brindock, 1990; Hu, Marquis & Shortall, 1999). While long-term clinical studies are the best way to evaluate the durability of these materials, clinical trials are time-intensive and often technically challenging to execute. The desire for reliable *in vitro* wear testing to shorten the time for obtaining meaningful data predictive of a material's clinical performance (Mazer & others, 1992) has been expressed.

Considerable efforts to develop an *in vitro* test that can simulate the masticatory conditions leading to material wear and reliably predict clinical performance (DeGee, Pallav & Davidson, 1986; Sakaguchi & others, 1986; Leinfelder, Beaudreau & Mazur, 1989; Suzuki & Leinfelder, 1994) have been made. Kawai and Leinfelder (1995) have described wear as initiated by generalized conditions (the type of wear generated by a food bolus during mastication) or localized conditions

(represented by direct tooth-to-materials contact). While several clinical studies have concentrated on generalized loss of material (Mair, 1990; Freilich & others 1992; Tyas & Wassennar, 1991; Dickinson, Gerbo & Leinfelder, 1993), Lutz & others (1984) and Lambrechts, Braem and VanHerle (1985) have suggested that localized wear may be more than twice as great as that in non-contact areas.

Leinfelder and colleagues (1989, 1999) developed a system which transfers masticatory-like stresses to a composite specimen by means of a flattened polyacetal stylus (generalized wear) or a stainless steel conical stylus (localized wear) in the presence of a slurry of polymethylmethacrylate beads (PMMA). This system has been used for evaluating the wear characteristics on numerous dental materials (Suzuki & Leinfelder, 1994; Leinfelder & Broome, 1994; Suzuki & others, 1995; Suzuki, Leinfelder & Shinkai, 1995; Leinfelder & Suzuki, 1999).

Recently developed hybrid composite resins have shown excellent resistance to wear in clinical trials (Christensen, 1998; Latta & others 1998). Continued development of composite resins has led to formulations designed to improve the handling characteristics of these materials. Of particular note has been the development of the so-called high viscosity, packable or condensable composites whose handling has been modified to mimic the condensability of amalgam (Leinfelder, Radz & Nash, 1998). These materials employ new approaches to the glass filler systems and new resin chemistries to theoretically offer superior handling and mechanical properties (product information literature, Dentsply/Caulk, Jeneric Pentron, & Heraeus Kulzer, 1999). This new class of composite resins is specifically designed for posterior restorations where wear resistance is of paramount importance. This study evaluated and compared the *in vitro* wear resistance of three new high viscosity composite resins and three conventional hybrid resins.

METHODS AND MATERIALS

An acrylic-filled custom fixture was used to place the composite resin materials for testing in a Leinfelder wear simulator. Ten specimens of three high viscosity composite and 10 specimens of three conventional hybrid resins (Table 1) were prepared. Cavities 6 mm in diameter and 3 mm deep were lathe cut into the custom fixture and composite resin materials were placed in two increments into the prepared cavity. Each increment of composite was light polymerized for 40 seconds using an Optilux 500 curing unit (Demetron/Kerr, Danbury, CT 06810). The light output, as measured with the internal radiometer, ranged from 520 to 570 mW/cm^2. The cavities were slightly overfilled with the composite materials and the surfaces polished flat using a sequence of 320 to 4000 grit silicon carbide papers (SiC paper, Stuers, Eastlake, OH 44145). The final surface finish was generated using 0.05 micron alumina polishing paste (Buehler, Lake Bluff, IL 60044).

Prior to wear testing, each specimen was surface profiled with an MTS 3D Profiler (MTS Systems Corporation, Eden Prairie, MN 55344) using Capture software (Figure 1). A tight-fitting cylinder was placed around the specimens and the assembly mounted into a water bath fixture in the wear simulator. A slurry of unplasticized PMMA beads averaging 44 microns in diameter was poured into each cylinder, covering the resin specimens. A conical stainless steel stylus mounted in a spring-loaded piston was used to produce localized wear. At a rate of approximately 2Hz, the stylus was vertically loaded onto the specimen at a load of 78.5

Table 1: *High-Viscosity and Conventional Composite Restorative Materials*

High-Viscosity Composites	
Alert	Jeneric/Pentron Inc Wallingford, CT 06492
Solitaire	Heraeus Kulzer Inc South Bend, IN 46614
SureFil	DENTSPLY Caulk Milford, DE 19963
Conventional Composites	
Prodigy	Kerr Corporation Orange, CA 92867
Spectrum TPH	DENTSPLY Caulk Milford, DE 19963
Z100	3M Dental Products St Paul, MN 55144

Table 2: *Mean Wear Rates for Composite Restorative Materials*

Material	Volume Loss (mm^3)	Maximum Depth (μm)
Z100	0.010 ± 0.003	69.2 ± 8.8
SureFil	0.014 ± 0.004	82.6 ± 11.4
Alert	0.016 ± 0.005	80.9 ± 15.4
Spectrum TPH	0.042 ± 0.003	125.2 ± 15.4
Prodigy	0.055 ± 0.005	162.9 ± 22.2
Solitaire	0.062 ± 0.008	159.2 ± 14.9

Groups connected by vertical lines are not different at the 5% significance level.

Table 3: *Analysis of Variance*

	Sum-of Squares	df	Mean-Square	P
Volume Loss				
Source/Group	0.027	5	210.578	< 0.001
Maximum Depth				
Source/Group	86692.321	5	17338.464	< 0.001

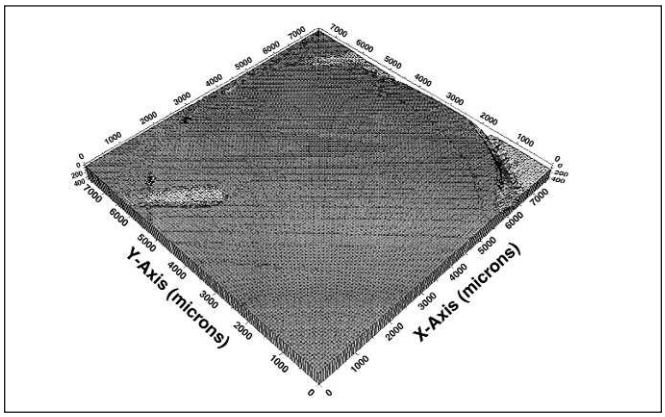

Figure 1. *Three-dimensional surface profile of a composite specimen prior to wear testing as generated with Capture software.*

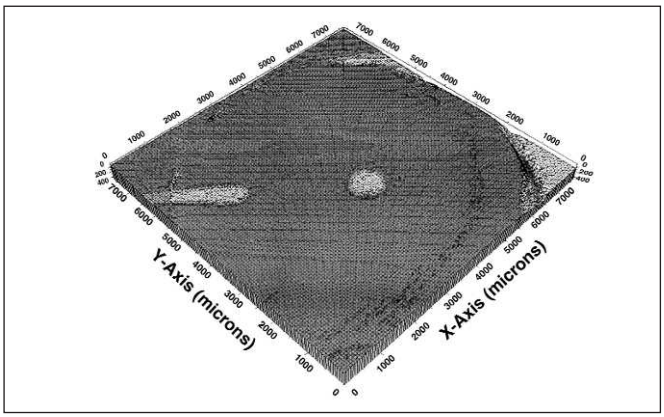

Figure 2. *Three-dimensional surface profile of specimen illustrated in Figure 1 after wear simulation in the Leinfelder apparatus.*

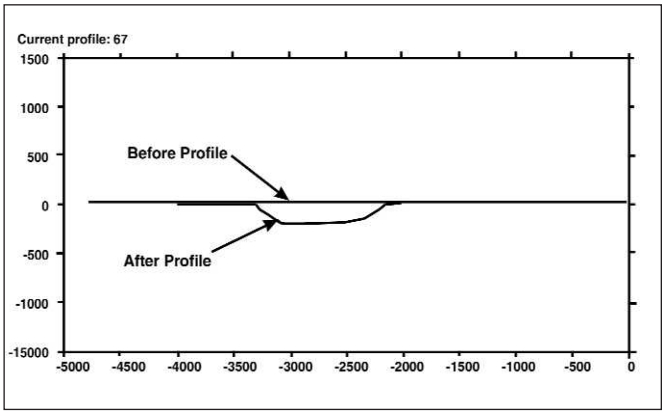

Figure 3. *Cross-sectional tracings of superimposed splines from pre- and post-wear test data sets fitted using AnSur software.*

Newtons. As the maximum load was achieved, the stylus rotated 30 degrees, then counter-rotated and moved to its original position. Four hundred thousand cycles were generated for each specimen. The specimens were removed from the testing apparatus, ultrasonically cleaned in deionized water and re-profiled in the MTS Profiler (Figure 2). The pre- and post-test surface maps were digitally compared (Figure 3) using AnSur 3D software (Minnesota Dental Research Center for Biomaterials and Biomechanics, University of Minnesota, Minneapolis, MN 55455). Volume loss in cubic millimeters (mm^3) and maximum depth in microns (μm) were calculated from differences observed between the before and after test data sets. A one-way ANVOA and Tukey's post-hoc test were used for data analysis.

RESULTS

The mean values for volumetric loss and maximum depth of the wear facets are presented in Table 2. The one-way analysis of variance and Tukey's post hoc test showed significant differences among the materials tested for both volumetric loss and depth of the wear facets (Tables 2 & 3). There was no difference ($p>0.05$) in volumetric loss between Z100 and SureFil or SureFil and Alert. The volume loss of Spectrum TPH, Prodigy and Solitaire was significantly greater ($p<0.05$) than Z100, SureFil and Alert. There was no difference ($p>0.05$) in the maximum depth of the wear facets for Z100, SureFil and Alert. The depths of wear facets for Spectrum TPH Solitaire and Prodigy were significantly greater than Z100, Surefil and Alert.

DISCUSSION

Clinical wear of posterior composite restorations has been a major concern when considering the use of tooth colored alternatives for amalgam (Phillips, 1982). Studies found wear to be a significant problem for earlier generation composite resin materials (Leinfelder, 1985; Phillips & others, 1972). However, manufacturers of dental materials have continued to address the problems related to clinical performance of composite materials. Newer generation materials exhibit very minimal wear when compared to earlier generation materials (Christensen, 1998; Mair, 1998; Latta & others, 1998).

Clinical assessment of the performance of posterior composite restorations has been limited because of the time involvement and the costs associated with clinical studies. Various methods have been used for the quantitative assessment of wear in clinical studies (Leinfelder & others, 1986; Taylor & others, 1990; Peters & others, 1999). Newer technologies and computer-assisted analysis have greatly improved the assessment of clinical wear (Conry & others, 1992; Condon & Ferracane, 1996; Mehl & others, 1997; Pintado & others, 1997; Chadwick & others, 1997).

Laboratory wear simulation methods have also improved in recent years (deGee, Pallav & Davidson, 1986; Leinfelder, Beaudreau & Mazer, 1989). Dental manufacturers have a keen interest in the use of wear simulation of prototype materials as a screening tool and predictor of clinical performance.

Lienfelder (1989) developed a piston-driven wear simulator that can be used for the generation of both localized and generalized wear. In a study using a blunted stylus of hardened steel to produce localized wear, Kawai and Leinfelder (1995) found significant differences in the worn areas of nine composite materials following 100,000 cycles. The surface areas of the defects ranged from 17,410 μm^2 for P50 to 180,610 μm^2 for Prisma APH.

A device similar to the original Leinfelder wear machine was used in this study to produce localized wear in six composite resin restorative materials. However, the assessment method was improved by using before and after digitized profiles and a sophisticated software program which generated both volumetric loss and maximum depth of the facet created during the cycling process. The results of this study also found significant differences in laboratory wear rates among the composites evaluated.

The primary objective of *in vitro* studies is to help predict *in vivo* performance. Previously published studies have shown correlation between *in-vitro* wear and *in vivo* generalized wear of dental restorative materials (Leinfelder & Suzuki, 1999). Recent clinical trials have shown minimal generalized wear with newer generation composite restorative materials (Christensen, 1998; Mair, 1998; Ferracane & others, 1997). Because improved resin formulations and greater polymerization conversion of the resin matrix have nearly eliminated generalized wear as a reason for clinical failure, localized wear may be more discriminating and clinically relevant in assessing the potential of composite materials. The *in vitro* localized wear model used in this study represents an efficient and rapid predictive tool for the wear performance of modern composite resins.

There is a tremendous demand to develop composite resins that are easy to use and provide clinical longevity similar to amalgam restorations. The newer composites, marketed as high-viscosity, packable or high-density composite, may exhibit more desirable handling characteristics for posterior restorations when compared to conventional hybrid composite resins. However, the results of this study indicate that the laboratory wear rates of the three newer high viscosity composites evaluated are similar, and in one case more than wear rates for conventional or hybrid composites.

CONCLUSIONS

Based on the results of this study, which indicate a significant difference in *in vitro* wear rates of resin restorative materials, it appears that the selection of a high viscosity material should not be based solely on the expectation of superior wear performance.

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Composite-to-Dentin Bond Strength, Micromorphology of the Bonded Dentin Interface and Marginal Adaptation of Class II Composite Resin Restorations Using Self-Etching Primers

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Clinical Relevance

Measurement of shear bond strength and analysis of marginal adaptation in Class II composite resin restorations indicate that self-etching priming agents, based on phosphate derivatives of hydrophilic monomers, are effective adhesives for composite-to-dentin bonding restorative requirements.

SUMMARY

This *in vitro* study 1) investigated the composite-to-dentin bond strength, 2) analyzed the micromorphology of the resin-dentin interface and 3) evaluated the marginal adaptation of resin composite restorations in Class II cavities using three self-etching priming agents. In the first part of the study 30 extracted human third molars were embedded in acrylic resin and ground flat with 800-grit paper. The following three self-etching priming agents/composite resins were applied to the dentinal surfaces of 10 teeth each: Clearfil Liner Bond 2/Clearfil AP-X (Group I), Etch & Prime 3.0/Degufill mineral (Group II), Resulcin AquaPrime + Mono Bond/Arabesk (Group III). Shear bond strength values measured on a T 22 K testing machine (Lloyds Instr) at a crosshead speed of 1 mm/min were: 21.7 ± 2.6 MPa (Group I), 22.4 ± 1.4 MPa (II) and 29.5 ± 2.5 MPa (III). ANOVA revealed significant ($p<0.001$) differences in shear bond strength between groups, except comparison of Group I and II. In the second part of the study specimens were prepared by application of the above mentioned bonding materials to wet-ground dentinal surfaces of 24 freshly extracted caries-free human premolars. Morphology of the resin-

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dentin interface was studied by scanning and transmission electron microscopic analyses. Tag formation could be detected with all bonding agents. Thickness of the demineralized zone/resin infiltrated layer at the dentinal surface varied from 0.8 to 2.3 µm (Group I), 2.5 to 4.0 µm (Group II), 3.5 to 6.5 µm (Group III). In the third part of the study 18 standardized Class II cavities with the proximal box extending 0.5 mm beyond the CEJ were prepared in extracted human molars. Enamel margins were beveled, dentinal cavosurface margins were prepared as butt joint and the teeth were divided into three groups (n=6, each). Cavities were restored with composite resin using the self-etching priming agents Clearfil Liner Bond 2 (Group I), Etch & Prime 3.0 (Group II) and Resulcin AquaPrime + MonoBond (Group III). Marginal adaptation of the restorations was analyzed by SEM after thermocycling (5-55°C, 2,500 cycles) and mechanical loading (100 N, 500,000 cycles). Mean/median percentages of excellent, gap-free marginal adaptation observed at the restorations proximal dentinal margins after loading were 97.5%/99% in Group I, 90.7%/98.5% in Group II and 76.3%/98% in Group III. There were no statistically significant differences between the three groups ($p<0.01$). It was concluded that the three self-etching priming agents evaluated in this *in vitro* study have the potential to provide an effective bonding between composite and dentin.

INTRODUCTION

Currently, the vast majority of effective dentin bonding agents involve acid-etching, rinsing and drying for removal of the bur-prepared smear layer before primer application. The conditioning agent, the priming solution and the adhesive resin are subsequently applied in separate steps to accomplish the resin-to-dentin bonding. With these bonding systems, the demineralization depth is frequently greater than the zone of monomer diffusion and impregnation. The resulting quality of such resin dentin bonding is suspect (Van Meerbeek & others, 1992, 1993; Eick & others, 1997). Recently, self-etching priming agents which serve simultaneously as conditioner and primer without being rinsed off have been introduced as dentin adhesive systems (Watanabe, 1992; Chigira & others, 1994; Watanabe, Nakabayashi & Pashley, 1994). The reactive molecules in these self-etching/self-priming systems are esters from bivalent alcohols with methacrylic acid and phosphoric acid or derivates (Table 1). The combined self-etching, self-priming adhesive agent applied to a dentinal surface penetrates the substrate via three-dimensional, reticulate channels formed by the self-etching primer (Watanabe & others, 1994; Nakabayashi & Saimi, 1996). Demineralization and monomer infiltration of the dentin take place simultaneously, thereby creating a hybrid layer with no need for separately applied acid etching and priming (Nakabayashi, Nakamura & Nasuda, 1991; Watanabe, 1992; Nakabayashi & Saimi, 1996).

In vitro bond strength measurements reveal the potential of self-etching priming agents in composite-to-dentin as well as composite-to-enamel bonding (Barkmeier, Los & Triolo, 1955; Gordan & others, 1997; Prati & others, 1998; Hannig, Reinhardt & Bott, 1999). The self-etching/self-priming system Clearfil Liner Bond 2, which contains the so-called phenyl-P (2-Methacryloyloxyethyl-phenyl-hydrogenphosphate, Table 1) as reactive molecule has been studied extensively (Chigira & others, 1994; Watanabe & others, 1994; Watanabe, Saimi & Nakabayashi, 1994; Barkmeier & others, 1995; Nakabayashi & Saimi, 1996; Yoshiyama & others, 1996, 1998; Miyazaki & others, 1998; Hannig & others, 1999; Ogata & others 1999) and is considered a promising material for resin composite restorations (Hayakawa, Kikutake & Nemoto, 1998). In contrast, only sparse data have been published concerning the bonding potential of more recently introduced self-etching/self-priming adhesive systems containing 2-Methacryloyloxyethyl-dihydrogenphosphate and Di-Methacryloyloxyethyl-monohydrogenphosphate (Table 1) for enamel and dentin etching purposes (Reinhardt & Rüter, 1998; Hannig & others, 1999).

This *in vitro* investigation 1) measured the composite resin-to-dentin shear bond strength after dentin pretreatment with three different self-etching/self-priming bonding agents, 2) analyzed the micromorphological aspect of the resin-dentin interface after application of the self-etching primers and 3) evaluated the marginal adaptation of composite resin restorations placed in Class II cavities with proximal margins located in dentin by use of these self-etching/self-priming materials.

METHODS AND MATERIALS

Measurement of Shear Bond Strength

Shear bond strength measurement of the three bonding agents and composite resins listed in Tables 1 and 2 took place on human dentin. The buccal surfaces of 30 crowns cut off from freshly extracted human third molar teeth stored in water were affixed to a glass plate and embedded in self-polymerizing acrylic resin (Technovit; Kulzer, Wehrheim, Germany). The pulp chamber was blocked with cement to prohibit any infiltration of the monomer into the dentin. Buccal aspects of the crowns were ground on a wet-grinding disk (800-grit) to expose a dentinal area large enough for the shear bond test. Specimens were divided into three

Table 1: *Bonding Agents Used in Experimental Groups I to III (components, ingredients, application according to manufacturers' instructions)*

Group	Product (manufacturer)	Components (Lot #)	Principle Ingredients	Mode/Steps of Application
I	Clearfil Liner Bond 2 (Kuraray Co; Osaka, Japan)	LB PRIMER liquid A (Lot #41134)	2-Methacryloyloxyethyl-phenyl-hydrogen-phosphate N-Methacryloyl-5-aminosalicylic acid Ethylalcohol	-mix LB PRIMER liquid A and liquid B -apply to enamel and dentin for 30 seconds -air blow gently -apply LB Bond to enamel and dentin -air blow gently
		LB PRIMER liquid B (Lot #41134)	Hydrophilic dimethacrylate 2-Hydroxyethyl-methacrylate Water	-light-cure for 20 seconds
		LB BOND (Lot #41178)	10-Methacryloyloxydecyl-dihydrogen phosphate 2-Hydroxyethylmethacrylate Hydrophobic dimethacrylate Bis-phenol A diglycidyldi-methacrylate SiO_2	
II	Etch & Prime 3.0 (Degussa AG; D-63403 Hanau, Germany)	Etch & Prime 3.0 Universal (Lot #059703)	2-Hydroxyethylmethacrylate Ethanol Water	-mix Etch & Prime 3.0 Universal and Catalyst -apply to enamel and dentin for 30 seconds -air blow gently -light-cure for 10 seconds -repeat the above mentioned steps
		Etch & Prime 3.0 Catalyst (Lot #059703)	tetra-Methacryloyloxy ethylpyrophosphate* 2-Hydroxyethylmethacrylate	
III	Resulcin AquaPrime + MonoBond (Merz Dental; D-24319 Lütjenburg, Germany)	AquaPrime (Lot #97200061)	2-Methacryloyloxyethyl-dihydrogenphosphate**	-mix AquaPrime with water (1:1) -scrub into the enamel and dentinal surface for 30 seconds -gently air dry -apply MonoBond to enamel and dentin -air blow gently -light-cure for 20 seconds
		MonoBond (Lot #97200061)	Bis-phenol A diglycidyldi-methacrylate Triethylenglycoldi-methacrylate Polymethacryl-oligomaleic acid	

* Contrary to the manufacturer's declaration, no pyrophosphoric acid ester could be detected by NMR-spectroscopy of Etch & Prime 3.0 (Hannig & others, 1999), rather exclusively its hydrolyzed components (2-Methacryloyloxyethyl-dihydrogenphosphate and Di-Methacryloyloxyethyl- monohydrogenphosphate).
** Resulcin AquaPrime also contains Di-Methacryloyloxyethyl- monohydrogenphosphate (Hannig & others, 1999).

groups (I to III) with 10 specimens each. The dentin was conditioned by application of the self-etching bonding agents Clearfil Liner Bond 2 (Group I), Etch & Prime 3.0 (Group II) and Resulcin AquaPrime+ MonoBond (Group III) (Table 1). Application of the bonding agents and subsequent light curing adhered strictly to the manufacturers' instructions (Table 1). The priming agents were thoroughly rubbed into the dentinal surface with a little brush and left undisturbed for 30 seconds. The primed surfaces were dried with a gentle stream of air rather than vigorously blown dry. Glass tubes with a diameter of 4 mm were mounted on the pretreated dentin surfaces to apply the composite resins (Table 2). The glass tubes could be easily removed after light curing the composite materials for 40-seconds (Translux EC; Kulzer, Wehrheim, Germany). The test objects obtained by this procedure were stored in water at 37°C for 24 hours prior to the shear bond test. After the specimens had cooled to room temperature, their shear bond strength was measured on a T 22K testing machine (JJ Lloyds Instr, Gerlingen, Germany) at a crosshead speed of 1 mm/min. Statistical analysis of comparisons among the materials were achieved by one-way ANOVA and pairwise multiple comparison (Tukey-test). The level of significance was set at $p<0.01$.

Table 2: *Composite Resins and Bonding Agents Used in Experimental Groups I to III*

Group	Bonding Agent	Composite Resin (Manufacturer)
I	Clearfil Liner Bond 2	Clearfil AP-X (Kuraray Co; Osaka, Japan) Lot #0309A
II	Etch & Prime 3.0	Degufill mineral (Degussa AG; D-63403 Hanau, Germany) Lot #301
III	Resulcin AquaPrime + MonoBond	Arabesk (Voco; D- 27457 Cuxhaven, Germany) Lot #55155

Table 3: *Dentin-to-Composite Bond Strength Measured in Groups I to III (vertical lines indicate significant differences between groups; ANOVA, p<0.001, Tukey-Test p<0.01)*

Group	Bonding Agent	Shear Strength [MPa]
I	Clearfil Liner Bond 2	21.7 ± 2.6
II	Etch & Prime 3.0	22.4 ± 1.4
III	Resulcin AquaPrime + MonoBond	29.5 ± 2.5

Table 4: *Marginal Integrity of the Proximal Region of the Restorations Expressed as Mean Percentages (± standard deviations) and Medians of Perfect, Continous Gapfree Marginal Adaptation (before and after thermo-mechanical loading)*

Group	Proximal Enamel Margins		Proximal Dentinal Margins	
	Before Loading	After Loading	Before Loading	After Loading
I	99.0 ± 1.7 100	97.6 ± 3.5 99	99.2 ± 1.9 100	97.5 ± 6.1 99
II	98.4 ± 2.6 100	96.1 ± 6.9 98	98.0 ± 3.0 100	90.7 ± 19.1 98.5
III	98.8 ± 1.8 100	89.6 ± 15.3 91	96.6 ± 8.1 100	76.3 ± 31.8 98

Micromorphology of the Resin-Dentin-Interface

To evaluate the resin-dentin interface by scanning electron microscopy, the buccal surfaces of 12 extracted human premolars were ground down using 600-grit paper to expose the dentinal surface. The three self-etching bonding agents and composite resin materials listed in Table 2 were applied to four of these dentinal surfaces. Application and light curing were performed as described above (Table 1). The bonded samples were fractured perpendicular across the resin-dentin interface, demineralized by 30 second phosphoric acid (35%) treatment and deproteinized by 5 min NaOCl (5%) treatment, water-rinsed and air-dried. SEM-analysis was performed after sputter coating with gold at 1,250x magnification.

Specimens for transmission electron microscopic analysis were also cut from 12 freshly extracted caries-free human premolars. The buccal surface was removed by wet-grinding with 600-grit paper and the exposed dentin was polished by 1,200 grit paper. The three self-etching priming agents were applied to four dentinal surfaces each, strictly following the manufacturer's instructions for each material (Table 1). No composite resin was applied to the specimens' surfaces after light curing of the adhesive bonding layer. Ultrathin sections were cut from the specimens without embedding and demineralization on an Ultracut E ultramicrotome (Reichert, Benzheim, Germany) equipped with a Microstar 45° diamond knife. Sections were mounted on Pioloform-coated copper grids, contrasted with uranyl acetate and lead citrate and investigated in a TEM 201 (Philips, Eindhoven, The Netherlands) at 80 kV. Representative photographs were obtained at 3,000 to 10,000 fold magnification.

SEM-Analysis of the Marginal Integrity of Class II Composite Restorations

Standardized, box-shaped proximo-occlusal cavities with rounded inner angles were prepared in 18 freshly extracted human third molar teeth. Gingival margins of the proximal box ended 0.5 mm beyond the cemento-enamel junction. Dimensions of proximal box preparations were 4.0 mm in width and 1.5 mm in depth (at the bottom of the box). Dimensions of the occlusal isthmus were 2-3 mm in width and 2 mm in depth. The cavo-surface margins located in enamel were beveled at a width of 0.5 mm with a diamond finisher. The gingivo-proximal margins located in dentin were prepared as butt joint. After preparation the teeth were randomly assigned to three experimental groups (I-III), each containing six teeth. Application of bonding agents in Groups I-III was performed according to the protocol summarized in Table 1 strictly following the manufacturers' directions. Dehydration and overwetting of the dentin was avoided. All priming agents were applied in excess during conditioning of the enamel and dentin. Subsequently, the pretreated cavities in Groups I-III were restored with the fine-particle hybrid composite materials listed in Table 2. Before application of the composite resin materials, a steel matrix band was placed and tightly adapted to the gingivo-proximal cavity margin. In proximal areas, up to five composite increments with a thickness of less than 1.5 mm were applied. At the occlusal part of the cavities the restorations were built up in three increments. Each composite layer was individually light cured for 40 seconds (Translux EC; Kulzer, Wehrheim, Germany) from the occlusal direction. After removing the steel matrix

band, additional light curing was performed for 60 seconds from the buccal and lingual aspects. Removing excesses, contouring and final finishing of the restorations were performed with diamond finishers (Composhape H40/H15; Intensiv, Lugano, Switzerland) and flexible disks of decreasing grain sizes (Sof-Lex Pop-On; 3M, St Paul, MN, USA).

After placement of the restorations the teeth were subjected in sequence to thermal cycling and occlusal load. Thermal cycling included 2,500 cycles within a temperature range of 50 K for the duration of 60 seconds at a minimum temperature of 5°C and a maximum of 55°C. The occlusal load involved 500,000 cycles with a force of 100 N. A stamp made of Co-Cr-Mo-alloy (Remanium CD; Dentaurum, Pforzheim, Germany) and coated with composite served as the antagonist during occlusal load. Load was applied to the restored teeth axially via the antagonist resting solely on the occlusal surface of the composite resin fillings.

Marginal integrity of the restorations was analyzed by scanning electron microscopy performed on epoxy resin replica models (Stycast; Grace, Westerlo, Belgium) before and after *in vitro* load. Marginal adaptation of the fillings was evaluated in steps of 100 µm at a 300x magnification according to the following morphologically defined parameters: "perfect margin," defined as a continuous, gap-free transition between filling and dentin or enamel, respectively; "marginal gap" (gap formation/loss of interfacial adhesion); "overhang;" and "marginal irregularity," characterized as a non-continuous, yet gap-free transition between filling and dentin or enamel. Means and medians for the percentage distribution of the varying qualities of marginal adaptation in the three groups were calculated for the gingival margins located in dentin as well as for the proximal margins located in enamel. Statistical analyses took place with non-parametrical tests (H-test according to Kruskal-Wallis at a 0.01 level of significance, the Mann-Whitney U-test for pairwise comparison of the groups with a Bonferroni-adjusted p-value of 0.01 and the Wilcoxon test for pre- and post-loading comparisons within groups at a 0.05 level of significance).

RESULTS

Shear Bond Strength

Table 3 summarizes the results of the shear bond strength measurement. ANOVA indicated significant differences ($p<0.001$) between groups. The application of Resulcin AquaPrime + MonoBond resulted in the significantly highest shear bond strength (29.5 MPa). The application of Etch & Prime 3.0 and Clearfil Liner Bond 2 resulted in significantly lower values of shear bond strength (22.4 MPa and 21.7 MPa, respectively). Shear bond strength values using Clearfil Liner Bond 2 and Etch & Prime 3.0 showed no statistically significant differences.

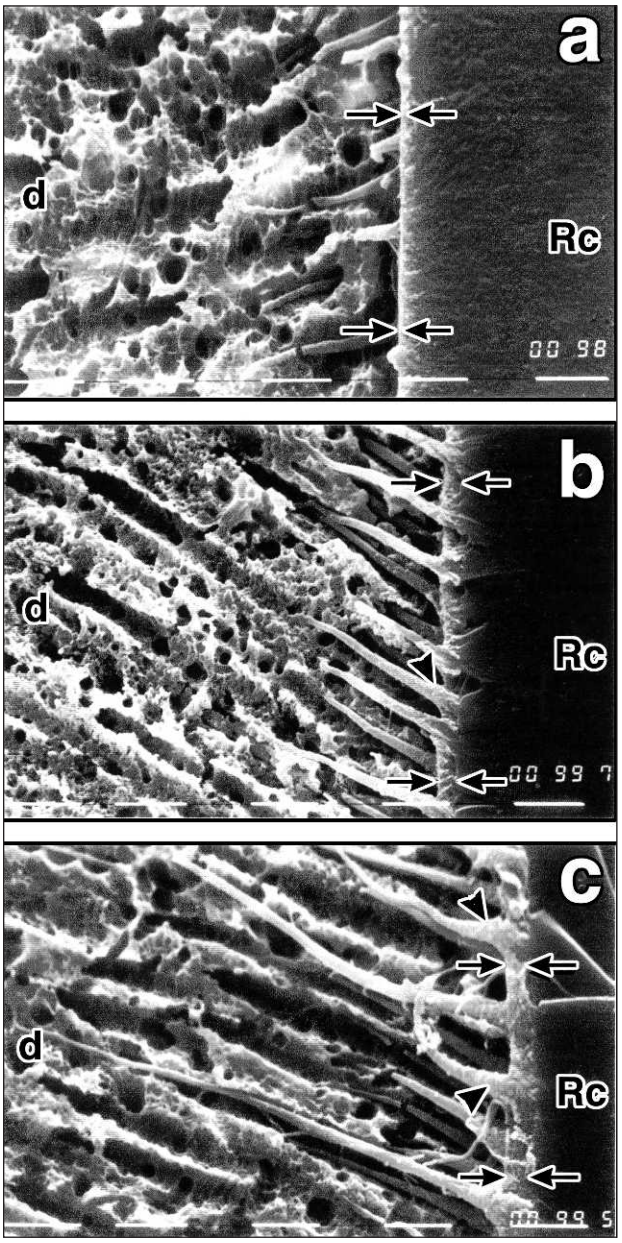

Figure 1. *SEM micrographs showing the resin composite (Rc)-dentin (d) interfaces of fractured, demineralized and deproteinized specimens treated with Clearfil Liner Bond 2 (a), Etch & Prime 3.0 (b), and Resulcin AquaPrime + MonoBond (c). Arrows indicate the hybrid layer (resin-infiltrated layer). Note the funnel-shaped morphology of the resin tags (triangle markers) directly adjacent to the hybrid layer in micrographs b and c indicating hybridization of the peritubular dentin. The resin tags exhibit multiple lateral extensions in micrographs b and c. Original magnification: x1,250; bar indicates 10 µm.*

Scanning Electron Microscopic Analysis of the Adhesive Resin-Dentin Interface

Characteristic SEM micrographs of representative specimens from Groups I-III are found in Figures 1a-c. SEM showed resin tag formation of different morphology

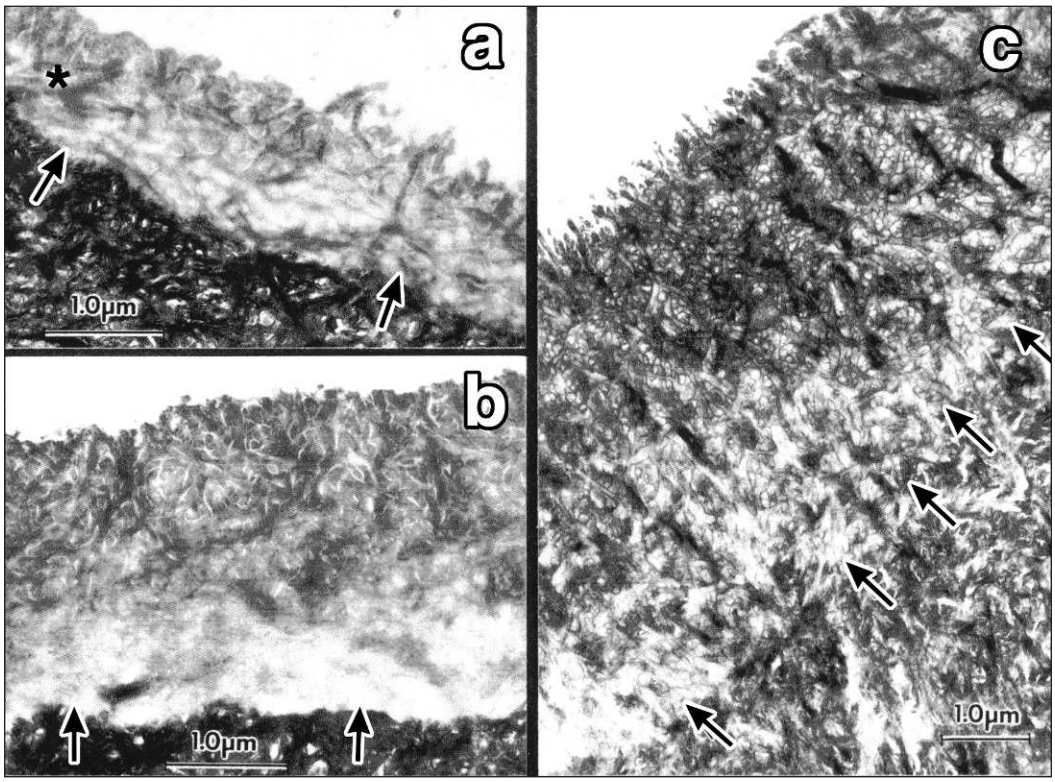

Figure 2. *TEM micrographs illustrating the resin-infiltrated dentinal surface layer obtained after application of Clearfil Liner Bond 2 (a) Etch & Prime 3.0 (b) Resulcin AquaPrime + MonoBond (c) arrows indicate the transition of the hybrid layer (demineralized, resin-infiltrated dentin) and the unaltered (non-demineralized) dentin. The electron density of the hybrid layer gradually diminishes from the dentinal surface toward the transition to the unaltered dentin. In micrograph c multiple electron-lucent channels separating the collagenic fibrils inside the hybrid layer are detectable. Note the crossbanding of the collagenic fibrils in micrograph a (*). Microfiller particles belonging to the LB Bond resin can be seen above the hybrid layer in micrograph a. Original magnification: x 10,000 (a,b), x 7,000 (c).*

and length depending on the self-etching dentin bonding agent used. Tags measured 10-40 µm (Group I and II) and 10- 70 µm (Group III) in length. Treatment with Liner Bond 2 revealed a very thin hybrid layer of ca 1 µm thickness in SEM micrographs (Figure 1a), whereas application of Etch & Prime 3.0 and Resulcin AquaPrime resulted in resin-infiltrated zones of 2.5- 4 µm and 3.5-6 µm thickness, respectively. Adjacent to the hybrid layer, resin tags appeared funnel-shaped in Groups II and III. There were few extensions of the resin tags into the lateral branches of the dentinal tubules in Group I. When the dentin was treated with Etch & Prime 3.0 (Group II) and Resulcin AquaPrime (Group III), many resin tags exhibited lateral extensions.

Transmission Electron Microscopy

Transmission electron microscopic analysis of the adhesive-dentin interface revealed ultrastructurally different resin-infiltrated dentin surface layers after application of the three self-etching primers (Figure 2a-c). In TEM micrographs from ultrathin sections of specimens belonging to Group III (Resulcin AquaPrime + MonoBond) the dentinal surface appeared less altered by the self-etching priming agents as compared to specimens of Groups I (Clearfil Liner Bond 2) and II (Etch & Prime 3.0). In Groups I and II a rather abrupt transition existed between the base of the resin-infiltrated layer and the adjacent mineralized dentin, whereas in Group III the transition between the partially demineralized superficial dentin and the unaltered dentin was smooth rather than demarcated. Thickness of the demineralized resin-infiltrated intertubular dentinal surface layer was 0.8 to 2.3 µm in Group I, 2.5 to 4.0 µm in Group II and 3.5 to 6.5 µm in Group III.

In all three groups the superficial dentin layer was characterized by a loose meshwork of demineralized collagenous fibrils which showed the typical cross-banding in longitudinally sectioned fibrils, particularly near the dentinal surface. In Groups I and II, the deeper zone of the resin-infiltrated layer adjacent to the mineralized dentin appeared less dense than the outer zone. At the dentinal surface there was no evidence for residues of the original smear layer. Longitudinally-sectioned collagen fibrils at the top of the resin-infiltrated layer in all three groups were often directed upward and appeared frayed at their ends (Figure 2).

Quantitative Marginal Analysis

The results reported in this study refer to the percentages of gap-free perfect marginal adaptation (Table 4) as well as marginal gap formation as a loss of interfacial adhesion (that may be relevant for clinical failure of the restorations). Overfilled margins and marginal irregularities represented insignificant percentages of less than 0.5%. Therefore, these data are not reported.

The proximal, dentinal and enamel margins of the restorations in Groups I-III revealed high rates of "perfect" marginal adaptation after application of the fillings, reaching levels of more than 96% (Table 4). No

significant differences were found between groups. The quality of the marginal adaptation decreased only slightly and insignificantly as a result of thermo-mechanical loading in Groups I and II (Table 4), whereas in Group III, a significant ($p<0.05$) increase in gap formation due to the loading tests was observed at the dentin-restoration interface. However, differences between Groups I, II and III with respect to the percentage frequency of "perfect margins" as well as marginal gaps after loading were not statistically significant ($p>0.01$). Mean (median) percentages of gap formation at the proximal margins located in dentin after thermo-mechanical loading were 2.5±6.1 (median: 0) in Group I, 9.2±19.1 (median: 0) in Group II and 23.7±31.8 (median: 2.0) in Group III. Debonding at the dentin restoration interface consistently took place at the top of the hybrid layer (resin adhesive layer).

DISCUSSION

Concerning the dentin-adhesive resin bonding via hybridization, the depth of demineralization and the depth of monomer diffusion have to be considered. Self-etching priming agents are very effective in penetrating the dentin while simultaneously promoting monomer impregnation at the same depth (Nakabayashi & Saimi, 1996). Hybridization created in this way is free from defects and shows a continuous transition from resin to non-demineralized dentin as clearly seen in the non-decalcified TEM micrographs of the three products evaluated in this study. However, as also shown by the SEM and TEM investigation, the hybrid layer produced by the Clearfil Liner Bond 2 system was very shallow, with a depth of only 0.8 to 2.3 µm. Similar data (ca 1 µm thick resin-infiltrated layer) has been previously published for Clearfil Liner Bond 2 (Yoshiyama & others, 1996, 1998; Hayakawa & others, 1998; Ogata & others 1999). Despite the limited resin-infiltrated dentinal surface layer, the Clearfil Liner Bond 2 is known to produce high immediate bond strengths (Gordan & others, 1997; Prati & others, 1998). In this study shear bond strength values of Clearfil Liner Bond 2 were in the same magnitude as those measured for the Etch & Prime 3.0 system which caused formation of a 2.5 to 4.0 µm thick hybrid layer. Resulcin AquaPrime + MonoBond, however, characterized by the most extensive hybrid layer formation in this investigation, revealed significantly higher composite-to-dentin shear bond strength as compared to the other two bonding systems.

SEM and TEM investigations revealed distinct differences in the ultrastructural appearance and thickness of the intertubular resin-infiltrated layer depending on the particular self-etching priming agent used. The differences in the interfacial hybridization process to produce the resin-dentin bond could be explained by the specific etching components contained in the primer solutions of the bonding agents. Etch & Prime 3.0 and Resulcin AquaPrime contain considerably more acidic 2-Methacryloyloxyethyl-dihydrogenphosphate and Di-Methacryloyloxyethyl-monohydrogenphosphate, while Clearfil Liner Bond 2 contains phenyl-P along with methacryloyl-aminosalicylic acid as reactive agents. The ultrastructural differences in hybrid layer formation observed after application of Etch & Prime 3.0 and Resulcin AquaPrime, which contain similar self-etching molecules, could be related to the fact that Resulcin AquaPrime is a mixture of water with phosphoric acid esters, whereas Etch & Prime contains water, ethanol and HEMA in the primer solution. In the case of Resulcin AquaPrime, the purely water-based solution might have favored dissociation of the phosphoric acid residues in primer molecules, causing deeper demineralization of the dentinal surface as compared to the application of Etch & Prime 3.0. The extensive tag formation observed with all three self-etching priming agents reflects the good wetting and penetration properties of the ethanol/water or solely water-based bonding materials.

Due to its intrinsic acidity, the self-etching primer is able to penetrate the smear layer and the dentinal surface and thereby creates a three-dimensional reticulate system of diffusion channels around the dentin collagen fibrils (Nakabayashi & Saimi, 1996) (Figure 2). As the self-etching process proceeds into the intertubular dentin, the perifibril porosities previously occupied by apatite crystallites become filled with the self-etching primer solution which must reach near-saturation levels of calcium and phosphate (Eick & others, 1997). Since the primer is not rinsed but only air-dried, the calcium and phosphate ions that were solubilized from the hydroxy-apatite crystals must be suspended in the watery solution of the primer. When the water is evaporated, the concentrations of calcium and phosphate in the interfibril spaces may exceed the solubility product constants for a number of calcium phosphates (Yoshiyama & others, 1996). Presumably, these minerals might precipitate as amorphous calcium phosphate particles dispersed throughout the resin infiltrated layer, like a colloidal suspension (Eick & others, 1997). The high concentrations of calcium and phosphate will tend to limit further dissolution of the apatite and thereby quickly limit the depth of surface demineralization (Yoshiyama & others, 1996; Eick & others, 1997). In addition, buffer capacity of the dentin, evaporation of water during air drying and light curing of the primer and subsequently applied bonding agents will restrict and inhibit the self-etching effect of the primer molecules.

The establishment and maintenance of an effective marginal seal should be a major criterion in evaluation of materials and techniques for Class II composite resin restorations (Garberoglio, Coli & Brännström,

1995). Adhesion of composite resin materials to enamel has become a routine and reliable aspect in restorative treatment of Class II cavities (Swift, Perdigão & Heymann, 1995; Hannig & others, 1999), but dentinal adhesion has proved to be more difficult and less predictable. The ability to render a non-leaking, gap-free Class II composite resin restoration beyond the cemento-enamel junction depends on how the dentin adhesive/bonding agent performs in resisting polymerization contraction, thermal and occlusal loading stresses on the resin composite (Retief, 1994). After placement of the restorations, high rates of more than 96% gap-free perfect marginal seal were established in all test groups at the interface both between restoration material and enamel and dentin. Thus, polymerization shrinkage alone did not cause any significant marginal disintegration at the cervico-proximal area of the Class II restorations placed with the adhesive-restorative material combinations chosen in this study. Similar findings have been previously reported by Da cunha Mello & others (1997).

Concerning the median values of perfect marginal adaptation obtained in Groups I, II and III after thermocycling and mechanical loading, all three material combinations tested in this study provided a satisfactory marginal integrity in Class II cavities with proximal margins located in dentin. However, loading tests led to a significant loss of the restorations' seal at the cervical dentinal margins in Group III, whereas in Groups I and II no significant load-induced marginal disintegration could be detected. In addition, a greater variability in the percentages of perfect marginal integrity was observed with the Resulcin AquaPrime + MonoBond (Group III) as compared to the Clearfil Liner Bond 2 and Etch & Prime 3.0 systems. One major difference among the three self-etching priming agents tested in this study is that Clearfil Liner Bond 2 and Etch & Prime 3.0 have alcohol as a solvent in their composition, compared to Resulcin AquaPrime + MonoBond, which is a solely water-based system. The alcohol containing systems showed less variability in marginal sealing compared to the water-based system. The presence of alcohol in the priming solution might have favored evaporation of water during air drying of the primer treated dentinal surface.

Water persisting within the bonding resin could adversely affect co-polymerization between the restorative material and the adhesive treated dentinal surface, thereby causing marginal disintegration during thermo-mechanical loading of the composite resin restorations. Further studies are underway to clarify these presumptions.

The data on the excellent marginal adaptation of the Liner Bond 2 fillings in Class II cavities after *in vitro* loading match previous findings indicating that only a small decrease in bond strength to dentin is observed after extensive thermal cycling (30,000 cycles) of Liner Bond 2 specimens (Miyazaki & others, 1998). The Etch & Prime 3.0 bonding system evaluated in this study, in combination with a composite resin material, also performs well in combination with an Ormocer material in Class II cavities with proximal margins located in dentin (Hannig & Bott, 2000). Comparison of the present data on marginal integrity obtained by the use of the self-etching bonding agents with data on marginal seal achieved with other adhesive systems is limited by the fact that only few studies have been published on the marginal adaptation of Class II composite restorations using a similar experimental design of *in vitro* loading as in this study. Gap formation on less than 10% of the dentin-filling interface after *in vitro* loading was found in Class II composite restorations placed by use of the Scotchbond Multi-Purpose or the All-Bond 2 adhesive system after total etching with phosphoric acid (Thonemann & others, 1999). Dietschi & Herzfeld (1998) reported a value of 74.6% continuous margins at the cervico-proximal area of direct Class II composite resin restorations after thermal cycling and mechanical loading when using the Syntac Classic adhesive systems. These results indicate that the self-etching priming agents evaluated in this study have at least the same potential as the well established adhesive systems mentioned above to provide a load resistant adaptation at the dentinal proximal margins of Class II composite resin restorations.

Previous studies concerning the effect of the smear layer on dentinal bonding mediated by self-etching adhesive materials indicated that the smear layer should possibly be removed prior to application of the self-etching primer even when reinforced by diffused and polymerized resin (Watanabe & others, 1994; Toida, Watanabe & Nakabayashi, 1995). However, no special treatment for smear layer removal was performed in this study; nevertheless, high percentages of continuous gap-free marginal adaptation were detected. Therefore, a separate previous removal of the smear layer does not appear essential for obtaining a perfect marginal adaptation when using self-etching priming agents.

High levels of gap-free marginal adaptation were obtained not only at the restoration-dentin interface but also at the restoration's proximal margins located in enamel using the self-etching primers. These results are consistent with other data on the marginal adaptation of Class II composite resin restorations placed by use of self-etching priming agents without phosphoric acid pretreatment of the enamel (Hannig & others, 1999).

CONCLUSIONS

The results of this *in vitro* study indicate that self-etching primers are effective in conditioning the dentinal

surface to secure a durable bonding and marginal seal of composite resin restorations.

The composite-to-dentin bond strengths attained by the three tested self-etching primers were comparable to that attained by the conventional acid-etch technique at the enamel surface. Hybrid layer formation, as well as extensive tag formation, could be observed with the three self-etching/self-priming systems involved in this investigation. However, depending on the particular self-etching primer used, distinct differences in ultrastructural appearance and thickness of the resin-infiltrated layer were detected.

Placement of Class II composite resin restorations using self-etching primers revealed a satisfactory marginal adaptation at the restoration's margins located in dentin and enamel even after thermo-mechanical loading.

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Color Stability of Ionomer and Resin Composite Restoratives

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Clinical Relevance

Perceptible changes in color were recorded for the conventional glass ionomer, resin-modified glass ionomer and compomer materials tested in this study. Therefore, those materials should not be considered color stable.

SUMMARY

This study compared the color stability of a conventional glass ionomer (Ketac-Fil), a light polymerized resin-modified glass ionomer (Photac-Fil), a polyacid-modified resin composite or compomer (Dyract) and a microfilled resin composite (Silux Plus). Thirty-two specimens (n=8/material) were fabricated and stored in artificial saliva at 37°C for seven weeks. A colorimetric evaluation, according to the CIE L*a*b* system, was performed at 24 hours (baseline) and at the end of each week. Color difference values (ΔE*ab) were calculated. The conventional glass ionomer, resin-modified ionomer and compomer materials underwent significant color changes over time ($p<0.01$). Those materials darkened and showed color shifts in both the red-green and yellow-blue axes.

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INTRODUCTION

Glass-ionomer (GI) restorations are known to release fluoride and are indicated for use in teeth with a high caries potential (Swartz, Phillips & Clark, 1984; Hattab, Mok & Agnew, 1989). However, the materials are also technique sensitive and their aesthetic properties have limited their use as dental restoratives. Early glass-ionomers lacked color stability and were likely to yellow and darken over time, leading to unaesthetic restorations. Recent improvements have made newer generations of glass ionomers a potential alternative in many restorative situations (Mount, 1994). The resin-modified glass ionomers and polyacid-modified resin composites (compomers) may possess superior aesthetic properties when compared to traditional glass ionomers (Burgess, Norling & Summitt, 1994; Inokoshi & others, 1996). This study evaluated the color stability of a conventional GI, a resin-modified GI and a polyacid-modified resin composite (compomer) compared to a microfilled resin composite material.

METHODS AND MATERIALS

Table 1 lists the restoratives selected for this investigation. The materials included a conventional GI (Ketac-

Table 1: *Manufacturers' Data for Materials Used*

Material (n=8/group)	Composition	Manufacturer/Batch No
Ketac-Fil (encapsulated, conventional, glass ionomer, shade=Y)	sodium, calcium aluminum fluorosilicates, shade pigments, polycarboxylic acid, tartaric acid, water	ESPE GmbH, Seefeld-Oberbay, Germany (Lot 043/11x95)
Photac-Fil (encapsulated, resin-modified, glass ionomer, shade=B3)	sodium, calcium, aluminum fluorosilicates, shade pigments, vacuum dried copolymer of acrylic and maleic acids, HEMA, camphorquinone, water	ESPE GmbH (Lot 0011x204)
Dyract (encapsulated, polyacid-modified, resin composite, shade= B3)	strontium, aluminum fluorosilicates, UDMA, diester of 2-hydroxyethylmethacrylate and butan tetracarboxylic acid	L D Caulk Company Milford, DE 19963 (Lot 9510158)
Silux Plus (microfilled, resin composite, shade=Y)	Bis-GMA, TEGDMA, colloidal silica	3M Dental Products, St Paul, MN 55144 (Lot 5702U6DD)

Fil), a resin-modified GI (Photac-Fil) and a polyacid-modified resin composite or compomer (Dyract). A microfilled resin composite (Silux Plus) was used as reference. For each material, eight disks (n=8), 10 mm in diameter and 1.2 mm in depth, were fabricated. The materials were mixed according to manufacturers' instructions and polymerized within a metal ring placed between two glass slabs. The chemically activated specimens remained in the mold for 10 minutes during polymerization. The top surface of the light-polymerized specimens was initially irradiated for 40 seconds with a visible light (Elipar II, ESPE GmbH). An additional 20-second exposure was administered to the bottom surface following removal from the mold. The light output was verified to be 350 mW/cm^2. All samples were polished to a thickness of 1.0 ± 0.025 mm using moist 400, 600 and 800 grit silicon carbide papers. A carborundum disc was used to create a small alignment notch on the side of each specimen. Samples were immediately placed in artificial saliva solution, pH=6.0 (el Mallakh & Sarkar 1990) at 37°C. The incubator did not allow exposure to ambient light. The storage solution was changed weekly during the course of the study.

Sample color was measured with a Chroma Meter (CR-221, Minolta Corporation, Ramsey, NJ 07446) using standard illuminant C with a 45° illumination and a 0° viewing angle geometry. Data were recorded as L*a*b* coordinates established by the Commission International de l'Eclairage (CIE).

Color measurements were made at 24 hours (baseline) and weekly for seven weeks after specimen fabrication. Samples were blotted dry with tissue paper and measured 30 seconds after removal from artificial saliva. An alignment device was fabricated for the colorimeter head to correspond with the notch placed in each sample to ensure repeatable orientation between weekly measurements.

The color measurements were determined against a neutral gray background. Color difference values (ΔE*ab) between baseline and subsequent measurements were expressed as a distance between two points in three dimensional space and calculated according to the following formula: $\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Data were analyzed using mixed linear model theory for repeated measures with a sandwich estimator for the variance-covariance matrix (Diggle, Liang & Zeger, 1994; Littell & others, 1996). At each week's interval, a test of group effect was performed, when appropriate, followed by multiple comparisons testing from the mixed linear model. For the post-hoc tests, the p-value was adjusted using the formula: $\alpha^*=1-(1-\alpha)^{1/k}$, where k is the number of groups (four) and α is the significance level (set at 0.05) (Miller, 1981). All tests were performed using SAS (*SAS User's Guide*, 1988).

RESULTS

Group mean values, standard deviations and post-hoc tests are presented in Tables 2-5. On average, the L* values of the conventional GI (Ketac-Fil) and the resin-modified GI (Photac-Fil) decreased over time, while the L* value of the polyacid-modified resin composite (Dyract) increased (Table 2). On the red-green axis (a* values), the materials averaged a slight shift toward the red direction (Table 3). On the yellow-blue axis (b* values), a slight shift toward the blue was evident for Silux Plus, Ketac-Fil and Dyract (Table 4). Photac-Fil demonstrated an initial shift towards yellow and returned to baseline value over the length of the experiment. Table 5 presents the calculated average color difference, ΔE*ab. A higher value represents increasing discoloration of the materials. Significant color changes were observed after the seven-week period for each material not withstanding the resin composite group.

DISCUSSION

The CIE L*a*b* color order system provides a useful tool for quantifying color properties of dental materials.

Table 2

L* coordinate. Raw data and post-hoc tests

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	63.87 (0.3)	63.97 (0.42)	63.92 (0.57)	64.22 (0.37)	64.50 (0.43)	64.36 (0.36)	63.82 (0.39)	64.3 (0.36)
Ketac-Fil	69.22 (0.81)	66.35 (0.67)	64.03 (1.29)	64.37 (1.19)	64.75 (1.44)	64.41 (1.20)	63.80 (1.09)	66.47 (0.95)
Photac-Fil	62.93 (2.0)	61.43 (1.89)	60.17 (1.45)	60.62 (1.87)	60.34 (2.21)	59.71 (1.57)	59.53 (1.37)	59.87 (1.70)
Dyract	58.91 (1.23)	59.01 (1.37)	59.41 (1.38)	59.25 (1.02)	60.03 (1.66)	60.76 (1.57)	61.52 (1.75)	61.38 (1.89)

Standard deviations in parentheses.

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	A	A	A	A	A	A	A	A
Ketac-Fil	B	B	B	A	A	A	A	B
Photac-Fil	A	C	C	B	B	B	B	C
Dyract	C	D	C	B	B	B	B	C

Group means, by time, with the same letter are not statistically significant ($p<0.001$).

Table 3

a* coordinate. Raw data and post-hoc tests.

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	-3.13 (0.06)	-3.05 (0.05)	-3.28 (0.06)	-2.84 (0.05)	-3.21 (0.05)	-3.07 (0.03)	-2.9 (0.03)	-2.56 (0.07)
Ketac-Fil	-0.94 (0.10)	-0.95 (0.01)	-1.28 (0.12)	-0.82 (0.10)	-1.22 (0.12)	-1.07 (0.15)	-0.92 (0.09)	-0.38 (0.08)
Photac-Fil	-0.32 (0.11)	-0.32 (0.05)	-0.52 (0.05)	-0.18 (0.05)	-0.52 (0.06)	-0.41 (0.05)	-0.24 (0.06)	0.12 (0.05)
Dyract	-0.40 (0.05)	-0.47 (0.08)	-0.64 (0.07)	-0.33 (0.09)	-0.68 (0.07)	-0.6 (0.05)	-0.43 (0.07)	-0.06 (0.08)

Standard deviations in parentheses.

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	A	A	A	A	A	A	A	A
Ketac-Fil	B	B	B	B	B	B	B	B
Photac-Fil	C	C	C	C	C	C	C	C
Dyract	D	D	D	D	D	D	D	D

Group means, by time, with the same letter are not statistically different ($p<0.001$).

Color is described using a mathematical three-dimensional system based on an equal distance in the color space that is directly correlated with equally perceived gradations. This system divides color into three attributes. L* is a measure of value or brightness. The a* measures the hue-chroma in the red-green direction, while b* measures hue-chroma in the blue-yellow axis. High L* values are obtained for bright or white samples. Positive a* values are red, negative values are green. Positive b* values are yellow, negative values are blue. Each unit of color difference (ΔE^*ab) represents the delineation point of human detection for 50% of the subjects studied (Kuehni & Marcus, 1979). Colorimetric measurements have correlated well with visual observations (Johnston & Kao, 1989; Seghi, Hewlett & Kim, 1989) and changes in color difference values of less than 3.3 are considered clinically insignificant (Ruyter, Nilnu & Moller, 1987).

The discoloration of dental materials is multifactorial and related to water sorption, cracks, porosities and surface finish, conversion rates and thermal postcuring or photochemical aging (Dietschi & others, 1994). In this study, the conventional ionomer (Ketac-Fil) showed the most abrupt and significant color change. The newer generation materials (Photac-Fil and Dyract) showed a more gradual color change over time. However, by the end of the seven weeks, those three types of materials showed color differences greater

Table 4

b* coordinate. Raw data and post-hoc tests.

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	6.81 (0.19)	6.69 (0.23)	6.94 (0.09)	6.75 (0.20)	6.81 (0.32)	6.44 (0.26)	6.36 (0.36)	6.06 (0.27)
Ketac-Fil	12.42 (0.48)	11.51 (0.72)	12.62 (1.21)	11.80 (1.27)	11.40 (1.70)	10.95 (1.43)	11.14 (1.08)	8.27 (1.18)
Photac-Fil	7.66 (0.74)	7.79 (0.84)	8.42 (0.44)	8.17 (0.97)	8.28 (0.97)	8.31 (0.67)	8.30 (0.50)	7.61 (0.65)
Dyract	6.70 (0.62)	6.59 (0.64)	6.32 (0.63)	6.42 (0.49)	6.21 (1.07)	4.90 (1.19)	4.36 (0.95)	4.17 (1.12)

Standard deviations in parentheses.

	Baseline	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	A	A	A	A	A	A	A	A
Ketac-Fil	B	B	B	B	B	B	B	B
Photac-Fil	C	C	C	C	C	C	C	C
Dyract	A	A	A	A	A	A	A	A

Group means, by time, with the same letter are not statistically different ($p<0.001$).

Table 5

Calculated color difference (ΔE*ab) and post-hoc tests.

	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	0.33 (0.30)	0.50 (0.22)	0.56 (0.17)	0.72 (0.21)	0.64 (0.28)	0.78 (0.37)	1.08 (0.26)
Ketac-Fil	3.05 (0.66)	5.36 (1.52)	5.01 (1.19)	4.93 (1.38)	5.30 (0.70)	5.75 (1.20)	5.14 (0.80)
Photac-Fil	1.54) (0.71	2.91 (1.36)	2.50 (0.61)	2.78 (1.14)	3.43 (1.29)	3.54 (1.46)	3.46 (1.37)
Dyract	0.54 (0.60)	0.89 (0.83)	0.94 (0.41)	1.51 (1.11)	2.60 (1.29)	3.52 (1.45)	3.58 (1.74)

Standard deviations in parentheses.

	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
Silux Plus	A	A	A	A	A	A	A
Ketac-Fil	B	B	B	B	B	B	B
Photac-Fil	C	C	C	C	C	C	C
Dyract	A	D	D	C	C	C	C

Group means, by time, with the same letter are not statistically different ($p<0.001$).

than 3.3, while the microfilled resin composite (Silux Plus) showed minimal color change (ΔE*ab = 1.08, Table 5).

Inokoshi & others (1996) reported that resin-modified GIs undergo an abrupt change in color. Other studies have shown that the intrinsic coloration of composites is affected by storage conditions (Powers, Barakat & Ogura, 1985; Asmussen, 1981; Fruits, Duncanson & Miranda, 1997). Inokoshi & others (1996) accelerated the aging of samples by storing them at 37°C between two glass slides for one week followed by water storage at 60°C. Their sample surfaces were coated with light-polymerized unfilled resin and not polished. The reported rapid change in color may reflect the rapid deterioration of the thin resin film during the stress of accelerated aging. In contrast, Hotta, Hirukawa & Yamamoto (1992) concluded that light-polymerized bonding agents maintained the color stability of glass ionomer cements by limiting water movement across the setting-cement surface. It may be that the bonding agent can minimize initial color change but cannot compensate for long-term discoloration.

The GI samples in this study were not coated with unfilled resin, so as to standardize the testing surface between the glass ionomers and the resin composite material. Burgess, Norling & Summitt (1994) recommend the application of unfilled resin to the surface of resin ionomers only in low caries-risk patients because

the resin film fills in small defects but decreases fluoride release and uptake. Our samples also underwent progressive surface finishing to optimize the surface finish and remove the "resin-rich layer" obtained when composite has been polymerized against a glass surface. The improved resistance to discoloration in polished samples has been previously documented (Hachiyha & others, 1984; Stanford & others, 1985).

An attempt was made to confirm the shade of all materials tested. Vita B3 shade (Vita-Zahnfabrik, Bad Säckingen, Germany) was selected for Photac-Fil and Dyract. Ketac-Fil and Silux Plus are not available in Vita shades; thus, the corresponding available "yellow" shade was tested. A yellow, high chroma shade was selected because a previous study identified the main component of discoloration for resin-modified GIs to be a decrease in lightness (Inokoshi & others, 1996). It was the authors' intent to investigate differences in a color rich shade. Indeed, the conventional and resin-modified GIs used in this study darkened over time (lower L* value). The compomer material (Dyract) showed a gradual increase in lightness. During this investigation all materials showed a slight increase in a* values (shift towards red) and a slight up and down variation in b* values (yellow to blue).

Clinical evaluations of resin-modified glass ionomers have reported favorable color retention after one year (Maneenut & Tyas, 1995) or slight, but acceptable color shifts after three years (van Dijken, 1996). Other studies have shown evidence of darkening after two or three years of service (Abdalla, Alhadainy & García-Godoy, 1997; de Araujo, Araujo & Marsilio, 1998). Brackett & others (1999) judged 34 Class V Photac-Fil restorations and reported 100% acceptable color match at placement. However, by 12 months, 7% of the restorations were judged to have an unacceptable mismatch and 17% showed evidence of marginal discoloration.

Conventional glass ionomers have demonstrated substantial cavosurface discoloration during clinical service (Osborne & Berry, 1990). Brackett & others (1999) reported that 27% of Ketac-Fil restorations had a color mismatch (although acceptable) and 7% showed evidence of marginal discoloration as early as 12 months. Brackett & others (1999) concluded that Ketac-Fil and Photac-Fil demonstrated adequate clinical performance but warned that conventional GI and resin-modified GI restorations would be subject to discoloration in the anterior maxilla of smokers.

Recently, the manufacturers of Photac-Fil introduced Photac-Fil Quick. The newer product incorporates the acid into the liquid component to facilitate the bond to dentin and enamel and discontinue the use of Ketac-conditioner (a 25% polyacrylic acid surface cleaning solution). A radiopaque, strontium-lanthanum-aluminum-silicate filler was also incorporated. Dyract AP has superseded Dyract with changes in the particle size of their $SrAlFSiO_4$ filler. However, the HEMA or UDMA content of Photac-Fil Quick and Dyract AP, respectively, remain the same when compared to the HEMA and UDMA content of their predecessors. Those methacrylate components are hydrophilic and susceptible to water uptake and water-based staining (Mount, 1999). Thus, the color stability of the older and newer versions should be similar (Paul Hammesfahr, LD Caulk Company, personal communication; Robert May, ESPE GmbH, personal communication).

In this study, the authors did not dismiss the active role of dietary and hygiene habits in maintaining the integrity of dental restorations. While the study did not duplicate intraoral conditions, it is interesting to note that the conventional ionomer, resin-modified ionomer and compomer materials exhibited color changes even under minimally taxing conditions. It was the authors intent to identify short-term discoloration characteristics. This finding is of value to the clinician when selecting a restorative material for use in an aesthetically demanding situation.

CONCLUSIONS

The conventional GI (Ketac-Fil), the resin-modified GI and the compomer (Dyract) exhibited significant color change over time. Thus, although resin-modified glass ionomers and compomers may be less technique sensitive, the material types represented in this investigation should not be considered color stable.

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Microleakage of "One Bottle" Dentin Adhesives

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Clinical Relevance

There was no significant difference in microleakage scores between the fifth generation (One Bottle) and fourth generation dentin adhesive resins.

SUMMARY

This study evaluated the marginal sealing ability of five "One Bottle" fifth generation dentin adhesive resins. Bond 1, Single Bond, Tenure Quick with fluoride, One-Step and Prime & Bond 2.1 were evaluated. Tenure All-Surface Bonding System, a fourth generation dentin adhesive resin, was used as the control group.

A Class V preparation (3 mm diameter, 1.5 mm deep) was placed at the cemento-enamel junction of 60 extracted human premolar teeth. A 1 mm 45° bevel was placed at the enamel margin. Each group of cavities were restored using one of the dentin adhesives and the same restorative resin. Following five days storage in 37°C water, the restored teeth were thermocycled for 500 cycles between 5°C and 55°C for one minute in each cycle. Microleakage was assessed by dye penetration using 0.2% Basic Fuchsin dye. After 24 hours the teeth were sectioned longitudinally and evaluated for microleakage. The results were analyzed using the non-parametric Kruskal-Wallis Test.

Microleakage at the enamel margins was not evident in any group. However, leakage was present at the gingival margin (cementum) in all of the treated groups. There were no significant differences between gingival margins ($0.75>p>0.5$). When comparing the gingival margin microleakage scores between two groups or within the same group, statistical analysis showed no significant difference. The new "One Bottle" dentin adhesives have similar marginal sealing ability to that of the control group.

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INTRODUCTION

The effects of bacterial leakage upon the dental pulp are well documented (Bergenholtz & others, 1982; Brannstrom, 1981 & 1987). Prevention of bacterial access along the margins of restorations are therefore a high priority. As early as 1861, in an effort to determine the effectiveness of dental restoratives as sealant, microscopic examination of amalgam marginal contraction was carried out by Tomes (Blackwell, 1955), followed by experiments into the leakage of dye indicators around the margins of amalgam packed into glass tubing.

Since these early experiments, countless workers have attempted to demonstrate microleakage and improve the marginal seal. Microleakage may be defined as the passage of bacteria, fluid, molecules or ions between a cavity wall and the restorative material applied to it (Kidd, 1976). Many different techniques have been used to demonstrate microleakage. These techniques include the use of bacteria, compressed air, chemical and radioactive tracers, electrochemical investigations, scanning electron microscopy, and perhaps most common of all, dye penetration. These methods have also been used with varying degrees of success in the study of modern endodontic materials (Taylor & Lynch, 1992). Investigation of leakage has been carried out both *in vivo* and *in vitro*, but the latter is more common. *In vitro* experiments fall broadly into two categories—those which use a clinically relevant model that attempts to reproduce the oral situation and those where the model does not represent a clinical simulation and is purely a test of the materials behavior (Taylor & Lynch, 1992). The most currently used dentin adhesive resins (DAR) are known as fourth and fifth generation. The use of fourth generation DAR involves three steps: etching with an acidic conditioner, priming with hydrophilic resin in solvent and bonding with an unfilled or lightly filled resin (Pilo & Ben-Amar, 1999). Newer generations of DAR combine both primer and adhesive resin into a single solution and is referred to as the fifth generation. The use of one bottle makes their use in the clinic simpler and less time-consuming (Pilo & Ben-Amar, 1999). There is little published data available comparing the fourth and fifth generations. Castelnuovo, Tjan & Liu (1996) have found less microleakage at the cementum margins with OptiBond FL and One-Step compared to their multi-step versions. Pilo & Ben-Amar (1999) have reported that the Scotchbond Multi-Purpose and Single Bond adhesives provided the best seal for enamel margins, and One-Step and OptiBond FL adhesives were best for cementum margins. This study evaluated five "One Bottle" fifth generation dentin adhesive resins in preventing microleakage.

METHODS AND MATERIALS

Sixty non-carious extracted human permanent premolars were used. The teeth were stored in 0.1% thymol solution at room temperature after extraction. They were cleaned by removing the remaining soft tissue and stored in a saline solution until use. The apices of the roots were removed with a separating disc. Immediately prior to the cavity preparation, the tooth surfaces were cleaned with pumice and water with a rubber cup using a slow speed handpiece. Class I preparations were made at the cut root surfaces with an inverted cone carbide bur. Two coats of Copal cavity varnish were applied to the preparations and the specimens were restored with Dispersalloy amalgam. This procedure effectively eliminates microleakage at the root apices. A Class V cavity was prepared in the buccal surface of each tooth with a #330 carbide bur in a high speed handpiece with water coolant.

Each cavity preparation included an occlusal margin in enamel and a gingival margin in dentin or cementum. All cavities were prepared as uniformly as possible with a mesio-distal length of 3 mm and an occluso-gingival width of 3 mm. The axial wall was prepared at a depth of 1.5 mm. A short bevel (45°, 1 mm) was prepared at the occlusal margin using a fine diamond point. The cavities were conditioned using one of the dentin adhesive resins. The six dentin adhesives were Bond 1 (J/P Inc Wallingford, CT), Single Bond (3M, St Paul, MN), Prime & Bond 2.1 (Caulk/Dentsply, Milford, DE), Tenure Quick with Fluoride (DenMat, Inc, Santa Maria, CA), One-Step (BISCO, Inc, Itasca, IL) and Tenure All-Surface Bonding System (DenMat, Inc, Santa Maria, CA). Each adhesive was handled according to the manufacturer's instructions. The cavities were restored with the composite resin (Z100 A4 - 3M, St Paul, MN) and cured for 40 seconds. Ten specimens were made for each adhesive material. During composite placement, a two-step procedure was used. The first increment was placed into the gingival part, condensed and cured. The second increment was applied to fill the rest of the cavity and cured. Finishing and polishing were accomplished using Sof-lex discs. The restored teeth were stored in water at 37°C for five days before further treatment.

The teeth in each group were thermocycled for 500 cycles at 5°C and 55°C. Immersion time was 30 seconds in each bath. Following thermocycling, all teeth were coated with a nail polish 1 mm short of the restoration margins. The restoration was evaluated for microleakage by immersion in 0.2% Basic Fuchsine dye for 24 hours. Following removal from the solution, the teeth were rinsed in tap water. Each tooth was mounted in cold cure acrylic resin using a plastic mold. The restored area was protected by sticky wax followed by clear nail polish to avoid dissolution of the dye during the mounting procedure. Each tooth was sectioned buccolingually through the center of the restoration with a diamond blade (ISOMET, Buehler Ltd, Evanston, IL). The specimens were examined under a microscope at 10X magnification. Microleakage scores were assigned according to the criteria shown in Table 1.

RESULTS

Tables 2 and 3 list the microleakage scores at the enamel and gingival margins. No microleakage was evident in any group at the enamel margins. However, leakage was present at the gingival margin in all treatment groups. Kruskal-Wallis non-parametric analysis showed no significant difference between all treatment groups ($0.75<p>0.5$). However, Tenure All-Surface Bonding system (Group 5) was the only group that showed a

Table 1: *Microleakage Scoring System*

Score	Description
0	No microleakage.
1	Dye penetration extending less than or up to one half of the cavity depth.
2	Dye penetration greater than one half of the cavity dept but not extending to the axial wall.
3	Dye penetration involving the axial wall.

Table 2: *Microleakage Scores - Enamel Margin*

Type of Resin	(N=10) SCORE			
	0	**1**	**2**	**3**
Bond 1 (J/P)	10	0	0	0
Single Bond (3M)	10	0	0	0
One Step (BISCO)	9	1	0	0
Tenure Quick (DenMat)	10	0	0	0
Prime & Bond 2.1 (Caulk)	10	0	0	0
Tenure All Surface Bonding System (DenMat)	10	0	0	0

Table 3: *Microleakage Scores—Gingival Margin*

Type of Resin	(N=10) SCORE			
	0	1	2	3
Bond 1 (J/P)	5	4	1	0
Single Bond (3M)	2	7	1	0
One Step (BISCO)	2	8	0	0
Tenure Quick (DenMat)	1	7	2	0
Prime & Bond 2.1 (Caulk)	3	5	2	0
Tenure All Surface Bonding System (DenMat)	3	3	2	2

microleakage score of 3 at the gingival margins (two samples).

DISCUSSION

It was suggested that microleakage is the result of polymerization shrinkage and the thermal expansion coefficient differences between tooth structure and restorative material. The polymerization shrinkage and expansion coefficient differences can exert significant forces at the restorative material/tooth interface, resulting in bond failure and gap formation. Clinical symptoms of bond failure and gap formation include post-insertion sensitivity, marginal staining, recurrent decay and/or possible loss of the restoration (Reeves & others, 1995; Phillips, 1996). Many controversies were found in the literature when comparing *in vivo* and *in vitro* microleakage testing and whether the results from *in vitro* investigations can be applied to clinical situations. Barnes & others (1993) reported that *in vitro* studies are more prone to dye penetration at the resin composite/tooth interface than *in vivo* studies. Sidhu & Henderson (1992) found that *in vitro* studies are useful but may not reproduce the materials performance *in vivo*.

In vitro studies the fourth and fifth generations are reported. Santini & Mitchell (1998) compared three new DAR (Syntac Single-Component, Scotchbond 1 & Prime & Bond 2.1) using two dentin bonding techniques on microleakage. Their results showed microleakage at both the enamel and gingival margins. At the gingival margin, there was no significant difference between any of the experimental materials and the control for either wet bonding or dry bonding or between the two techniques for each material. Castelnuovo & others (1996) evaluated the microleakage of three pairs of multi- and simplified-step DAR (OptiBond vs OptiBond FL, AllBond2 vs One-Step and Tenure vs Tenure Quick). Their results showed less microleakage at the cementum margins of OptiBond FL and One-Step compared to their multi-step versions. At the enamel margins Tenure Quick showed less microleakage compared to Tenure, and none of the other DARs tested showed significant dye penetration of that interface. In this study One-Step was the only DAR that showed dye penetration at the enamel margins and Tenure All Surface Bonding System was the only DAR that showed dye penetration involving the axial wall at the gingival margins. However, there was no statistically significant difference in microleakage scores among all treatment groups in both enamel and gingival margins. The authors' results showed that "One Bottle" DAR performed equally in terms of microleakage compared with multi-step DAR. These results are in agreement with other studies (Fortin, Perdiãgo & Swift, 1997; Pilo & Ben-Amar, 1999; Castelnuovo & others, 1996; Santin & Mitchell, 1998; Settembrini & others, 1997).

The composite restorations showed relatively greater leakage at the gingival than at the occlusal margin. The most likely cause for this phenomenon is the polymerization contraction of the composite, which is manifested in three ways: shrinkage towards the center of the restoration; towards the "stronger" enamel-composite interface and towards the light source (Yap, Stokes & Pearson, 1996; Felizer, deGee & Davidson, 1987). The magnitude of this contraction may be so great that water sorption and stress relaxation cannot compensate for it (Yap & others, 1996). Since many variables make it difficult to assess the absolute value of microleakage for a given material, only one type of composite resin

was used as a filling material for all Class V restorations. Microfilled composite resins are supposed to give better marginal performances in non stress-bearing areas (Sidhu & Henderson, 1992), and because of their high elasticity and flow ability, they are the material of choice for cervical Class V restorations (Van Meerbeek & others, 1993). Two previous studies used different numbers of cycles during thermocycling—300 cycles without loading (Castelnuovo & others, 1996) and 1400 cycles after application of occlusal load of 10 kg for 0.5 second for 500 times (Pilo & Ben-Amar, 1999). This study used 500 cycles without loading forces. As with this study, both studies concluded no significant difference in microleakage of both margins.

Masticatory loading has been found to promote gap formation and subsequent marginal leakage in Class V cervical restorations due to the bending of tooth structure, creating compressive and tensile stress (Ferrari & others, 1994; Rigsby & others, 1992; Van Meerbeek, 1993). Rigsby & others (1992) reported higher microleakage values when thermocycling was followed by load-cycling. Future comparative studies for the same DAR using thermocycling followed by load-cycling are recommended.

The results of this study suggested that none of the bonding agents tested was consistently capable of resisting the forces exerted during polymerization and/or thermocycling, especially at the gingival margin. However, because of the numerous uncontrolled variables encountered in patient treatment, laboratory studies cannot reliably predict clinical performance of adhesives or other dental materials (Jeffery & Edward, 1994). Clinical trials are needed to assess the performance of these new dentin adhesives.

CONCLUSIONS

1. The new "One Bottle" DAR have similar marginal sealing ability to that of the control group.
2. Clinical trial is needed to assess the performance of these new dentin adhesives.

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Determination of the Minimum Irradiance Required for Adequate Polymerization of a Hybrid and a Microfill Composite

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Clinical Relevance

The generally accepted minimum irradiance value of 300 mW/cm^2 may be insufficient for adequate polymerization of some microfilled resin composites.

SUMMARY

This *in vitro* study determines the minimum irradiance values required for adequate polymerization of a microfill and a hybrid resin composite when cured for 40 and 60 seconds.

A curing light (Optilux 401) with an 8-mm-diameter tip (SaniCure) was used as the light source. The irradiance output of the light unit, measured with a laser power meter, was varied by altering the input voltage using a variable power supply. Two-mm-thick hardness test specimens were made with a microfil composite (Silux Plus) and a hybrid composite (Z-100) for each combination of exposure time (40, 60 seconds) and irradiance value (100 mW/cm^2 to 700 mW/cm^2 in 25-mW/cm^2 increments). After 24 hours, Knoop hardness (KH) measurements were made for each side of each specimen, means were calculated and a top/bottom KH percentage was determined. A value of at least 80% was used to indicate satisfactory polymerization. A linear regression of irradiance versus KH percentage was performed and the resulting equation used to predict the irradiance value required to produce a KH value of 80% for the test conditions.

Results showed that the hybrid composite, Z-100, required 260.1 mW/cm^2 @ 40 seconds or 185.0 mW/cm^2@ 60 seconds for satisfactory polymerization. The microfil, Silux Plus, required 542.9 mW/cm^2 @ 40 seconds or 449.0 mW/cm^2 @ 60 seconds. These findings indicate that previously stated minimum irradiance values may be insufficient for adequate polymerization of microfil resin composites.

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INTRODUCTION

Visible light-curing units are used extensively in dentistry. They are commonly used to polymerize light-sensitive restorative materials, such as resin composites,

resin-modified glass ionomers, polyacid-modified resin composites and pit and fissure sealants. In addition, visible light-curing units are required for most bonding systems, an increasing number of bases and liners, various luting agents and some provisional restorative materials. Adequate polymerization of these materials depends on the light source intensity (irradiance), wavelength and curing time. Unless all three are adequate, the materials will not completely polymerize and exhibit poor physical properties that may lead to early failure (Rueggeberg, Caughman & Curtis, 1994a; Cook, 1982).

Visible light-activated resins utilize a diketone absorber, such as camphoroquinone, to create free radicals that initiate the polymerization process (Council on Dental Materials, 1985; Cook, 1982). The effective wavelength range to activate camphoroquinone has been reported to be between 410 nm and 500 nm, with a peak wavelength of 470 nm (Cook, 1982; McCabe & Carrick, 1989). Research has shown that an irradiance of from 300 mW/cm^2 to 400 mW/cm^2 is necessary to adequately cure a 2-mm thick resin composite specimen (Bayne & Taylor, 1995; Rueggeberg & others, 1994a). This assumes that the correct wavelength of light (390 nm to 520 nm) is used as well as a minimum 40-second curing time. Irradiance values less than 300 mW/cm^2 can be compensated for by longer exposure times, however light sources with irradiance values less than 233mW/cm^2 should not be used (Rueggeberg & others, 1994a). Ideally, a 60-second cure of 1-mm-thick resin composite increments using a light irradiance of at least 400 mW/cm^2 is recommended (Rueggeberg & others, 1994a).

The degree to which a resin composite can be polymerized using a visible light-curing unit is affected by characteristics inherent to the particular material being polymerized. For example, for adequate polymerization, previous investigations have concluded that microfil resin composites require greater irradiance than hybrids (Rueggeberg & others, 1994b; Atmadja & Bryant, 1990). Although some studies have found that darker shades are more difficult to polymerize than lighter shades (Cook & Standish, 1983; Swartz, Phillips & Rhodes, 1983), other work indicates that depth of cure may actually be less dependent on shade than on translucency (Ferracane & others, 1986).

Minimal irradiance values previously cited have either been unsupported by scientific studies or nonspecific with regard to the particular type of resin composite being polymerized. This study determined the minimum irradiance required to adequately polymerize a 2-mm increment of a hybrid and a microfil resin composite.

METHODS AND MATERIALS

An Optilux 401 curing light (Demetron Research Corporation, Danbury CT 06810) with an 8-mm diameter SaniCure tip (Dentsply/Caulk, Milford DE 19963) was used as the light source for all procedures. The curing light's power was measured with a laboratory-grade power meter (PowerMax 500D with PM10 Probe, Molectron Detector, Inc, Portland OR 97224) and the irradiance calculated. The irradiance output of the curing light was varied by altering the input voltage using a variable AC power supply (Model 1001P, California Instruments, San Diego CA 92129). The power supply maintained the selected line voltage, thereby negating the effect of transient line voltage fluctuations on the light's intensity during testing (Fan & others, 1987). Three 60-second exposures of the curing light spaced one second apart were performed before any irradiance measurements were made. This was done to eliminate the possibility of irradiance variations as a result of a cool bulb (Rueggeberg, 1993). Initial testing with the Demetron light indicated that the irradiance peaked immediately after initiating an exposure but returned after 20 seconds to a lower stable level for the remainder of the exposure. For that reason, all timed light exposures began after the light had been operating for 20 seconds. Spectral radiance plots from 100 mW/cm^2 to 700 mW/cm^2 in 100-mW/cm^2 increments were obtained with a Photo Research PR-650 SpectraColorimeter (Photo Research, Inc, Chatsworth CA 91313-2192) and found to be similar. This eliminated concerns that the light unit's spectral radiance plots might be different when the unit's output irradiance was altered by changing the voltage to the curing light.

A polytetrafluoroethylene mold 2-mm high and 8 mm in diameter was used to prepare five depth-of-cure test specimens. To prepare each specimen, the mold was placed on a clear glass slide and the resin composite placed in the mold. The resin composite was then covered with a second glass slide to ensure that the exposed surface of the composite was flat and parallel to the surface of the mold. One side of the specimen was then exposed to the visible light polymerization unit for 40 or 60 seconds at various experimental irradiance levels. A hybrid resin composite (Z-100 shade A-3, 3M Dental Products, St Paul MN 551444-1000) and a microfil resin composite (Silux Plus, universal shade, 3M Dental Products) were used to address reported different degrees of cure between hybrid and microfil resins (Atmadja & Bryant, 1990). Following fabrication, specimen thickness was measured with an electronic digital caliper (Fowler & NSK, Newton MA 02166) to ensure proper dimensions (± 0.1 mm). Twenty-four hours after polymerization, hardness indentations were made with a Knoop hardness tester (M-400-G2, LECO, St Joseph MI 49085) using a 100-gram load and a dwell time of 10 seconds. For each specimen, three hardness measurements were made for the top surface and three for the bottom surface. Mean hardness values were then calculated for each surface. These values were then averaged

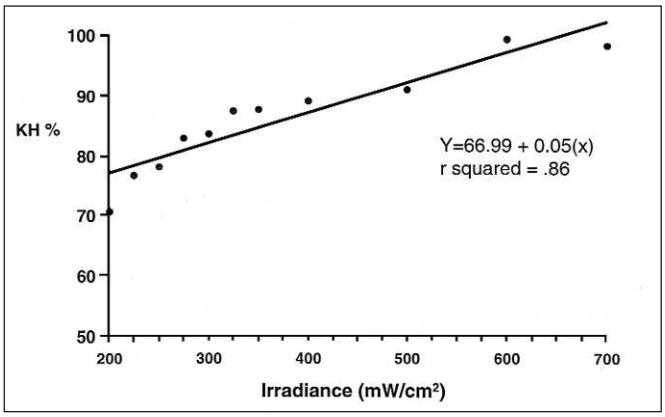

Figure 1. *Correlation and linear regression between the measured Knoop hardness percentages of Z100 and irradiance values of the light unit using a 40-second exposure time.*

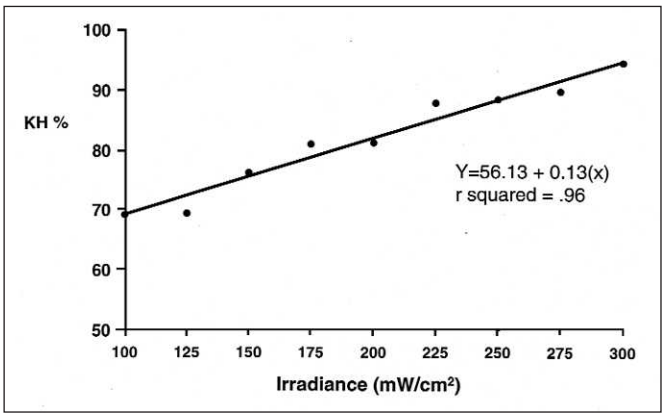

Figure 2. *Correlation and linear regression between the measured Knoop hardness percentages of Z100 and irradiance values of the light unit using a 60-second exposure time.*

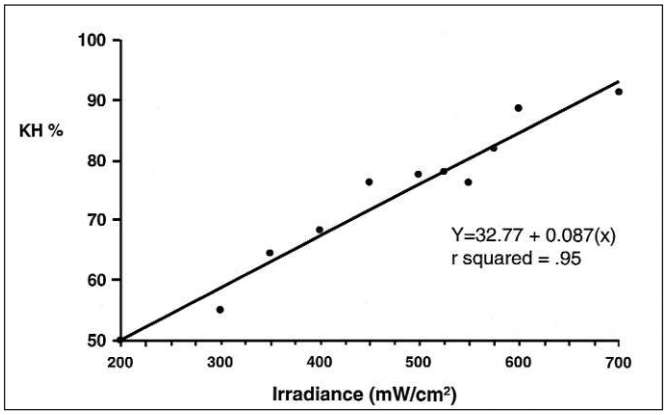

Figure 3. *Correlation and linear regression between the measured Knoop hardness percentages of Silux Plus and irradiance values of the light unit using a 40-second exposure time.*

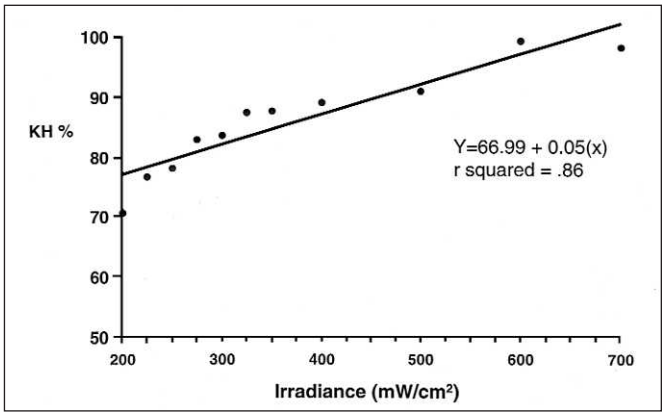

Figure 4. *Correlation and linear regression between the measured Knoop hardness percentages of Silux Plus and irradiance values of the light unit using a 60-second exposure time.*

for the five specimens to obtain a mean top surface value and a bottom surface value. The bottom value was then divided by the top value and multiplied by 100 to obtain percentage depth of cure. If that mean value exceeded 80%, the specimen was considered adequately polymerized (Watts, Amer & Combe, 1984; Breeding, Dixon & Caughman, 1991; Manga, Charlton & Wakefield, 1995).

For each resin composite and exposure time, the data were plotted and a simple linear regression was performed with Knoop hardness (KH) percentage as the dependent variable and irradiance as the independent variable. The resulting regression equation was used to predict the irradiance value required under the test conditions to produce a specimen with a KH percentage of 80%.

RESULTS

Data for KH percentage at the difference irradiance levels are presented in Figures 1-4. Each point represents the mean KH percentage of five specimens. As can be seen in Figure 1, the first mean KH percentage value above 80% for Z100 using a 40-second exposure time was recorded when the irradiance value was 275 mW/cm^2. Analysis showed that the irradiance values correlated significantly with the measured KH percentages of the specimens ($p<0.0001$, $r^2=0.86$). From the regression equation, the predicted irradiance value required to produce a specimen with KH percentage of 80% is 260.1 mW/cm^2.

Figure 2 shows that the first mean KH percentage value above 80% for Z100 using a 60-second exposure time was recorded when the irradiance value was 175 mW/cm^2. The irradiance values correlated significantly with the KH percentages of the Z100 specimens ($p<0.0001$, $r^2=0.96$). The regression equation revealed that the predicted irradiance value required to produce a specimen with KH percentage of 80% under these test conditions is 185.0 mW/cm^2.

The first mean KH percentage value above 80% measured for Silux Plus using a 40-second exposure time

Table 1

	Exposure Time	
Material	**40 Seconds**	**60 Seconds**
Silux Plus	542 mW/cm^2	449.0 mW/cm^2
Z-100	260.1 mW/cm^2	185.0 mW/cm^2

(Figure 3) was recorded when the irradiance value was 575 mW/cm^2. Statistical testing found that the irradiance values correlated significantly with the KH percentages ($p<0.0001$, $r^2=0.95$). Based on the regression equation, the predicted irradiance value required to produce a Silux Plus specimen with KH percentage of 80% is 542.9 mW/cm^2.

For Silux Plus using a 60-second exposure, the first mean KH percentage value above 80% was recorded when the irradiance value was 350 mW/cm^2. The irradiance values correlated significantly with the KH percentages of the specimens ($p<0.0014$, $r^2=0.66$). The regression equation revealed that the predicted irradiance value required to produce a specimen with KH percentage of 80% under these test conditions is 449.0 mW/cm^2.

The predicted irradiance required to produce a specimen with KH percentage of 80% for each material at 40 and 60 seconds is summarized in Table 1.

DISCUSSION

Because of the large number of light-activated dental materials, visible light-curing units have become common equipment in dental offices. The proper performance of these units (that is, their ability to provide adequate irradiance) is crucial to optimizing the physical properties of light-activated materials. Inadequate polymerization has been associated with inferior physical properties, higher solubility, retention failures and adverse pulpal responses due to unpolymerized monomers (Council on Dental Materials, 1985; Blankenau & others, 1991).

The minimum irradiance necessary to adequately polymerize a 2-mm thickness of composite resin is generally accepted to be 300 mW/cm^2. At least one textbook cites this value, and curing light manufacturers reinforce it in their operating instructions. However, recent research suggests that this value may not be adequate. In a study using two brands of resin composite, Rueggeberg & others (1994a) recommended 400 mW/cm^2 for 60 seconds to ensure adequate polymerization. Manga & others (1995) found that an irradiance of 600 mW/cm^2 for 40 seconds was required to be 75% confident that a 2-mm-thick hybrid composite specimen was adequately polymerized.

This study found adequate polymerization was not only a function of curing time and irradiance, but was also significantly affected by composition of the resin composite. The microfil composite Silux Plus required more than twice the irradiance required by the hybrid composite, Z-100 in order to be considered adequately polymerized. This is in agreement with previous studies that found that microfil resin composites demonstrate a decreased depth of cure compared to hybrid and macrofilled resin composites (Ruyter & Oysaed, 1982; Atmadja & Bryant, 1990; Ferracane & others, 1986). It is believed that microfills exhibit this reduced depth of cure because their small filler particles cause light scattering, which decreases the effectiveness of the curing light.

The results of this study indicate that the minimum irradiance value of 300 mW/cm^2 recommended by curing light manufacturers may be adequate for hybrid resin composites but is insufficient for microfil resins. This appears to be true for both 40- and 60-second exposure times. This finding is important given the fact that many practitioners use lights that provide inadequate irradiance. Barghi, Berry & Hatton (1994) measured the irradiance levels of 209 curing lights from 122 private practice offices and found that 45% had light outputs of less than 300 mW/cm^2. Of these, 65% had outputs of less than 200 mW/cm^2. What was most disconcerting was that only 10% of the clinicians realized that their units were providing inadequate irradiance. Using this study as a baseline, it is conceivable that a significant number of hybrid and a majority of microfil resin composites are inadequately polymerized.

Microfills are commonly used in the anterior region where esthetics is a primary concern. Frequently, they are also the material of choice for direct placement veneers and esthetic alterations. In these situations, clinicians often use larger-diameter curing tips to expose the entire area of the resin composite to the light. The use of these larger tips, however, further reduces the light intensity level. A recent study by Leonard, Charlton & Hilton (1999) found that using a 12-mm-diameter curing tip reduced the curing light's irradiance by 39% when compared to a standard 8-mm curing tip. In addition, the study found that many of the most popular radiometers on the market overestimated the true irradiance from 12-mm tips by as much as 50%. Therefore, even clinicians who periodically assess their light unit's irradiance with a commercial radiometer may be unaware of this reduction. These findings, coupled with the poor performance of the majority of curing lights in use and the observed need for higher irradiance levels with microfil resin composites, strongly suggests that a substantial number of resin composite restorations currently being placed are potentially underpolymerized.

CONCLUSIONS

The effect of resin composite composition (that is, hybrid versus microfil) on the minimum irradiance required to adequately polymerize a 2-mm increment of

the composite was evaluated. The results of this study indicate a significant difference between the minimum irradiance required to adequately polymerize the hybrid resin composite, Z-100, and the microfil, Silux Plus. The generally accepted value of 300 mW/cm^2 appears to be adequate for proper polymerization of the hybrid resin composite used in this study. However, the microfil resin composite required twice the irradiance as that of the hybrid for adequate polymerization. Higher minimum irradiance values need to be established and recommended for microfil resin composites.

Note

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Defense or other departments of the United States Government.

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Pulpal Temperature Change with Visible Light-Curing

C Porko • E-L Hietala

Clinical Relevance

The warming effect of the light curing lamp on pulp should be taken into account when curing large restorations or inlays/onlays that need several consecutive light curing exposures.

SUMMARY

In vitro **measurements were made to reveal the heat transference to the pulp chamber during light curing. Ten extracted human teeth were kept in physiologic saline at body temperature. In the first part of the study, five light curing exposures of 40 seconds were given to the occlusal surface of each tooth with a light curing unit.The temperature of the pulp was measured by a thermocouple probe that was inserted into the pulp through the apex. The maximal temperature rise was 2.2°C. Thereafter, standard occlusal cavities were prepared in all 10 teeth and filled with composite resin filling material in three parts. The dental adhesive was light cured for 20 seconds and each composite increment for 40 seconds. An extra cycle of 40 seconds was given when the cavity was filled as a post cure. The maximal temperature difference during the total procedure was 7.2°C. The heating effect of light curing should thus be taken into account when restorations are cured.**

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INTRODUCTION

The dental pulp is vulnerable tissue whose viability may be compromised during cavity preparation and other restorative procedures. Consecutive hole drilling and placing of four dentin pins caused a statistically significant increase in temperature in the pulp chamber (Anil & Keyf, 1998). Thermal injury can occur due to the exothermic hardening process of filling materials or the heating effect of the curing lamp. Hussey (1995) has measured a maximum temperature rise of 12°C in the composite *in situ* during polymerization, although this may only be for a short period. When Castelnuovo & Tjan (1997) measured temperature rise in the pulp during fabrication of provisional resinous crowns, the results demonstrated that the amount of heat generated during resin polymerization and transmitted to the pulpal chamber could be damaging to pulpal tissues, including odontoblasts. Hartanto, Benthem & Ott (1990) have also pointed out the possibility of high temperatures observed in the polymerization of most composites and their adverse effects on pulp tissue. The greatest rise in temperature occurred when the first layer of composite was light cured (Goodis & others, 1990). When the temperature in the pulp chamber rises by 5.5°C, the pulp is irreversibly damaged (Zach & Cohen, 1965). On the other hand no signs of pulpal inflammation were observed four weeks after electrothermal debonding of ceramic brackets. In this *in vitro* experiment, the maximum temperature increase at the enamel-dentin inter-

face was 6.9°C (Jost-Brinkmann & others, 1997). Curing lamps vary from one to another in the amount of heat generated (Goodis & others, 1990), and the most effective light sources give the highest temperature rise (Hansen & Asmussen, 1993). According to a recent paper by Powell, Anderson & Blankenau (1999), pulp chamber temperature increases from laser units were significantly lower than those of conventional curing lights tested *in vitro*. In that study, temperature increases for the argon laser for the recommended curing time were 3°F or less. Dentin has low thermal conductivity, but its insulation property diminishes when the thickness decreases (Thompson, Gomez & Puckett, 1997; White, Fagan & Goodis, 1994; Lauer & others, 1990). When the remaining dentin thickness was 1.0 mm or less, the percentage of teeth with abscess formations increased in composite filled teeth (Stanley, Going & Chauncey, 1975). Also, the thickness of remaining dentin was significant for the amalgam restorations when temperature rise in the pulp due to finishing of direct restorative materials was measured (Stewart, Bachman & Hatton, 1991). Glass ionomer cements are more irritating, especially when used as luting agents in areas where the remaining dentin thickness is 0.5 mm or less (Stanley, 1992). The balancing factor *in vivo* is blood flow (Andersen, Aars & Brodin, 1994; Raab & Muller, 1989).

Little research has been published concerning the effect of light curing on the dental pulp. This study explored the effect of light curing on the pulpal temperature *in vitro*.

METHODS AND MATERIALS

Ten third molars were voluntarily donated after extraction from young healthy students. All extractions were carried out in the course of normal student dental care due to lack of space. The molars were put in physiological saline immediately upon extraction.

Due to the fragility of the thermocouple probe, the access through the apex was confirmed by pre-opening the canal through the apex with a root canal reamer #30. In some teeth, the most apical 2-3 mm of the root was cut off with a diamond bur to enable access. The teeth were transferred into a water bath kept at body temperature (37.0 +- 0.1°C). The temperature of the water bath was checked with both an ordinary mercury thermometer and the thermocouple probe (+- 0.1°C). The needle probe (Hypodermic Needle Probe HYP-30-1/2-T-G-60-SMP-M, Omega Engineering, Inc, Stamford, CT 06906 USA) connected to a NiCr-NiAl thermocouple thermometer (Fluke 52 K7J Thermometer, John Fluke Mfg Co, Inc, Everett, WA, USA) was pushed through the apical foramen into the coronal pulp chamber up to the widening of the neck in the probe or until resistance was felt. The probe remained in place without any special fixing because of the narrowness of the root canal. The exact location of the probe was checked radiographically. The teeth were adjusted with sticky wax in a cover on a stand so that the crown of the tooth was above liquid level and the root was in a water bath at 37.0+-0.1°C. The room temperature was about 21°C. Five consecutive 40 second light curing exposures (3M Curing Light XL3000, made in Germany for 3M Dental Products Division, St Paul, MN, USA; light output 650 mW/cm^2) were directed on the occlusal surface of the teeth and the temperature rise was registered immediately after each exposure. The time interval between each consecutive light curing set was five to 10 seconds. The teeth were thereafter preserved totally under water in the same water bath until an occlusal cavity was prepared.

A standard occlusal cavity (2 mm broad, 5 mm long and 2 mm deep extending just to the dentin) was prepared with a diamond high speed friction grip bur under water cooling and the teeth were preserved in a water bath as above. The thermoprobe was pushed through the apical foramen and the tooth was adjusted, using sticky wax when needed, with the crown above the liquid level and the root in a water bath (37.0+-0.1°C). The temperature was allowed to settle for two minutes The cavities were then etched with 30% phosphoric acid for 20 seconds (Delton Etching Liquid, Ash/Dentsply, York, GB), rinsed with water for 15 seconds and dried gently for two seconds. For bonding, Scotchbond Multi-Purpose Dental Adhesive system (3M Dental Products, St Paul, MN, USA) was used. The primer was applied to enamel and dentin and dried gently for five seconds. Then the adhesive was applied into the cavity and light cured for 20 seconds. Temperature was measured immediately after each stage. Each cavity was filled in three increments (3M Restorative Z100, batch number 1999-1014 FX, Vita Shade C4, 3M Dental Products, St Paul, MN, USA) and each increment was light cured for 40 seconds immediately after application. One extra light curing interval of 40 seconds was used to confirm the polymerization. Temperature rise during the procedure was registered as described above. After the last curing interval, the temperature was allowed to settle for two minutes and measured once again.

Statistically significant differences between the temperatures were assessed using paired sample *t*-test (SPSS 8.0 for Windows).

RESULTS

Radiographs revealed that the end of the thermocouple probe was situated in the pulp just beneath the dentin (Figure 1). Because the crown of the tooth was above the liquid level, the temperature of the pulp decreased by 0.4-2.1°C during the settling time of two minutes. Light exposures caused the temperature to rise in all teeth examined. The mean temperature at the beginning of the experiment, after settling time, was 35.89°C (SD 0.62°C) and the mean temperature after five con-

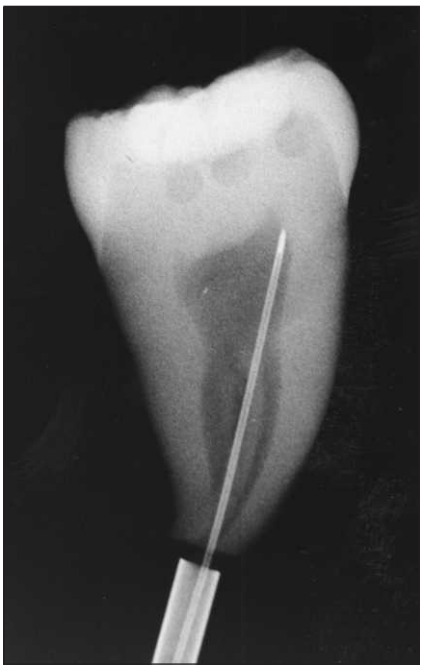

Figure 1. *Radiograph representing the situation of the thermoprobe just beneath the dentin in the pulp.*

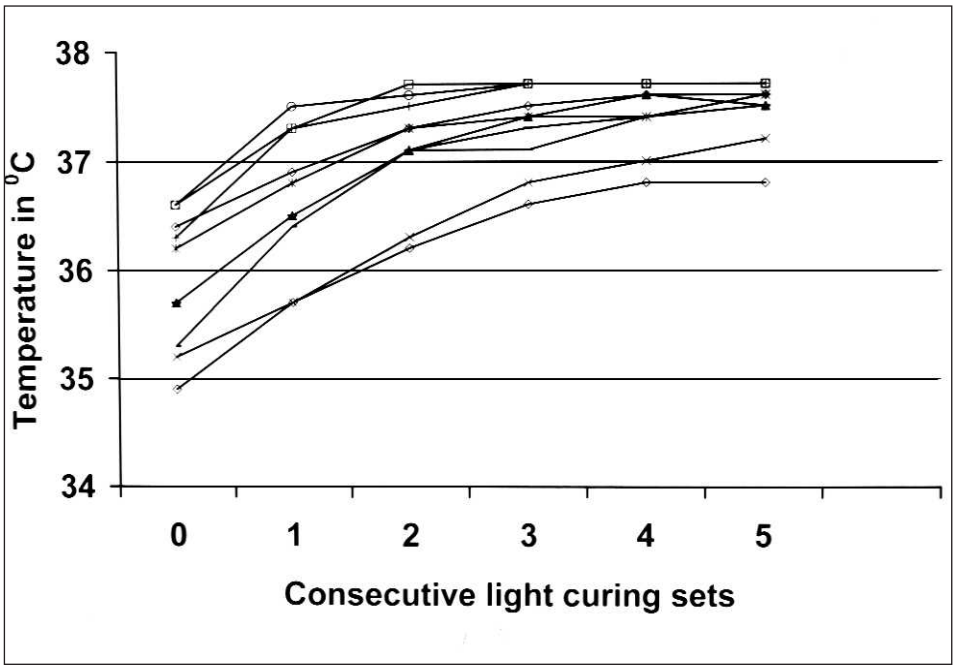

Figure 2. *Temperature rise (°C) in the pulp of 10 third molars when five 40-second light intervals were directed on the surface of the teeth with a light curing lamp. Vertical axis: Temperature °C; horizontal axis: number of light curing exposures.*

secutive light curing sets was 37.49°C (SD 0.28°C). The difference was statistically significant ($p<0.01$). The highest temperature registered in unprepared teeth was 37.7°C, and the lowest 36.8°C after five 40-second light curing exposures. The maximum temperature rise in unprepared teeth was 2.2°C after five consecutive 40-second light exposures, and the minimum temperature rise was 1.1°C, respectively (Figure 2).

The temperature curves during restoration procedures are shown in Figure 3. The mean starting temperature was 35.77°C (SD 0.67°C). The curves show that temperature rise follows a very similar pattern in all molars examined. The lowest temperatures were registered after etching and rinsing with water (mean 32.51°C, SD 1.34°C). The highest temperatures (mean 37.15°C, SD 0.54°C) were registered in all teeth after five light curing exposures (20 seconds for adhesive and 4x40 seconds for restoration). The difference was statistically significant ($p<0.01$).

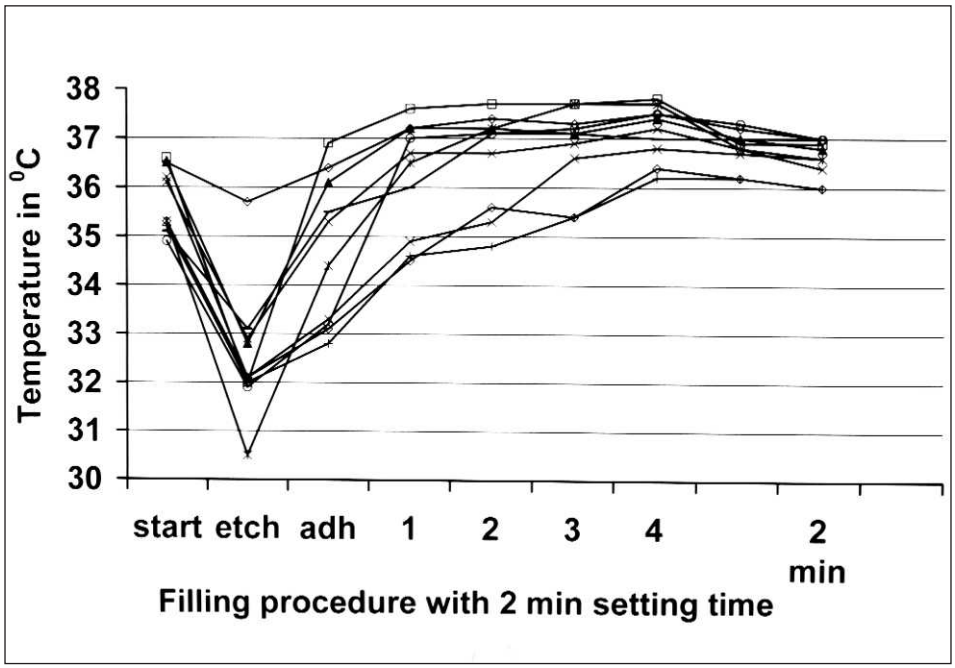

Figure 3. *Temperature rise (°C) in the pulp of 10 third molars when the cavity was filled with three increments of composite and each increment was light cured for 40 seconds. An extra "post curing shot" of 40 seconds was given. Vertical axis: Temperature °C; horizontal axis: stages of the filling procedure. Abbreviations: Start = first registration of the temperature after two minutes settling time; etch = temperature after etching for 20 seconds and rinsing for 15 seconds and gentle drying for two seconds; adh = temperature after priming and gentle drying for five seconds and curing the adhesive for 20 seconds; 1-3 = 40 seconds light curing intervals after each increment; 4 = 40 seconds post curing shot immediately after filling the cavity, 2 min = temperature after two minutes settling time.*

Table 1:

	Mean Temp Before	Mean Temp After	Range of Temp Change (Before/After)	Range of Max Temp Differential (Anytime)
No Prep	35.89°C	37.49°C	2.8°C	2.2°C
Prep + Restored	35.77°C	37.15°C	2.9°C	7.2°C

Summary of the most meaningful results. Abbreviations: Temp = temperature, Prep = preparation, Max = maximum, Before/After = temperature difference between the start and the end of the measurements, Anytime = temperature difference between the lowest and highest temperature during the whole procedure.

The difference between the starting temperatures and the maximum temperatures after light curing was also statistically significant ($p<0.01$). The maximum temperature difference between the lowest and the highest temperature during the total procedure was 7.2°C, and the minimum was 1.8°C, respectively. The maximum difference between starting and ending temperatures was not more than 1.4°C. The highest temperature registered was 37.8°C and the lowest maximum temperature after light curing was 37.2°C. Immediately after light curing, the temperatures began to fall. Table 1 summaries the most meaningful results.

DISCUSSION

Cavity preparation under water cooling, and the subsequent etching and priming, lowered the pulpal temperature. In this experimental procedure, it was impossible to simulate the stabilizing effect of blood flow in a vital tooth, which the authors tried to compensate for with the constant temperature of the surroundings. Water bath has a very stabilizing effect on pulpal temperatures. This fact was further emphasized when intrapulpal temperatures were tested while holding the extracted tooth in the air with forceps. An increase in temperature up to 15 degrees was achieved when stabilizing water was removed from the system. In clinical circumstances, the surrounding temperature may vary more during restorative procedures, for example, because of breathing. *In vivo* rubber dam inhibits the effect of breathing, and the circumstances are similar to this experiment. The balancing blood flow is often suppressed by local anesthesia (Muller & Raab, 1990) depending on the type of anesthetic used. On the other hand, it has been concluded that painful stimulation can induce significant increases in blood flow in the region adjacent to the stimulus (Kemppainen & others, 1994).

The distance from the light source to the tip of the temperature probe was not exactly the same. Combined with individual variation in tooth morphology and dentin structure, this may explain the temperature differences between the teeth tested.

The temperature curves presented clearly show that both curing light *per se* and in connection with composite filling techniques can affect pulpal temperature *in vitro*. The polymerization process is known to be an exothermic reaction (Hartanto, Benthem & Ott, 1990; Hussey, 1995; Castelnuovo & Tjan, 1997) which is enhanced by light curing, as shown in this study. The rise of temperature by 2°C is within the limit of pulpal physiology (Ma, Marangoni & Flint, 1997). The temperature rises in this study stayed mostly within this limit, although temperature differences of as high as 7.2°C could be registered during the total filling procedure when the cooling effect of etching and rinsing was also taken into account. According to studies related to laser irradiation, Chang & Wilder-Smith (1998) stated that pulp tissues must be present to ensure clinical relevance of thermal measurements. So, the procedure does not allow the authors to draw any conclusion on the absolute temperatures which may be reached *in vivo*.

It is known that composite filling should be cured in increments of 2 mm thickness to assure maximal polymerization of the material. The depth of curing depends on the material, for example, shade and filler size. It should also be kept in mind that a small increase in the depth of cure is followed by a disproportionately high increase in temperature (Hansen & Asmussen, 1993). Because the depth of curing cannot be effectively compensated for by prolonged light curing, which also causes a marked warming effect on dental pulp as shown in this study, it is rational to restore with incremental curing of thin layers of composite, rather than bulk placement of composite and extended light curing, which can cause a marked rise in pulpal temperature.

CONCLUSIONS

The warming effect of light curing devices *per se* and in connection with composite filling can affect pulpal temperature *in vitro*. When five consecutive light curing sequences were applied to the occlusal surface of unprepared teeth, the maximum temperature rise of 2.2°C was measured in the pulp. This could simulate the curing process of an inlay or onlay. When placing a direct composite restoration in three increments, the temperature difference between the start and end of the process was maximally only 1.4°C, and thus within the range of pulpal physiology. However, the maximum difference between the lowest and highest tempera-

ture in the pulp during the total process was as high as 7.2°C. The cooling effect of the rinsing water after etching causes the pulpal temperature to fall quickly, and thus causes extra stress on the pulp. With respect to the postoperative sensitivity of composite fillings or inlays and onlays, reaction to temperature differences should be taken into account. More sophisticated methods are needed to solve the problem *in vitro* and *in vivo*.

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Colorimetric and Roughness Changes of Ceramic Blocks by Polishing and Glazing

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HH Son • HC Kwon • CM Um

Clinical Relevance

Color changes caused by polishing or glazing of porcelain blocks could be easily perceived by the naked eye.

SUMMARY

After polishing or glazing, slight color changes of machined porcelain restorations may be perceived, compared to the originally selected shade. This study compared the precision of the tristimulus colorimeter with the spectrophotometer to quantitatively measure the color changes of milled porcelain restorations after polishing or glazing and to evaluate the relationship between the color changes and the surface roughness. Ten two-millimeter thickness specimens of each shade were prepared from five shades of Vita Cerec Mark II porcelain blocks. Each specimen was ground with #220 grit SiC paper on an automatic polishing machine to simulate the surface roughness of milled restoration ground with 54 or 64 µm diamond grinding tools. To compare the precision of the spectrophotometer with the tristimulus colorimeter, CIE Lab* values of each specimen were measured and the coefficients of variation (CV) for each instrument computed. Ra values were also obtained using a Surface Analyzer. After verifying the precision of the tristimulus colorimeter, a second set of measurements were taken after the polishing or glazing procedure to quantitatively evaluate the effect of these procedures on the shade of the milled restorations. To evaluate the relationship between the color change and the surface roughness, a second set of Ra measurements were taken and the correlation between them analyzed. The tristimulus colorimeter measured the L* value more precisely than the spectrophotometer ($p<0.05$), but on the a* and b* color coordinates, it was not significantly superior to the spectrophotometer ($p>0.05$). The color difference values produced by polishing or glazing were greater than 2 ΔE units. After polishing and glazing, among the three coordinates examined, ΔL* was the most prominent determinant on ΔE*(ΔR^2/polishing=0.9744 and ΔR^2/glazing=0.9413),

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but Δa* and Δb* had little effect. There was no statistically significant correlation between the changes in surface roughness and color in either polishing (r=0.3555, p=0.0812) or glazing (r=-0.1570, p=0.4520).

INTRODUCTION

Traditionally, porcelain laminates, inlays and onlays were fabricated by the refractory die method, but recently a method to fabricate these restorations with milling tools was developed—the so-called "milling method." The CAD/CAM and copy-milling methods are included in this category. In this method, porcelain restorations are made from porcelain blocks pre-fabricated under closely controlled conditions in the factory. These new restorative materials have improved physical properties when compared with traditional powder-type ceramic materials (Jedynakiewicz & Martin, 1993; Eidenbenz, Lehner & Schärer, 1994).

However, these pre-fabricated porcelain blocks have limitations. Although the manufacturers supply the blocks in several shades, they are monochromatic, and it is difficult to express the various color changes from the cervical to the incisal segments of the natural tooth. Secondly, porcelain laminates, inlays and onlays made by the milling method must be polished after cementation or glazed before cementation. This is because milling is performed with 54 or 64 μm diamond grinding tools (Mikrona Technology AG, 1995; Pfeiffer, 1996). Clinically, slight color changes may be perceived in the porcelain restorations after polishing or glazing. Therefore, it was hypothesized that the color of milled porcelain restorations would change from the originally selected shade after polishing or glazing, and this change could be perceived by the naked eye.

To assess the color of the teeth being restored, various shade guides were used. This empirical method is unreliable because it is highly dependent on subjective assessment and a lack of standardization. Optical electronic instruments have been developed for more precise and reliable quantification of the color than visual shade tabs (Bangtson & Goodkind, 1982; Goodkind, Keenan & Schwabacher, 1985; Wozniak & others, 1985; van der Burgt & others, 1990; O'Brien, Boenke & Groh, 1991; Swift, Hammel & Lund, 1994). In dentistry, quantitative color measurements were carried out with a spectrophotometer and the CIELAB system for quality control (Brewer & others, 1985; Seghi, Johnston, & O'Brien, 1986a; ten Bosch & Coops, 1995). Recently, portable tristimulus colorimeters were evaluated to measure the color of natural teeth in the mouth. Their accuracy and effectiveness were compared with those of the well-studied reference instrument, a spectrophotometer (Bangtson & Goodkind, 1982; Seghi, Johnston & O'Brien, 1986b; Seghi, Johnston & O'Brien, 1989a; van der Burgt & others, 1990; Seghi, 1990).

This study compared the precision of the tristimulus colorimeter with the spectrophotometer to quantitatively measure the color changes of the milled porcelain restorations after polishing or glazing and evaluated the relationship between color change and surface roughness.

METHODS AND MATERIALS

Sample Preparation

In this study commercially available porcelain blocks (Vita Cerec Mark II, I8 size; Vita Zahnfabrik H Rauter GmbH & Co, KG, D-79704 Bad Säckingen, Germany) of five different shades were used. The shades were #A1, A2, A3, A3.5 and B3. Ten specimens were prepared from each shade by sectioning the blocks into 2 mm slabs with a diamond saw (Isomet; Buehler Ltd, Lake Bluff, IL 60044, USA), then grinding with #220 grit SiC paper on an automatic polishing machine (LotoPol-V & Pedemat; Struers Ltd, Glasgow G60 5EU, UK) to simulate the surface roughness of milled restoration with 54 or 64 μm diamond grinding tools (European FEPA standard).

Comparison of Spectrophotometric and Colorimetric Measurements

To evaluate the precision of the tristimulus colorimeter (Chroma Meter CR-321; Minolta Co Ltd, Osaka 541, Japan) utilizing 45° illumination/0° viewing angle geometry, a spectrophotometer (Spectrophotometer CM-3500d; Minolta Co Ltd, Osaka 541, Japan) with diffuse illumination/10° viewing angle geometry was used as a reference instrument. For reference purposes, spectrophotometric measurements were performed under conditions of standard C-illumination (C: representative of overcast whole sky illumination), specular component excluded, 3 mm target mask and the absolute black acrylic plate on 50 specimens ground with #220 grit SiC paper. Initially, CIE Lab* values were measured at five points on the ground surfaces of the 50 ground specimens. Because each shade was sampled 10 times, 50 measurements were performed on each shade group. A total of 250 measurements were taken.

Colorimetric measurements were performed in the same manner to evaluate the coefficient of variation between the two instruments using standard C-illumination and on the standard photographic 18% gray card (Eastman-Kodak Co, Rochester, NY 14624, USA) in a darkroom.

Colorimetric Comparison Between Before and After Polishing or Glazing

After verifying the precision of the colorimeter, this instrument was used to take additional measurements after polishing or glazing to quantitatively evaluate the effect of these procedures on the shade of the milled restorations. Ten specimens in each of five shade groups were divided into two subgroups of five specimens. The

Table 1: *CIE Lab* Values of Five Shades of Vita Cerec Mark II Porcelain Blocks Ground with #220 SiC Paper Measured with Spectrophotometer and Colorimeter. (Numbers in parentheses are standard deviations, n=10)*

Instrument	Shade	L*	a*	b*
Spectrophotometer	A1	53.96 (0.64)	-0.81 (0.05)	1.55 (0.23)
	A2	53.11 (0.75)	-0.92 (0.04)	1.49 (0.35)
	A3	52.16 (0.74)	-0.35 (0.05)	5.77 (0.28)
	A3.5	53.13 (1.25)	-0.16 (0.04)	8.39 (0.53)
	B3	51.82 (0.97)	-0.74 (0.04)	6.43 (0.32)
Colorimeter	A1	60.85 (0.65)	-1.22 (0.05)	2.78 (0.30)
	A2	59.52 (0.73)	-1.38 (0.04)	3.14 (0.31)
	A3	58.42 (0.26)	-1.08 (0.11)	8.63 (0.23)
	A3.5	57.89 (0.75)	-1.07 (0.19)	13.39 (0.67)
	B3	57.78 (0.71)	-1.61 (0.15)	9.88 (0.49)

Table 2: *Paired* t*-Test of Coefficient of Variation (CV) of Two Instruments by Color Coordinates*

Color	Instruments	Mean of CVs	Standard Deviation	t	*p*-Value
L*	Colorimeter	1.0528	0.3499	3.0659	0.0374
	Spectrophotometer	1.6483	0.4659		
a*	Colorimeter	-8.851	5.9020	-1.197	0.2972
	Spectrophotometer	-11.04	8.7413		
b*	Colorimeter	6.6585	3.4994	1.7399	0.1569
	Spectrophotometer	10.895	8.1652		

Table 3: *Forward Stepwise Regression Analysis for ΔE* Dependent on ΔL*, Δa* and Δb* Values After Polishing or Glazing*

Treatment	Variables	Steps	R^2	ΔR^2	*p*-Value
Polishing	ΔE* - ΔLab*	ΔL* entered	0.9744	0.9744	<0.0001
		Δb* entered	0.9951	0.0207	0.0099
		Δa* entered	0.9965	0.0014	<0.0001
Glazing	ΔE* - ΔLab*	ΔL* entered	0.9413	0.9413	<0.0001
		Δb* entered	0.9985	0.0572	0.0392
		Δa* entered	0.9988	0.0003	<0.0001

ground surfaces of the specimens of one subgroup were polished using the Soflex Finishing/Polishing System (3M Dental Products, St Paul, MN 55144, USA), and those of the other subgroup were glazed with the glaze of Vita Shading Paste (sp 15; Vita Zahnfabrik H Rauter GmbH & Co, KG, D-79704 Bad Säckingen, Germany). CIE Lab* values were then measured in the manner described above. From the two sets of CIE Lab* measurements, color differences (ΔE*) of each group were obtained from the following equation :

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

Surface Roughness Analysis

To evaluate the relationship between the surface roughness and the color change, average roughness (Ra) values of the 50 specimens of porcelain blocks ground with #220 grit SiC paper were obtained with a Surface Analyzer (Form Talysurf Plus; Rank Taylor Hobson Ltd, Leicester LE4 9JQ, England). For each specimen five one-millimeter line-scans were performed in different areas. After the previously described polishing or glazing procedures, the Ra values of all the specimens were obtained with the same instrument. From these measurements, the correlation between the changes of the CIE Lab* values and those of the Ra values for each specimen were analyzed.

Statistical Analysis

The coefficients of variation (CV) for each instrument on each of the three color coordinates L*, a* and b* were

Table 4: *Pearson Product Moment Correlation Analysis Between the Changes of the Average Roughness Values and Color Difference Values of Different Shades of Ceramic by Polishing or Glazing. (Numbers in parentheses are standard deviations, n=25, unit of Ra: μm)*

Treatment	Shade	Ra (#220)†	Ra (treated)‡	ΔRa§	ΔE*	r¶	*p*-Value
Polishing	A1	0.51 (0.09)	0.21 (0.20)	-0.30 (0.24)	3.93 (0.44)	0.3555	0.0812
	A2	0.29 (0.09)	0.11 (0.03)	-0.18 (0.10)	1.62 (0.80)		
	A3	0.34 (0.06)	0.14 (0.08)	-0.21 (0.12)	2.07 (0.35)		
	A3.5	0.40 (0.12)	0.22 (0.23)	-0.18 (0.18)	2.19 (1.07)		
	B3	0.35 (0.10)	0.12 (0.04)	-0.23 (0.12)	2.11 (0.82)		
Glazing	A1	0.32 (0.08)	0.88 (0.26)	0.57 (0.29)	3.39 (0.59)	-0.1570	0.4520
	A2	0.35 (0.13)	1.04 (0.28)	0.69 (0.35)	3.29 (0.82)		
	A3	0.35 (0.09)	1.06 (0.29)	0.71 (0.31)	2.09 (0.27)		
	A3.5	0.26 (0.05)	0.92 (0.36)	0.66 (0.36)	2.28 (0.59)		
	B3	0.28 (0.10)	0.65 (0.14)	0.37 (0.16)	3.09 (0.35)		

†Ra (#220): average roughness values of specimens ground with #220 SiC paper.
‡Ra (treated): average roughness values of specimens after polishing with Soflex Finishing/Polishing System or glazing with the glaze of Vita Shading Paste.
§ ΔRa: Ra(polishing or glazing) – Ra(#220)
¶ r: Correlation Coefficient

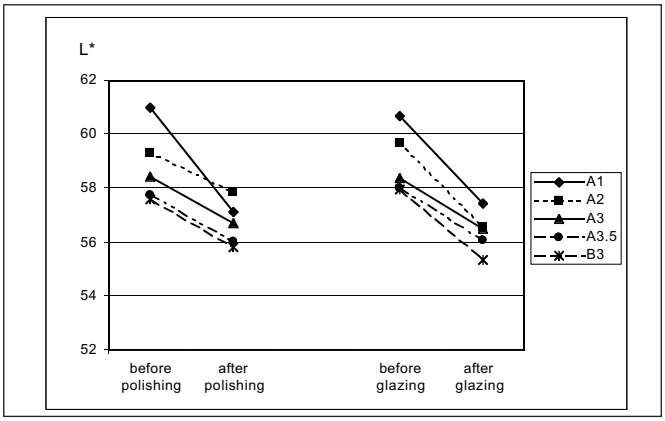

Figure 1. *Changes of L* values before and after polishing or glazing.*

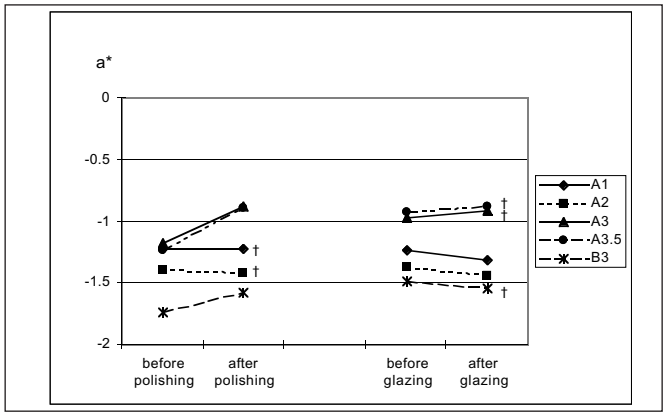

Figure 2. *Changes of a* values before and after polishing or glazing. (†: the color coordinates whose changes after polishing or glazing are statistically not significant (*p*>0.05)).*

computed to compare the precision of the two instruments. The results were analyzed using the paired *t*-test. To evaluate changes in the colorimetric values between before and after polishing or glazing procedures, the paired *t*-test analyzed the statistical significance of changes in each color coordinate of all the subgroups. The Forward Stepwise Regression Analysis evaluated the effect of the changes of each color coordinate on the color differences (ΔE*) after polishing or glazing. Finally, the correlation between the color differences and the changes of the average roughness values (ΔRa) were analyzed using Pearson Product Moment Correlation Analysis. Statistical analyses were carried out using SigmaStat software system (SigmaStat for windows version 1.0; Jandel Scientific Co, San Rafael, CA 94912-7005, USA).

RESULTS

Table 1 shows the CIE Lab* values of the five shades of Vita Cerec Mark II porcelain blocks ground with #220 grit SiC paper obtained from both instruments. Using these data, the coefficient of variation (CV) of each instrument for the three different color coordinates L*, a* and b* were computed. The mean CV of the tristimulus colorimeter was smaller than the spectrophotometer. In detail, the tristimulus colorimeter measured the L* value more precisely than the spectrophotometer ($p<0.05$). Although on the a* and b* color coordinates, the mean CV values of the tristimulus colorimeter were smaller than the spectrophotometer, the former was not significantly superior to the latter ($p>0.05$) (Table 2).

After polishing, L* values decreased ($p<0.05$) and a* and b* values increased ($p<0.05$) except for shades A1-a* ($p=1.0000$) and A2-a* ($p=0.1194$) (Figures 1-3). L* values also decreased after glazing ($p<0.01$; Figure 1). The a* values decreased after glazing in the A1 and A2 shade groups ($p<0.05$) and remained unaltered in the A3 ($p=0.0971$), A3.5 ($p=0.5012$) and B3 ($p=0.1573$) shade groups (Figure 2). However, glazing increased the b* values in all shade groups ($p<0.05$; Figure 3). Therefore, colorimetric measurements indicated that the L* values (brightness) of the porcelain specimens

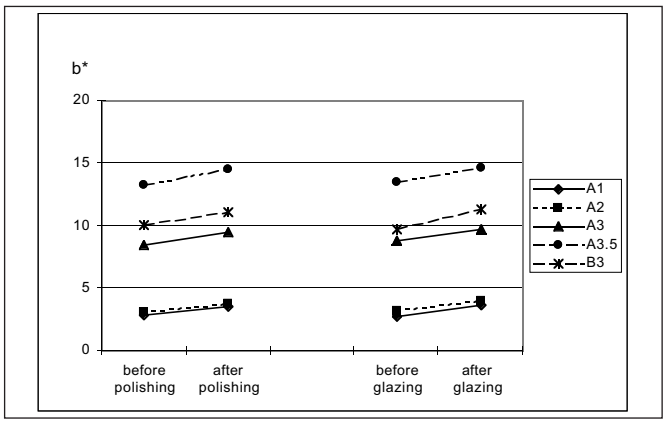

Figure 3. *Changes of b* values before and after polishing or glazing.*

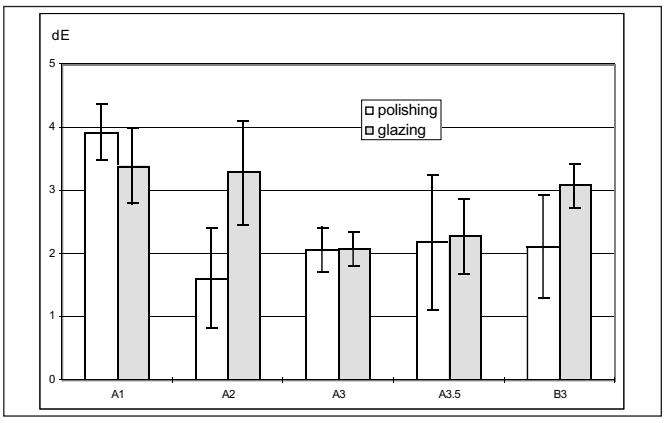

Figure 4. *ΔE* values of different shades of ceramic by polishing or glazing.*

were decreased and the b* values shifted towards the yellow region by both the polishing and glazing procedures. However, the color changes in a* values were dependent on the original shades of the porcelain blocks.

Considering that color difference values greater than 2 ΔE units were correctly judged by the observer group 100% of the time (Seghi, Hewlett & Kim, 1989b), the color changes of all the shades produced by polishing or glazing would be easily perceived, with the exception of shade A2 by polishing (Figure 4). After polishing, ΔL* was the most prominent determinant on ΔE* among the three coordinates (ΔR^2=0.9744, p<0.0001), but Δa* (ΔR^2=0.0014, p<0.0001) and Δb*(ΔR^2=0.0207, p=0.0099) had little effect. After glazing, ΔE* was also determined primarily by ΔL* (ΔR^2=0.9413, p<0.0001) and not by Δa* (ΔR^2=0.0003, p<0.0001) or Δb* (ΔR^2=0.0572, p=0.0392) (Table 3).

The average roughness values of the polished specimens decreased from their original ground values, but those of the glazed specimens increased (Table 4). Pearson Product Moment Correlation analysis showed no statistically significant correlation between changes in the average roughness values and the color differences for both polishing (r=0.3555, p=0.0812) and glazing (r=-0.1570, p=0.4520).

DISCUSSION

In the dental industry, color monitoring and evaluation have been carried out using both tristimulus colorimeters and spectrophotometers. Although the spectrophotometer had tremendous potential for its use in population samples, manufacture of porcelain and the development of shade guides, it was too complex and expensive for routine use in the dental office or laboratory. The main disadvantage of this instrument was that teeth must be extracted and placed in the machine (Miller, 1987). To overcome this problem, small area colorimeters used in the mouth were introduced, and their accuracy and effectiveness have been evaluated against the spectrophotometer (Bangtson & Goodkind, 1982; Seghi & others, 1986b; Seghi & others, 1989a; van der Burgt & others, 1990; Seghi, 1990).

In this study, the shades of Vita Cerec Mark II blocks were measured with both instruments. As the shade designation number increased, L* values decreased and a* and b* values increased; that is, the brightness (Value) of the color decreased and the Hue shifted toward red and yellow (Table 1). However, the absolute values of the translucent ceramic blocks measured by the spectrophotometer were lower in L* and b* coordinates and higher in a* coordinate than the results of the colorimeter. These differences can be explained by the different backgrounds used, that is, spectrophotometric measurements were obtained using the absolute black acrylic plate, but colorimetric results were obtained using the 18% standard gray card. This observation is in partial agreement with Knispel. All three values rose significantly when the sample was moved from a black to a white background (1991). Another explanation might result from the edge loss phenomenon (van der Burgt & others, 1990). During color measurement, sideward displacement of light in a specimen causes severe edge loss when the same small window is used for both the illumination and the collection of light. Because the spectrophotometer detects the reflected light from a 10° viewing angle and excludes scattered components, 3 mm diameter windows might give significant edge loss in the case of the spectrophotometer. Moreover, because light scattering and absorption resulting in edge loss showed a degree of wavelength dependence, it may also play a role in edge loss. Edge loss affects Value, Chroma and Hue scores. Because the values obtained by various instruments were not the same, Seghi recommended these instruments be restricted to the use of differential assessments (1990).

The effectiveness of utilizing instrumental colorimetric techniques in dentistry will ultimately depend on the accuracy and precision of the measurements on

translucent dental structures. The accuracy of an instrument was assessed by comparing the measurements obtained on the test instrument with corresponding values obtained on the reference instrument, and the instrument precision by evaluating the errors associated with the repeatability of the L*, a* and b* measurements for each instrument (Seghi & others, 1989a). The colorimetric instruments were capable of producing color measurements with precision (Seghi & others, 1986b; Seghi & others, 1989a; Seghi & others, 1989b; van der Burgt & others, 1990; Seghi, 1990; Goldstein & Schmitt, 1993). However, because the degree of accuracy with which the color measurements were made varied depending on the instrument used and the type of material surface being measured, the accuracy of the instrument is of least importance (Seghi & others, 1989a). Nevertheless, the authors needed to decide which instrument to use to measure the shade changes caused by polishing or glazing, and compare the coefficients of variation (CV) of each instrument to evaluate its precision. The CV can be used to evaluate the sampling errors of the unit in the estimation of the population. This study used the CV values to compare the measuring precision of both instruments. The CV value of the tristimulus colorimeter was smaller than the spectrophotometer. Actually, the tristimulus colorimeter measured the L* value more precisely than the spectrophotometer ($p<0.05$), but on the a* and b* color coordinates, it was not significantly superior to the spectrophotometer ($p>0.05$) (Table 2).

Thus, the colorimeter was used for subsequent measuring. In the past, zero-degree viewing-type instruments were considered sensitive to variations in surface finishes, which have the effect of varying the amount of surface-scattered light. However, with vastly improved electronics and circumferential illuminating optics, the sensitivity to specimen orientation has been reduced (Seghi, 1990). The translucency, thickness, repeated firing, background and even minor variations, such as surface geometry and texture, can also significantly affect the data collected by a colorimeter (Jorgenson & Goodkind, 1979; Obregon, 1981; Sorensen & Torres, 1987; Seghi & others, 1986a). To lessen the effects of these factors in this experiment, the flat-polished standard surfaces of specimens were used by grinding ceramic blocks with #220 SiC paper on an automatic polishing machine. Colorimetric values were measured using a 45° illumination/0° viewing angle geometry, which had smaller CV values than the spectrophotometer.

The polishing and glazing procedures decreased the values of the porcelain specimens (Figure 1) and shifted the Hue to yellow in the yellow-blue axis (Figure 3). However, the Hue changes in the red-green axis were dependent on the original shade of the porcelain (Figure 2). From the two sets of CIE Lab* measurements, color differences (ΔE*) of each group were calculated. Many suggestions concerning the validity of ΔE* values higher than those detectable by the human eye have been made (Farbmessung, 1981; Seghi & others, 1989b; Wozniak, 1987; Ruyter & others, 1987). Generally, these suggestions agree that a measured color difference value (ΔE* value) of 1.0 to 2.0 is usually accepted by observers as being identical, and those with differences greater than two units correctly assessed them to be different 100% of the time. Bearing in mind these suggestions, it appears that the color changes produced in all shades by polishing and glazing would be readily perceived by well-trained clinicians, except for shade A2 by polishing (Figure 4).

After polishing and glazing, the major changes in ΔE* values resulted from a decrease in ΔL* values, but Δa* and Δb* values had little, if any, determining power in the changes in ΔE* values (Table 3). These observations agree with the observations of Goldstein & Schmitt (1993), who also concluded that major changes were due to variations in the L* values. After polishing, the average surface roughness (Ra) values decreased in all shade groups, but after glazing, they increased. Pearson Product Moment Correlation analysis showed that the ΔE* values had no statistically significant correlation with the ΔRa values in either polishing or glazing (Table 4). However, the distribution of ΔE* values of all shade groups after glazing was within a narrower range than after polishing (Figure 4). These findings might consider the inherent color of the glazing material as a cause for the measured color difference. More research with various glazing materials would be needed to evaluate the influence of the inherent shade of the materials and the relationship between color differences and surface roughness. Conclusively, the color changes after polishing or glazing could be easily perceived by the naked eye.

CONCLUSIONS

The tristimulus colorimeter measured the value more precisely than the spectrophotometer. As the color difference values measured were greater than two ΔE units, the color changes in all the shades produced by polishing or glazing would be readily perceived. After polishing and glazing, ΔE* was mostly affected by ΔL*. However, no correlation was found between the changes in ΔE* values and the changes in surface roughness.

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Microleakage and Internal Voids in Class II Composite Restorations with Flowable Composite Linings

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Clinical Relevance

In a simulated Class II box-only composite restoration, the use of a flowable resin composite lining achieved a reduction in the number of internal voids but no benefit regarding marginal sealing. In addition, this study revealed no absolute correlation between the extent of microleakage and the presence of internal voids in a restoration.

SUMMARY

This study determined the influence of a flowable composite lining on marginal microleakage and internal voids in a Class II composite restoration. Forty-eight extracted molars were prepared with Class II cavities and randomly divided into four groups: Group I–Prodigy filling/ Revolution lining; Group II–Prodigy filling only; Group III–Tetric Ceram/Tetric Flow lining; Group IV–Tetric Ceram filling only. After thermocycling tests and dye soaking, these teeth were sectioned longitudinally. Gingival-marginal microleakage and internal voids in three separate portions of the restoration (Interface, Cervical and Occlusal voids) were observed with a stereomicroscope. Results revealed no significant difference in the marginal sealing between pairs with or without the flowable composite lining. Restorations conducted with a flowable composite lining (Groups I and III) exhibited fewer total voids and fewer voids in the interface ($p<0.05$). However, there was no significant correlation between the number of restoration voids and the associated microleakage. A flowable composite lining in a Class II resin filling could effectively reduce the voids in the interface and the total number of voids in the restoration, but may not necessarily improve marginal sealing.

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INTRODUCTION

Dentistry is facing a transition into the age of adhesive dental restorations (Christensen, 1995). Considering issues such as perceived mercury toxicity, overall restoration aesthetics and patients' discretion, since the 1980s more and more clinicians have been choosing composite restoration materials in lieu of amalgam for posterior teeth fillings. Lutz (1996) referred to resin composite materials as viable amalgam alternatives given the material's compressive strength, wear resistance, longevity and radiopacity, etc. In the ADA Council on Dental Benefit Programs (1998), potential uses for posterior teeth resin-based composites were discussed. Apart from teeth that are subject to heavy occlusal stress and for patients who are allergic or sensitive to resin-based materials, posterior resin composite restorations have been well accepted due to improvements in the materials and the development of better dentin adhesives.

There are, however, some problems associated with composite resin restorations for posterior teeth, including a less-than-optimal wear resistance, a lack of fracture toughness and marginal adaptation problems (Leinfelder, 1988). Wear resistance and mechanical strength, however, have recently been improved by the optimization of the filler particle used, with the particle size reduced and the filler loading increased. Some softer filler particles have been incorporated in order to decrease the modulus of elasticity of the resin and to prevent fracture, reducing wear rate from nearly 100 μm/year, previously, to less than 10 μm/year, currently (Leinfelder, 1995). These materials remain technique-sensitive, however, due to the extensive contraction which accompanies polymerization (from 1.67 to 5.68%; de Gee & others, 1981) and negatively influences marginal sealing (Ferracane, 1995).

To improve the marginal sealing of a composite restoration, many clinical techniques have been tested. These include incremental techniques (Tzan & others, 1992) and various modifications to the light-curing technique used (Lutz & others, 1986), although no notable benefit from these modifications has been demonstrated. Use of low-modulus lining material such as glass ionomers (Aboushala & others, 1996; Crim & Chapman, 1994), resinous liners (Kakaboura & others, 1996; Ulusu & others, 1996) or new-generation dentin bonding agents (Chan & Swift, 1994; Goracci & others, 1995; Nakabayashi & Saimi, 1996) have been proposed. However, these lining materials reduced but did not completely eliminate microleakage. Recently, packable or condensable composites were developed by densely loading fillers into hybrid composites (Nash, 1998), with all mechanical properties except flowability being further improved (Perry & others, 1999). The resulting high viscosity could, however, increase the possibility of internal voids (Opdam & others, 1996).

Flowable composite resins were introduced in late 1996 and were characterized by fluid injectability into cavities. Bayne & others (1998) classified modern resin-based restorative materials according to their filler content—for example, pit and fissure sealant resins, microfill composite resins, flowable composite resins, hybrid composite resins and packable/condensable composite resins. The filler particle size used for these resins is similar to that used for hybrid composites, but the volume content ranges between that of hybrid composites and microfill composite resins (Bayne & others, 1998). In that paper, the physical and mechanical properties of several commercial flowable composites were investigated, with the authors concluding that mechanical properties (compressive strength, diametral tensile strength, toughness) of these materials were generally about 60-90% of those of conventional composite resins. They suggested that flowable composites may be used in initial Class I and II restorations, but felt that clinical application in high-occlusal load areas should be avoided. Another practical application for such flowable resins appears to be as liners in areas of difficult access, such as proximal box restorations of Class II cavities. When used as lining materials beneath composite resin restorations, they may improve marginal adaptation.

Recently, some *in vitro* studies have reported a reduction in microleakage but an increase in the presence of internal voids in conservative Class I & II flowable resin composite fillings when compared to hybrid composite restorations (Ferdianakis, 1998; Payne, 1999). A recent study describing the use of low-viscosity intermediate resins as lining materials (Swift & others, 1996) reported reduced microleakage with several different dentinal adhesive systems, although long-term investigation of commercial flowable composite linings has yet to be reported.

This study investigated the influence of two commercial flowable composite linings on marginal microleakage and the presence of internal voids in Class II composite restorations. It has always been presumed that the presence of internal voids in a restoration positively correlates to microleakage. In this study, the potential correlation between these two variables was investigated.

METHODS AND MATERIALS

Forty-eight freshly-extracted human molars without decay, cracks or previous restorations were chosen. The teeth were scaled and cleaned with tap water. To simulate clinical posterior teeth alignment, the teeth were mounted in stone jigs with one premolar and one molar each on mesial and distal sides. Two Class II box-only cavities without retention lock (a bucco-lingual width of 4 mm, an occluso-gingival height of 3 mm and a pulpal depth of 2 mm) were prepared in mesial and distal surfaces. The margins were all located within enamel. All the margins were kept as close as possible to a 90°cavo-surface angle. Two flowable composite resins, Revolution (Kerr Corp, Orange, CA, USA, 906838) and Tetric Flow (Vivadent Ets, Schaan, Liechtenstein, A02474), and their compatible hybrid composites, Prodigy (Kerr Corp, Orange, CA, USA, 608743) and Tetric Ceram (Vivadent Ets, Schaan, Liechtenstein, A07008) respectively, were selected as experimental materials. Table 1 lists a summary of experimental materials used, their manufacturers, type, composition and filler content, with experimental design depicted in Figure 1. These teeth were randomly divided into two groups. Then, two cavities on the same tooth in each group were randomly assigned "with and without" (Group I-II or III-IV) flowable composite lining groups to reduce the inter-tooth variation. One well-trained specialist in operative dentistry undertook the

Table 1: *Experimental Restorative Materials and Dentin Bonding Agents Used in This Study*

Material	Manufacturer	Type	Composition	Lot No	Filler Content
Revolution	Kerr Corp, Orange, CA, USA	Flowable resin	Filler: Barium glass; synthetic silica Matrix: Bis-GMA	906838	Weight%:62 Volume%:46
Tetric Flow	Vivadent Ets, Schaan, Liechtenstein	Flowable resin	NA*	A02474	NA*
Prodigy	Kerr Corp, Orange, CA, USA	Hybrid resin	Filler: Barium fluorosilicate Matrix: Bis-GMA	608743	Weight%:79 Volume%:59
Tetric Ceram	Vivadent Ets, Schaan, Liechtenstein	Hybrid resin	Filler: Barium glass, ytterbium trifluoride, Ba-Al-F silicate glass, silicon dioxide Matrix: Bis-GMA, UDMA, TEG-DMA	A07008	Weight%:80 Volume%:60
Optibond Solo	Kerr Corp, Orange, CA, USA	Single component Dentin-bonding system	Filler: Fumed silica, Barium glass Matrix: NA	812088	Volume%: 25
Syntac Single Component	Vivadent Ets, Schaan, Liechtenstein	Single component Dentin-bonding system	maleic acid, HEMA, methacrylate modified polyacrylic acid, initiators, stabilizers, water	926755	NA*

*NA: Information not available.

entire filling and testing procedures. All specimens were polished with pumice powder and rinsed with tap water after cavity preparations. The teeth were then wrapped with metal matrix and matrix retainers, and two wooden wedges were inserted at the buccal and lingual sides to tightly seal the matrix—cavity margin.

For Group I and II restorations, the entire cavity (enamel and dentin) was etched with 35% phosphoric acid (Ultraetch, Untradent Products Inc, South Jordan, Utah, USA) for 15 seconds, then washed with tap water and air dried. A single-component dentin adhesive (Optibond Solo; Kerr Corp, Orange, CA, USA, 812088) was brushed into the cavity with a mini-brush for 15 seconds and light cured (Curing light XL 3000, 3M Co, St Paul, MN, USA) for 20 seconds. For Group I restorations, cavities were covered with Revolution about 1 mm thick and light cured from the occlusal surface for 20 seconds. The hybrid composite Prodigy was then placed and packed over the Revolution lining with a resin instrument (LM 437-445si, LM-Dental, Finland) in two increments each about 1 mm thick in order to conform to the tooth morphology, then light cured for 40 seconds. For Group II restorations, the cavity floor was first covered with Prodigy to a depth of one millimeter, with the remaining restoration process being the same as for Group I restorations. After removal of the metal matrix and wooden wedges, the restorations were both light cured from the buccal and lingual sides for 20 seconds.

The cavities of Group III and IV restorations were also etched with 35% phosphoric acid for 15 seconds, washed and air dried. The compatible bonding system Syntact Single component (Vivadent Ets, Schaan, Liechtenstein, 926755) was applied and allowed to stand for 20 seconds before air drying and light curing for 20 seconds. According to the manufacturer's instructions, a second layer of Syntact Single component was then applied in the same manner. For Group III restorations, Tetric Flow was injected into cavities to a depth of about one millimeter, then light cured for 20 seconds. Tetric Ceram was placed in cavities and light cured in two increments for 40 seconds each. For Group IV restorations, cavities were filled with Tetric Ceram and light cured in three consecutive increments of 40 seconds each. After removal of the metal matrix and wooden wedges, the restorations were both light cured from the buccal and lingual sides for 20 seconds.

The restorations were finished with a scalpel and fine diamond burs, then polished with paper disks (Sof-Lex, 3M Co). After finishing and polishing, the experimental teeth were removed from the stone mounting jigs and

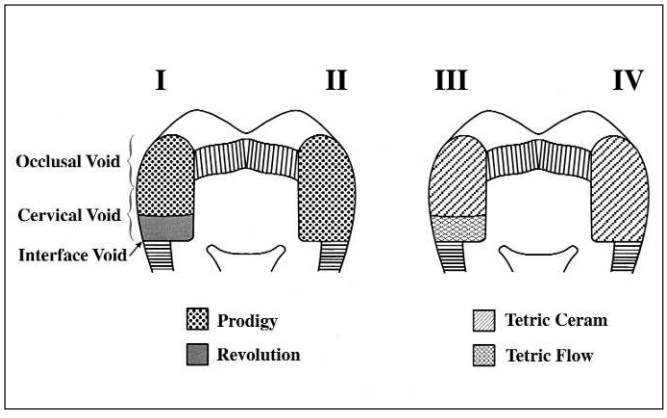

Figure 1. *Illustration of experimental model and description of three separated parts of internal voids.*

placed in isotonic saline at 37°C in a water bath for 24 hours (Crim & García-Godoy, 1987). The teeth were then placed in a thermocycling machine for 1,500 cycles ranging from 5-60°C (each dwelling time for 20 seconds), after which the root apex was sealed with utility wax. The teeth were entirely coated with nail varnish except for the restoration and one millimeter beyond the margins, then soaked in a 2% basic-Fuchsin dye for 24 hours. Subsequent to this, the teeth were removed from the bath, embedded in epoxy resin and sectioned in a mesio-distal direction along their longitudinal axis using an Isomat 2000 precision saw (Buehler Ltd, USA). The sectioned teeth were observed with a 50x stereomicroscope (Stemi SV 6, Zeiss, Germany) and scored for the degree of dye penetration and internal porosity. The assessor was blind to which group the teeth belonged. The scoring scales for marginal microleakage are shown:

Score 0 = No dye penetration

Score 1 = Dye penetration into enamel only

Score 2 = Dye penetration beyond the Dentino-Enamel Junction

Score 3 = Dye penetration into the pulpal wall

The scoring system for internal voids was modified from Ferdianakis's study (Ferdianakis, 1998). For the description of the location and semi-quantitative analysis of the internal porosity in the restoration, the assessment of the voids present was performed in three different parts of the restoration (Figure 1):

The gingival margin—resin interface (Interface void).

The cervical half (Cervical void) or the occlusal half (Occlusal void) of the entire restoration.

Scores for recording voids in the three parts are shown as:

Score 0 = no void

Score 1 = some voids exist

The sum of the scores for each of the three parts (Interfaced void, Cervical void and Occlusal void) was expressed as Total voids. Scores for Total voids ranged from 0-3, depending on the sum of the three individual void scores.

The Kruskal-Wallis test statistically examined the data for microleakage and internal voids (three separated parts and the Total voids) in four groups. The computation of significant differences was assigned at a $p<0.05$ level. Correlation between marginal microleakage and internal voids in any of the three restoration regions was examined by the Pearson test, with $p<0.05$ considered significant and $p<0.01$ as very significant.

RESULTS

Ninety-six restorations were prepared. During the processing and sectioning procedures two specimens from Group I were excluded due to damage. The specimen number of Group I was 22, whereas the other groups was 24.

None of the groups showed complete prevention of dye penetration. Table 2 demonstrates the frequency of the scores for marginal microleakage. Except for Group I, there was severe gingival marginal microleakage (score 3) in the other groups. Group I (Prodigy/Revolution lin-

Table 2: *Frequency of Dye Penetration Scores as an Indicator of Marginal Microleakage*

Group		Score			
		0	1	2	3
I. Prodigy/Revolution Lining	(n=22)	6	10	6	0
II. Prodigy	(n=24)	2	13	6	3
III. Tetric Ceram/Tetric Flow Lining	(n=24)	0	11	11	2
IV. Tetric Ceram	(n=24)	2	8	7	7

Kruskal-Wallis test: Significant difference ($p<0.05$) between Group I-III, I-IV.

Table 3: *Frequency of Scores of Three Parts of Internal Voids and Total Voids*

Group		Interface Void		Cervical Void		Occlusal Void		Total Void			
		0	1	0	1	0	1	0	1	2	3
I. Prodigy/ Revolution Lining	(n=22)	22	0	10	12	11	11	2	17	3	0
II. Prodigy	(n=24)	10	14	0	24	9	15	0	5	9	10
III. Tetric Ceram/ Tetric Flow Lining	(n=24)	24	0	13	11	12	12	6	13	5	0
IV. Tetric Ceram	(n=24)	11	13	6	18	13	11	0	12	6	6

Kruskal-Wallis test:

Interface void: Significant difference (p<0.05) between Group I-II, I-IV, II-III, III-IV.

Cervical void: Significant difference (p<.05) between Group I-II, II-IV, II-III, III-IV.

Total void: Significant difference (p<0.05) between Group I-II, I-IV, II-III, III-IV.

ing) restorations demonstrated superior marginal sealing, compared to Group III (Tetric Ceram/Tetric Flow) and Group IV (Tetric Ceram only) ($p<0.05$). There was no statistical difference for marginal microleakage between Group I and II, and Group III and IV, both with and without flowable composite lining pairs at $p=0.05$ level.

The results of the assessment of internal voids present in the restoration are expressed as internal void results for each of the three separate parts of the restoration and a value for the total voids (Table 3). The value for Interfaced void in Groups I and III restorations was zero, suggesting effective elimination of voids within the composite in the restoration–tooth interface region for groups using flowable composite linings ($p<0.05$). Compared to without-lining groups (II and IV), flowable composite lining groups (I and III) exhibited less void formation in the filling—tooth interface of the restoration ($p<0.05$). In the cervical area, results showed significant differences ($p<0.05$) between Groups I-II, III-IV pairs and II-III, II-IV comparisons. Thus, the use of flowable composite linings clearly reduces the likelihood of Interface voids and Cervical Voids. Observing the Occlusal voids showed no significant differences among any of the four experimental groups at the $p=0.05$ level. Total voids were also lower for restorations utilizing a flowable composite lining. There were significant differences ($p<0.05$) between Group I-II, III-IV pairs and I-IV, II-III comparisons.

The Pearson test examined the correlation between marginal microleakage and internal voids in the three restoration regions (Table 4). There was no correlation between marginal microleakage and the presence of Total voids or voids in any region of the restoration ($p>0.05$). Even the value for Interfaced voids did not correlate with the microleakage value ($p>0.05$).

From microscopic examination, some flowable composite lined specimens with no Interface voids revealed extensive dye penetration (score=3). Although specimens from Groups II and IV exhibited little voids in the tooth-resin interface, only minor dye penetration (score 0 or 1) was noted. There were 26 specimens with Interface voids present that also exhibited marginal leakage. In about 50% of the specimens demonstrating microleakage, the progression of dye penetration was found adjacent to the Interfaced void. It may be that the progression of dye penetration into the restoration is reduced or stopped when voids in the resin are encountered.

DISCUSSION

Marginal gaps and internal voids exist between cavity walls and restorative materials when these materials are poorly adapted. Microleakage may result from many factors, such as the extent of the marginal gap, polymerization shrinkage of materials used (Eick & Welch, 1986), the degradation of the particular bonding or restorative material used (Õilo, 1992), dissolution of liners or smear layers (Fortin & others, 1994), varying coefficients of thermal expansion for restoration and native materials and varying degrees of deformation upon mechanical loading for restoration (Suzuki & others, 1985). Microleakage via the tooth restoration interface may lead to a marginal stain, post-operative sensitivity, recurrent caries and possibly pulpal problems (Brannstrom, 1986), thus prevention of microleakage is very important in restorative dentistry.

Ferdianakis (1998) tested a flowable composite resin (Revolution) for initial Class I restorations. Compared to the control group of hybrid composite resins, flowable composite resins more effectively reduce marginal leakage in shallow pit and fissure caries, depending on their flowability. However, this study revealed that the use of flowable composite resins as a restoration lining material should result in a reduction in the likelihood of the formation of internal voids although no evidence has been presented suggesting any substantial reduction in marginal microleakage.

Flowable composite resins exhibit a lower filler content (60-70% by weight and 46-70% by volume) and a greater proportion of resin matrix than hybrid resins. The greater proportion of resin matrix in flowable composite resins may contribute to their greater polymerization shrinkage. In a related sense, the elastic modulus of flowable composite resins is lower than that for hybrid resins. When overlying hybrid composite resins are light-irradiated, the contraction stress generated as a result of the curing process may pull the lining materials away from the tooth wall. Recently, some factors, such as the configuration of the cavity, the

Table 4: *Significant Correlation Between the Variables (Marginal microleakage, three parts of internal voids, total void)*

	Marginal Microleakage	Interfaced Void	Cervical Void	Occlusal Void	Total Void
Marginal Microleakage					
Interfaced Void			**		**
Cervical Void		**			**
Occlusal Void					**
Total Void		**	**	**	

Pearson test: ** Correlation is very significant at the 0.01 level (2-tailed).

degree of shrinkage of the composite mass (de Gee & others, 1993) and the direction of the shrinkage vectors (Versluis & others, 1998) have been investigated and appear to be important influences on the degree of marginal microleakage of a restoration. While this study revealed that flowable composite linings improve marginal adaptation, concomitant contraction stresses generated during curing may result in a restoration with no real improvement in marginal sealing compared to restorations without such linings.

Porosity is considered an undesirable property in dental materials. The porosity of impression materials, poured casts and finished castings may lead to poor quality of restorations. It is generally believed that poor marginal adaptation is related to internal porosity and that the more voids present at a restoration interface, the lower the bonding efficiency of the restoration to the tooth structure (Opdam & others, 1996). However, there are suggestions that a reduction of contraction may result from the presence of some degree of porosity (Alster & others, 1992). These authors created porosity in the lining by stirring the luting cement and claimed that a certain number of retained pores contributed to the stress reduction of the restoration and the maintenance of marginal integrity. These investigations found that in most specimens with voids, the progression of dye penetration into the restoration was halted when encountering a void. They suggested that "tension" due to void-entrapped air presumably inhibited further dye penetration. However, this study had a very limited sample size and the theory needs further investigation.

Unrestrained porosity still provides a number of problems for restoration integrity. For example, large voids will reduce the mechanical strength of the restoration. Huysmans & others (1996) reported that improper placement of resin composite may interfere with cavity-wall adaptation and decrease the overall flexural strength of the restoration. Extensive internal porosity distributed throughout the restoration will decrease the contact surface area between the restoration and the tooth. Porosity of the external surface of the restoration will result in surface roughness and may lead to staining. Thus it appears that a technique attempting to improve the chances of success of such restorations by creating porosity either at the inner interface or within the body of the restoration itself may elicit unpredictable results.

Currently, flowable composite resins are considered an emerging concept for conservative restorative dentistry (Bayne & others, 1998) that has the potential to save practitioners' time. Combined with an air-abrasion procedure, initial Class I and II caries may be easily and efficiently addressed by such a technique (Ferdianakis, 1998; Payne, 1999). Further, when access to the cavity is limited, the relatively fluid nature of the material virtually guarantees effective marginal sealing.

Many materials, such as glass-ionomer cements, resin-based materials and even dentinal adhesive have been considered as a lining under composite restorations, and most have exhibited some degree of improvement in marginal sealing (Crim & Chapman, 1994; Hotta & Aono, 1994; Friedl & others, 1997). An appropriate evaluation of these lining materials related to their long-term biodegradation, will warrant additional trials. Another advantage associated with the use of flowable composite resins is their mechanical strength compared to other analogous materials. One deficiency of glass-ionomer cement is its lower mechanical strength (Gladys & others, 1997), with even resin-modified glass ionomers failing to perform well in shear-loading tests (Sidhu & others, 1999). According to Bayne & others (1998), many flowable composite resins demonstrate sufficient biaxial flexural strength and fracture toughness to warrant their use as restorative materials. In addition, the radiopacity of flowable composite resins facilitates the distinction of the material from secondary caries (Bouschlicher & others, 1999). As a lining material under a restoration, flowable composites thus constitute the more appropriate choice compared to other currently available restorative materials.

CONCLUSIONS

Results from this study reveal a reduction in the presence of internal restoration voids when using flowable composite resins (Revolution or Tetric Flow) as a lining material for composite restorations. The incidence of internal voids was significantly reduced at both the restoration's interface and within its mass. No significant difference in the likelihood of marginal microleakage between pairs with or without flowable composite resin linings was demonstrated ($p<0.05$). No significant correlation between the number of voids detected in any part of the restoration and marginal microleakage has been found ($p<0.05$). The influence of the internal porosity on marginal microleakage and restoration stress-relief warrants further research.

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Pulp Tissue Reaction to Four Dental Cements

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Clinical Relevance

Protection of pulp is recommended in deep cavities to prevent post-cementation sensitivity, which may be caused by chemical irritation of the dental cements.

SUMMARY

Pulp tissue reactions to four commonly used dental cements were histo-pathologically evaluated by placing the cements on exposed monkey dental pulp followed by a surface-sealed adhesive restoration. Evaluations were done at 3 or 5, and 30 and 90 days after operation. No serious inflammatory reaction of the pulp, such as necrosis or abscess formation, was observed. However, the conventional dental cements showed irritating effects on the exposed monkey dental pulp without bacterial contamination. Reactions of exposed dental pulp beneath the dental cements differed depending on the materials used.

INTRODUCTION

Dental cements have been widely used in conservative dentistry for 70 years. Clinical experience indicates that dental cements placed in deep cavities without a protective sublining might damage the dental pulp, therefore, concern was directed at the acidity of the cement. A number of instances of post-operative sensitivity following the use of glass ionomer cements as luting agents for crowns and bridges have been reported (Council on Dental Materials, Instruments and Equipment, 1984).

Toxic components of various dental materials were reported as the main cause of inflammation and necrosis (Retief, Austin & Fatti, 1974). It has been suggested in recent investigations by several researchers that the chemical toxicity of these materials, related to their acidity, might not completely explain the harmful effects on the pulp and that micro-organisms might also be implicated. Bacterial infection through the restoration interface was the most causative factor of pulp infection (Brännström & Nyborg, 1972). Bacterial micro-organisms' infiltration through marginal leakage is the greatest threat to the pulp, rather than the toxicity of the restorative materials. The dental pulp has an adequate healing potential, and some of the previously reported failures in pulp capping were due to microleakage and pulp infection (Cox, Bergenholtz & Fitzgerald, 1982). Therefore, to understand the role of toxicity of dental materials, it is important to prevent bacterial leakage in pulp tissues. The development of an isolator with surgical facilities enabled studies to be conducted on germ-free rats, thus eliminating any possibility of bacterial contamination (Kakehashi, Stanley & Fitzgerald, 1965). Adhesive resin was also used to prevent bacterial infiltration through marginal leakage.

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Those resin composite restorations, etched and successfully sealed, failed to show bacterial growth by culture or staining methods (Inokoshi, Iwaku & Fusayama, 1982; Fujitani, 1986; Cox & Suzuki, 1994).

This study evaluated the chemical toxicity of commonly used dental cements by placing them on exposed monkey dental pulp followed by a surface-sealed adhesive restoration.

METHODS AND MATERIALS

Materials

Table 1 lists the materials, manufacturers and batch numbers. Dycal, a $Ca(OH)_2$ cement, was used as control material. The four dental cements used in this study were glass ionomer, polycarboxylate, zinc oxide eugenol and zinc phosphate.

Methods

A total of 180 intact teeth of eight Japanese monkeys (Macaca Fuscata) were randomly distributed throughout the dentitions. The monkeys were placed under general anesthesia by intramuscular injection of ketamine (Ketaral, Sankyo Co, Tokyo, Japan) 20 mg/kg and intravenous injection of pentobarbital sodium (Nembutal Sodium Solution, Abbott Laboratories, North Chicago, USA) 10 mg/kg. A Class V cavity was prepared on the facial surface of each tooth using a high-speed tapered diamond bur (ISO #170, GC Co, Tokyo, Japan) under water-spray coolant. The pulps were intentionally exposed with a sterile round carbide bur (ISO #1, Shofu Inc, Kyoto, Japan) of 0.8 mm diameter. Local infiltration anesthesia around the root apex was applied with 2% lidocaine (Xylocaine, Fujisawa Co, Osaka, Japan) containing 1: 80,000 epinephrine to control hemorrhaging and exudation from the exposed pulp. The exposed area was irrigated immediately after perforation with 3% H_2O_2 and 6% NaOCl to remove tooth debris, and all hemorrhaging was controlled (Katoh, Kidokoro & Kurosu, 1978). The exposed area was carefully dried with a sterile cotton pellet and the exposed pulp was capped with one of the five capping materials.

The cavities were lined with a glass ionomer cement (Fuji I, GC Co), totally etched with 37% phosphoric acid and sealed with an adhesive resin composite (Clearfil Photo Bond and Photo Clearfil Bright, Kuraray Co, Osaka, Japan).

At 3 or 5, and 30 and 90 days after the operation the monkeys were sacrificed by intravenous injection of thiopental sodium (Ravonal, Tanabe Pharmaceutical Co, Osaka, Japan), 250 mg/kg. The teeth were removed from the jawbones and immersed in 10% neutral buffered formalin solution for one week. Before immersion, the mesial and distal approximal surfaces of the

Table 1: *Restorative Materials Employed*

Code	Material	Brand Name	Content	Setting Time	Batch No	Manufacturer
DY	$Ca(OH)_2$	Dycal cement	Base: Calcium phosphate, Calcium Tungstate, Zinc Oxide, Glycol Salicylate Catalyst: Calcium hydroxide, Zinc Oxide, Zinc Stearate, Ethyltoluene Sulfonamide	1'00"	920519	Dentoply Caulk, Milford, DE, USA
GI	Glass Polyalkenoate Cement	Fuji I	P: Fluoro-aluminosilicate glass L: Acrylic-maleic acid copolymer, Polybasic carboxylic acid, Water P/L ratio = 1.8 (g/g)	4'30"	P: 310841 L: 310841	GC Co, Tokyo Japan
PC	Polycarboxylate Cement	LIVCARBO	P: Zinc oxide, Magnesium oxide, Polyacrylic acid powder, binder L: Polyacrylic acid, Water P/ L ratio = 2.0 (g/g)	6'15"	P: 300841 L: 300841	GC Co
ZE	Zinc Oxide Eugenol Cement	EUGEDAIN	P: Zinc oxide, Benzoic acid, Stearic acid magnesium, L: Rosin Clove oil, Rosin P/L ratio = 5.0(gml)	5'00"	P:3063R L:1059S	SHOWA, Co, Tokyo, Japan
ZP	Zinc Phosphate Cement	Elite 100	P: Zinc oxide, Magnesium oxide L: Phosphoric acid, Aluminum, Water P/L ratio = 1.45 (g/ml)	7'00"	P: 271231 L: 271231	GC Co

teeth were reduced with a high-speed diamond bur under water spray coolant until the pulp became almost visible through the remaining dentin to facilitate the penetration of the fixing solution. The teeth were demineralized with Plank-Rychlo's decalcifying solution at 4° for five days, neutralized with 5% sodium sulfate for six hours and washed with running water for six hours. After removing the adhesive resin composite, the teeth were dehydrated and embedded in paraffin. Histopathological serial sections at 5 μm thickness of the cavities and pulp were prepared, obtaining approximately 80 to 100 sections per cavity. These were stained with hematoxylin and eosin for routine histological evaluation or with Taylor's modification of Gram's staining technique for detecting micro-organisms (Taylor, 1966).

Histopathological changes of the pulp were analyzed on decalcified serial sections. The acute inflammatory cell infiltration and chronic inflammatory cell infiltration were classified into four grades: none, slight, moderate and severe (Mjör & Tronstad, 1972). The dentin bridge formation was classified into five grades: none, initial dentin bridging, partial dentin bridging, almost complete dentin bridging and complete dentin bridging (Kitasako & others, 1998). The presence of bacteria along the cavity walls and floor was also evaluated. The diameter of the exposed area and was measured on each section. Among the 80 to 100 serial sections per cavity, one section with the largest diameter of exposed area was selected for assessment as a representative section of the tooth.

Results of the pulpal responses were statistically analyzed by the Kruskal-Wallis one-way analysis of variance (Siegel & Castellan, 1988) for differences among the five groups at each time interval and Fisher's PLSD test for differences between control and experimental groups at each time interval. One-way analysis of variance (ANOVA) was used to determine significant differences in the diameter of the exposed areas among the five groups at each time interval.

RESULTS

Figure 1 and Table 2 summarize the findings on the histological sections. All reactions were restricted to directly beneath the exposure site. The diameter of the exposed areas generated in this study ranged from 0.22 to 1.56 mm (average is 0.68 mm). There were no statistically significant differences among the five groups for each time interval (f=1.68; df=14, 135; p=0.07).

Acute Inflammatory Cell Infiltration

After three or five days, group DY showed none-to-slight acute inflammatory cell infiltration. In the groups of four dental cements, moderate-to-severe reactions were observed in 6-9 out of 10 cases. The reactions were statistically significantly higher than that of group DY (KW=21.8, p=0.0002).

After 30 days, group DY showed still none-to-slight reaction. Moderate-to-severe reactions observed at three or five days subsided in groups GI, PC and ZP but still persisted in group ZE. The reaction of group ZE was statistically significantly higher than that of group DY (KW=12.8, p=0.012).

After 90 days, no acute reaction was observed in group DY. Although one to three cases of slight-to-moderate reactions were observed in groups with four dental cements, the other cases showed no acute reactions. No statistically significant difference in acute reaction occurred among all groups.

Chronic Inflammatory Cell Infiltration

After three or five days, chronic inflammatory cell infiltration was slight-to-moderate in all groups and not statistically significant among them.

After 30 days, group DY showed slight reaction. The other groups showed slight-to-moderate reactions com-

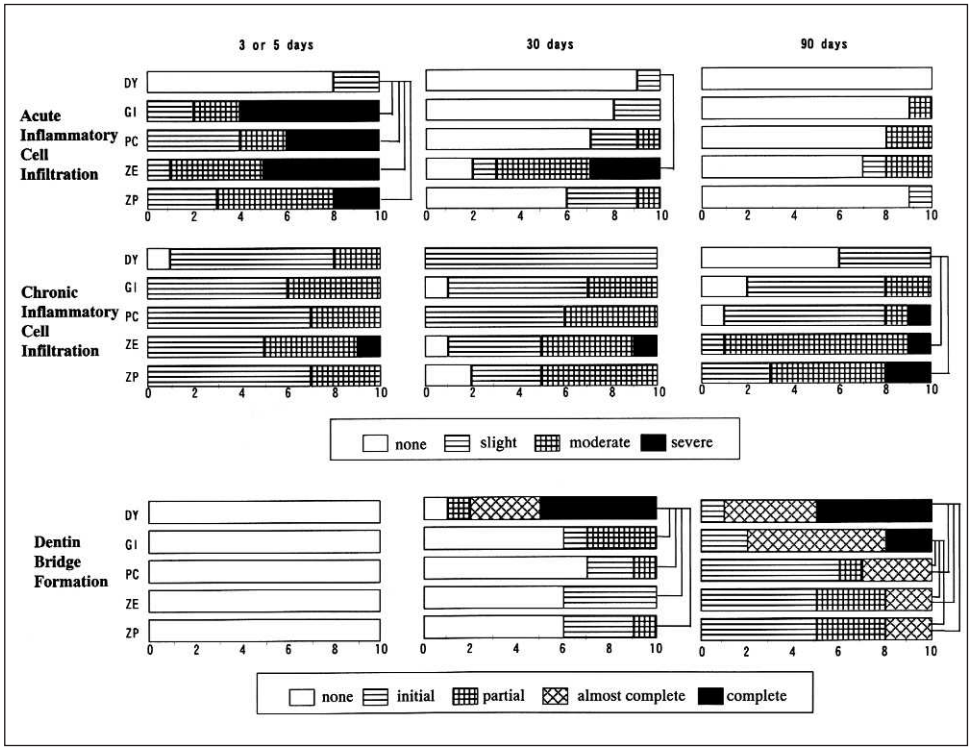

Figure 1. *Pulpal responses of the five experimental groups. Vertical lines indicate that bar charts at both ends are statistically significantly different (Fisher's PLSD test, p<0.05).*

Table 2: *Results of the Histopathological Findings*

Time Intervals		3 or 5 Days					30 Days					90 Days				
Experimental Groups		DY	GI	PC	ZE	ZP	DY	GI	PC	ZE	ZP	DY	GI	PC	ZE	ZP
# of Specimens		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Acute Inflamation	none	8	0	0	0	0	9	8	7	2	6	10	9	8	7	9
Cell Infiltration	slight	2	2	4	1	3	1	2	2	1	3	0	0	0	1	1
	moderate	0	2	2	4	5	0	0	1	4	1	0	1	2	2	0
	severe	0	6	4	5	2	0	0	0	3	0	0	0	0	0	0
Chronic Inflamation	none	1	0	0	0	0	0	1	0	1	2	6	2	1	0	0
Cell Infiltration	slight	7	6	7	5	7	10	6	6	4	3	4	6	7	1	3
	moderate	2	4	3	4	3	0	3	4	4	5	0	2	1	8	5
	severe	0	0	0	1	0	0	0	0	1	0	0	0	1	1	2
Dentin Bridge	none	0	0	0	0	0	1	6	7	6	6	0	0	0	0	0
Formation	initial	0	0	0	0	0	0	1	2	4	3	1	2	6	5	5
	partial	0	0	0	0	0	1	3	1	0	1	0	0	1	3	3
	almost comlpete	0	0	0	0	0	3	0	0	0	0	4	6	3	2	2
	complete	0	0	0	0	0	5	0	0	0	0	5	2	0	0	0
Diameter of	mean	0.76	0.68	0.58	0.65	0.65	0.71	0.68	0.70	0.61	0.57	0.67	0.80	0.67	0.62	0.85
Exposed Area	minimum	0.54	0.34	0.38	0.30	0.42	0.42	0.44	0.22	0.30	0.28	0.22	0.48	0.36	0.46	0.48
(mm)	maximum	0.94	1.00	0.74	0.96	0.94	0.86	0.96	0.96	0.74	0.90	0.96	0.94	0.98	0.80	1.56

parable to those of the three or five days groups. No statistical difference was found among all groups.

After 90 days, group DY showed none-to-slight reaction. Moderate-to-severe reaction was observed in 7-9 out of 10 cases in groups ZE and ZP. Groups GI and PC showed less reaction than groups ZE and ZP. Groups ZE and ZP showed statistically significantly higher incidence of chronic inflammatory cell infiltration than group DY (KW=22.4, p=0.0002).

Dentin Bridge Formation

After 30 days, group DY showed statistically significantly higher incidence of dentin bridge formation than other groups (KW=17.3, p=0.0017). In group DY, it ranged from almost-complete to complete in eight out of 10 cases.

After 90 days, almost-complete to complete reaction was observed in 8-9 out of 10 cases in groups DY and GI. Groups PC, ZE and ZP showed less formation than groups DY and GI (KW=16.4, p=0.0025).

Bacterial Penetration

Bacterial penetration along the cavity walls/floors could not be detected in any cases of the 3 or 5, and 30- and 90-day groups.

DISCUSSION

In this study, dental cements were applied directly to the exposed pulp and the cavities were sealed with glass-ionomer cement and adhesive composite resin. By eliminating bacterial leakage, the actual chemical toxicity of the cements could be determined.

All four dental cements showed moderate-to-severe acute inflammation at three or five days, which was significantly greater than that of the Dycal-capped group (control) (Figures 2a, b, c & d). These initial reactions subsided in three dental cements and persisted only in the zinc oxide eugenol cement. These findings suggested that the four dental cements used in this study were chemical irritants, and the degree of irritation depended on the materials used.

It has been reported that eugenol can cause pulpal reaction, occasionally with thrombosis and aggregation of both red and white blood cells (Brännström & Nyborg, 1976). Since no bacterial penetration was observed in the pulp tissue in this study, the pulpal reactions in the ZE group can probably be attributed to the eugenol.

When a ZOE cement was placed directly onto the exposed pulp, chronic inflammation was maintained for 21 days (Watts & others, 1985). Wilson and Batchelor (1970) reported that when a ZOE cement was immersed in water, eugenol was eluted, and there was a continuous removal of eugenol from the cement. Prolonged chronic inflammation observed in the ZE group at 90 days seemed to be caused by the chemical irritating effect of eugenol after setting (Figure 3d).

The liquids in the zinc phosphate and polycarboxylate cements reacted rapidly with the zinc oxide powder,

Figure 2. *Three or five days after operation.*

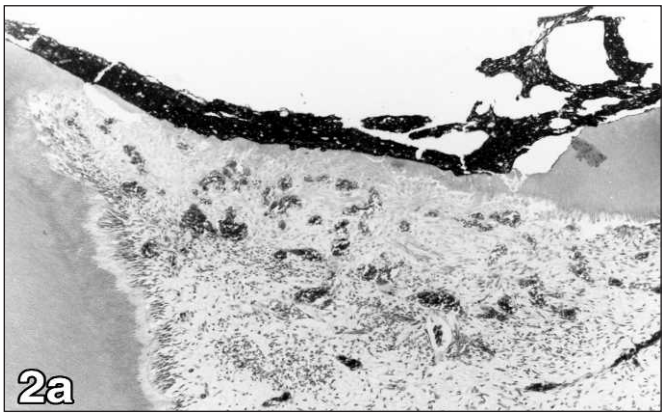

Figure 2a. *Group DY showed slight inflammatory cell infiltration at the periphery of exposed area.*

Figure 2b. *Group GI showed moderate inflammatory cell infiltration, localized reduction of pulp fibroblasts, and reduced odontoblasts at the periphery of exposed area.*

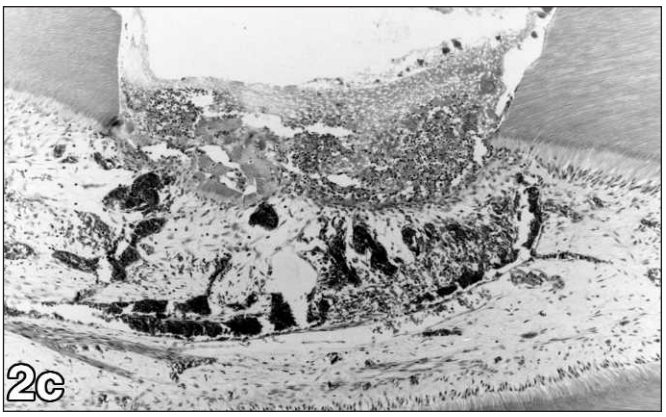

Figure 2c. *Group ZP.*

Figure 2d. *Group ZE. Both groups (ZP and ZE) showed severe inflammatory cell infiltration at the periphery of exposed area (all magnification X25) (all stained with hematoxylin and eosin).*

with the pH being above two at one minute after mixing (Smith & Ruse, 1986). At three or five days, the low pH of the zinc phosphate and polycarboxylate cements before setting was considered responsible for initial pulp inflammation (Plant, 1970; Eames, Hendrix & Mohler, 1979).

In group ZP at 30 days, acute inflammatory cell infiltration of none-to-slight was observed in nine out of 10 cases and chronic inflammatory cell infiltration of none-to-slight was observed in five out of 10 cases. At 90 days the ZP group showed chronic inflammatory cell infiltration of moderate-to-severe in seven out of 10 cases. However, polycarboxylate cement showed a milder response to the pulp at 90 days. The powder of both zinc phosphate and polycarboxylate cements are composed of zinc oxide. Some chemical irritation persisted, with chronic inflammation observed in group ZP (Figure 3c) much longer than group PC. The differences in irritation between the zinc phosphate and polycarboxylate cements might be caused by the differences in liquid composition or solubility of the cement.

When a glass-ionomer cement was placed on the exposed pulp in a germ-free rat, round cell infiltration occurred in the pulp tissue area adjacent to the cement with a localized reduction of pulp fibroblasts, and reduced odontoblasts were seen near the filling cement (Paterson & Watts, 1987). It was similar to those in this study (Figure 2b). The main factor for the severe irritation of the glass-ionomer cement might be in the polyacrylic acid and co-acids. The acidity of the cement was close to a pH of 2 at five minutes and only a pH of 3 at 10 minutes after mixing (Smith & Ruse, 1986). Un-set glass ionomer cement has a low pH, which could affect exposed pulpal tissues in contact with the cement.

On the other hand, the milder effect of the polycarboxylate cement on the pulp was remarkable despite a pH of 1.5 of the polyacrylic acid liquid of the cement.

Figure 3. *Ninety days after operation.*

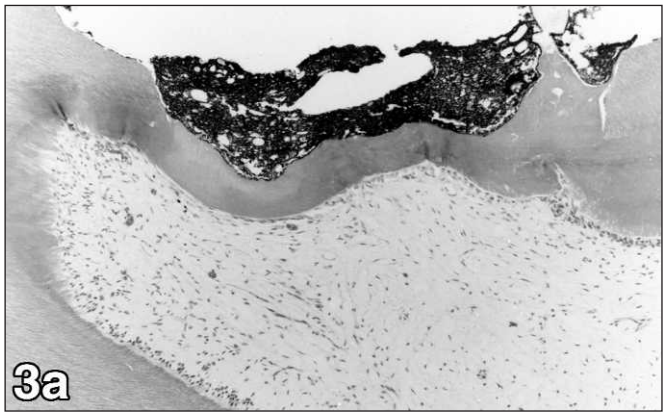

Figure 3a. *Group DY.*

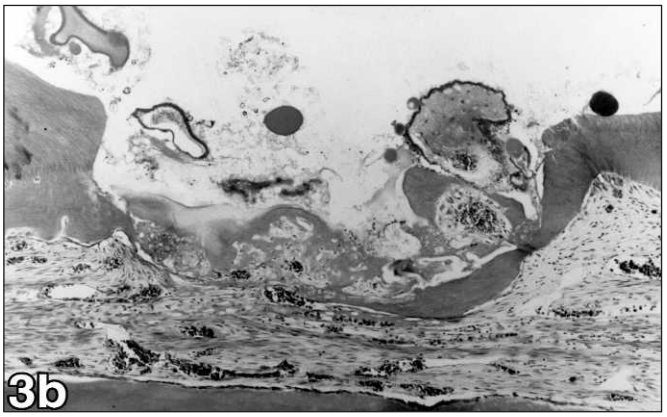

Figure 3b. *Group GI. Both groups (DY and GI) showed almost complete dentin bridge formation and mild inflammatory cell infiltration at the periphery of exposed area.*

Figure 3c. *Group ZP.*

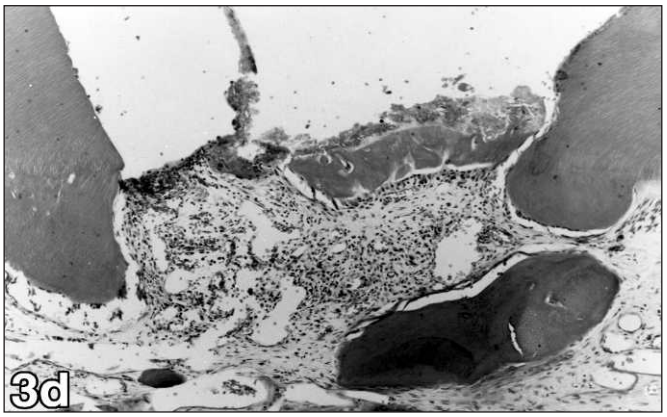

Figure 3d. *Group ZE. Both groups (ZP and ZE) showed partial dentin bridge formation and moderate inflammatory cell infiltration at the periphery of exposed area (all magnification X25) (all stained with hematoxylin and eosin).*

This might result from a rapid rise of pH during setting, so that the period of a pH below 4 was brief (Smith & Ruse, 1986).

At 30 and 90 days the glass ionomer cement elicited a very mild inflammatory reaction (Figure 3b). Kawahara, Imanishi and Oshima (1979) reported that the irritation of the cement decreased in the setting process after mixing and almost disappeared after setting in their experiment using the cell culture technique. These findings suggest that this cement had little irritating effect on the living pulp tissue after setting.

At 90 days dentin bridge formation was observed in all groups (Figures 3a, b, c & d). However, it occurred in fewer teeth in groups PC, ZE and ZP, confirming the less favorable result observed within these groups. Many of the specimens capped with PC, ZE and ZP showed incomplete bridging with soft tissue in various stages of vitality between the bridge and the capping materials. However, almost-complete to complete bridging was observed in groups DY and GI. In group GI, it might be suggested that chemical irritation of the glass ionomer cement only caused initial acute inflammation and did not last long.

This study demonstrated the importance of chemical irritation in the response of the exposed monkey pulps capped with four dental cements. According to the study, the conventional dental cements showed irritating effects on the pulp without bacterial contamination. Previous clinical evidence indicated that post-cementation sensitivity appeared immediately after cementation with glass ionomer luting agents. This sensitivity may be caused by chemical irritation of the material where the remaining dentin was very thin. Paterson (1974) observed that small exposures might remain undetected in deep cavities. In view of the possibility of

an undetected exposure, protection of the pulp from irritants should be recommended in deep cavities.

CONCLUSIONS

- The four commonly used dental cements tested caused moderate-to-severe acute inflammation at three or five days when placed directly on the exposed dental pulp of monkeys.
- The irritation by the cements tested appears to be chemically mediated since the restorations were sealed and no bacterial leakage was detected.
- Calcium hydroxide (control) and glass ionomer cement produced almost-complete to complete dentin bridging in 90 days.

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Clinical Technique/Case Report

Fabricating A Natural Tooth Pontic Bridge Using a Pre-Impregnated Fiber-Reinforced Composite Technique

JC Meiers • MA Freilich

ABSTRACT

Pre-impregnated fiber reinforced composites (FRC) can be used chairside for splinting and immediate tooth replacement. These materials may provide a more predictable long-term result than previous adhesive techniques employing composite reinforcement because of their improved mechanical properties. This article describes a technique using pre-impregnated FRC for the immediate replacement of an extracted tooth using the crown of the extracted tooth as the pontic.

INTRODUCTION

The use of a natural tooth crown as a pontic is a technique that can be performed for immediate tooth replacement in situations involving traumatic tooth loss or extractions due to periodontal complications (Ibsen, 1973; Antonson, 1980; Strassler, 1995). The technique involves removing the root and residual pulp tissue from the extracted or avulsed tooth and attaching the crown to the abutment teeth with particulate composite via an acid etch technique. This approach is often considered a temporary phase of tooth replacement until healing of the extraction site is achieved, but in some cases the patient/clinician may desire a long-term result. The weak link in this technique is usually the particulate composite joint/connector between the pontic and the abutment teeth. When these natural tooth pontics fail, it usually results from a cohesive fracture within the composite joint/connector (Jensen & Meiers, 1984). To provide additional reinforcement of this joint, the use of either polyethylene fiber (Strassler, 1995) or resin pre-impregnated fiber reinforced composite (Meiers & others, 1998) has been suggested. The properties of resin pre-impregnated fiber reinforced composite (FRC) significantly improve the mechanical properties of particulate composites (Golberg & Burstone, 1992; Freilich & others, 1997; Goldberg & others, 1998; Freilich & others, 1999a) and may allow this technique to be considered more of a long-term tooth replacement for those patients not desiring a removable acrylic partial denture and who, because of the periodontal prognosis of abutment teeth or for financial or medical reasons, cannot have a more traditional fixed bridge or single tooth implant.

This article describes and illustrates a technique using a commercially available resin pre-impregnated FRC which allows for the efficient and predictable placement of a chairside fixed bridge using the patient's

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extracted tooth crown as the pontic. The technique has been adapted from a previously reported approach using a denture tooth (Meiers & others 1998; Freilich & others 1999b).

TECHNIQUE

Figures 1–20 illustrate this technique for a patient having a mandibular central incisor removed for periodontal reasons. There are two phases in this technique—the pontic preparation phase, Figures 3–12, and the chair-side insertion phase, Figures 13-20.

Pontic Preparation Phase

This involves two steps: 1–Modification of the extracted tooth to serve as a pontic, and 2–Fabrication of an incisal intra-oral putty positioning matrix for pontic insertion. At a previous appointment a model is made from an alginate impression of the arch where the anterior tooth is to be extracted. The tooth to be extracted is removed on the model, leaving the model ready for use at the chair for pontic modification of the extracted tooth. After extraction, Figures 2-3, the pontic length is measured on the model and the tooth root removed to allow the crown to fit the pontic space, Figures 4-5. The residual pulp tissue is removed via the usual lingual access opening using appropriate broaches/files, Figures 6-7. The lingual and apical openings of the crown are sealed with flowable particulate composite, Figure 8. The crown (pontic) is positioned on the model with rope wax to secure it to the edentulous ridge, and the location of the lingual groove to receive the FRC is placed with a pencil on the pontic and the abutment teeth, Figure 9. Two modifications are made on the crown of the pontic, Figure 10. The first is a lingual groove placed at the desired location, approximately 1.5 – 2 mm in width and 1.5 mm in depth. This will receive the FRC strips and is deep enough to receive three layers of unidirectional FRC without overbulking the lingual contour. The second are Class III preparations placed on the mesial facial and distal facial of the crown. These act to carry particulate composite to the mouth for initial facial tacking of the pontic when it is first positioned in the mouth and to provide some bulk and mechanical resistance form to this particulate composite joint of the pontic attachment.

An intra-oral incisal putty-positioning index is now fabricated with polyvinyl siloxane putty as displayed in Figures 11-12. The index allows for access to the Class III preparations and locks into the lingual groove. The mesial/distal length of the index has to fit inside the planned location of the rubber dam retainers so as to be placed without interference. This will be used to hold the pontic during etching, adhesive placement and particulate composite loading of the Class III preparations, and finally to carry and accurately position the pontic in the mouth.

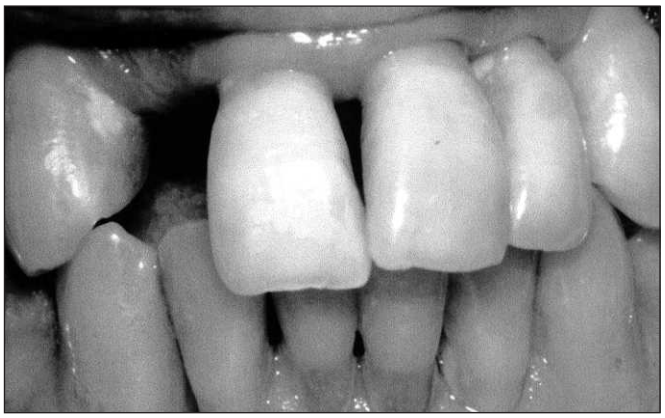
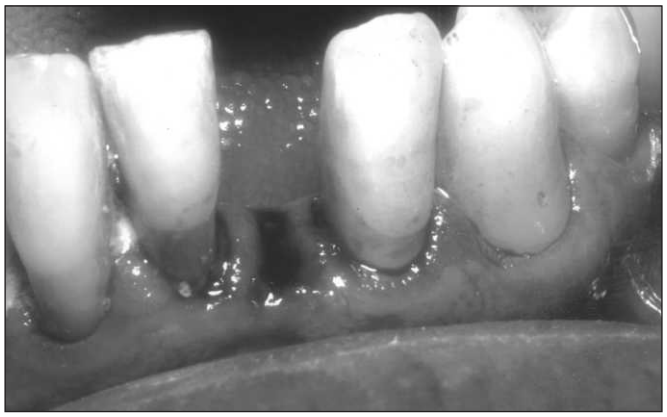


Figure 1. *Facial view. The patient has a hopelessly periodontally-involved left mandibular central incisor, #24, that is scheduled for extraction.*



2. *View after tooth #24 has been extracted.*

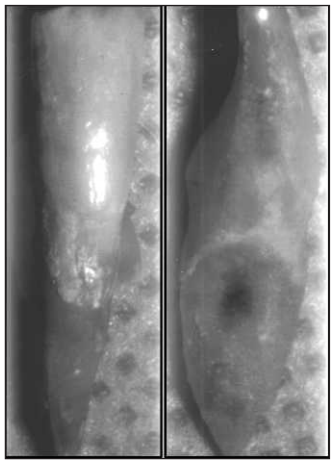


Figure 3. *Extracted tooth saved for pontic—before modifications.*

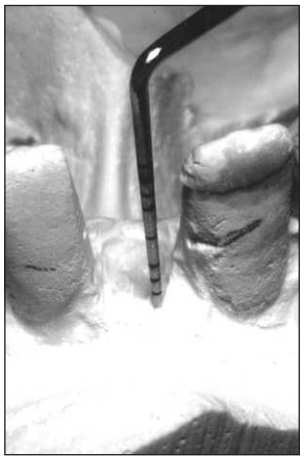


Figure 4. *On a previously poured lower impression where #24 has been removed in anticipation of the extraction, the pontic height is measured to determine how much of the root needs to be removed on the extracted tooth to fit the edentulous space.*

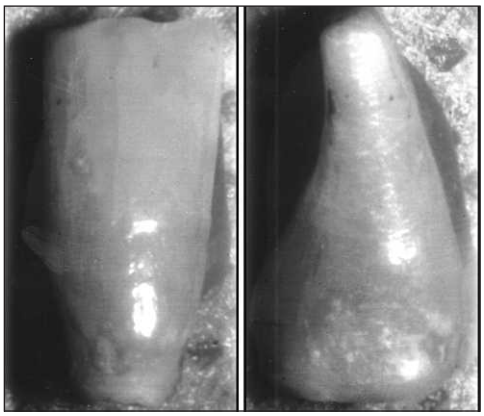


Figure 5. *Facial and lateral views of the modified extracted tooth to be used as the pontic.*

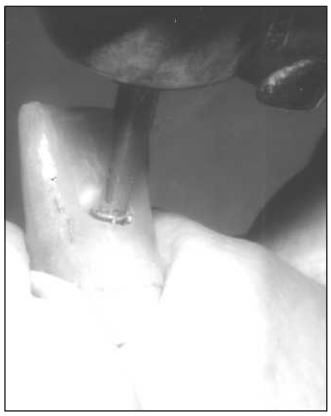


Figure 6. *Access opening being prepared on the lingual of the pontic crown to permit removal of the pulp tissue.*

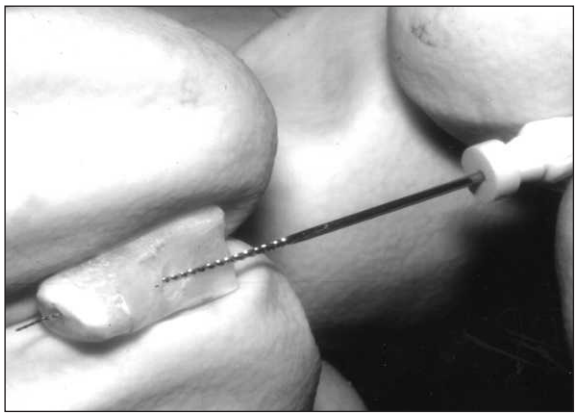


Figure 7. *Endodontic file being inserted into root canal, exiting out of the apex of the pontic, removing pulp tissue.*

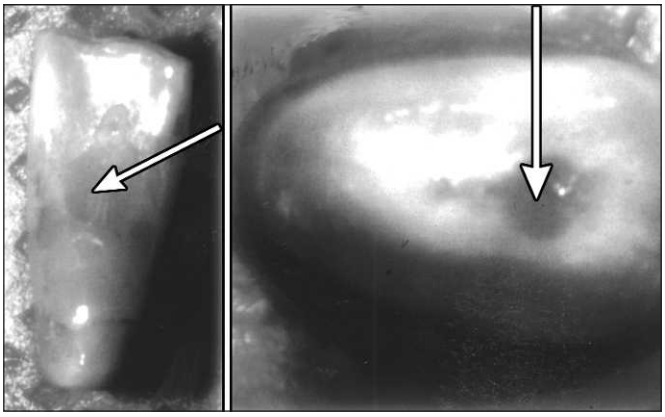


Figure 8. *Crown pontic showing the lingual access opening and apical foramen sealed with composite resin (arrows).*

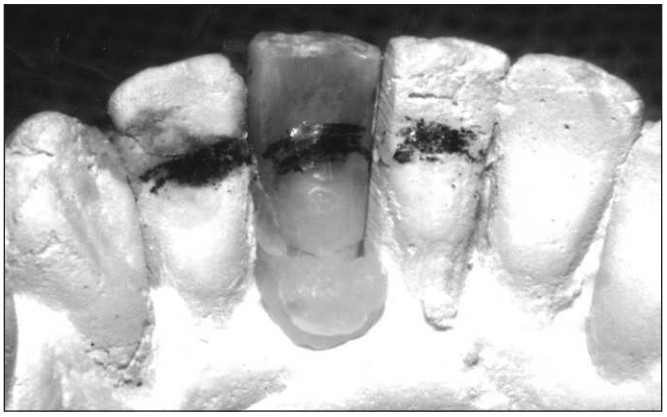


Figure 9. *Pontic crown positioned on the modified stone model showing the prepared lingual groove for the placement of the reinforcing pre-impregnated FRC. The groove was placed to coincide with the intended location of the lingual grooves to be placed on the adjacent abutment teeth (pencil lines shown on model).*

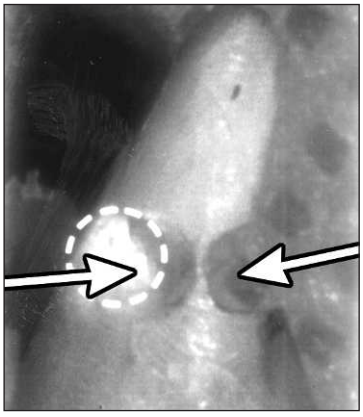


Figure 10. *Modified pontic crown showing the two internal retentive features (arrows). The lingual groove is deep enough to allow three thicknesses which will measure 1.2 mm of FRC material. The Class III preparations on the proximal surfaces permit mechanical retention of composite placed prior to oral placement of the pontic and allow labial VLC of the pontic to "tack" it into position prior to lingual FRC placement.*

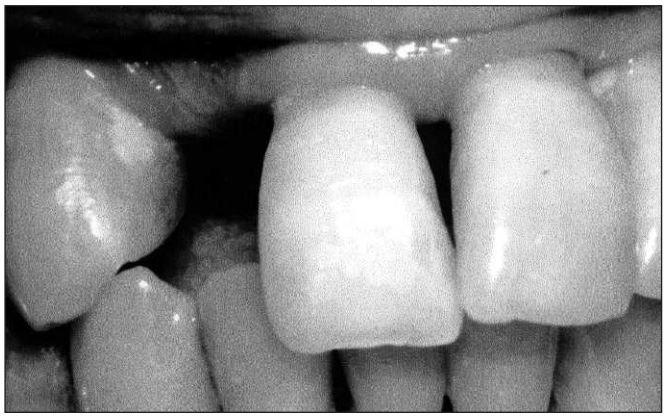
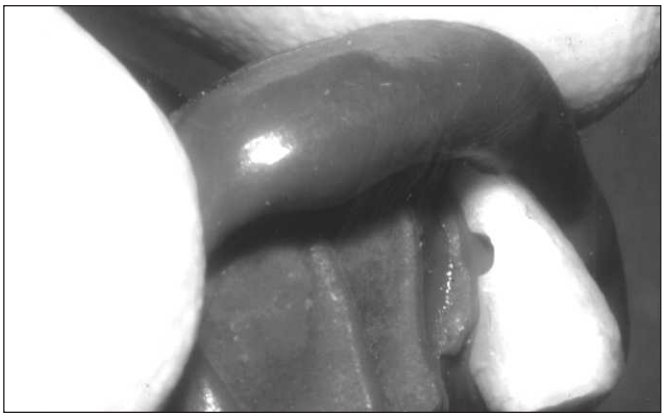
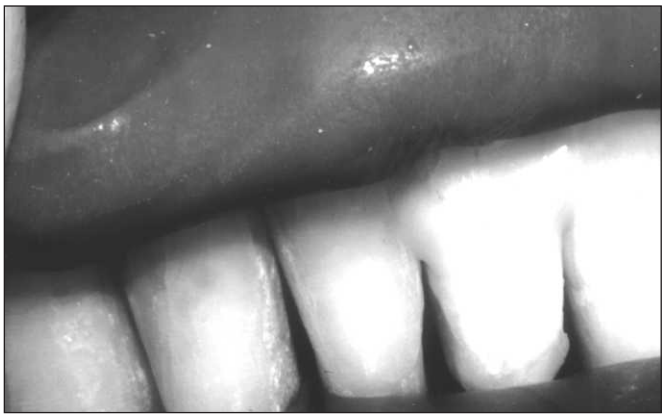


Figure 11. *The intra-oral putty incisal positioning matrix is fabricated and in place on the stone model. The Class III preparations are left exposed to permit access to the composite resin to be contained in these areas for VLC polymerization. The proper fabrication of this positioning matrix is a critical part of this technique.*



12. *Lateral view of the intra-oral putty incisal-positioning matrix shown holding the modified pontic crown. The lingual groove helps lock the tooth into the matrix so it can be held securely during pontic manipulation and placement in the mouth. Notice the detail of the adjacent teeth lingual surfaces in the positioning matrix.*



13. *The pontic is shown in position in the mouth, with the particulate composite resin held in the Class III preparations visible. The excess is removed and the facial is VLC to hold the pontic in position allowing the removal of the positioning matrix.*

CHAIRSIDE INSERTION PHASE

The patient has a rubber dam applied and the pontic is carried to the mouth via the positioning index to check on proper alignment. If accurate, the Class III preparations of the pontic and the interproximals of the abutment teeth adjacent to the edentulous ridge are etched, adhesive applied and visible light cured. Flowable particulate composite is applied to the pontic Class III preparations in slight excess and the pontic is positioned in the mouth via the positioning index, Figure 13. The excess particulate composite is removed and the pontic tacked into position by visible light curing from the facial. The index is removed and the pontic evaluated for position, Figures 14-15. If incorrect, the pontic can now be removed by fracturing the adhesive joint and the composite removed with the pontic repositioned again. If correct, the lingual grooves for the FRC are placed on the abutment teeth. These are aligned with the existing groove in the pontic and placed about 1.5 mm in depth, with their lateral extension short of the mid-lingual aspect of the tooth, Figure 15. The lingual groove is measured and three FRC strips cut to this length. The lingual groove is etched, adhesive applied and visible light cured, then a thin layer of flowable particulate composite is placed on the pulpal floor to act as a recipient bed to hold the initial layer of FRC. The precut strips of unidirectional FRC (Spint-It, Jeneric/Pentron) are removed from their sheets, Figure 16, placed and condensed into the particulate composite bed in the base of the lingual groove, Figure 17, and visible light cured. The three layers of FRC should not extend beyond the margins of the lingual groove. The air-inhibited layer of the pre-impregnated FRC strips allows for maximum cross-linking within the adhesive, particulate composite, FRC assembly. A final layer of particulate composite is added

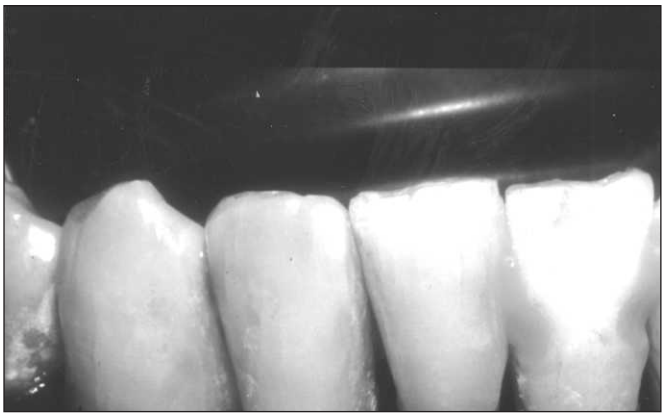


Figure 14. *The positioning matrix is removed and the pontic is securely held in place by the interproximal particulate composite resin. The pontic should be placed precisely as planned on the stone model.*

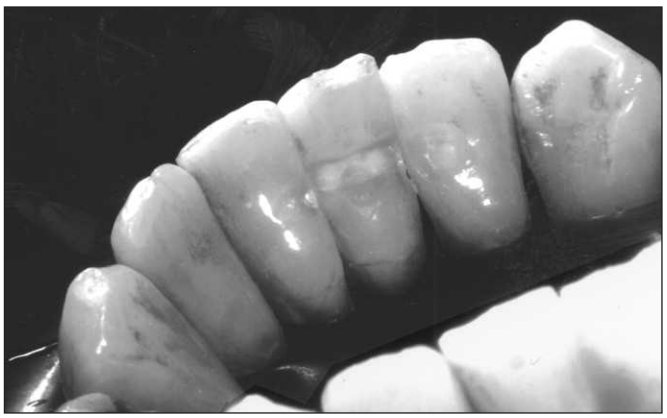


Figure 15. *Lingual view of the secured pontic. The abutment tooth FRC grooves are placed to align with the previously placed pontic groove.*

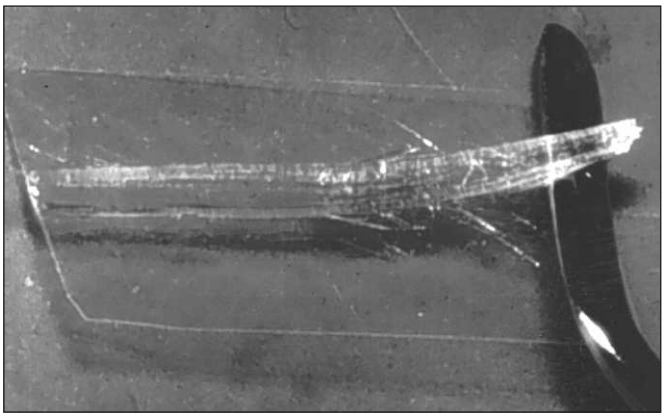


Figure 16. *A pre-impregnated strip of unidirectional FRC (Splint-It', Jeneric/Pentron) is removed for placement in the lingual groove. Notice the "wet" appearance due to the resin matrix, which imbeds the glass fibers.*

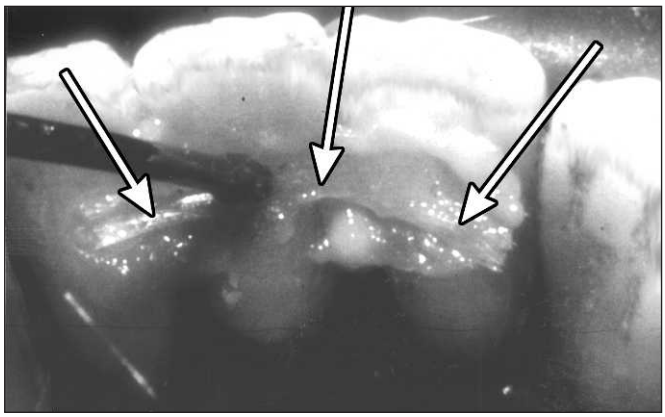


Figure 17. *The lingual FRC groove is shown with the bed of particulate composite having received its first layer of pre-impregnated FRC (arrows). The FRC is condensed into the base of the groove to allow for the placement of additional FRC layers.*

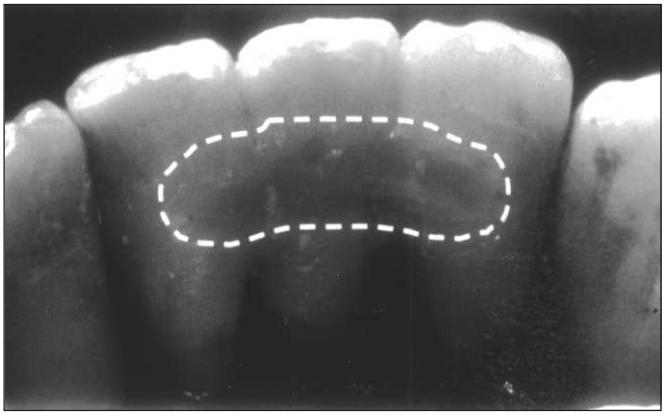


Figure 18. *Lingual view of finished FRC natural tooth pontic bridge. The dashed line outlines the extent of the lingual groove. The lingual surface should be contoured to exactly reproduce the original contours of the teeth.*

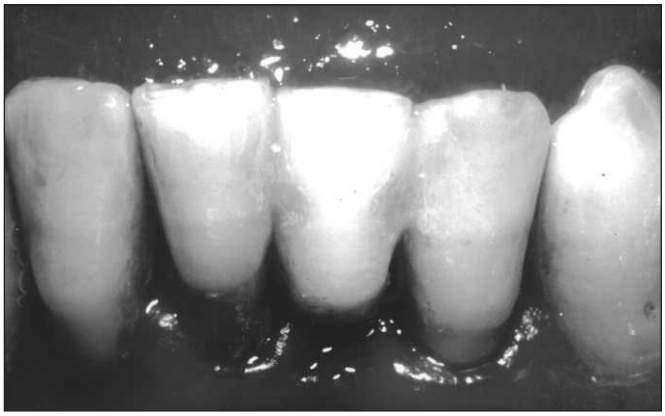
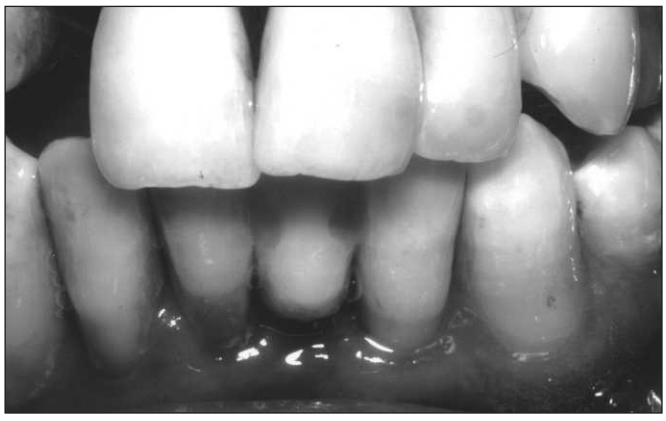


Figure 19. *Facial view of FRC natural tooth pontic bridge.*



20. *Facial view with maxillary teeth in occlusion with the bridge.*

to the FRC assembly to ensure the glass fibers within the FRC are protected against oral exposure and to blend the lingual groove with the lingual contours of the abutment teeth, Figure 18. The rubber dam is removed and occlusion is checked and adjusted, as required, Figures 19-20.

SUMMARY

A chairside natural tooth bridge technique using a commercially available chairside resin pre-impregnated FRC has been presented. The described technique takes about one hour of chair time. It provides a timely, esthetic and cost effective method for single tooth replacement which has the potential for long-term durability because of the mechanical properties of the FRC reinforcement at the critical proximal joints. Non-resin pre-impregnated polyethylene fiber, that is, Ribbond (Ribbond, Inc) or Connect (Kerr, Inc), could also be used as a joint reinforcement material, though

the mechanical properties of these chairside resin impregnated materials are not as good as the pre-impregnated glass fiber products (Goldberg & others, 1998; Freilich & others, 1999a).

The patient in the illustrated case wanted this to be his "final bridge," so the use of intra-coronal slots maximizing FRC volume without lingual bulk were used. The disadvantage to this approach is if the pontic needs to be removed due to joint failure, the patient has had the abutment teeth irreversibly modified with small lingual grooves. Another alternative would be to not place lingual grooves on the abutment teeth but to lay the FRC on the etched, unprepared lingual surfaces of the abutment teeth. This would permit removal of the pontic at a later date, if desired, without irreversible preparation damage to the abutment teeth. The disadvantage to this approach would be the added bulk on the lingual and the more difficult placement of the FRC since it would have to made to adapt to the contour change between the slot of the pontic onto the full lingual contours of the abutment teeth.

(Received 15 May 2000)

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Awards

Academy of Operative Dentistry
Award of Excellence
Dr Richard B McCoy

The Academy of Operative Dentistry Award of Excellence is given to recognize outstanding contribution to the discipline of operative dentistry in the areas of service to the Academy, teaching of operative dentistry and promotion of excellence in operative dentistry at a national/international level. Dr Richard McCoy certainly qualifies in all areas.

Dr McCoy has been a member of this Academy since its inception and has actively participated in all aspects of its growth, including serving as President in 1993. He assumed the editorship of Operative Dentistry in 1995 and, over the next five years, increased the quality, content and subscription base of our journal making it the premier publication in our discipline. Dr McCoy's memberships in other professional organizations include the American Dental Association, International Association for Dental Research, American Academy of Gold Foil Operators, American Association of Dental Schools and the American Academy of Restorative Dentistry.

Dr McCoy enjoyed a distinguished Navy career at duty stations from Sasebo, Japan to London, England. During his military service he received advanced training earning both a Certificate of Postgraduate Study in General Dentistry from the Naval Dental School, Bethesda Maryland, and an MS degree in Restorative Dentistry/Applied Gnathology from Loma Linda University School of Dentistry. He also acquired a love for teaching and a dedication to excellence that still drive him today.

Dr McCoy's teaching activities began in the Navy Dental Corps as both an Instructor in Operative Dentistry and Occlusion and then as Chairman and Director of those areas at the National Naval Dental Center. After his retirement in 1988, he did not disappear into the sunset, but chose to spend his time in the lab and clinic teaching young minds how to live, learn and work toward their chosen profession. He joined the faculty at Northwestern University Dental School where he served as Professor and Chair, Department of Restorative Dentistry. In 1992 he returned to his alma mater, the University of Washington School of Dentistry, as Director of the Division of Operative Dentistry. Dr McCoy recently added the title of Interim Chair for the Department of Restorative Dentistry.

Richard B McCoy

Dr McCoy's commitment to excellence and service is reflected in all the activities mentioned and reinforced by his research and publication efforts. These include numerous articles and contributions to two textbooks, which he co-authored with Dr Lloyd Baum. It is, however, the love, appreciation and respect from his students and colleagues that give the best measure of the man. One must wonder how he still finds time to be a caring, supportive family man, world-class fisherman and outstanding cook.

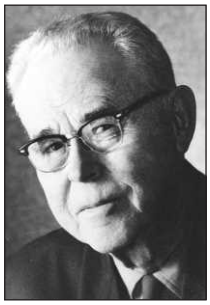
For his friendship, his dedication and example, the Academy of Operative Dentistry proudly presents the 2001 Award of Excellence to Dr Richard B McCoy.

Lloyd Baum

Academy of Operative Dentistry

Hollenback Memorial Prize

Dr Richard D Norman



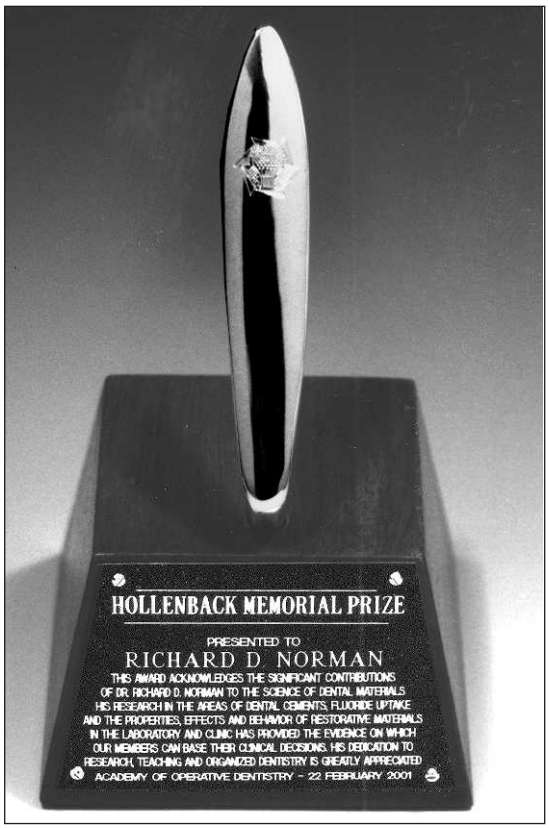
George Hollenback

Richard D Norman

The 2001 Hollenback Memorial Prize is awarded to Dr Richard D Norman. Dr Norman received his AB degree from Franklin College and his DDS and MSD degrees from Indiana University. While a student at Indiana University, he started his research with Dr Ralph Phillips and Professor Marjorie Swartz on the solubility of cements and the influence of various materials on the uptake and retention of fluoride by enamel.

Additional studies were conducted on mechanical properties of materials, the effect of materials on plaque accumulation, contact angles of materials applied to enamel and the clinical behavior of restorative materials. These later studies were in cooperation with others: Dr John Osborne and Drs Margaret and Nairn Wilson, as examples. In addition to his research, Dr Norman has served on the Oral Biology and Medicine Study Section of the National Institutes of Health, the Dental Panel for the FDI, the Research Committee of the John Cochran Veterans Administration Hospital and the Council on Dental Materials and Devices. He has also been active on several Test Construction committees for the American Dental Association and was Chairman for more than 25 years of Group III, MD 156, American National Standards Institute. He has served on numerous committees of the IADR and as President of the Dental Materials Group of that organization.

Dr Norman taught in the Dental Materials Department at Indiana University for 20 years. He served as Chairman of Restorative Dentistry, Director of Research and currently serves as Research Professor at Southern Illinois University. He has taught as an adjunct professor at Fairleigh Dickenson University and Washington University, St Louis. He was Director of Dental Clinical Research at Johnson and Johnson.

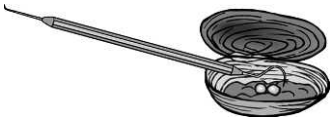


Dr Norman lives in Alton, Illinois, with Joan, his wife of 50 years. They have two daughters, Beverly and Elizabeth. The Academy is pleased and honored to present the Hollenback Memorial Prize for 2001 to Dr Richard D Norman.

Ivar A Mjör

Departments

Operative Pearls



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

THE MODIFICATION OF A #12 SURGICAL BLADE TO TRIM COMPOSITE RESIN RESTORATIONS

Contributed by:
Dr Randall M Pohjola
Medical College of Georgia School of Dentistry
Department of Oral Rehabilitation, Augusta, GA

There are many instruments available to trim and contour composite restorations. Often the interproximal areas are the most difficult to reach and treat. A #12 blade (not a #12B) on a surgical handle is a favorite for many operators, but the length of the cutting edge is too long for the intended purpose. To make the blade safer and easier to use, remove the cutting edge from the base of the blade within 2-3 mm of the tip. Use any bur on the high speed handpiece. This alteration will allow the use of a palm-thumb grip for greater control and more force. It will also reduce the chance of lacerating the operator's thumb or the patient's gingiva during the removal of resin flash.

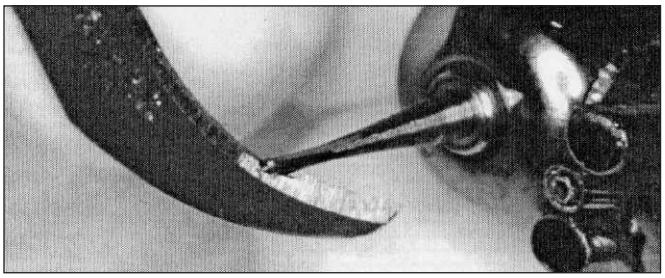


Figure 1. *Cutting edge being removed to within 2-3 mm of the tip.*

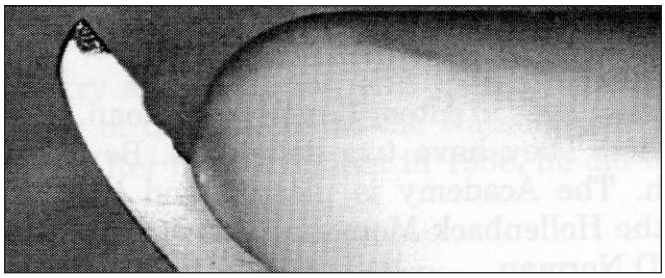


Figure 2. *Palm-thumb grip.*

Classifieds: Faculty Positions

University of Pennsylvania—Assistant or Associate Professor

The Department of General Restorative Dentistry, University of Pennsylvania, School of Dental Medicine, invites applications for a full-time tenure track or clinician educator track position available at the assistant or associate professor level. Responsibilities include development and direction of the Division of Operative and Aesthetic Dentistry; predoctoral preclinical and clinical teaching; research and service. Clinical practice within the University is available and encouraged. Preference will be given to candidates who have completed an advanced education program in Operative/ Restorative Dentistry or Materials Science and who have previous teaching and research experience. The successful candidate must possess or be eligible for a Pennsylvania dental license. The position is available effective July 1, 2001. Applications should be received by April 30, 2001. Women and minority candidates are encouraged to apply. Send a letter of interest and curriculum vitae to Dr Gerald Weintraub, Chairperson, Department of General Restorative Dentistry, University of Pennsylvania School of Dental Medicine, 4001 Spruce Street, Philadelphia, PA 19104-6003. The University is an Affirmative Action, Equal Opportunity Employer.

University of Iowa

The University of Iowa's College of Dentistry is conducting a search to fill a full-time tenure track faculty position in the Department of Operative Dentistry. Major responsibilities include teaching operative dentistry to predoctoral/postdoctoral students, research and intramural practice. The position will be available July 1, 2001; screening begins immediately. Applicants must have: DDS/DMD from an ADA-accredited institution or a foreign dental degree with certification or a Masters degree in operative dentistry from an ADA-accredited institution. Desirable qualifications include teaching experience in operative dentistry; background in clinical esthetic dentistry; dental research training or experience; clinical practice experience. Academic rank/salary are commensurate with qualifications/experience. Submit CV and three letters of recommendation to Dr Daniel Boyer, 229 Dental Science Building South, College of Dentistry, University of Iowa, Iowa City, IA 52242. The University of Iowa is an affirmative action/equal opportunity employer; women/minorities are encouraged to apply.

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