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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 also are published.

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Editorial Office
University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457
Telephone: (206) 543-5913, FAX (206) 543-7783
URL: http://weber.u.washington.edu/~opdent/

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EDITORIAL

The Knee-Jerk Virus

Dental education is constantly under attack. A few years ago an 18-member committee was appointed to assess dental education in the United States and to make recommendations for its future. A summary of the resulting Institute of Medicine (IOM) report (Dentistry at the Crossroads—Summary, *Journal of Dental Education* 1995:**59**;7-15) described a document that wanted everything for everybody. As a result, the cry for "patient-centered care" became the buzzword throughout dental school administrations. Clearly, the faculties teaching clinical dentistry were and are being pinpointed as the creators of a segmented, procedure-driven environment that does not include total patient treatment! The following statement was made in the IOM summary report: "Comprehensive care is more an ideal than a reality in clinical education, and instruction still focuses too heavily on procedures rather than on patient care."

Now what are dental schools doing about this perceived problem? Well, the knee-jerk virus has already struck and infected some dental school administrations. Rapid action is being taken by these schools to change over to comprehensive treatment groups for fourth-year and, in many cases, third-year students as well, without a clear vision of the end result other than the perception that to create these groups and combine multiple clinical disciplines into single groups necessarily means that patient-centered care is going to be provided. The ability of faculty to <u>teach</u> is being reduced to checking off procedures. Can the faculty do what is being required of them? Of course: checking off procedures is easy; clinical teaching is the difficult and demanding part. So clinical instruction for patient-centered care in many instances is being provided by those with far fewer qualifications than in the past just because of the edict to change to this "do-everything-in-one-group" philosophy. To further this frenzy to provide patient-centered care by edict rather than planning, comes the structure of "patient treatment groups," where a mentor is in charge of 20 to 25 students, supported by general dentists, and occasionally a periodontist and/or a prosthodontist. This module seems to be perfect for total patient care, since students have no performance requirements nor patient management problems. In other words, the patients belong to the group, not to the individual student. This, in effect, takes away a very valuable student learning experience while in dental school: learning to communicate with, gain rapport with, and effectively manage his/her own dental patients. In fact, it would appear that we are moving towards training students to be active members of large dental group practices like HMOs, where patient rapport is secondary, rather than to become involved practitioners who are active participants in their communities. On top of that, how can one mentor keep track of the clinical experiences of 25 students and 500 patients? He/she can't. Dental schools going to this pseudo-patient-care-oriented training are graduating students who may not have even completed a posterior or anterior bridge while in dental school. If there are no requirements or solid competency criteria for graduation, then a student need only put in the required time in dental school. Believe it or not, there are schools without clinical requirements that are graduating students who have completed no bridges, inlays, or onlays and, in at least one case, as few as seven complete crowns during their dental school training. No wonder the Navy is desperately trying to increase its AEGD capabilities so every dental student can experience concentrated clinical practice in a supervised atmosphere for his/her first year out of dental school!

What lessons should we learn from all of this? That just because someone mandates that students learn to provide comprehensive care in a "patient-centered care environment" does not mean that it will happen, nor does it mean it is better. Planning <u>must</u> be done by the clinical departments who will be responsible for making this paradigm shift work, <u>not</u> by dental school administrations. The clinical faculty can be considered the antivirus program, for they have the clearest understanding of the requirements for success and can make it happen. If careful planning by the right educators doesn't occur, the knee-jerk virus will continue to contaminate the teaching environment, and we will have made changes only for change's sake, not for progress into the 21st century!

RICHARD B McCOY
Editor

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BUONOCORE MEMORIAL LECTURE

Michael Buonocore

Tooth-colored Posterior Restorations, 1997

GORDON J CHRISTENSEN

INTRODUCTION

Tooth-colored posterior tooth restorations for intra- and extracoronal situations have been evolving slowly since the late 1960s when Johnson & Johnson promoted Adaptic as a replacement for amalgam. The evolution has been a painful one, fraught with minimally documented promotions, overly optimistic expectations, and many failures. However, tooth-colored posterior restorations are used currently to some degree by the majority of dentists, and around 22% use tooth-colored restorations as their most common class 2 material (Christensen & Christensen, 1995). Tooth-colored posterior restorations must be working, or dentists wouldn't continue to place them. Patients love them! What is the state of the art and science in 1997? The following information describes the most promising tooth-colored posterior restorations available in 1997.

Clinical Research Associates, 3707 North Canyon Road, 3D, Provo, UT 84604

Gordon J Christensen, DDS, MSD, PhD, director, practical clinical courses, co-founder and senior consultant

DIRECT RESIN RESTORATIONS

Nearly 30 years have passed since the first commercial stimulation for use of resin in class 2 situations. In the late 1960s, the first generation of resins had large particle size (about 5 μ or more average), significant color degeneration over time, high wear, and some lingering postoperative sensitivity. After brief use of these first materials and disappointment with the clinical results, most dentists became frustrated and discontinued use of the resins for class 2 situations.

Products were modified over the ensuing years. Smaller particle sizes were introduced, producing lower wear during service. Improved initiator and catalyst systems evolved, light curing became available, and by the mid-1980s, composite resin for class 2 situations became relatively acceptable. The service characteristics of brand names such as Heliomolar (Ivoclar Vivadent, Amherst, NY 14228); Herculite (Kerr, Romulus, MI 48174); and others started to impress dentists. Clinical Research Associates' in vivo research (Christensen &

Christensen, 1994) accomplished on dies made from vinyl polysiloxane impressions of restorations in actual clinical service has shown that Heliomolar and Herculite, placed by general dentists, compete well with amalgam. Are these and other current materials without weaknesses?

There are still a few remaining obstacles to be overcome with resin for class 2 situations. The main ones are: (1) polymerization shrinkage of about 3%; (2) wear characteristics slightly higher than amalgam; (3) thermal expansion-contraction during service higher than desirable; and (4) some restorations produce lingering tooth sensitivity. Manufacturers are aware of these challenges, and research is underway to reduce or eliminate all of them.

In the meantime, expansion-contraction and sensitivity negatives can be reduced by placing more primer and bonding resin than normal into tooth preparations. It is suggested that this concept provides a thicker layer of primer and bond than normal, allowing flexibility between tooth structure and restorative material, and sealing dentinal canals better. Similarly, a stress-releasing resin-reinforced glass ionomer or compomer can be placed internally. These techniques provide flexibility in the tooth-restoration unit and reduction of the negative influence of polymerization shrinkage and expansion-contraction during service. Clinical empirical evidence shows near elimination of tooth sensitivity. Excessive occlusal wear in class 2 resins can be overcome by placing hybrid resins internally and lower-wear microfill resin (Heliomolar, Vivadent) on the most superficial occlusal layer of the restoration.

The current generation of light-curing resins, including Charisma (Kulzer, South Bend, IN 46614); Conquest Crystal (Jeneric/Pentron, Wallingford, CT 06492); Heliomolar (Ivoclar Vivadent); Herculite and Prodigy (Kerr); TPH Spectrum (Dentsply/Caulk, Milford, DE 19963); Tetric (Ivoclar Vivadent); Z-100 (3M Dental Products, St Paul, MN 55144), etc, used properly, in small to medium-sized restorations are very adequate clinically and quite comparable to amalgam during service.

INDIRECT RESIN RESTORATIONS

Most dentists place small posterior direct resin restorations, but they hesitate to accomplish larger sized direct class 2 restorations because of time involvement and difficulty. Resin in large class 2 situations can be placed relatively easily using the <u>indirect</u> technique. A brand name that has been most popular in the US is Concept (Ivoclar Vivadent) (Christensen, 1995). This heat- and pressure-cured microfill indirect resin has shown excellent wear resistance and esthetics, and relatively good service over time (Christensen & Christensen, 1994). However, indirect resin restorations require two appointments, a provisional restoration, contamination of the tooth preparation with temporary cement, a significant laboratory fee, placement of resin material that is not active chemically because of the lapse of time between restoration construction and seating, and a cost to patients equal to cast gold or ceramic restorations. Nevertheless, many dentists are using indirect resin in larger class 2 inlays and onlays.

Several new brand names of indirect polymer restorations appear to be promising, including Artglass (Kulzer), belleGlass (belle de St Claire/Sybron Dental Specialties, Glendora, CA 91740), and the Targis System (Ivoclar). If these new materials, claiming better physical characteristics than previous materials, are in fact better, polymer-based indirect restoration use will increase. One of the major reasons for their popularity is the simplicity of both the laboratory and clinical procedures.

INDIRECT-DIRECT RESIN RESTORATIONS

Most dentists use educated auxiliaries to make provisional restorations for inlays, onlays, crowns, and fixed prostheses. These people or in-house laboratory technicians can easily construct similar restorations on rapidly made dies <u>at the tooth preparation appointment</u>. Subsequently, only minutes later these restorations can be placed during the same one appointment. The advantages of the indirect-direct concept are: only one appointment is necessary; the second anesthetic delivery is eliminated; provisional restorations are not required; contamination of the tooth preparation with temporary cement is avoided; cementation of the restoration minutes after making it ensures active chemistry in the restoration for bonding; the laboratory cost is eliminated; dentists may use their regular direct class 2 resin materials; and patients have a lower cost than with indirect restorations.

Several materials or concepts can be used with the indirect-direct technique. A relatively new concept uses Mach-2 (Parkell, Farmingdale, NY 11735) fast-setting vinyl polysiloxane as a die material. The technique has had good acceptance by practitioners (Christensen & Christensen, 1996).

PRESSED CERAMIC RESTORATIONS

Although the concept of "pressing" molten ceramic into lost wax molds is over 60 years old, its current revival and popularity are evident. IPS Empress (Ivoclar) and Optimal (Jeneric/Pentron) are making a significant impact on the tooth-colored inlay-onlay marketplace. The popularity and promise of this concept was shown recently when 71% of members and guests at a meeting of the American Academy of

Esthetic Dentistry expressed their opinion that Empress had the most potential as a ceramic tooth-colored posterior tooth inlay or onlay (Christensen, 1995).

Why is this concept popular? It uses the wax pattern technique, well-known to technicians and dentists; the restorations fit well; and the Lucite ceramics used are translucent and can be used either with or without superficially placed fired ceramic. The internal surfaces can be etched or sandblasted well, providing optimum bonding possibilities. The esthetic result of inlays, onlays, and crowns can be excellent.

Although some ceramic restorations made of Empress or Optimal break during service, and much more research is needed, their potential for long-term service is high. Continuing research is coming forth to guide clinical procedures.

FIRED CERAMIC INLAYS AND ONLAYS

There is no question that fired ceramic inlays and onlays can be excellent restorations. A problem, as evaluated by Clinical Research Associates, is the nearly impossible optimum interaction and cooperation between dentists and laboratory technicians. Most dentists have seen examples of beautiful fired ceramic restorations shown by world-class clinicians, but the implementation of the fired ceramic concept into routine dental practice by general dentists is highly doubtful. There are too many variables and too many laboratory challenges.

THE FUTURE OF METAL RESTORATIONS

Cast gold inlays and onlays, properly placed, with optimum consideration for avoiding unesthetic use of gold, are unequalled, and many dentists prefer them for themselves (Christensen, 1995). However, the long history of cast gold restorations, spanning over 90 years, shows that they will never be popular restorations. This should not discourage high-quality restorative dentists from accomplishing cast gold restorations for their patients.

Amalgam restorations are and will continue to be the mainstay of posterior tooth restoration for many years to come. Esthetic, health, and environmental concerns will gradually cause the demise of silver amalgam. About 14% of US dentists are undecided about continued use of amalgam, and 9% feel amalgam should not be used (Christensen & Christensen, 1995). Amalgam use is declining in numerous other countries also.

CONCLUSIONS

Various types of tooth-colored posterior tooth restorations are available. Their clinical success is increasing as products and clinical techniques are improved. Patient demand is evident for tooth-colored restorations. By far, the most popular type is direct resin, which has been shown to be excellent for small to medium-sized class 2 situations since 1985. Indirect resin restorations are used infrequently, but with success. Their expense limits their acceptance. Interest in indirect-direct resin restorations is increasing because of less expense than indirect restorations, use of auxiliary persons already educated, and simple techniques. Pressed ceramic inlays and onlays lead the ceramic type of restorations in popularity. Although they are expensive for patients, their obvious clinical success will ensure their continued use. Fired ceramic restorations, long used but never very popular, will continue to be used, but do not appear to be capable of becoming commonly used restorations. Tooth-colored posterior restorations will gradually but persistently increase in use.

(Delivered 20 February 1997)

References

CHRISTENSEN GJ (1995) Acceptability of alternatives for conservative restoration of posterior teeth *Journal of Esthetic Dentistry* **7(5)** 228-232.

CHRISTENSEN RP & CHRISTENSEN GJ (1994) Comparative performance of 21 class 2 materials at 3 years *Clinical Research Associates Newsletter* 18(5) 1.

CHRISTENSEN RP & CHRISTENSEN GJ (1995) Product use survey *Clinical Research Associates Newsletter* **19**(10) 4.

CHRISTENSEN RP & CHRISTENSEN GJ (1996) One-appointment indirect resin restorations *Clinical Research Associates Newsletter* **20(6)** 1.

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ORIGINAL ARTICLES

Biocompatability of Compomer Restorative Systems on Nonexposed Dental Pulps of Primate Teeth

B TARIM • A A HAFEZ • S H SUZUKI
S SUZUKI • C F COX

Clinical Relevance
Compomers are not irritating to pulp when bacterial microleakage is excluded by a proper clinical seal.

SUMMARY

This study evaluated the histologic response of total-etched and nonetched compomer restored cavity preparations. One hundred fifteen class 5 cavity preparations were placed in the teeth of four healthy adult monkeys at 7, 27, and 90 days. A 37% H_3PO_4 was applied for 10 seconds and rinsed in total-etched preparations. No statistical differences were seen in inflammatory reactions among total-etched or nonetched compomers at 7, 27, and 90 days. There were no statistical differences in inflammatory cell responses among all compomer systems in regard to time intervals. Pulpal responses of compomers were greater than IRM at each time period. Pulp responses were associated with stained bacteria in 32 of 89 compomer teeth. No necrotic pulps were seen in any teeth. Statistical data show a positive correlation ($P < 0.05$) between bacterial presence and pulpal inflammation. IRM pulps showed no inflammation or bacterial staining. Compomers are biologically compatible with pulp tissues when bacteria are excluded.

University of Alabama at Birmingham, School of Dentistry, Departments of Restorative Dentistry and Biomaterials, 1919 Seventh Avenue South, Birmingham, AL 35294-0007

Berna Tarim, DMD, PhD, visiting research scientist; assistant professor, Istanbul University, Istanbul, Turkey

Abeer A Hafez, DDS, MS, research associate

Satoko Suzuki, DDS, research associate

Shiro Suzuki, DDS, PhD, associate professor, director of clinical research

Charles F Cox, DMD, FADI, professor

INTRODUCTION

Reports (Brännström & Nyborg, 1969; Bergenholtz & others, 1982; Cox & others, 1987) demonstrated that bacterial microleakage is the principal irritant to the dental pulp when the restorative seal fails. In attempting to duplicate the acid-etch enamel technique of Buonocore (1955), Fusayama (1980) acid etched dentin to provide increased micromechanical retention of the adhesive and resin composites into the dentin tubules. Since the mid-1950s, various publications have reported that acid etching vital dentin causes pulp inflammation and eventual necrosis (Stanley, Going & Chauncey, 1975; Eriksen & Leidal, 1979). Fujitani, Inokoshi, and Hosoda (1992) reported an initial transitory pulp response under acid-etched dentin that decreased with time, especially when a proper cavosurface seal was present. Studies (Inokoshi, Iwaku & Fusayama, 1982; Harnirattisai & Hosoda, 1991) demonstrated that application of various adhesive systems to vital dentin provided an effective seal against bacterial microleakage. Recent histologic studies (Snuggs & others, 1993; White & others, 1994) reported no pulp inflammation when vital dentin was acid etched, reconfirming that pulpal inflammation was due to bacterial microleakage and not to the material per se.

Modifications of traditional (Wilson & Kent, 1972) glass ionomers have led to the development of light-cured resin-modified glass-ionomer hybrids (Mitra, 1991). Combining acid-base setting reactions and resin polymerization has resulted in higher dentin bond strengths and less microleakage than conventional glass ionomers (Mitra, 1991; Crim, 1993; Cortes, García-Godoy & Boj, 1993; Sidhu, 1994). Many glass-ionomer pulp studies (Browne & others, 1983; Tobias & others, 1989; Plant & others, 1991; Schmalz & others, 1994) inferred a positive correlation between pulp inflammation and bacterial microleakage.

Combined resin composite and glass-ionomer light-cured technologies have only recently received critical histological evaluation, especially regarding their potential to protect vital dentin and pulp from microleakage. Felton and others (1991); Cox, Erickson, and Glasspoole (1993); and Gaintantzopoulou, Willis, and Kafrawy (1994) have all reported acceptable pulpal responses to light-activated glass-ionomer systems.

Compomers have recently been developed for definitive class 3, class 5, and cervical/erosion restorations, reporting higher shear bond strength to dentin and enamel and suggesting a better cavosurface seal than conventional glass ionomers (Cortes & others, 1993; Triana & others, 1994; Flessa & others, 1995). Compomers combine the major benefits of glass-ionomer cements (adhesion to tooth substance, fluoride release, and biocompatibility) with the easy handling of a light-curing composite. To date, there are no publications that report the histologic evaluation of compomer systems in nonexposed pulps.

In this study, we used light-cured Compoglass (total-etched and nonetched) and Dyract compomers for histological comparison in nonexposed monkey teeth. All materials were evaluated per current ISO and ADA usage guidelines and observed for their capacity to protect the dentin and pulp from bacterial microleakage.

Table 1. Restorative Materials

Material	Brand Name	Contents	Batch #	Manufacturer
compomer	Compoglass	barium fluorosilicate glass, UDMA, TEGDA, CADCADM, ytterbium trifluoride	648530	Ivoclar/Vivadent, Amherst, NY 14228
		methacrylate-mod*, polyacrylic acid, H_2O, HEMA, maleic acid	648529	
compomer	Dyract	strontium fluorosilicate glass, UDMA	931123	De Trey/Dentsply, Konstanz, Germany
		PENTA, TGDMA, acetone**	931020	
zinc oxide & eugenol polymethyl methacrylate reinforced cement	IRM	calcinated zinc oxide, magnesium oxide	062691	L D Caulk, Milford, DE 19963
		H_2O, H_3PO_4, buffered Al salts, eugenol	052491	

UDMA = urethane dimethacrylate
CADCADM = cycloaliphatic dicarboxylic acid dimethacrylate
PENTA = dipentaerythritol penta acrylate monophosphate
*SCA = bonding agent
TEGDA = tetraethyleneglycol dimethacrylate
HEMA = hydroxyethyl methacrylate
TGDMA = triethylene glycol dimethacrylate
**PSA = primer/adhesive

METHODS AND MATERIALS

Table 1 shows the materials used in this study. Four adult rhesus *Macaca nemestrina* monkeys (4 to 5 years old) provided 115 vital teeth for this study. Prior to operative procedures, each animal was tranquilized with an intramuscular injection of Ketamine hydrochloride (Parke-Davis, Rochester, MI 48307). The surface of each tooth was scaled and polished. Class 5 cavity preparations were prepared with a #330 carbide bur at ultra-high speed under water spray with a new bur employed on every fourth cavity preparation. Cavity depth was verified with an electrical device (Endocater, The Hygienic Corp, Akron, OH 44310), allowing placement of the axial floor to the inner third of remaining dentin. Teeth were isolated with sterile cotton rolls and saliva controlled with high-speed evacuation. Each preparation was restored with a material listed in Table 1.

Compomers were incrementally placed in class 5 cavities to the cavosurface margin at time intervals of 7, 27, and 90 days per usage guidelines. All materials were placed per the manufacturers' instructions. Twenty-six nonexposed control preparations were restored with ZnOE (IRM); 31 nonetched class 5 preparations were restored with Compoglass; 29 total-etched class 5 preparations were restored with Compoglass; and 29 teeth were restored with Dyract. Total-etched preparations were treated with 37% H_3PO_4 for 10 seconds, rinsed for 10 seconds, and air dispersed for 5 seconds. The cavosurface margin was finished with a 12-blade bur and polished with the Ivoclar finishing system.

Tissues were collected by left ventricular flushing with 0.9% physiologic saline, followed by perfusion with a fast-penetrating GTA-PBF fixative (Cox & others, 1982) at appropriate time periods. Each tooth was cut from its alveolus, the root apex removed with a #557 carbide bur, the tooth immediately placed into GTA-PBF fixative and post fixed for 24 hours at 4 °C. Each tooth was demineralized in EDTA and changed until endpoint demineralization was determined radiographically. Tissues were rinsed in distilled water for 4 hours, placed in 30% N-butyl alcohol, dehydrated, and embedded in Paraplast-plus as described by Cox and others (1982). Serial sections of 7 µm were cut on a rotary microtome and placed on gelatin-coated slides for staining. Glass microslides were stained with hematoxylin and eosin, Masson trichrome, and McKay bacterial stain according to published procedures (Brännström & Nyborg, 1969; Bergenholtz & others, 1982). Tissue sections were independently evaluated prior to material identification using criteria in Table 2. Remaining and reparative dentin were measured as described by Cox and others (1992).

Table 2. Evaluation Criteria

Inflammatory Cell Response

1 None or a few scattered inflammatory cells present in the pulp beneath the cut tubules of the cavity preparation floor

2a Acute inflammatory cell lesion is predominated by polymorphonuclear leukocytes.

2c Chronic inflammatory cell lesion is predominated by mononuclear lymphocytes.

3 Severe inflammatory cell lesion appears as an abscess or dense infiltrate of polymorphonuclear leukocytes involving one-third or more of the coronal pulp.

4 A necrotic pulp

Soft Tissue Organization

1 Normal or almost-normal tissue morphology below the tubules of the remaining dentin and throughout the pulp

2 Lack of complete tissue morphology below the remaining dentin; the deeper pulp tissue is normal.

3 Necrosis in at least the coronal third or more of the pulp

Reparative Dentin Deposition

1 No abnormal or reparative dentin seen below the cut tubules of the cavity preparation

2 A small thin rim of reparative dentin seen below the cut tubules of the cavity preparation

3 A large bulk of new reparative dentin seen below the cut tubules of the cavity preparation

Bacterial Staining

1 Absence of bacterial staining in any section

2 A positive bacterial staining reaction seen along the cavity preparation walls

3 A positive bacterial staining reaction seen within the cut dentinal tubules of the cavity preparation

4 A positive bacterial staining reaction seen within the dental pulp

Figure 1

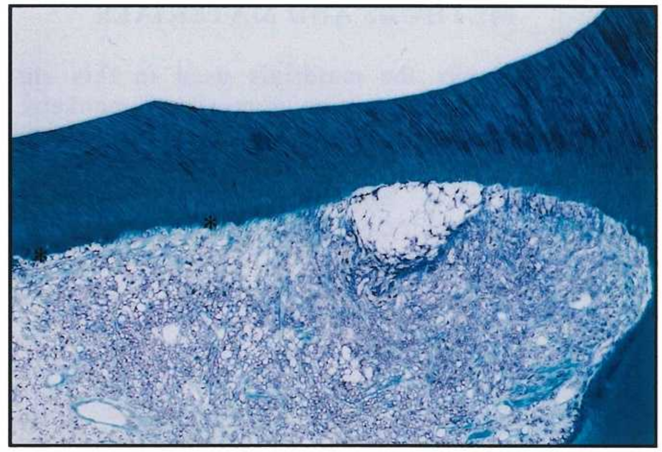

Figure 2

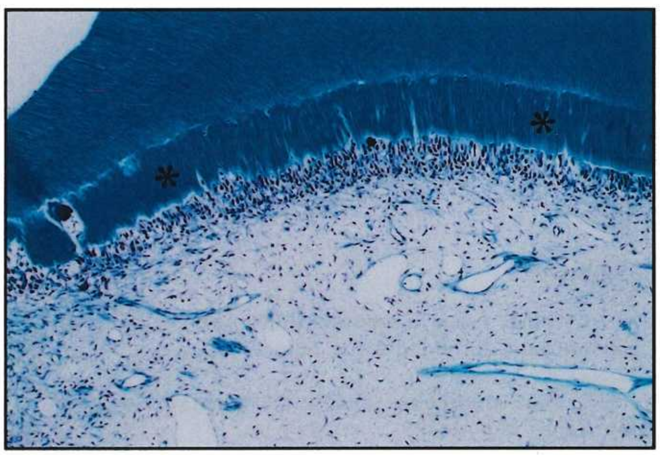

Figure 3

Figure 4

Figure 5

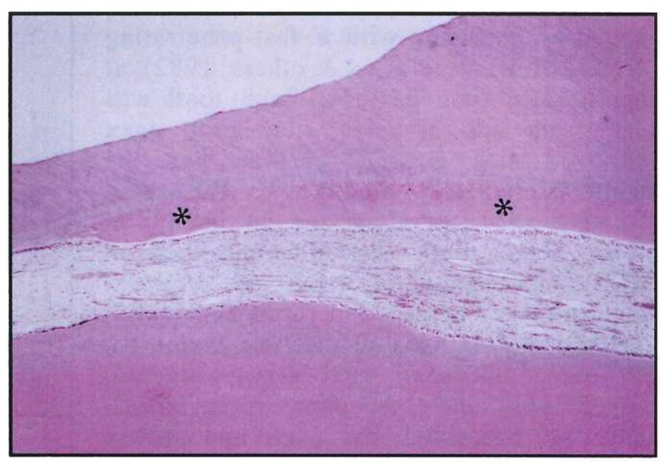

Figure 6

Figure 1. *Pulp of a cavity preparation that was total etched with 37% H_3PO_4, SCA treated, and restored with Compoglass for 7 days. There is only slight primary odontoblast disruption with aspiration of the odontoblast nuclei into the dentinal tubules. The clear area in the upper right is the preparation floor. The remaining dentin is approximately 165 µm in thickness. There is no subjacent or deeper pulp inflammation. (hematoxylin and eosin, original magnification X7.7)*

Figure 2. *Pulp of a cavity preparation that was treated with PSA and restored with Dyract for 27 days. The clear area on the top is the preparation floor with approximately 125 µm of underlying remaining dentin. The subjacent pulp shows an abscess with a grade 3 (severe) pulp response. Note the small thin rim of reparative dentin (20 µm) formation (*) below the cut tubules of remaining dentin. (Masson Trichrome, original magnification X7.7)*

Figure 3. *Pulp of a cavity preparation that was total etched with 37% H_3PO_4, SCA treated, and restored with Compoglass for 27 days. The clear area on the upper left is the preparation. The remaining dentin is approximately 125 µm thick, with a pulp response of grade 1. The subjacent pulp shows a layer of new odontoblastoid cells with approximately 100 µm of reparative dentin (*) deposition. (Masson Trichrome, original magnification X7.7)*

Figure 4. *Pulp of a cavity preparation that was treated (nonetched) with SCA and restored with Compoglass for 90 days. The clear area on the upper right is the cavity preparation with approximately 700 µm of remaining dentin with no pulp inflammation. Note the large bulk of approximately 250 µm of reparative dentin (*) with newly formed secondary odontoblastoid cells, continuous with primary odontoblasts at the periphery of the new reparative dentin. The pulp response is a grade 1. (hematoxylin and eosin, original magnification X3.08)*

Figure 5. *Pulp of a cavity preparation that was total etched with 37% H_3PO_4, SCA treated, and restored with Compoglass for 90 days. Note the presence of dark blue Gram-positive stained bacteria (arrows) lying on the floor of the preparation (yellow stained). (McKay bacterial stain, original magnification X15.4)*

Figure 6. *Pulp of a cavity preparation that was treated with PSA and restored with Dyract for 90 days. The clear area on the upper left is the preparation with approximately 350 µm of underlying remaining dentin. The pulp response is grade 1 with approximately 200 µm of reparative dentin (*). (hematoxylin and eosin, original magnification X3.08)*

The thickness of remaining and reparative dentin was statistically analyzed using ANOVA and differences among respective materials evaluated by Scheffé tests. Inflammatory response, soft tissue organization, reparative dentin, and bacteria staining were expressed as numerical scores. Statistics employed chi-square analysis for inflammatory response data within the compomer systems and IRM at 7, 27, and 90 days. A correlation between presence of inflammation and bacteria was tested using Kendall Correlation analysis. A value of $P \leq 0.05$ probability was considered statistically significant.

RESULTS

Histologic findings are seen in Table 3. Figures 1-6 show various histologic effects. There were no statistically significant observable differences in inflammatory reaction within any of the three compomer groups at 7, 27, and 90 days. There were no statistically significant differences in inflammatory cell responses among the compomer systems for time intervals, nor in remaining dentin thickness within any of the four groups at 7, 27, and 90 days (Table 4).

Compomers showed greater pulpal responses than IRM controls; however, no necrotic pulps were seen in any teeth. Gram-positive bacteria were seen in most teeth with pulpal inflammation. However, no bacterial profiles were observed in any IRM-restored teeth. There were no statistically significant differences in reparative dentin thickness within any of the four groups at 27 and 90 days (Table 4). All groups exhibited significant increases in reparative dentin thickness after 27 days ($P = 0.0001$).

The 7-day histologic responses of cavities restored with nonetched Compoglass showed 9 of 11 teeth with no pulp response, and two teeth demonstrated a grade 2 pulp response. In the total-etched Compoglass group, five pulps showed grade 2 response, while no pulp response was seen in the remaining teeth (Figure 1). In the Dyract group, one pulp showed a severe grade 3 response. No reparative dentin was present in any pulp at 7 days. In all IRM teeth, the nonmineralized predentin was a uniform thickness.

At 27 days, there were no histologic differences between any compomer groups. Cavities restored with nonetch Compoglass showed seven of 10 pulps with grade 2 response and one tooth with grade 3. One tooth showed grade 2 pulp response and two teeth showed grade 3 in teeth restored with Dyract (Figure 2). In addition, a new odontoblastoid cell zone had completely reorganized with a localized thin rim of new reparative dentin (Figure 3) in most teeth. When viewing the zone of reparative dentin throughout serial sections in most teeth, the center of each reparative dentin zone presented the greatest measurable thickness at its middle, as if viewing the

Table 3. Distribution of Teeth and Materials Placement with Their Respective Graded Pulp Responses

Materials	Days	Total Teeth	Inflammatory Cell Response					Soft Tissue Organization				Reparative Dentin			Bacterial Staining			
			1	2a	2c	3	4	1	2	3	4	1	2	3	1	2	3	4
SCA & Compoglass	7	11	9	0	2	0	0	8	3	0	0	11	0	0	5	6	0	0
	27	10	3	0	7	0	0	6	1	3	0	0	10	0	0	10	0	0
	90	10	5	0	5	0	0	9	1	0	0	0	0	10	1	6	2	1
Total-etch SCA & Compoglass	7	9	4	2	3	0	0	0	8	1	0	9	0	0	3	4	2	0
	27	10	5	1	3	1	0	6	4	0	0	0	10	0	1	5	4	0
	90	10	8	0	2	0	0	10	0	0	0	0	0	10	2	3	5	0
PSA & Dyract	7	10	9	0	0	1	0	2	7	1	0	10	0	0	7	2	1	0
	27	10	7	1	0	2	0	7	1	2	0	1	9	0	7	2	1	0
	90	9	7	0	2	0	0	9	0	0	0	0	0	9	3	6	0	0
IRM	7	10	10	0	0	0	0	10	0	0	0	10	0	0	10	0	0	0
	27	8	8	0	0	0	0	8	0	0	0	0	8	0	8	0	0	0
	90	8	8	0	0	0	0	8	0	0	0	0	0	8	8	0	0	0

Table 4. Mean Values of the Reparative and Remaining Dentin Thickness (μm)

Materials	Days	Reparative Dentin Mean ± SD	Remaining Dentin Mean ± SD
SCA & Compoglass	7	0	739 ± 232
	27	84 ± 28	480 ± 219
	90	240 ± 50	631 ± 249
Total-etch SCA & Compoglass	7	0	345 ± 195
	27	87 ± 27	520 ± 260
	90	234 ± 51	507 ± 205
PSA & Dyract	7	0	410 ± 238
	27	65 ± 24	330 ± 127
	90	263 ± 67	452 ± 194
IRM	7	0	622 ± 191
	27	83 ± 14	515 ± 207
	90	260 ± 92	655 ± 204

middle of a three-dimensional pyramid.

At 90 days, five of 10 teeth restored with nonetched Compoglass showed no pulp response (Figure 4) and five teeth demonstrated a grade 2 pulp response. Two teeth showed grade 2 inflammatory response in the total-etch Compoglass with some bacterial staining (Figure 5). In the Dyract groups seven pulps demonstrated no inflammatory response (Figure 6) and two pulps demonstrated grade 2 pulp response. The compomers showed no severe pulp inflammation and only one pulp with grade 2 soft tissue disorganization. All control IRM teeth presented normal pulps with no cell disruption or inflammation. At 90 days serial sections of reparative dentin presented a uniform thickness throughout its entire length in most teeth.

Kendall correlation showed a positive statistical correlation (P = 0.03, r = +0.53) between the presence of the inflammatory reactions and the presence of bacteria on dentinal walls, and in dentinal tubules (Figure 7).

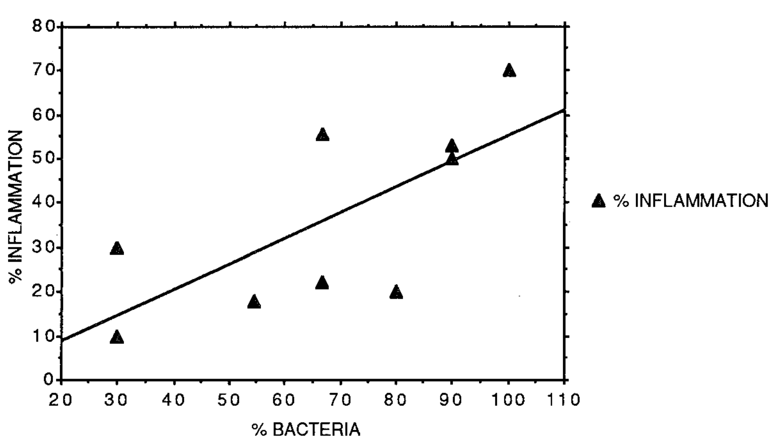

Figure 7. *Correlation between pulpal inflammation and the presence of stained bacteria on the cavity wall and/or within the dentinal tubules (P = 0.03; r = +0.53.)*

DISCUSSION

Our data demonstrate that compomers are biologically compatible with vital pulps. However, compomers failed to provide a complete seal, as bacterial staining was grade 2 in 44 teeth. Pulpal responses were observed in 32 of 89 compomer restored teeth, each associated with the presence of stained bacteria. Numbers of teeth with stained bacteria increased from 7 to 90 days. Our data agree with Qvist (1980), who demonstrated a correlation between pulp inflammation and presence of bacteria under various composite resin restorations in human teeth.

As seen from our bacterial staining data (Table 3), compomers fail to provide a complete biological seal against bacterial microleakage. A positive statistical correlation was demonstrated between the presence of the inflammatory reaction and bacterial staining (Figure 7), also reported in other studies (Bergenholtz & others, 1982; Cox & others, 1985; Cox & others, 1987; Plant & others, 1991; Harnirattisai & Hosoda, 1991). Stained bacteria were occasionally seen on localized areas (Figure 5) with a corresponding subjacent area of inflammation.

Using SEM, Flessa and others (1995) compared the marginal integrity of a light-cured glass ionomer with Dyract, suggesting favorable results were due to the hygroscopic expansion of the PSA primer, which successfully sealed the contraction gap. Wieczkowski and others (1992) suggested that forces of polymerization shrinkage were stronger than the bond between glass ionomer and dentin. Hotta and Aono (1994) demonstrated no clear relationship between the adhesion to dentin and the adaptation to the dentin cavity floor. Sim and Sidhu (1994) reported that dentin etching did not prevent gap formation nor the sealing capability of a light-cured glass ionomer. Although reports (Cortes

& others, 1993; Triana & others, 1994) indicate that Dyract has a significantly higher shear bond strength to etched dentin and enamel, our data showed 60 of 89 teeth with stained bacteria between the compomer and the cavity. Consequently, our data reconfirmed that high bond strengths of in vitro studies should not be equated with long-term in vivo resistance to bacterial microleakage. In addition, high bond strength should not be misconstrued with long-term clinical success, and in vitro studies should be modified to simulate the clinical situation.

Carvalho and others (1996) have noted that resin-bonded composite restorations compete between polymerization contraction forces and bond strength to the tooth structure. Consequently, successful bonding of adhesive systems to acid-etched dentin requires the use of hydrophilic resins that bond equally well to peritubular and intratubular dentin (Pashley, 1992). Etching vital dentin was believed to increase pulp irritation by facilitating the penetration of irritants into the tubules (Stanley & others, 1975; Eriksen & Leidal, 1979). However, in our study, there were no significant statistical differences in pulp inflammation of total-etched and nonetched Compoglass at 7 days. Fujitani and others (1992) reported disarrangement and reduction of the odontoblasts at 3 days, indicating that total-etched dentin showed a greater reduction of primary odontoblasts than nonetched cavities, and that irritation originated from initial chemical and mechanical irritation of H_3PO_4 acid etching, rinsing, and air drying. At 27 and 90 days the pulp responses to total and nonetched Compoglass were statistically the same. Etching of vital dentin for 15 seconds with 40% H_3PO_4 acid (Torstenson, Nordenvall & Brännström, 1982) and 10% H_3PO_4 acid (White & others, 1992), even in deep cavities, did not cause pulpal inflammation or necrosis. Brännström and Nordenvall (1978) filled total-etched (37% H_3PO_4) cavity preparations with a composite using a bonding agent and reported no bacterial staining nor pulp inflammation. Inokoshi and others (1982) reported that total-etched cavity preparations restored with Clearfil bond system-F showed only a slight pulpal response and no bacterial penetration. In this study, the total-etch Compoglass technique was expected to reduce the risk of bacteria growth. However, comparison of both Compoglass groups demonstrated no advantage to total etching the dentin and enamel.

Our IRM data are comparable with Möller, Schroder, and Granath (1983) and White and others (1994). The optimum sealing capacity of IRM is its biological capacity to prevent bacterial microleakage. Brännström, Nordenvall, and Torstenson (1981) showed that IRM cement does not permit bacterial growth from the tooth surface due to its bactericidal properties.

Our findings are in general agreement with earlier studies that demonstrated that light-cured glass-ionomer cements do not impair the healing response of the dental pulp (Felton & others, 1991; Cox & others, 1993; Gaintantzopoulou & others, 1994). Schmalz and others (1994), observing a glass-ionomer base material containing strontium glass, reported a moderate pulp response in three teeth at 5 days, with no pulp response when bacterial contamination was excluded at 30 and 90 days.

At 27 and 90 days, bacterial staining had increased along the preparation walls. In vitro studies of the sealing capability of light-cured glass ionomer indicated that they provided an acceptable seal (Crim, 1993; Sidhu, 1994), but there was a discernible gap between the restoration and the tooth, indicating an imperfect seal, possibly from shrinkage during setting contraction. Sidhu, Sherriff, and Watson (1995) showed that resin-modified glass ionomers (Fuji II LC, Vitremer, Photac-Fil) were susceptible to dehydration shrinkage for 3 months. Consequently, the presence of gaps along the dentin cavity walls may allow bacterial microleakage and eventual pulp irritation. Fusayama (1987) suggested the fundamental factor of pulp irritation could be separation or debonding of the resin from dentin, and that thermal and mechanical stress upon the restoration would cause a pumping action of dentinal fluid into the space along the dentinal floor, probably pressing irritants or bacterial toxins into the tubules.

In this study, the poor marginal seal may have been due to the resin component of the compomer system undergoing differential polymerization shrinkage during light curing. Polymerization shrinkage may be a more significant problem in compomers with resin-like characteristics. The rate and degree of shrinkage of a restorative material depends on many factors, such as the monomer system, catalyst concentration, filler type, size, amount, as well as clinical manipulation regarding bulk or incremental filling. Compomers behave more like resin composites; consequently they might be more rigid (higher elastic modulus) than light-cured glass ionomers. Properties of higher thermal expansion are seen when a material moves along the scale from a pure glass ionomer to a pure resin composite. Tam, Dev, and Pilliar (1995) reported that the addition of an intermediary dentin bonding agent significantly increased the fracture resistance of a dentin/light-cured glass-ionomer bonded interface. They indicated that formation of a dentin interdiffusion zone and resin tags between the dentin and glass-ionomer substrates may improve the bond of dentin bonding agents to a light-cured glass ionomer. In addition, a resin-dentin interdiffusion zone as an elastic bond area may have the strain capacity sufficient to relieve stresses between the shrinking composite restoration and the rigid dentin substrate, thereby improving the conservation of the dentin bond, marginal integrity, and retention of the restoration (Van Meerbeek & others, 1993). Moreover, adding an intermediary resin adhesive layer between the glass ionomer and the dentin may prevent or reduce the amount of fluoride incorporation into the adjacent dentin as suggested by Carvalho and others (1996).

The authors are in agreement with Sidhu and Watson (1995), who suggested that some resin-modified restorative materials should not be classified in the same category as resin-modified glass ionomers, as they do not have an auto-set acid-base reaction occurring without photoactivation, and when set, they do not exhibit the typical properties of true glass-ionomer cements. A true resin-modified glass ionomer is a two-part system characterized by an acid-base reaction (critical to its cure), a diffusion-based adhesion between the tooth surface and the cement, and a continuing fluoride release. Forsten (1994) suggested that Dyract does not release fluoride in the same way as conventional glass-ionomer cements, nor does it harden without light activation. Further studies are needed to characterize long-term in vivo and in vitro properties of these materials and to evaluate the nature of the hybrid layer in vital dentin. From a clinical standpoint, it may be necessary to place multiple repetitive coats of the "one bottle" priming and bonding systems.

CONCLUSIONS

1. Compomers are not biological irritants to the underlying primary odontoblasts or the subjacent pulp tissues when placed in class 5 cavity preparations.
2. Statistical data demonstrate a positive correlation between bacterial presence and pulpal inflammation.
3. Compomers are associated with more pulpal inflammation than the control material, IRM.
4. Total etching of the vital dentin with 37% H_3PO_4 is not injurious to the primary odontoblasts or subjacent pulp tissue.
5. There is no biological advantage for total etching with H_3PO_4, as bacterial staining was observed in several teeth when total etching was employed.
6. Data show no statistical correlation regarding the type of restorative treatment (material) and thickness of reparative dentin beneath the remaining dentin.

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References

BERGENHOLTZ G, COX CF, LOESCHE WJ & SYED SA (1982) Bacterial leakage around dental restorations: its effect on the dental pulp *Journal of Oral Pathology* **11** 439-450.

BRÄNNSTRÖM M & NORDENVALL K-J (1978) Bacterial penetration, pulpal reaction and the inner surface of Concise enamel bond composite fillings in etched and unetched cavities *Journal of Dental Research* **57** 3-10.

BRÄNNSTRÖM M, NORDENVALL K-J & TORSTENSON B (1981) Pulpal reaction to IRM cement: an intermediate restorative material containing eugenol *Journal of Dentistry for Children* **48** 259-263.

BRÄNNSTRÖM M & NYBORG H (1969) Points in the experimental study of pulpal response to restorative materials *Odontologisk Tidskrift* **77** 421-426.

BROWNE RM, TOBIAS RS, CROMBIE IK & PLANT CG (1983) Bacterial microleakage and pulpal inflammation in experimental cavities *International Endodontic Journal* **16** 147-155.

BUONOCORE MH (1955) A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces *Journal of Dental Research* **34** 849-853.

CARVALHO RM, PEREIRA JC, YOSHIMAYA M & PASHLEY DH (1996) A review of polymerization contraction: the influence of stress development versus stress relief *Operative Dentistry* **21** 17-24.

CORTES O, GARCÍA-GODOY F & BOJ JR (1993) Bond strength of resin-reinforced glass ionomer cements after enamel etching *American Journal of Dentistry* **6** 299-301.

COX CF, BERGENHOLTZ G, FITZGERALD M, HEYS DR, HEYS RJ, AVERY JK & BAKER JA (1982) Capping of the dental pulp mechanically exposed to the oral microflora—a 5 week observation of wound healing in the monkey *Journal of Oral Pathology* **11** 327-339.

COX CF, BERGENHOLTZ G, HEYS DR, SYED SA, FITZGERALD M & HEYS RJ (1985) Pulp capping of dental pulp mechanically exposed to oral microflora: A 1-2 year observation of wound healing in the monkey *Journal of Oral Pathology* **14** 156-168.

COX CF, ERICKSON RL & GLASSPOOLE E (1993) Histologic pulp response of a new tri-cure glass ionomer *Journal of Dental Research* **72** *Abstracts of Papers* p 348 Abstract 1960.

COX CF, KEALL CL, KEALL HJ, OSTRO E & BERGENHOLTZ G (1987) Biocompatibility of surface-sealed dental materials against exposed pulps *Journal of Prosthetic Dentistry* **57** 1-8.

COX CF, WHITE KC, RAMUS DL, FARMER JB & SNUGGS HM (1992) Reparative dentin: factors affecting its deposition *Quintessence International* **23** 257-270.

CRIM GA (1993) Marginal leakage of visible light-cured glass ionomer restorative materials *Journal of Prosthetic Dentistry* **69** 561-563.

ERIKSEN HM & LEIDAL TI (1979) Monkey pulp response to composite resin restorations in cavities treated with various cleansing agents *Scandinavian Journal of Dental Research* **87** 309-317.

FELTON DA, COX CF, ODOM M & KANOY BE (1991) Pulpal response to chemically cured and experimental light-cured glass ionomer cavity liners *Journal of Prosthetic Dentistry* **65** 704-712.

FLESSA HP, KUNZELMANN KH, VON KNOERZER H & HICKEL R (1995) Marginal seal of light-curing glass ionomer cements and Dyract in Class V cavities *Journal of Dental Research* 74 *Abstracts of Papers* p 18 Abstract 53.

FORSTEN L (1994) Fluoride release of glass ionomers *Journal of Esthetic Dentistry* **6** 216-222.

FUJITANI M, INOKOSHI S & HOSODA H (1992) Effect of acid etching on the dental pulp in adhesive composite restorations *International Dental Journal* **42** 3-11.

FUSAYAMA T (1980) *New Concepts in Operative Dentistry: Differentiating Two Layers of Carious Dentin and Using an Adhesive Resin* Chicago: Quintessence Publishing Co pp 61-156.

FUSAYAMA T (1987) Factors and prevention of pulp irritation by adhesive composite resin restorations *Quintessence International* **18** 633-641.

GAINTANTZOPOULOU MD, WILLIS GP & KAFRAWY AH (1994) Pulp reactions to light-cured glass-ionomer cements *American Journal of Dentistry* 7 39-42.

HARNIRATTISAI C & HOSODA H (1991) Pulpal responses to various dentin bonding systems in dentin cavities *Dental Materials Journal* **10** 149-164.

HOTTA M & AONO M (1994) Adaptation to the cavity floor of the light-cured glass ionomer cement base under a composite restoration *Journal of Oral Rehabilitation* **21** 679-685.

INOKOSHI S, IWAKU M & FUSAYAMA T (1982) Pulpal response to a new adhesive restorative resin *Journal of Dental Research* **61** 1014-1019.

MITRA SB (1991) Adhesion to dentin and physical properties of a light-cured glass-ionomer liner/base *Journal of Dental Research* **70** 72-74.

MÖLLER B, SCHRÖDER U & GRANATH L (1983) Effect of IRM on human dental pulp *Scandinavian Journal of Dental Research* **91** 281-287.

PASHLEY DH (1992) The effects of acid etching on the pulpodentin complex *Operative Dentistry* **17** 229-242.

PLANT CG, TOBIAS RS, RIPPIN JW, BROOKS JW & BROWNE RM (1991) A study of the relationship among pulpal response, microbial microleakage, and particle heterogeneity in a glass-ionomer-base material *Dental Materials* 7 217-224.

QVIST V (1980) Correlation between marginal adaptation of composite resin restorations and bacterial growth in cavities *Scandinavian Journal of Dental Research* **88** 296-300.

SCHMALZ G, THONEMANN B, RIEDEL M & ELDERTON RJ (1994) Biological and clinical investigations of a glass ionomer base material *Dental Materials* **10** 304-313.

SIDHU SK (1994) Marginal contraction gap formation of light-cured glass ionomers *American Journal of Dentistry* 7 115-118.

SIDHU SK, SHERRIFF M & WATSON TF (1995) Effect of maturity and dehydration shrinkage on resin-modified glass ionomer materials *Journal of Dental Research* **74** *Abstracts of Papers* p 18 Abstract 49.

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

SIM TP & SIDHU SK (1994) The effect of dentinal conditioning on light-activated glass-ionomer cement *Quintessence International* **25** 505-508.

SNUGGS HM, COX CF, POWELL CS & WHITE KC (1993) Pulpal healing and dentinal bridge formation in an acidic environment *Quintessence International* **24** 501-510.

STANLEY HR, GOING RE & CHAUNCEY HH (1975) Human pulp response to acid pretreatment of dentin and to composite restoration *Journal of the American Dental Association* **91** 817-825.

TAM LE, DEV S & PILLIAR RM (1995) Fracture toughness of conventional or photopolymerized glass ionomer/dentin interfaces *Operative Dentistry* **20** 144-150.

TOBIAS RS, PLANT CG, RIPPIN JW & BROWNE RM (1989) Pulpal response to an anhydrous glass ionomer luting cement *Endodontics and Dental Traumatology* **5** 242-252.

TORSTENSON B, NORDENVALL K-J & BRÄNNSTRÖM M (1982) Pulpal reaction and microorganisms under Clearfil Composite Resin in deep cavities with acid etched dentin *Swedish Dental Journal* **6** 167-176.

TRIANA R, PRADO C, GARRO J & GARCÍA-GODOY F (1994) Dentin bond strength of fluoride-releasing materials *American Journal of Dentistry* **7** 252-254.

VAN MEERBEEK B, WILLEMS G, CELIS JP, ROOS JR, BRAEM M, LAMBRECHTS P & VANHERLE G (1993) Assessment by nano-indentation of the hardness and elasticity of the resin-dentin bonding area *Journal of Dental Research* **72** 1434-1442.

WHITE KC, COX CF, KANCA J 3rd, DIXON DL, FARMER JB & SNUGGS HM (1994) Pulpal response to adhesive resin systems applied to acid-etched vital dentin: damp versus dry primer application *Quintessence International* **25** 259-268.

WIECZKOWSKI G, JOYNT RB, DAVIS EL, YU XY & CLEARY K (1992) Leakage patterns associated with glass-ionomer-based resin restorations *Operative Dentistry* **17** 21-25.

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

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Resin-Dentin Shear Bond Strength and Interfacial Ultrastructure with and without a Hybrid Layer

M A VARGAS • D S COBB • S R ARMSTRONG

Clinical Relevance
Shear bond strengths were significantly enhanced by removing the collagen network with NaOCl after conditioning the dentin with phosphoric acid for All-Bond 2 dentin adhesive and were not significantly different for Scotchbond Multi-Purpose.

SUMMARY

The purpose of this study was (1) to evaluate the effect of a 2-minute exposure of 5% NaOCl following acid conditioning of the dentin on the shear bond strength for two adhesive systems and (2) to examine the ultrastructure of the resin-dentin interface under SEM. The mesial and distal surfaces of 28 extracted human third molars were ground to expose dentin, then polished with 600-grit SiC. Teeth were randomly assigned to four test groups (n=14) and received the following treatments: *Scotchbond Multi-Purpose (SBMP)*--Samples were conditioned with 37% phosphoric acid, rinsed and left moist, SBMP primer and adhesive were applied according to the manufacturer's directions, and Restorative Z-100 composite resin was bonded to the dentin surface. *SBMP/NaOCl*--The same procedures were followed as for SBMP except the surfaces were treated with 5% NaOCl for 2 minutes, after acid conditioning. *All-Bond 2 (AB2)*--The same technique was followed as for SBMP, using AB2 according to the manufacturer's recommendations. *AB2/NaOCl*--The same procedure was followed as for SBMP/NaOCl, using AB2. Specimens were thermocycled in a water bath 300 times between 5°-55°C, then sheared in a Zwick Universal Testing Machine. A one-way ANOVA and Duncan's Multiple Range Test were used for statistical analysis of the data. A 2-minute exposure of dentin to 5% NaOCl following acid conditioning of the dentin had no significant effect on the dentin shear bond strength for Scotchbond Multi-Purpose, but significantly increased the bond strength of All-Bond 2 specimens. The interfacial structure of the dentin to resin bond for two dentin treatments and two adhesive systems was studied morphologically under the scanning electron microscope. Argon ion beam etching and acid demineralization clearly revealed the hybrid layer for the conventional treatment with phosphoric acid and indicated an absence of this resin-impregnated collagen network in those specimens treated with both phosphoric acid and NaOCl.

The University of Iowa, College of Dentistry, Department of Operative Dentistry, Iowa City, IA 52242

M A Vargas, DDS, MS, assistant professor

D S Cobb, DDS, MS, assistant professor

S R Armstrong, DDS, graduate student

INTRODUCTION

The clinical success of composite restorations depends on adhesive systems that provide durable bonding of composite to dentin and effectively seal the dentin tubules to prevent postoperative sensitivity and microleakage (Titley & others, 1994). This adhesive bond between the restoration and dentin must withstand the stresses created in the oral environment over time (Chappel, Spencer & Eick, 1994).

Achieving predictable bonding to dentin has long been a goal and challenge in restorative dentistry. The high organic content of dentin, along with its tubular structure and outward flow of fluid, make dentin bonding difficult to attain (Pashley, 1990).

Recent advances in resin to dentin adhesion are due to resin infiltration of a chemically altered dentin surface. The micromechanical bond is generated by first acid conditioning of the dentin to remove the smear layer and decalcify the outer dentin, followed by the use of an amphiphilic primer, which facilitates resin penetration into the demineralized dentin substrate (Nakabayashi, 1991). Subsequent polymerization creates a transitional zone of resin-reinforced dentin called the hybrid layer, between the cured resin and the unaltered dentin, which was first described by Nakabayashi (Nakabayashi, 1982; Nakabayashi, Kojima & Masuhara, 1982). This hybridization of demineralized dentin and resin monomers is composed of two interphases. The larger outermost region is a network of resin-impregnated collagen largely devoid of mineral content. Below this is a narrow partially demineralized band of dentin mainly composed of resin-encapsulated hydroxylapatite crystals (Nakabayashi, Ashizawa & Nakamura, 1992). Thus, most current adhesive systems rely on this reaction between the collagen-rich surface and a wettable primer resin to form the resin-reinforced hybrid layer, which is the basis for the micromechanical retention of the adhesive system to dentin (Wakabayashi & others, 1994).

Optimal bond strength is derived from complete resin diffusion into the chemically altered dentin. It has been suggested that dentin bonding agents do not fully diffuse through the collagen network that remains after acid conditioning of dentin. Failure to adequately penetrate the collagen network into the partially demineralized dentin may produce a weak porous layer of collagen not protected by hydroxylapatite or encapsulated by resin. Subsequent hydrolysis of the exposed collagen peptides could lead to degradation of the dentin to resin bond, resulting in decreased bond strength and increased microleakage over time (Sano & others, 1994). Nakabayashi and others (1992) have suggested that the demineralized zone be kept to a minimum to reduce the possibility of long-term bond degradation caused by incomplete penetration of resin through the collagen network. Removal of the organic collagen layer following acid conditioning and subsequent bonding directly to the partially demineralized dentin layer may produce more durable adhesion to the hydroxylapatite component of the dentin substrate. It is theorized that this dentin substrate conditioning would significantly enhance the long-term strength and durability of the resin to dentin bond for adhesive systems.

The purpose of this study was (1) to evaluate the effect of a 2-minute exposure of 5% NaOCl following acid conditioning of the dentin on the shear bond strength for two adhesive systems (Scotchbond Multi-Purpose and All-Bond 2), and (2) to examine the ultrastructure of the resin-dentin interface using SEM.

METHODS AND MATERIALS

Shear Bond Strength

Twenty-eight recently extracted sound human third molars stored in an aqueous solution of 2% thymol were used in this study. Teeth were cleaned with scalers and flour of pumice and stored in distilled water for 1 week before the study. The teeth were mounted in phenolic rings 1 inch in diameter with cold-cure acrylic resin. The mesial and distal surfaces were ground flat to expose dentin and polished on wet 240-, 400-, and 600-grit SiC paper for a total of 56 prepared dentin surfaces. The specimens were observed with a dissecting microscope to ensure that no enamel remained. The surfaces were randomly assigned to four groups of 14 each and received the following treatments:

1) **Scotchbond Multi-Purpose** (3M Dental Products, St Paul, MN 55144) (SBMP). Dentin surfaces were conditioned with 37% phosphoric acid for 15 seconds, rinsed with water for 30 seconds, and air dried for 1 second to remove excess water, leaving a moist surface. Three coats of SBMP primer were applied to the dentin. The surface was dried thoroughly, then SBMP adhesive resin was applied and light cured for 20 seconds with an Optilux 401 visible light-activation unit (Demetron Research Corp, Danbury, CT 06810). The light output, measured with a curing radiometer (Demetron) every 10 samples, was greater than 400 mW/cm^2. A 1.5 mm increment of Restorative Z-100 composite resin, shade A-2, was loaded into a #5 gel capsule (Torpac Inc, East Hanover, NJ 07936) that was partially filled with prepolymerized composite resin. The capsule was gently seated onto the flattened surface and excess composite removed. The specimen was polymerized for 40 seconds from three directions, for a total of 120 seconds.

2) **SBMP/NaOCl** The same procedures were followed as in the SBMP group, but a solution of 5%

by weight of sodium hypochlorite was applied for 2 minutes after acid conditioning and then rinsed before application of the primer.

3) **All-Bond 2** (Bisco Inc, Itasca, IL 60143) (AB2). Surfaces were conditioned with 37% phosphoric acid gel for 15 seconds, rinsed with water for 30 seconds, and air dried for 1 second to remove excess water, leaving a moist surface. Five coats of a mixture of one drop each of Primer A and B were applied to the dentin. The surface was dried thoroughly, then All-Bond 2 Dentin/Enamel Bonding Resin was applied and cured for 20 seconds. Restorative Z-100 composite resin, shade A-2, was loaded into a #5 gel capsule and gently seated onto the flattened surface. Excess composite was removed before light curing the resin for a total of 120 seconds.

4) **AB2/NaOCl** The same procedures were followed as for the AB2 group except that a solution of 5% by weight of sodium hypochlorite was applied for 2 minutes after acid conditioning and then rinsed before application of the primer.

Ten minutes after bonding, the specimens were immersed in distilled water and stored for 24 hours at 37° C. The samples were then thermocycled for 300 cycles between 5 and 55° C, with a dwell time of 30 seconds in each bath. Twenty-four hours after thermocycling shear bond strength was measured in a Zwick Universal Testing Machine (Zwick of America, East Windsor, CT 06088). A parallel knife-edge shearing device was aligned 0.05 mm from the bonded interface and force was applied to failure using a crosshead speed of 5 mm/min. The data were analyzed using one-way ANOVA and Duncan's Multiple Range Test to evaluate differences among groups.

Shear Bond Strength between Acid-etched and Deproteinized Dentin Surfaces (MPa)

Group	Mean	SD	Min	Max
SBMP	17.37	1.89	14.90	20.98
All-Bond 2 /NaOCl	17.06	1.92	14.09	20.64
SBMP/NaOCl	16.83	2.15	14.18	20.98
All-Bond 2	14.43	1.86	11.14	17.36*

*Mean shear bond strength significantly lower than all other groups

SEM Ultrastructure

Eight dentin disks 800 μm thick were obtained by parallel sectioning of the crown portion of freshly extracted human third molar teeth. Pairs of dentin disks were prepared according to the four dentin treatments used for the shear bond strength portion of the study. The treated surfaces of each pair were then bonded together with Z-100 Restorative composite resin. Specimens were stored in distilled water for 7 days at 37°C. Each disk was sectioned perpendicular to the bonded interface, using a Silverstone-Taylor (Sci Fab, Lafayette, CO 80026-1536) hard tissue microtome under copious water lavage, to obtain four 700 μm-thick specimens. Specimens were then metallurgically polished with 50 μm-, 15 μm-, and 5 μm-grit sandpaper, followed by a 2-4 μm and 0.01 μm diamond paste and polishing cloth. Specimens were rinsed between grits with distilled water and 50% ethanol. All specimens were subjected to argon-ion-beam etching (Dual Ion Mill Model 600, Gatan Inc, Pleasanton, CA 94566) for 2 minutes. Operating conditions for the argon-ion-beam etching were: accelerating voltage of 5 kV, an ion current density of 1 mA/cm², and the ion beam directed 35° to the polished surface. Half of the specimens were decalcified in a 5N solution of HCl for 2 minutes, rinsed in running distilled water, and deproteinized in 5% NaOCl for 20 minutes to expose resin tags. The specimens were then sputter-coated with Au-Pd and observed under a Hitachi S-4000 field-emission scanning electron microscope (Hitachi Scientific Instruments, Mountain View, CA 94043) (Inokoshi & others, 1990; Van Meerbeek & others, 1992).

RESULTS

Mean shear bond strengths in MPa ± SD for the groups were: SBMP 17.37±1.89; AB2/NaOCl 17.06±1.92; SBMP/NaOCl 16.83±2.15; and AB-2 14.43±1.86 as shown in the table and Figure 1. A

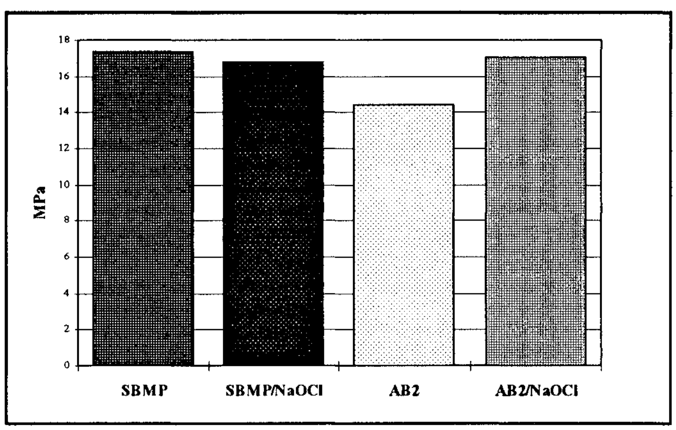

Figure 1. Shear bond strength between acid-etched and deproteinized dentin surfaces

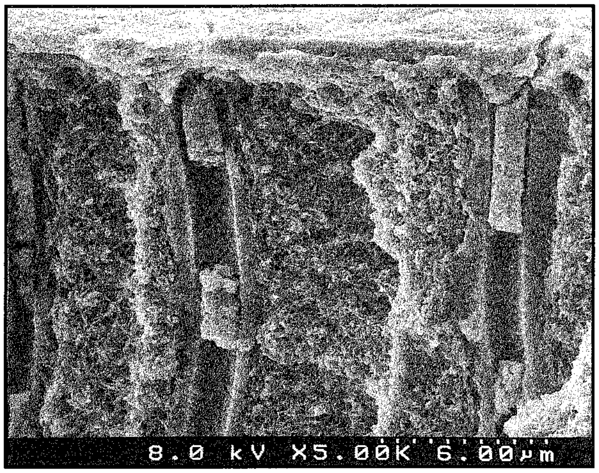

Figure 2. *Cross-sectional view of the dentin surface revealing the smear layer and smear plugs*

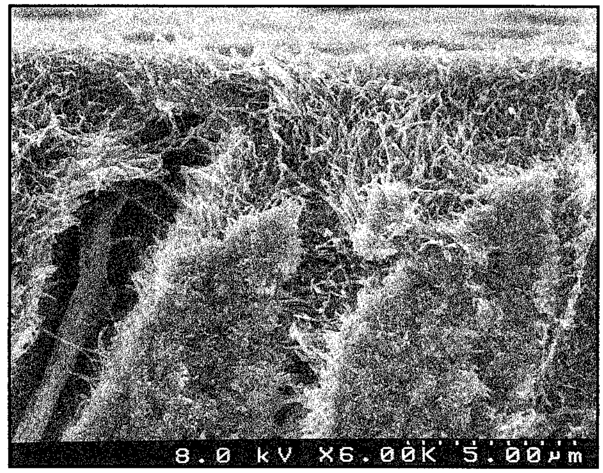

Figure 3. *Cross section of the dentin surface after removal of the inorganic component by acid conditioning. Note the abundance of collagen fibers in the demineralized zone.*

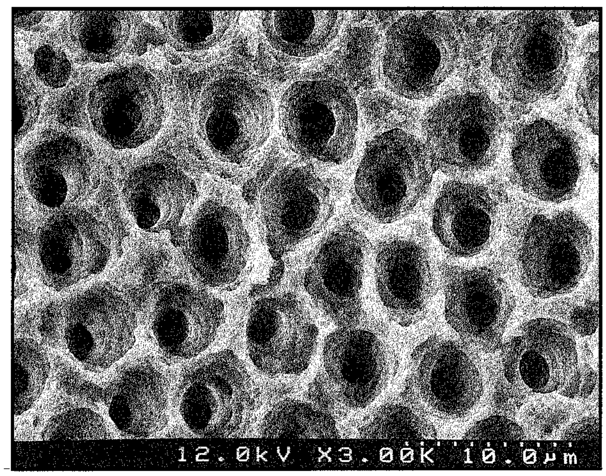

Figure 4. *Top view of a specimen treated with NaOCl for 2 minutes after acid conditioning to remove organic component. Note that no organic elements can be observed in the pictures.*

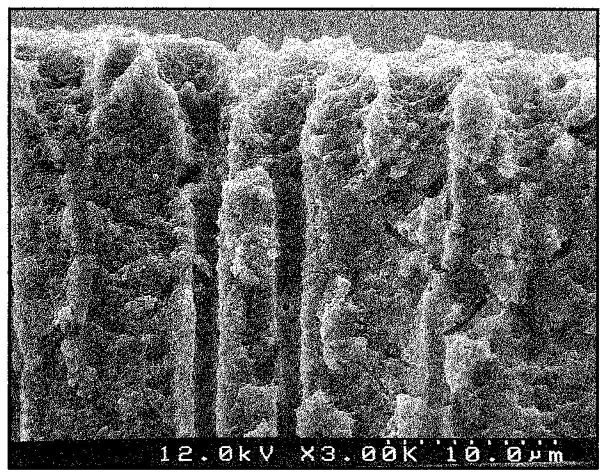

Figure 5. *Cross section of a specimen treated with NaOCl for 2 minutes after acid conditioning. In contrast to Figure 2, no collagen fibers remain either in or around the dentin tubules after treatment with NaOCl.*

one-way ANOVA and Duncan's Multiple Range Test were used for statistical analysis of the data. There was no statistical difference ($P < 0.05$) in the shear bond strengths of Groups SBMP, AB2/NaOCl, and SBMP/NaOCl. Mean shear bond strength for AB2 was significantly lower than for all other groups. Specimen failure appeared to be interfacial based on visual observation.

The photomicrograph in Figure 2 shows a cross section of dentin smear layer and plugs. Figure 3 shows a cross section of the dentin surface after acid conditioning. Figures 4 and 5 show a top view and cross section of a specimen treated with NaOCl for 2 minutes after acid conditioning. Figures 6 and 7 show the interface between SBMP and phosphoric acid-treated dentin. Figures 8 and 9 show the interface between SBMP and phosphoric acid/NaOCl-treated dentin. In these photomicrographs an increased number of resin-filled anastomoses can be observed when compared with those specimens from the SBMP group, where collagen was not removed (Figure 7).

Similar results were observed when examining specimens treated with the All-Bond 2 adhesive system (Figures 10-13). A difference existed in the All-Bond 2/NaOCl-treated group when compared to the SBMP/NaOCl in that there was no evidence of a hybrid layer remaining in the AB2/NaOCl specimen.

DISCUSSION

The integrity of the bond between dentin and resin adhesive systems has important implications for clinical dentistry in improving the success of composite resin restorations. Considerable effort has been directed

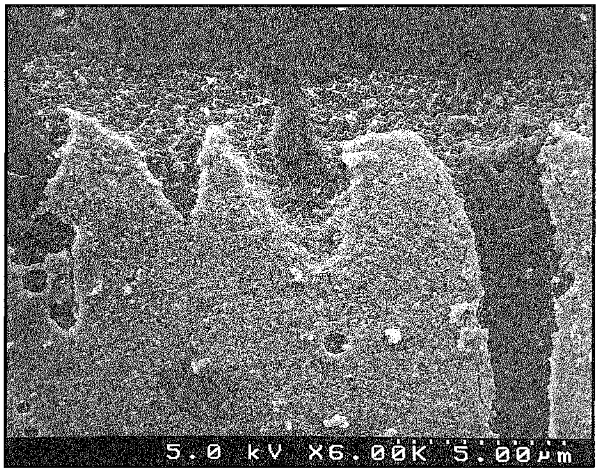

Figure 6. *Cross section of interface between SBMP and 37% phosphoric acid-treated dentin. A distinct hybrid layer 2 μm thick can be observed. Note resin-impregnated collagen with no gap formation between the resin and dentin.*

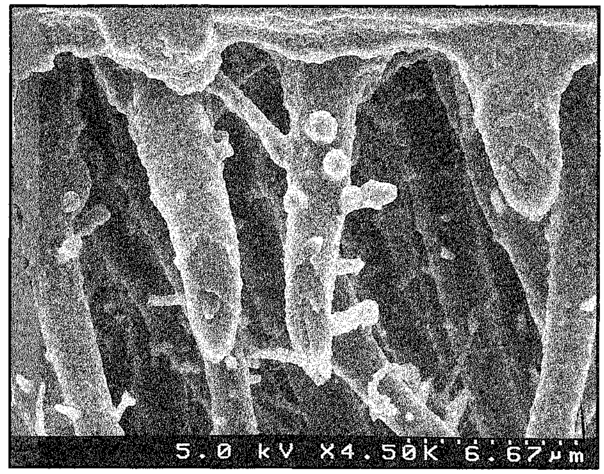

Figure 7. *Cross section of interface between SBMP and 37% phosphoric acid-treated dentin. The dentin was removed by HCl and NaOCl treatment, which clearly reveals penetration of resin tags into the tubules and partial penetration into tubular anastomoses.*

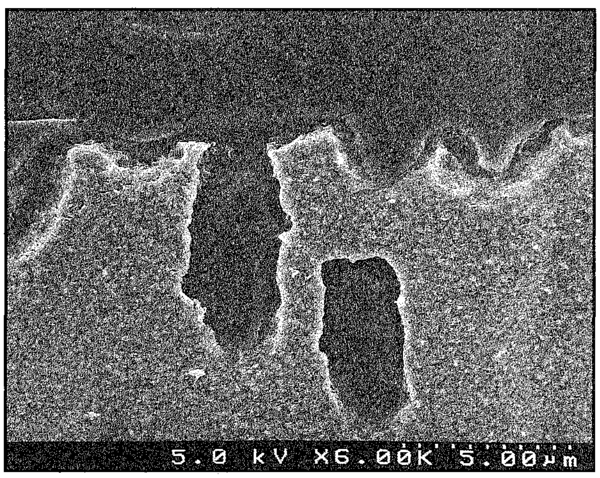

Figure 8. *Cross section of interface between SBMP and dentin substrate treated with 37% phosphoric acid and NaOCl. There is an almost nonexistent hybrid layer, although no gap formation can be observed.*

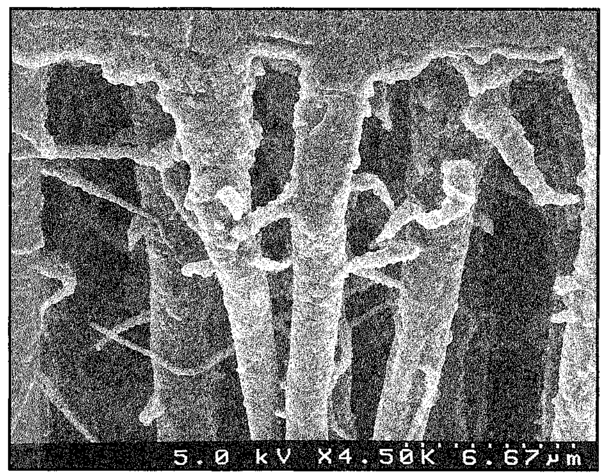

Figure 9. *Cross section of interface between SBMP and dentin substrate treated with 37% phosphoric acid and NaOCl. The dentin was removed by HCl and NaOCl, clearly revealing penetration of resin tags into the dentin tubules and into tubular anastomoses. More anastomoses can be observed when compared to the specimens where dentin was treated with phosphoric acid alone (Figure 7).*

toward the attainment of predictable long-term bonding to dentin. Adhesion of resin to dentin is more complicated and less predictable than adhesion to enamel. The high organic content and tubular structure of dentin as well as the odontoblastic processes and the outward flow of fluid make dentin bonding difficult to attain (Pashley, 1990). The strength and integrity of these bonds have been shown to be inferior to those of enamel (Swift, Perdigao & Heymann, 1995; Bayne, Heymann & Swift, 1994; Heymann & Bayne, 1993). The strong micromechanical bond between the resin adhesive and the high inorganic (92 vol % hydroxylapatite) substrate of enamel produces durable bonded restorations with high strength and minimal microleakage (Swift & others, 1995). In contrast to enamel, the composition of dentin consists of only 45 vol % inorganic hydroxylapatite randomly arranged in an organic collagen matrix (Swift & others, 1995). These factors reduce the adhesive potential of the dentin substrate.

Bonding to dentin relies on the penetration of adhesives into the collagen fibers (polypeptides) and encapsulation of the irregular hydroxylapatite crystals at the bottom of the decalcified area, to create the resin-reinforced interdiffusion zone called the hybrid layer

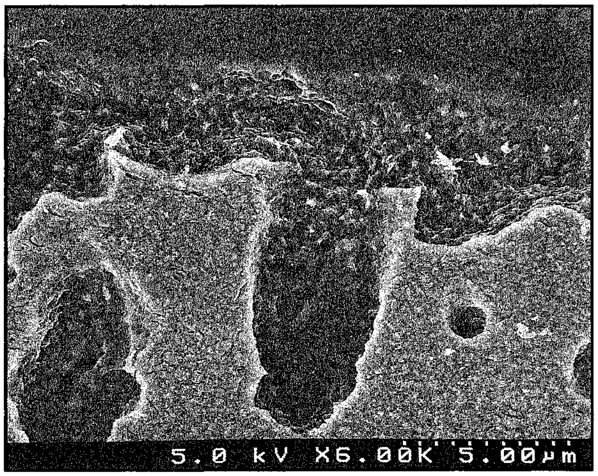

Figure 10. *Cross section of interface between All-Bond 2 and 37% phosphoric acid-treated dentin. A distinct hybrid layer 2.5 μm thick can be observed. Note resin-impregnated collagen with no gap formation between the resin and dentin.*

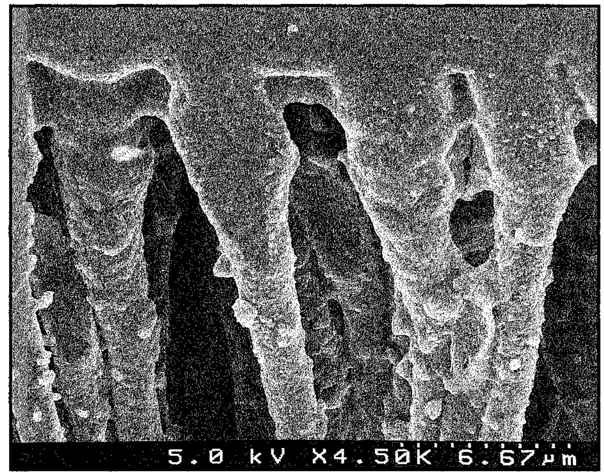

Figure 11. *Cross section of interface between All-Bond 2 and 37% phosphoric acid-treated dentin. The dentin was removed by HCl and NaOCl, clearly revealing penetration of resin tags into the dentin tubules; tubular anastomoses are not as evident as observed in the SBMP group.*

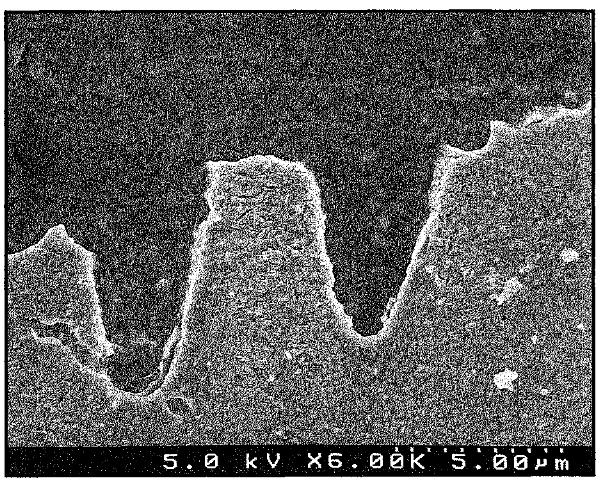

Figure 12. *Cross section of interface between All-Bond 2 and dentin substrate treated with 37% phosphoric acid and NaOCl. There is an almost nonexistent hybrid layer, although no gap formation can be observed.*

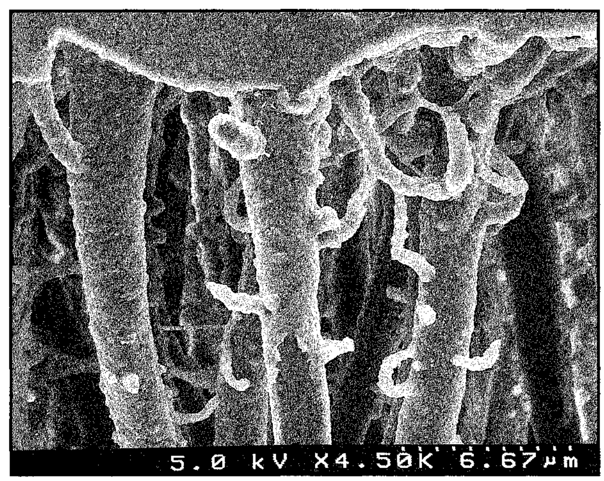

Figure 13. *Cross section of interface between All-Bond 2 and dentin substrate treated with 37% phosphoric acid and NaOCl. The dentin was removed by HCl and NaOCl, clearly revealing penetration of resin tags into the dentin tubules and tubular anastomoses. Increased penetration into tubular anastomoses can be observed when compared to the specimens treated with phosphoric acid alone (Figure 11).*

(Nakabayashi, 1982; Titley & others,1994). Concerns have been raised that dentin bonding agents do not fully diffuse through the collagen network that remains after acid conditioning of dentin (Sano & others, 1994; Nakabayashi, 1993). This unprotected collagen may potentially be a weak physical link in the long-term adhesion of dentin to resin. Hydrolysis of these bands of exposed collagen not protected by resin ("nonhybridized collagen") would occur with long-term exposure to water. This could lead to deterioration of the adhesion between resin and dentin, resulting in decreased bond strength (Nakabayashi, 1993). Wakabayashi and others (1994) indicated that bond strengths after long-term water immersion were significantly higher for those specimens where the collagen was removed after acid conditioning, suggesting that degradation of the bond was due to hydrolysis of unprotected collagen fibers. Photomicroscopy using SEM has demonstrated this porous zone of collagen between the resin-impregnated hybrid layer and the underlying partially demineralized dentin (Sano, 1994; Inai & others, 1995; Nakabayashi & others, 1982). The demineralized zone should be kept to a minimum due

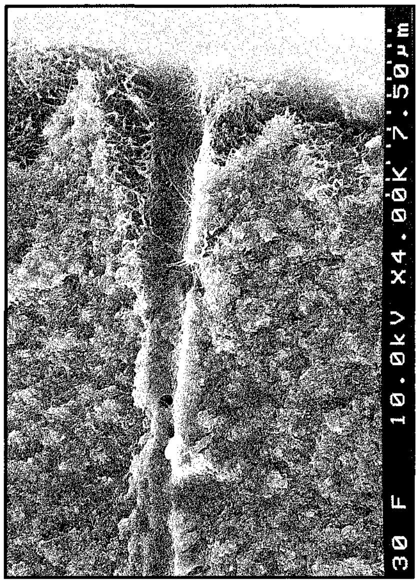

Figure 14. *Cross section of dentin surface conditioned with 37% phosphoric acid for 30 seconds. A demineralized layer approximately 2 µm thick is apparent.*

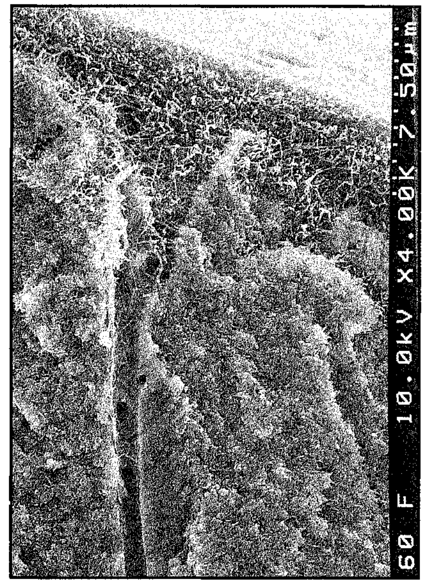

Figure 15. *Cross section of dentin surface conditioned with 37% phosphoric acid for 60 seconds. In contrast to Figure 14, a thicker demineralized layer, approximately 3.5 µm, can be observed.*

to the hydrolytic vulnerability of the unimpregnated collagen (Nakabayashi & others, 1992). This would facilitate resin penetration into the partially demineralized dentin, which relies on micromechanical retention between the resin and the hydroxylapatite crystals (Nakabayashi, 1991; Nakabayashi & others, 1992; Eick, 1992; Van Meerbeek & others, 1993; Van Meerbeek, Conn & Duke, 1995).

Our study agrees with Gwinnett's conclusion (1994) that the collagen layer does not significantly contribute to the interfacial strength of resin to dentin. Furthermore, removal of the collagen layer may be beneficial for resin to dentin bonding in some adhesive systems and not in others. Another study found similar shear bond strength trends; however, increased marginal gap formations were observed with deproteinization (Uno & Finger, 1995). In this study removal of the collagen layer with NaOCl enhanced the bond strength between the adhesive resin and dentin for All-Bond 2 but not for Scotchbond Multi-Purpose. This may indicate more efficient penetration of SBMP primer compared to AB2 primer.

Several factors may affect the ability of resin to adequately penetrate into the demineralized dentin. Prolonged exposure to acid conditioning leaves a thicker band of exposed collagen as observed under SEM microscopy: Figure 14 shows a specimen conditioned for 30 seconds with phosphoric acid; Figure 15 shows a specimen conditioned for 60 seconds. Resin penetration through a thicker collagen layer might be more difficult, resulting in a porous band of collagen at the base that is not protected by resin. Hydrolytic breakdown of this unprotected collagen may compromise the long-term integrity of the resin to dentin interface (Sano & others, 1994; Nakabayashi, 1993).

Another factor shown to influence resin penetration and resultant bond strength is primer application. Increasing the number of primer coats resulted in improved adhesion to dentin (Vargas, Fortin & Meckes, 1995). This enhancement may have been due to the greater time allowed for primer to penetrate through the collagen network. In another study, when the primer was applied with agitation, bond strength was enhanced, although differences were not significant (Haws, Vargas & Denehy, 1996). SEM revealed that agitation increased penetration of the resin into the tubules and anastamoses. In the current study, deeper penetration of resin into the dentin tubules and anastamoses was observed when the collagen was removed (Figures 9 & 13). This suggests that removal of the collagen layer allows better resin penetration into dentin. Further studies are warranted to evaluate this dentin substrate conditioning system.

CONCLUSIONS

Resin-dentin shear bond strength and ultrastructure were evaluated following the removal of the collagen layer. The results of this study support the theory that the collagen layer may not be crucial to the mechanism of adhesion between resin and dentin. In fact, this unsupported collagen layer may inhibit penetration of resin into the dentin substrate and undermine the long-term durability of the resin to dentin bond. Durable bonding may be facilitated by collagen layer removal, allowing more complete resin diffusion into the partially demineralized dentin. The optimal dentinal surface pretreatment has yet to be determined for adhesive integrity of resin to dentin.

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References

BAYNE SC, HEYMANN HO & SWIFT EJ Jr (1994) Update on dental composite restorations *Journal of the American Dental Association* **125** 687-701.

CHAPPELL R, SPENCER P & EICK J (1994) The effects of current dentinal adhesives on the dentinal surface *Quintessence International* **25** 851-859.

EICK JD (1992) Smear layer—materials surface *Proceedings of the Finnish Dental Society* **88 (Supplement 1)** 225-242.

GWINNETT AJ (1994) Altered tissue contribution to interfacial bond strength with acid conditioned dentin *American Journal of Dentistry* 7 243-246.

HAWS SM, VARGAS MA & DENEHY GE (1996) Ultrastructure and bond strength to dentin using different primer applications *Journal of Dental Research* **75** *Abstracts of Papers* p 386 Abstract 2949.

HEYMANN HO & BAYNE SC (1993) Current concepts in dentin bonding: focusing on dentinal adhesion factors *Journal of the American Dental Association* **124** 26-36.

INAI N, MAMIYA T, BURROW MF, SANO H & TAKATSU T (1995) Nanoleakage of several new dentin bonding systems *Journal of Dental Research* **74** *Abstracts of Papers* p 36 Abstract 198.

INOKOSHI S, HOSODA H, HARNIRATTISAI C, HIMIDA Y & TATSUMI T (1990) A study on the resin-impregnated layer of dentin: Part I. A comparative study on the decalcified and undecalcified sections and the application of argon ion beam etching to disclose the resin impregnated layer of dentin *Japanese Journal of Conservative Dentistry* **33** 427-442.

NAKABAYASHI N (1982) Resin reinforced dentin due to infiltration of monomers into the dentin at the adhesive interface *Journal of Japanese Society for Dental Materials and Devices* **1** 78-81.

NAKABAYASHI N (1991) Dentin bonding mechanisms [letter] *Quintessence International* **22** 73-74.

NAKABAYASHI N (1993) Polymer materials for some therapeutic applications In *Biomedical Applications of Polymeric Materials* Boca Raton: CRC Press pp 241-248.

NAKABAYASHI N, ASHIZAWA M & NAKAMURA M (1992) Identification of a resin-dentin hybrid layer in vital human dentin created in vivo: durable bonding to vital dentin *Quintessence International* **23** 135-141.

NAKABAYASHI N, KOJIMA K & MASUHARA E (1982) The promotion of adhesion by infiltration of monomers into tooth substrates *Journal of Biomedical Materials Research* **16** 265-273.

PASHLEY DH (1990) Interactions of dental materials with dentin in Proceedings of Conference on Enamel-Dentin-Pulp-Bone-Periodontal Tissue Interactions with Dental Materials *Transactions of the Academy of Dental Materials* **3** 55-73.

SANO H, SHONO T, TAKATSU T & HOSODA H (1994) Microporous dentin zone beneath resin-impregnated layer *Operative Dentistry* **19** 59-64.

SWIFT EJ, PERDIGAO J & HEYMANN HO (1995) Bonding to enamel and dentin: a brief history and state of the art, 1995 *Quintessence International* **26** 95-110.

TITLEY K, CHERNECKY R, MARIC B & SMITH D (1994) Penetration of a dentin bonding agent into dentin *American Journal of Dentistry* **7** 190-194.

UNO S & FINGER WJ (1995) Function of the hybrid zone as a stress-absorbing layer in resin-dentin bonding *Quintessence International* **26** 733-738.

VAN MEERBEEK B, CONN LJ & DUKE ES (1995) Correlative imaging of the resin-dentin interface using TEM and SEM *Journal of Dental Research* **74** *Abstracts of Papers* p 32 Abstract 166.

VAN MEERBEEK B, DHEM A, GORET-NICAISE M, BRAEM M, LAMBRECHTS P & VANHERLE G (1993) Comparative SEM and TEM examination of the ultrastructure of the resin-dentin interdiffusion zone *Journal of Dental Research* **72** 495-501.

VAN MEERBEEK B, INOKOSHI S, BRAEM M, LAMBRECHTS P & VANHERLE G (1992) Morphological aspects of the resin-dentin interdiffusion zone with different dentin adhesive systems *Journal of Dental Research* **71** 1530-1540.

VARGAS MA, FORTIN D & MECKES M (1995) Effects of primer coats on composite bond strength to dentin *Journal of Dental Research* **74** *Abstracts of Papers* p 34 Abstract 182.

WAKABAYASHI Y, KONDOU Y, SUZUKI K, YATANI H & YAMASHITA A (1994) Effect of dissolution of collagen on adhesion to dentin *International Journal of Prosthodontics* **7** 302-306.

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Comparison of Aesthetic Properties of Tooth-colored Restorative Materials

A U J YAP • K B C TAN • S BHOLE

Clinical Relevance
Composite resins had better hue/chroma, value, and translucency match to the Vita shade guide than the other materials evaluated, although none was rated good or excellent.

SUMMARY

The objective of this study was to compare the aesthetic properties of color and translucency of Vita shade-based tooth-colored restorative materials, including composite resins, a polyacid-modified composite resin, and resin-modified glass-ionomer cements via clinical discrimination by human evaluators. The hue/chroma, value, and translucency of the five different materials chosen to represent the range of commercially available tooth-colored restoratives were graded by 40 dental personnel against the body of their respective Vita shade tabs using a five-point scale (1=very poor; 2=poor; 3=average; 4=good; 5=excellent). Results confirm the clinical observation that the hue/chroma, value, and translucency of the different materials evaluated do not match the Vita shade guide to which they are supposedly keyed. The aesthetic properties of hue/chroma, value, and translucency for the material evaluated were all shade dependent. Comparison of pooled results revealed that none of the materials had good or excellent ratings and that the composite resins had significantly better hue/chroma, value, and translucency match to the Vita shade guide than the other materials evaluated.

National University of Singapore, Faculty of Dentistry, 5 Lower Kent Ridge Road, Singapore 119074

Adrian U J Yap, BDS, MSc, MRSH, lecturer

Keson B C Tan, BDS, MSD, Cert Prosthodont, lecturer

Sameer Bhole, BDS, MDSc, FRSH, adjunct lecturer

INTRODUCTION

The ongoing search for biologically and aesthetically acceptable adhesive restorative materials has brought new types of materials to the dental market. Two of the more recently introduced materials are the resin-modified glass-ionomer cements and polyacid-modified composite resins. Resin-modified glass-ionomer cements are hybrid materials of traditional glass-ionomer cement with a small addition of light-curing resin. They remain glass-ionomer cements by their ability to set without light activation, although this reaction takes place more slowly than for the traditional cements (Sidhu & Watson, 1995). Polyacid-modified composite resins are composite resins with fluoride-leaching components. They, however, do not have an autosetting acid-base glass-ionomer reaction and are dependent on photoactivation for the setting process.

These new materials, as well as composite resins, are now often keyed to the Vita Lumin shade guide (Vita Zahnfabrik, Bad Säckingen, Germany), which is widely used for porcelain shade selection. The Vita shade range includes "A" shades, which have a brown character, "B" shades, which are considered to have a yellow character, "C" shades, a gray character, and "D" shades, a reddish character. The objective of keying new materials to this shade guide

Table 1. Materials Used and Shades Selected

Materials	Shades
Durafill (DF)	A1, A3, C3
Fuji II LC	A2, A3, B3
Dyract (DY)	A2, A3, C3
Z100 (ZO)	A2, A3, A4
Vitremer (VM)	C2, A3, C4

was to reduce the need for different shade guides, which were often subjective and varied (Wozniak & others, 1985), and to improve interpractitioner communication. Clinical procedures involving different materials would then be theoretically simplified as colors would be identical. It is, however, important to note that Vita shade tabs are characterized, each having cervical, body, and incisal colors over an opaque backing, and identified by the body shade (i e, A1, B3). While some manufacturers have stated that the shades of their products correspond to the central part (middle third) or body of the respective Vita tooth, others have been ambiguous about the shade selection procedure.

The aesthetic properties of these materials may be represented by their translucency and color-match with the Vita shade tabs to which they are keyed. Translucency is the appearance state between complete opacity and complete transparency (*Journal of Prosthetic Dentistry*, 1987). To define color, three parameters are important. These are the hue, chroma, and value. Hue can be defined as the particular variety of color, shade, or tint. The hue of an object can be yellow, red, green, etc, and is determined by the wavelength of the reflected and/or transmitted light observed. Chroma is defined as the intensity or strength of a given hue. Value is defined as the relative lightness or darkness of an object. The brightness of any object is the direct consequence of the amount of energy that the object reflects or transmits (Rosentiel, Land & Fujimoto, 1988).

The objective of this study was to compare the aesthetic properties of color and translucency of Vita shade-based tooth-colored restorative materials, including composite resins, polyacid-modified composite resins, and resin-modified glass-ionomer cements via clinical discrimination by human evaluators. The subjective clinical observation that the color and translucency of these materials do not match the Vita shade tabs to which they are keyed was also assessed.

METHODS AND MATERIALS

Five different types of restorative materials representing the range of commercially available tooth-colored restorative materials were evaluated. They included a microfilled composite resin (Durafill VS [DF]--Kulzer GmbH Dental Division, Friedrichsdorf, Germany); a hybrid composite resin (Z100 [ZO]--3M Dental Products, St Paul, MN 55144); a polyacid-modified composite resin (Dyract [DY]--De Trey Division, Dentsply Limited, Surrey, England); a dual-cure glass-ionomer cement (Fuji II LC [F2]--GC International Corporation, Tokyo, Japan) and a tri-cure glass-ionomer cement (Vitremer [VM]--3M Dental Products). Dual-cure glass-ionomer cements have a two-fold setting reaction involving the normal acid-base reaction of glass-ionomer cements and free-radical photochemical polymerization process. Tri-cure glass-ionomer cements have, in addition, a third polymerization reaction involving the use of water-activated redox catalysts. The lightest (highest value and lowest chroma), darkest (lowest value and highest chroma), and medium shade (A3) of each system were chosen to ensure an even distribution of colors (Table 1).

Table 2. Comparisons of Individual and Combined Shades for Glass-Ionomer and Composite Materials

	Light Shades
Hue/Chroma	DF, F2, DY > ZO, VM
Value	DF, F2, DY > ZO, VM
Translucency	DF, F2, DY, ZO > VM
	Medium Shades
Hue/Chroma	ZO > DF, DY, F2, VM Also DF, F2 > DY, VM Also VM > DY
Value	ZO > DF, DY, VM Also F2, DF, VM > DY
Translucency	DF, F2, ZO, VM > DY
	Dark Shades
Hue/Chroma	DF, ZO > DY, F2, VM Also DF > ZO
Value	DF, ZO > DY, F2, VM
Translucency	DF, ZO > DY, F2, VM Also F2 > VM
	All Shades
Hue/Chroma	DF, ZO > DY, F2, VM Also F2 > DY, VM Also DY > VM
Value	DF, ZO > DY, F2, VM Also F2 > DY, VM
Translucency	DF, ZO F2 > DY, VM

DF = Durafill VS; ZO = Z100; DY = Dyract; F2 = Fuji II LC; VM = Vitremer

Results of Kruskal-Wallis, Mann-Whitney U, and Wilcoxon Rank Sum W tests ($P < 0.05$); > indicates statistical significance.

Specimen disks, 10 ± 1 mm in diameter and 2 ± 0.5 mm thick, were fabricated using custom-made molds. Restorative materials were manipulated according to manufacturers' instructions and placed into the molds, and excess material was extruded by sandwiching the molds between two quartz glass plates. The specimens were light cured through the glass plate using a Max Polymerization unit (De Trey Division, Dentsply Limited, Milford, DE 19963), which was periodically checked with a Curite unit (Efos Inc, Mississawga, Ontario, Canada) to ensure consistent power output prior to the curing of each specimen. Overlapping radiation was essential due to the larger area of the specimen compared to the exit window of the light source. This was done until the whole specimen had been radiated for the manufacturer's recommended exposure time. Immediately after irradiation, the specimens were removed from their molds and the periphery finished with 1000-grit abrasive paper. A layer of unfilled resin (Scotchbond Multi-Purpose adhesive, 3M Dental Products) was applied over the resin-modified glass-ionomer cements and light polymerized for 10 seconds. All specimens were then mounted on a pale gray-blue plastic backing prior to storage in distilled water at 37°C for 48 hours. The specimens were then randomly arranged, and 40 dental personnel, consisting of 10 final-year dental students, 10 dental technicians, 10 general dental practitioners, and 10 prosthodontists, were asked to grade the hue and chroma, value, and translucency of the five different restorative dental materials against the body (middle third) of their respective Vita shade tabs using a five-point scale (1=very poor; 2=poor; 3=average; 4=good; 5=excellent). The evaluators were informed of possible false negatives, although none existed, and were blinded to the actual shade of the paired tab and specimen. Evaluations were carried out in the same dental operatory, which was illuminated with color corrected lighting (Trucolor TLM 40W/33 RS, Philips, Le Mans, France) and not influenced by external daylight conditions. Both specimens and shade tabs were viewed damp. The results were analyzed with Kruskal-Wallis one-way analysis of variance ($P < 0.05$), and intermaterial comparisons for light, dark, and medium shades were performed with the Mann-Whitney U and Wilcoxon Rank Sum W test ($P < 0.05$). Table 2 provides significant differences for individual and combined shades for the restorative materials.

Table 3. Mean Scores and Standard Deviations for Hue/Chroma, Value, and Translucency Match of Each Material and Shade Combination

Shade/ Material	DF	F2	DY	ZO	VM
HUE/CHROMA					
Light Shades	2.25 (0.78)	1.95 (0.78)	2.35 (0.98)	1.47 (0.64)	1.45 (0.64)
Medium	2.53 (0.99)	2.78 (0.95)	1.43 (0.90)	3.20 (1.04)	1.75 (0.84)
Dark	3.60 (1.00)	1.60 (0.59)	1.78 (1.05)	3.10 (1.15)	1.40 (0.63)
Pooled Scores	2.79 (1.09)	2.11 (0.92)	1.85 (1.04)	2.59 (1.25)	1.53 (0.72)
VALUE					
Light Shades	2.08 (0.76)	2.15 (0.86)	2.23 (0.83)	1.73 (0.72)	1.70 (0.72)
Medium	2.35 (0.98)	2.60 (1.03)	1.45 (0.78)	3.03 (1.05)	2.08 (0.88)
Dark	3.13 (1.09)	1.88 (0.65)	1.75 (0.98)	2.85 (1.17)	1.98 (0.89)
Pooled Scores	2.52 (1.05)	2.21 (0.91)	1.81 (0.92)	2.53 (1.14)	1.92 (0.85)
TRANSLUCENCY					
Light Shades	2.18 (0.81)	2.18 (0.87)	2.08 (0.83)	2.13 (0.88)	1.70 (0.69)
Medium	2.30 (0.79)	2.43 (0.98)	1.68 (0.86)	2.48 (1.01)	2.15 (0.83)
Dark	2.73 (1.01)	2.03 (0.77)	1.73 (0.91)	2.58 (0.93)	1.60 (0.74)
Pooled Scores	2.40 (0.90)	2.21 (0.89)	1.82 (0.88)	2.39 (0.96)	1.82 (0.79)

RESULTS

The mean scores and standard deviations for hue/chroma, value, and translucency match of each material and shade combination are presented in Table 3. Bar charts reflecting the mean scores for hue/chroma, value, and translucency match for light, medium, and dark shades are presented in Figures 1 to 3. The pooled mean scores for hue/chroma, value, and translucency match of each material are shown in Figure 4.

For light shades (Figure 1), the hue/chroma match of DF, F2, and DY was significantly better than ZO and VM. The value match of DF, F2, and DY was also significantly better than ZO and VM. The translucency match of VM was significantly poorer than all the other restorative materials evaluated.

For medium shades (Figure 2), the hue/

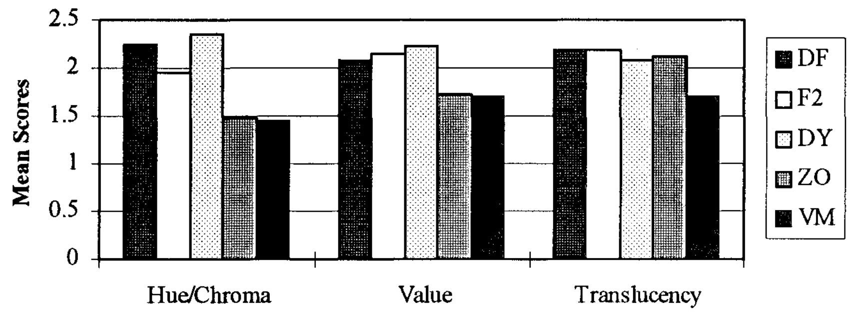

Figure 1. *Mean scores for hue/chroma, value, and translucency match for light shades; DF = Durafill; F2 = Fuji II LC; DY = Dyract; ZO = Z100; VM = Vitremer.*

chroma match of ZO was significantly better than DF, DY, F2, and VM. The hue/chroma match of DF and F2 was significantly better than DY and VM. VM had significantly better hue/chroma match when compared to DY. The value match of ZO was significantly better than DF, DY, and VM. The value match of F2, DF, and VM was significantly better than DY. The translucency match of DY was significantly poorer than all the materials evaluated.

For dark shades (Figure 3), the hue/chroma match of DF and ZO was significantly better than DY, F2, and VM. The hue/chroma match of DF was significantly better than ZO. The value and translucency match of DF and ZO was also significantly better than DY, F2, and VM. The translucency match of F2 was significantly better than VM.

When the data were pooled for all shades (Figure 4), the hue/chroma and value match of DF and ZO was significantly better than DY, F2, and VM. The hue/chroma and value match of F2 was significantly better than DY and VM. The hue/chroma match of DY was significantly better than VM. The translucency match of DF, ZO, and F2 was significantly better than DY and VM. No significant difference in translucency match was observed between DF, ZO, and F2. The value match of DF and ZO was significantly better than F2, DY, and VM. The value match of F2 was significantly better than DY and VM. Although the materials were keyed to the Vita shade guide, none of them had a good or excellent (pooled score greater than 3) rating for hue/chroma, value, or translucency match.

DISCUSSION

The protocol used in this study, in terms of specimen preparation and evaluation conditions, was validated in an earlier project (Yap, Bhole & Tan, 1995). Color perception between individuals is both subjective and variable (Wyszecki & Stiles, 1982). Culpepper (1970) conducted a comparative study of shade-matching procedures and found that critical color perception varies from one individual to another, and some individuals were not able to reliably duplicate their shade selections from one time to another. Although this fact was known, human eye assessment of the materials was still carried out, as it was the clinical discrimination or perception that was the area of interest. In order to minimize subjective errors, it was ensured that none of the dental personnel involved was color defective, as red-green color deficiencies have been shown to result in decreased color discrimination in the yellow hue (Farnsworth, 1957). Color sensitivity decreases rapidly as an object is observed, the original color becoming apparently less and less saturated until it appears almost gray. Simultaneously, the chroma of complementary colors appears greater. This phenomenon has led to the suggestion that shade selection can be enhanced if the operatory walls are painted pale blue (complementary to yellow) or a pale gray-blue card is glanced at between looking at the color choices (Rosentiel & others, 1988). The latter was done in our study to enhance the hue/chroma grading. As the hue and chroma of the materials evaluated was found to be difficult to differentiate through a pilot study, they were categorized together. The grading of value was done by standing at a distance and looking through squinted eyes. By squinting, the amount of light that reaches the retina is reduced, resulting in a decreased stimulation of cones and a greater sensitivity to achromatic conditions (complete lack of hue

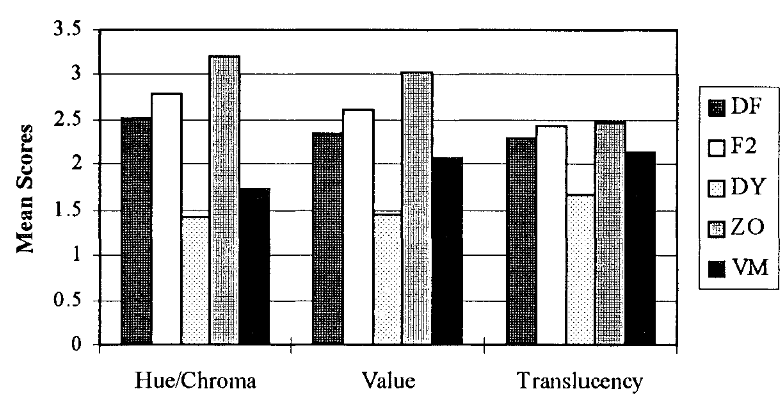

Figure 2. *Mean scores for hue/chroma, value, and translucency for medium shades; DF = Durafill; F2 = Fuji II LC; DY = Dyract; ZO = Z100; VM = Vitremer.*

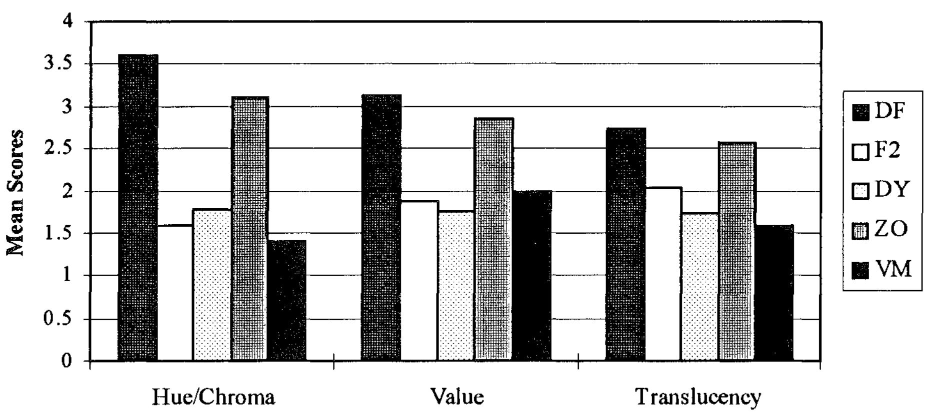

Figure 3. *Mean scores for hue/chroma value, and translucency match for dark shades; DF = Durafill; F2 = Fuji II LC; DY = Dyract; ZO = Z100; VM = Vitremer.*

sensitivity) (McPhee, 1978).

As the tooth-colored restorative materials evaluated were keyed to the Vita shade guide, the corresponding Vita shade tabs were used as baseline comparisons for the evaluation of color and translucency. Clinically, this would imply that the Vita shade guide can be used for color selection of these different materials and that teeth can be restored with materials matched to the same shade of adjacent porcelain crowns, if this is known. The forementioned is, however, only true if materials match the Vita shade guide in terms of color and translucency, which was not found to be the case in our study. This discrepancy may be due, in part, to the unrealistic method of fabrication of the Vita shade tabs (Sorensen & Torres, 1987). A typical shade tab measures 4 mm buccolingually and is made with high-fusing denture tooth porcelain, giving an unrealistic representation of metal-ceramic porcelain shades. Matching of acrylic shade tabs and restorative materials to the Vita shade guide is even more difficult to achieve due to the difference in optical properties. None of the materials evaluated had a good or excellent rating (pooled score greater than 3). The results from this study thus confirm the clinical observation that the hue/chroma, value, and translucency of the tooth-colored restorative materials evaluated do not match the Vita shade guide.

Results show that the hue/chroma match of the materials evaluated were not material dependent but shade (light, medium, or dark) dependent. For light shades, the polyacid-modified composite resin DY had the best hue/chroma match to the Vita shade tab. The composite resin DF, dual-cure resin-modified glass-ionomer cement F2, and polyacid-modified composite resin DY had significantly better hue/chroma match than the composite resin ZO and tri-cure resin-modified glass-ionomer cement VM. For medium shades, the composite resins DF and ZO, and dual-cure glass-ionomer cement F2 had significantly better hue/chroma match than the polyacid-modified composite resin DY and tri-cure glass-ionomer cement VM. The polyacid-modified composite resin DY, however, had the poorest hue/chroma match for medium shades. For dark shades, the hue/chroma match of the composite resin DF was best. The composite resins DF and ZO had significantly better hue/chroma match than the other materials evaluated for dark shades.

The value match of the materials evaluated was also found to be shade dependent. For light shades, the value match of the composite resin DF, dual-cure resin-modified glass-ionomer cement F2, and polyacid-modified composite resin DY were again significantly better than the composite resin ZO and tri-cure resin-modified glass-ionomer cement VM. The polyacid-modified composite resin DY also had the best value match for light shades. For medium shades, the composite resin ZO and dual-cure glass-ionomer cement F2 had significantly better value match than the polyacid-modified composite resin DY, and tri-cure glass-ionomer cement VM. The composite resin DF had significantly better value match than the polyacid-modified composite resin DY, which again ranked worst. For dark shades, the composite resins DF and ZO had significantly better

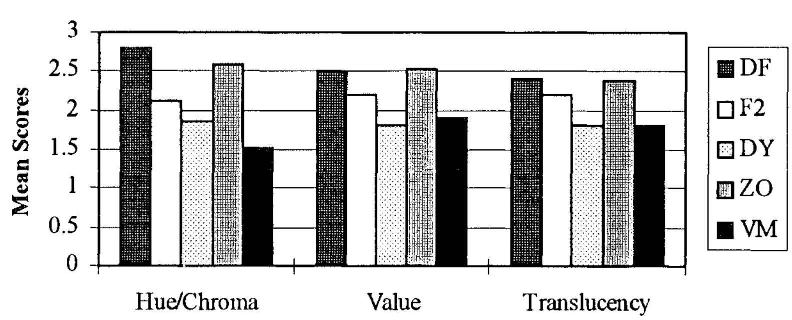

Figure 4. *Pooled mean scores for hue/chroma, value, and translucency match of the various restorative materials; DF = Durafill; F2 = Fuji II LC; DY = Dyract; ZO = Z100; VM = Vitremer.*

value match than the polyacid-modified composite resin DY and the glass-ionomer cements F2 and VM.

With the exception of dark shades for the polyacid-modified composite resin DY and tri-cure glass ionomer VM, materials were ranked similarly for hue/chroma and value. One possible explanation may be that materials with high hue/chroma also have low value and those with low hue/chroma have high value. The generally poor color (hue/chroma and value) match between the Vita shade tabs and the restorative materials may be explained in part by the fact that resin-based materials undergo a color change after polymerization. This characteristic chromatic shift is toward the blue-green region of the color space, resulting in perceived decrease in yellow chroma (Seghi, Gritz & Kim, 1990) and a possible decrease in value as well.

The translucency match of the materials was also shade dependent. For light shades, the tri-cure glass-ionomer cement VM was significantly more opaque than all the other materials evaluated. For medium shades, the polyacid-modified composite resin DY was significantly more opaque than the other materials evaluated. For dark shades, the composite resins DF and ZO had significantly better translucency match than the polyacid-modified composite resin DY and glass-ionomer cements F2 and VM. The dual-cure glass ionomer F2 was significantly better in terms of translucency match when compared to the tri-cure cement, VM.

Comparison of the pooled results for the different shades revealed that composite resins, as a class of restorative materials, had better hue/chroma, value, and translucency match than the other materials evaluated. With regard to the forementioned aesthetic properties, the dual-cure glass-ionomer cement F2 ranked second best and was followed by the polyacid-modified composite resin DY and tri-cure resin-modified glass-ionomer cement VM.

CONCLUSIONS

Although the tooth-colored restorative materials evaluated were keyed to the Vita shade guide, none of the materials evaluated had a good or excellent rating (pooled score greater than 3) for hue/chroma, value, and translucency match. This confirms the clinical observation that the hue/chroma, value, and translucency of the tooth-colored restorative materials evaluated do not match the Vita shade guide to which they are supposedly keyed. Vita shade tabs should, therefore, not be used for clinical shade selection of these materials. The manufacturers' shade guides or a custom shade guide from the actual restorative material is recommended. An alternative for shade selection is the placement and curing of the restorative material on a pretreated tooth prior to isolation, being careful to avoid dehydration of the tooth. The aesthetic properties of hue/chroma, value, and translucency for the materials evaluated were all shade dependent. Comparison of the pooled results for the different shades revealed that composite resins had better hue/chroma, value, and translucency match to the Vita shade guide than the other materials evaluated. More research should be directed towards formulation of materials with better match to the Vita shade guide.

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References

CULPEPPER W D (1970) A comparative study of shade-matching procedures *Journal of Prosthetic Dentistry* **24** 166-173.

FARNSWORTH D (1957) *The Farnsworth-Munsell Hue Test* Baltimore: Munsell Color Co.

JOURNAL OF PROSTHETIC DENTISTRY (1987) Glossary of prosthodontic terms *Journal of Prosthetic Dentistry* **58** 717-762.

McPHEE E R (1978) Light and color in dentistry. Part I—Nature and perception *Journal of the Michigan Dental Association* **60** 565-572.

ROSENSTIEL S F, LAND M F & FUIJMOTO J (1988) *Contemporary Fixed Prosthodontics* 1st ed St Louis: Mosby p 380.

SEGHI R R, GRITZ M D & KIM J (1990) Colorimetric changes in composites resulting from visible-light-initiated polymerization *Dental Materials* **6** 133-137.

SIDHU S K & WATSON T F (1995) Resin-modified glass ionomer materials. A status report for the American Journal of Dentistry *American Journal of Dentistry* **8** 59-67

SORENSEN J A & TORRES T J (1987) Improved color matching of metal-ceramic restorations. Part I: A systematic method for shade determination *Journal of Prosthetic Dentistry* **58** 133-139.

WOZNIAK W T, FAN P L, MCGILL S, MOSER J B & STANFORD J W (1985) Color comparisons of composite resins of various shade designations *Dental Materials* **1** 121-123.

WYSZECKI G & STILES W S (1982) *Color Science: Concepts and Methods, Quantitative Data and Formulae* 2nd ed New York: Wiley p 83.

YAP AU, BHOLE S & TAN KB (1995) Shade match of tooth-colored restorative materials based on a commercial shade guide *Quintessence International* **26** 697-702.

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REVIEW OF LITERATURE

Detection of Microleakage around Dental Restorations: a Review

A H ALANI • C G TOH

Clinical Relevance
Dentists can better evaluate marginal integrity of restorative materials if they understand how microleakage studies are conducted.

INTRODUCTION

Microleakage is defined as the clinically undetectable passage of bacteria, fluids, molecules, or ions between a cavity wall and the restorative material applied to it (Kidd, 1976a). Microleakage at the tooth/restoration interface is considered to be a major factor influencing the longevity of dental restorations. It may lead to staining at the margins of restorations, a hastening of the breakdown at the marginal areas of the restorations, recurrent caries at the tooth/restoration interface, hypersensitivity of restored teeth, and the development of pulpal pathology (Going, 1972).

It has been known for many years that conventional restorative materials and techniques produce dental restorations that do not provide a complete marginal seal, and numerous studies (Going, Massler & Dute, 1960a; Barber, Lyell & Massler, 1964) have demonstrated that leakage of fluid will occur between the filling and the prepared tooth surface. This marginal leakage has been implicated as an aetiological factor in inflammation of the dental pulp following the insertion of dental restorations (Zander, 1959; Cox, Felton & Bergenholtz, 1988; Alani, 1990).

University of Malaya, Faculty of Dentistry, Department of Conservative Dentistry, 50603 Kuala Lumpur, Malaysia

Adil Hamed Alani, BDS, HDD, PhD, assistant professor

Choói Gait Toh, BDS Hons, MSc, FDRCPS, DRDRCS, professor

Brännström and Nyborg (1971) proposed a possible cause of pulpal inflammation by demonstrating the occurrence of microbial leakage around dental restorations, proving that its prevention would eliminate the inflammation. The ingress of bacteria at the tooth/restoration interface is believed by many to be responsible for pulpal irritation (Brännström, 1986). Cox and others (1987) demonstrated that chemical toxic factors such as acid and components of the restorative materials per se are less significant in causing pulpal injury than bacterial leakage around the restoration margins. The studies by Paterson (1976), Browne and others (1983), and Alani (1990) also draw attention to the importance of bacteria in pulpal inflammation associated with dental restorations. Indeed they support the contention that many of the irritant properties previously associated with chemical action of the filling materials themselves are, in fact, related primarily to bacterial microleakage.

The purpose of this paper is to provide a summary of the various techniques used in microleakage studies as a guide for future investigations as well as aiding the clinician in evaluation of the reported research.

Table 1. Summary of Dye Choice and Immersion Time in Dye-Penetration Studies

Investigators	Dye Used	Concentration of Dye (%)	Time of Immersion
Hirsch & Weinreb (1958)	Aniline blue	2	72 hours
Going & others (1960b)	Crystal violet	--	24 hours
Christen & Mitchell (1966)	Fluorescein	2	5-12 minutes
Grieve & Parkholm (1973)	Eosin	5	48 hours
Sanders & Dooley (1974)	Methylene blue	0.5	30 hours
Barry & Friedl (1975)	Methylene blue	2	2, 4, 8, or 16 days
Al-Hammadani & Crabb (1975)	Alcian blue	2	72 hours
Fogel (1977)	Methylene blue	0.25	1 day, 1 week, & 1 month
Crim & Mattingly (1981)	Basic Fuchsin	0.5	25 hours
Kwan & Harrington (1981)	India ink	--	24 hours
Camp & Todd (1983)	Rhodamine B	--	60 hours
Alperstein & others (1983)	Fluorescein	20	1 hour
O'Neill & others (1983)	India ink	--	24 hours
Tagger & others (1983)	Procion Brilliant Green	1	4 days
Michanowicz & Czonstkowsky (1984)	Methylene blue	5	7 days
Munksgaard & others (1985)	Erythrosin	9	10 seconds
Jacobsen & others (1985)	Methylene blue	1	72 hours
Crim & others (1985b)	Basic Fuchsin	0.5	24 hours
El-Deeb (1985)	Methylene blue	2	48 hours
Ben Amar & others (1985)	Basic Fuchsin	0.5	14 days
Crim & Chapman (1986)	Basic Fuchsin	--	24 hours
Zidán & others (1987)	Basic Fuchsin	0.5	60 seconds
Glyn Jones & others (1988)	Eosin	4	48 hours
Callis & Paterson (1988)	Procion blue	1	1 week
Spangberg & others (1989)	Methylene blue	2	7 days
Youngson & others (1990)	Eosin	5	48 hours
Mathis & others (1990)	Methylene blue	0.5	17 hours
Cuicchi & others (1990)	Blue cresyl	0.5	48 hours
Arcoria & others (1991)	Methylene blue	0.5	24 hours
Saunders & others (1991)	Black india ink	--	14 days
Brackett & others (1995)	Methylene blue	10	4 hours

DETECTION OF MICROLEAKAGE

Many techniques have been devised to test the cavity-sealing properties of restorations both in vivo and in vitro. In vitro studies include the use of dyes, chemical tracers, radioactive isotopes, air pressure, bacteria, neutron activation analysis, scanning electron microscopy, artificial caries techniques, and electrical conductivity. The results of these studies have emphasized that margins of restorations are not fixed and inert with impenetrable borders, but as Myers stated in 1966 "possess dynamic microcrevices which contain a busy traffic of ions and molecules" (Kidd, 1976a).

Dyes

The use of organic dyes as tracers is one of the oldest and most common methods of detecting leakage in vitro. As far back as 1874 King used blue ink and Tomes (1875) used draper's ink in leakage studies. In 1895 Fletcher, as reported by Going (1972), used dyes to study the shrinkage of dental amalgam.

In general, this method for detecting microleakage in vitro involves placing a restoration in an extracted tooth and immersing it in a dye solution, after coating the unfilled parts of the tooth with a waterproof varnish. After an interval of time the specimen is removed, washed, and sectioned before visual examination to establish the extent of penetration of dye around the filling.

Review of the published literature showed that there have been wide variations in choice of dye used, either as solutions or particle suspensions of different particle size. The concentrations of dye used also ranged between 0.5%-10%, while the time of immersion of specimens in the dye varied between 4 hours to 72 hours or more (Table 1). It was found that different concentrations of dyes can vary in penetration time between 5 minutes to over 1 hour (Christen & Mitchell, 1966).

Fluorescent dyes were found to be particularly useful as tracers because they are detectable in dilute concentration, inexpensive, and being nontoxic can be used safely for clinical as well as laboratory investigations (Going, 1972).

Little mention has been given to the differing size of dye molecules/particles and their behavior when used under test conditions. Some dyes such as basic fuchsin have been shown to bind preferentially with carious dentin. Dyes that exhibit a propensity for bonding to tooth structure or restorative material under investigation can potentially demonstrate a wider and deeper gap than actually exists.

In a study comparing the use of three types of dyes and a radioactive tracer in the detection of microleakage of amalgam restorations, it was found that the amount of leakage detected was dependent on the technique used with 0.5% basic fuchsin, indicating the greatest amount of leakage followed in descending order by 1.5% reactive orange 14, Ca^{45}, and 2.0% fluorescent dye (González, 1992). The main problem with the results was that they were evaluated subjectively. The assessment of the restoration as a whole is difficult, because most sectioning is done on class 5 restorations in the saggital plane. Investigators have taken single sections from the mid point of class 5 restorations without evidence that such sections involved the best position to evaluate leakage.

Dye-penetration studies demand destruction of the specimen and thus make it impossible to use fully quantitative techniques for evaluation (Crisp & Wilson, 1980). However, others have suggested that dye penetration is nondestructive, thus allowing longitudinal study of restoration margins (Tsuchiya, Zidán & Gómez-Marín, 1986).

Dentin permeability is also another factor to be considered. The diameter of the dentinal tubules and the number of tubules per unit surface increase as the tubules converge toward the pulp. Practically, it is undesirable to use any dye particle that has a diameter greater than that of the internal diameter of the dentinal tubules (1-4 µm). Therefore, leakage studies in dentin will show some degree of dentin staining that should be differentiated from actual microleakage between the cavity and restoration. It has been suggested that dentin involvement might be used as a relative indicator of marginal leakage (Glyn Jones, Grieve & Youngson, 1988).

Chemical Tracers

Kornfield (1953) described a technique for assessing leakage around acrylic restorations by incorporating lead glass in the acrylic, so that when immersed in a solution of barium sulphide, areas of marginal discoloration indicated leakage.

The silver nitrate method of measuring microleakage is an acceptable technique (Hammesfahr, Huang & Shaffer, 1987). It is, however, a severe test because the silver ion is extremely small (0.059 nm) when compared to the size of a typical bacterium (0.5-1.0 µm) and thus is more penetrative. Therefore, it may be assumed that any system that prevents the leakage of the silver ion will also prevent leakage of bacteria (Douglas, Fields & Fundingsland, 1989).

A 50% silver nitrate solution is commonly used to immerse the in vitro model, which later is reacted with a photographic developing solution such as benzene 1, 4-diol (hydroquinone) (Douglas & others, 1989; Kanca, 1989; Holtan & others, 1990). Other investigators used 1% silver chloride, because the electrochemical technique provided no visual indication of what was occurring (Lim, 1987). This silver-staining technique gave a discrete, high-contrast marking of the restoration/dentin interface (Wu & others, 1983). The advantages of using this technique are: 1) more objective measurements, and 2) quantitative data could be collected for which parametric statistical analysis is appropriate (Crim, 1987). Special texts on silver indicated that finely divided silver might be colored silver, black, gray, blue, yellow, or brown and that the color of a suspension of silver particles depended upon the sizes of deposition of the particles (McWilliam, 1967). Chemical tracer studies had similar problems to that of the dye-leakage studies, especially for interpretation of results.

Radioactive Tracers

Another common method for detecting leakage patterns has involved the use of radioactive isotopes. The use of isotopes permits detection of minute amounts of leakage, as the smaller isotope molecules measure only 40 nm compared to the smaller dye particles (120 nm) (Going, 1964).

The tracers that have been used are Ca^{45} (Armstrong & Simon, 1951; Hembree & Andrews, 1978; Crim & others, 1985a; Puckett & others, 1995), C^{14} (Cantwell & others, 1959; Powis & others, 1988), I^{131} (Going, Massler & Dute, 1960a; Baumgartner, Bustard & Feierabend, 1963; Galan, Mondelli & Coradazzi, 1976), S^{35} (Barber & others, 1964), and Na^{22} (Brännström & Söremark, 1962).

In general, Ca^{45} in the form of calcium chloride at a concentration of 0.1 m Ci/ml, has been the most popular isotope to be used, because it is a low-energy beta emitter and does not readily penetrate enamel (Going, 1972). Alani (1990) found that Ca^{45} showed deep penetration into defects.

This method for detecting microleakage in vitro involves the use of extracted restored teeth. The roots and crowns of the teeth are painted with varnish except for the surface immediately adjacent to the experimental restoration. This is to prevent leakage through the root canal, cracks in the enamel, or exposed dentin, which can obliterate the true picture of marginal adaptation. The sealed teeth are immersed in the isotope solution for several hours. After removal from the isotope the teeth are subjected to prolonged rinsing before ground longitudinal sections are made through the restoration. The cut surfaces are applied to photographic film. The resulting autoradiographs indicate the presence and location of any radioactive isotope that has penetrated between the restoration and the cavity wall. However, the results are evaluated by subjective scoring.

Most investigators continued to assess leakage on a scoring system that increased with severity, although Gottlieb, Retief, and Bradley (1985) used a more objective method of scoring using the position of the dentinoenamel junction as a guide to isotope penetration. Other investigators (Fayyad & Shortall, 1987; Glyn Jones & others, 1988; Alani, 1990) endeavored to overcome the deficiencies of a subjective scoring system by recording the length of dye or isotope penetration along the cavity/restoration interface using an image analysis apparatus linked via a viewing tube to a stereomicroscope.

Long-term monitoring of microleakage can be obtained by using radioactive sucrose C^{14}; however, this is both destructive to tooth structure and lacks clinical relevance (Powis & others, 1988). The use of Ca^{45} may produce misleading results because the isotope has an affinity for tooth structure or for restorative materials that could cause scattering of the isotope to occur on the autoradiograph.

The main disadvantage of tracer studies whether by dyes or radioisotopes is that the results are subjectively assessed and the extent of leakage demonstrated is, to some extent, dependent on the plane of section used in the penetration of the specimens. In addition, the use of the radioactive tracer technique can prove to be quite complex, as elaborate precautions have to be devised to satisfy safety requirements at all stages of the procedure. The isotope is also comparatively very expensive. The technique is very sensitive with the occasional difficulty in interpretation arising from the possibility of isotope penetration by a route other than the tooth/filling interface, via cracks in the enamel of extracted teeth used during the study (Alani, 1990).

Bacteria

Bacteria have also been used in the study of microleakage. Probably the earliest such study was in 1929 when Fraser tested cements and restorative materials to determine whether they would allow bacteria to pass through or around them. Later workers investigating the marginal seal of acrylic restorations (Ross, Williams & Falcetti, 1955; Seltzer, 1955) placed filled teeth in broth cultures. The filling materials were subsequently removed and dentin shavings from the base of the cavity cultured.

This provided purely qualitative results, depending mainly upon the presence or absence of bacteria in part of the dentin shavings examined. Mortensen, Boucher, and Ryge (1965) developed a method for isolating the filled crown of a tooth from its root using a plastic tube sealed with epoxy resin. Broth inoculated with a bacterial culture was placed over the crown, while sterile broth was placed in contact with the root of the tooth. Microleakage was diagnosed if the sterile broth turned cloudy.

It has been claimed that bacterial penetration studies are more clinically related to leakage, because they may be associated with the carious process and recurrent decay (Mejàre, Mejàre & Edwardsson, 1979; Fayyad & Ball, 1987). All the bacterial tests described have the disadvantage that results are described in qualitative rather than quantitative terms. It might also be argued that the microleakage detected is gross if bacterial size is compared with that of the hydrogen ions, which according to Hals and Nernaes (1971) is implicated in the spread of caries around restorations (Kidd, 1976b).

Invasion of marginal gaps by bacteria would be expected to be in the region of 0.5-1.0 µm or larger. These techniques do not, therefore, take into account gaps that are smaller than this and the size of bacteria. Such gaps may not allow bacterial penetration but may allow the diffusion of toxins and other bacterial products that could be harmful to the tooth.

Air Pressure

Air pressure was introduced for detection of marginal leakage by Harper in 1912. He constructed class 2 amalgam restorations in a steel dye, delivered air under pressure to the floor of the cavity, and examined the restoration under water. Several investigators (Fiasconaro & Sherman, 1952; Pickard & Gayford, 1965; Granath & Svensson, 1970) have also used air pressure to evaluate restorative materials. Microscopic examination of the release of air bubbles from the margin of the submerged restoration provided a subjective view of the marginal seal. This method proved to be a valuable technique for comparing the sealing properties of different amalgams as well as cements (Moller, Schroder & Granath, 1983). The advantage of all these methods was that the results could be quantified. A further advantage was that the examination of the specimen did not necessitate its destruction. They were, therefore, able to study leakage over a period of time for the same restoration. The main limiting factor of this method of study is that it could only detect leakage pathways that were complete from the floor to the margin of the cavity. Clinically, it does not take into account the drying effect of compressed air that is passing through the restoration. It is also possible some leakage may occur through clinically sound tooth tissue (Taylor & Lynch, 1992).

Artificial Caries

Artificial secondary caries-like lesions have been produced in vitro using either bacterial cultures or a chemical system—the acidified gel technique. In 1967 Ellis and Brown, using a bacterial technique to produce artificial secondary caries at the interface of the amalgam restoration and the tooth, linked the development of carious lesions to microleakage. Microleakage has also been associated with spread of secondary (recurrent) caries (Hals & Nernaes, 1971; Grieve, 1973).

The first investigators to describe the production of caries-like lesions by the acid-gel technique were Muhlemann (1960), Von Bartheld (1961), and Silverstone (1968). The acid-gel technique developed for the production of secondary caries-like lesions around amalgam fillings by Hals and Nernaes (1971) has also been applied to the study of composites by Hals and Kvinnsland (1974), Kidd (1976b), and Kidd, Harrington, and Grieve (1978). The lesions produced by this technique are studied in polarized light, and two parts are described: an outer lesion and a cavity wall lesion. The outer lesion results from primary attack of the enamel surface adjacent to the restoration, while the cavity wall lesions are formed by microleakage of ions from the acidified gelatin around the restorations.

Using polarizing light microscopy, Jensen and Chan (1985) determined the extent of demineralization of cavity walls adjacent to composite resin restorations following application of an acidified gelatin to the tooth surface to simulate caries. The use of this technique in evaluation of microleakage has the advantage that microleakage may be linked directly with one of its possible consequences, namely the development and spread of secondary caries. Quantification of results is possible where depth of lesion penetration is chosen as a measurable parameter (Kidd 1976b) and the degree of demineralization may also be assessed quantitatively (Kidd, 1976b) or semiquantitatively (Grieve, 1973).

The acidified-gel technique is a valuable tool to create artificial caries that appears indistinguishable from the natural lesion when examined by polarized light and microradiography (Silverstone & others, 1981; Kidd, 1983). This technique has certain advantages: it eliminates the external variables (substrate and microflora) associated with the formation of natural caries, it is efficient in creating a carious lesion within a relatively short period of time, and the viscosity of the gel simulates a layer of plaque (Hattab, Mok & Agnew, 1989). In the artificial caries system, the surface enamel is subjected to a constant attack of hydrogen ions (that is, the dissolution of the mineral is rate controlled) while the gel acts as a diffusion barrier for the dissolved mineral.

Scanning Electron Microscopy (SEM)

The use of scanning electron microscopy (SEM) provides a means of direct visual observation of the adaptation of restorative materials to cavity margins because of its high magnification and depth of focus (Boyde & Knight, 1969). It has been pointed out that the SEM technique can be criticized for its potential for introducing errors and artifacts related to drying, cracking, distortion, and sectioning (Kidd, 1976a). The technique is limited to the evaluation of teeth outside the oral environment and is not oriented to diffusion and penetration as are most other studies (Going, 1972). However, many workers have used SEM to measure gap formation that occurred between the restorations and walls and floor of the preparation (Dávila, Gwinnett & Robles, 1986, 1988; Van Dijken & Horsted, 1989).

The method of SEM can be improved by the use of replicas. This allows change in the size of marginal defects to be followed on a longitudinal basis and can be applied clinically. Replicas may be repeated many times at different intervals, and this does not change the structures being evaluated. The use of a replica technique may avoid specimen shrinkage and some of the other artifacts usually associated with preparation of biological tissue for SEM examination. It is also difficult to quantify SEM results, and the technique is limited to demonstrating marginal defects (Barnes, 1977). SEM examination has also been used to detect crack defects created during the finishing of composites (Ferracane, Condon & Mitchem, 1992).

Neutron Activation Analysis

Neutron activation analysis has been used to study microleakage both in vitro and in vivo (Going, Myers & Prussin, 1968). It involves the immersing of restored teeth in an aqueous solution of a nonradioactive manganese salt. All of the salt adhering to the outside of the tooth is then removed and the whole tooth placed in the core of a nuclear reactor. This resulted in the nonradioactive Mn^{55} being activated to Mn^{56}, and the x-ray emission of Mn^{56} formed during irradiation was then measured. The number of radioactive counts is proportional to the uptake of Mn per tooth. Others have used this method to demonstrate the ability of a hydrophobic composite material to reduce marginal leakage compared to a conventional composite control (Douglas, Chew & Craig, 1980).

Going (1972) pointed out that this method had the advantage that results could be quantified, but he also highlighted the limitations of the technique. These were the very high costs and complexity of the method. Serial sections were made to define the path and depth of tracer penetration, and this sectioning may create a radiation hazard. It was also noted that the presence of manganese, either in the restorative material or in the tooth, caused variability of the results (Meyer, Dennison & Craig, 1974). This technique does not identify the point at which the restoration leaked, nor does it take into account manganese absorption at sites other than the restoration margin.

Electrical Conductivity

A conductimetric technique to evaluate changes in the dimensions of the cavity wall/restoration interspace using an electrochemical cell was developed by Jacobson and von Fraunhofer in 1975. This technique involves the use of glass tubes of 4 mm internal diameter and cut into lengths of 15 mm, because glass has a similar coefficient of thermal expansion to that of tooth substance. The floor of the "cavity" is formed by a nickel-plated brass electrode. After inserting the material, 4 mm of the glass tube is immersed in a 1% solution of lactic acid. A lead from the brass electrode is connected to one terminal of a 5V power source while the other terminal of the circuit is connected through a series of resistances to a reference electrode that is formed by a nickel-plated brass rod. The circuit is completed when the interspace between the test material and glass is occupied by electrolytes. Any change in the current passing through this electrochemical cell reflects changes in the dimensions of the interspace. Since the dimensions of the cavities are constant, the dimensional changes of the materials themselves are observed through measurements of the potential change in the experimental circuit.

Other investigators adapted this method to compare the leakage of two treatments of glass (ionomer) polyalkenoate cements placed in coronal restorations using a longitudinal study over 30 days. The results showed a decrease in current flow over time, although there were wide variations in the values (Lim, 1987).

This technique has been used in endodontic research (Momoi & others, 1990); it proved sensitive, and the results could be quantified (Shortall, 1982). The test method does not demand destruction of the specimen and thus allows changes in the dimensions of the interspace to be followed through different time periods. The test materials, however, are inserted into smooth glass cavities, while cavities cut in vitro are rough, moist, and have varying surface energies that affect their wettability and the intrusion of any chemical agent. It is destructive to tooth structure and cannot be used in the in vivo situation. It does not take into account the dielectric properties of the restorative material or that these (especially in the case of glass-ionomer polyalkenoate cements) may change with time as setting reactions continue. This method, therefore, seems to lack clinical realism. On the other hand, some investigators using natural teeth as specimens claimed superiority for the electrochemical method over dye or isotope penetration studies because it eliminated errors caused by laboratory preparation (Delivanis & Chapman, 1982).

INFLUENCE OF THERMAL CYCLING

Thermocycling is defined as the in vitro process of subjecting a restoration and tooth to temperature extremes that conform to those found in the oral cavity. Many studies of marginal leakage, especially the more recent ones, have included thermocycling in the experimental method (Kidd, 1976b; Glyn Jones, Grieve & Harrington, 1979; Grieve, Saunders & Alani, 1993; Rossomando & Wendt, 1995).

Nelsen, Wolcott, and Paffenbarger (1952) were probably the first to demonstrate marginal percolation due to thermal changes. It was pointed out that marginal percolation was caused by a difference in the coefficient of thermal expansion between the dental tissues and the restorative material and by thermal expansion of fluids occupying the crevice between tooth and restoration. Kidd (1976a) concluded that it was obvious that some form of thermal stressing should be incorporated in microleakage studies. However, later work by Kidd and others (1978); Glyn Jones, Grieve, and Kidd (1978); and Wendt, McInnes, and Dickinson (1992) suggested that in vitro thermocycling or thermal testing of a resin composite restoration using clinically realistic temperatures may not be of consequence.

The temperatures used for in vitro thermocycling have ranged from 0 °C to 68 °C (Shortall, 1982). Many investigators used temperatures of 15 °C and 45 °C for their thermocycling (Peterson, Phillips & Swartz, 1966; Guzman, Swartz & Phillips, 1969; Glyn Jones & others, 1979). These figures were based upon in vivo work carried out by the authors using thermocouples to measure the temperature on the surface of the tooth during imbibition of hot and cold drinks. Others utilized temperature changes from 4 °C to 60 °C (Morley & Stockwell, 1977; Kidd & others, 1978), while some cycled between 5°C and 55°C (Grieve & others, 1993). Harper and others (1980) suggested that the temperature variation in the mouth was quite small.

The time used for the alternate immersion of specimens in hot and cold solutions has ranged between 10 seconds (Saunders & others, 1990), 15 seconds (Retief, 1989; Mandras, Retief & Russell, 1991), 30 seconds (Darbyshire, Messer & Douglas, 1988; Moore & Vann, 1988), 60 seconds (Welsh & Hembree, 1985; Fayyad & Shortall, 1987), and 120 seconds (Momoi & others, 1990). Causton and others (1984) showed that cycling regimes using a short dwell time may be more realistic clinically. Crim and others (1985 b) found that the extent of penetration by dye or tracer in the detection of microleakage of composite restorations was independent of dwell time in the thermal baths. Rossomando and Wendt (1995) found that the extent of the leakage increased with the increase in dwell time for amalgam restorations, although there were no significant differences in dye penetration for thermocycled composite restorations. They thus concluded that during microleakage analysis, the need for thermocycling was dependent upon the extent the restorative material was thermally conductive in relation to its mass. However, when the teeth restored with composite were thermocycled immediately, a higher dye penetration was observed as compared to those that were stored in water before cycling. This finding was attributed to the water sorption potential of composite resins. It was thus recommended that microleakage tests on composite restorations be carried out only after 24 hours of specimen storage to permit water sorption of resin to occur first. It was further suggested that as thermal stresses act rapidly to produce microleakage, prolonged cycling was not necessary (Crim & García-Godoy, 1987). Eakle (1986) examined the effect of thermocycling on fracture strength and microleakage in posterior teeth restored with bonded composite resin. The results suggested that variations in temperature in the clinical range may reduce the fracture strength gained with bonded posterior composite resins.

The number of temperature cycles employed has ranged from 1 to 2,500. It was reported that microleakage increased with an increased number of cycles when resin restorative materials were tested (Peterson & others, 1966). Mandras and others (1991) have shown that the difference in microleakage of composites thermocycled 250 and 1000 cycles was not significant.

INFLUENCE OF LOAD CYCLING

Jorgensen (1970) introduced the term "mechanical percolation" to demonstrate mechanical factors in the oral environment that might produce asymmetric pressure on fillings and on the liquid in the microspace between filling and tooth structure. He suggested that mechanical percolation around loose fillings might be relatively intense.

It has been shown that mechanical cycling of restored teeth could increase the amount of deformation either permanently or only while the tooth was under stress (Jorgensen, Matono & Shimokobe, 1976). The dimensional instability of restorations in loaded teeth indicated a severe risk of percolation for several restorative materials and marginal fracture of brittle restorations (Shortall 1982). Other workers have found that load-cycling has no

Table 2. Summary of Advantages and Limitations of Different Methods of Detecting Microleakage

Method of Detection	Investigators	Advantages	Limitations
Dye	Going (1972) Crisp & Wilson (1980)	1) detectable in dilute concentration 2) inexpensive 3) nontoxic	1) results evaluated subjectively 2) demands destruction of the specimen
Chemical Tracers	Wu & others (1983) Crim (1987)	1) safer 2) depth of penetration much better defined 3) teeth observed directly in a microscope 4) more objective method	same as using dye as method of detection
Radioactive Tracer	Going (1964) Alani (1990)	1) detection of minute amounts of leakage 2) deep penetration into defects	1) results evaluated subjectively 2) complex, needs precautions in handling 3) expensive 4) destructive
Bacteria	Fayyad & Ball (1987)	more clinically relevant	results assessed qualitatively
Air Pressure	Moller & others (1983) Taylor & Lynch (1991)	1) Results can be quantified. 2) no destruction of specimen	1) detects leakage pathways from the floor to the margin of the cavity 2) Leakage may occur through clinically sound tooth tissue.
Artificial Caries	Silverstone (1968) Kidd (1976a) Grieve (1973) Hattab & others (1989)	1) Microleakage may be linked directly to secondary caries. 2) quantification of results 3) degree of demineralization assessed quantitatively 4) eliminates external variables associated with the formation of natural caries	not appropriate for examining marginal leakage where the cavity preparation includes acid etching

additional effect on marginal gap dimensions (Munksgaard & Irie, 1988). It was suggested that, in the evaluation of microleakage in the laboratory studies, restored teeth should be subjected to both thermal and occlusal stresses so that intra-oral conditions were more closely simulated (Mandras & others, 1991). Masticatory stresses may decrease long-term survival of dentinal bonded restorations in vivo as load cycling can induce bond failures (Munksgaard, Itoh & Jorgensen, 1985; Söderholm, 1991). On the other hand, no significant differences were found between chemocycling, thermocycling, thermocycling together with occlusal loading, and occlusal loading alone (Munksgaard & others, 1985; Darbyshire & others, 1988; Krejci, Kuster & Lutz, 1993). Prati and others (1994) found that neither thermocycling nor occlusal stresses increased the microleakage of the restorations.

CONCLUSIONS

The advantages and limitations of different methods of detecting microleakage are summarized in Table 2.

None of the methods used for the detection of microleakage is ideal. Probably the most practical method that provides an acceptable degree of reliability is penetration by tracers. As pointed out previously, tracers have a number of disadvantages. When compared with other methods, however, they provide an effective in vitro method that allows fair comparison between different restorative techniques and materials.

Radioactive isotopes have the advantage over dyes as tracers, for their presence can be readily detected in very small concentrations.

Bacterial microleakage is best examined in vivo,

but conducting strictly controlled in vivo experiments requires large numbers of specimens, is time consuming, and expensive.

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References

ALANI AH (1990) The influence of dentin bonding agents upon the microleakage associated with composite resin restorations and their effects upon the dental pulp PhD Thesis, University of Dundee, Scotland.

AL-HAMMADANI KK & CRABB HS (1975) Marginal adaptation of composite resins *Journal of Oral Rehabilitation* **2** 21-23.

ALPERSTEIN KS, GRAVER HT & HEROLD RCB (1983) Marginal leakage of glass-ionomer cement restorations *Journal of Prosthetic Dentistry* **50** 803-807.

ARCORIA CJ, FISHER MA & WAGNER MJ (1991) Microleakage in alloy-glass ionomer lined amalgam restorations after thermocycling *Journal of Oral Rehabilitation* **18** 9-14.

ARMSTRONG WD & SIMON WJ (1951) Penetration of radiocalcium at the margins of filling materials: a preliminary report *Journal of the American Dental Association* **43** 684-686.

BARBER D, LYELL J & MASSLER M (1964) Effectiveness of copal resin varnish under amalgam restorations *Journal of Prosthetic Dentistry* **14** 533-536.

BARNES IE (1977) The adaptation of composite resins to tooth structure Parts 1-4 *British Dental Journal* **142** 122-129, 185-191, 253-259, 319-326.

BARRY GN & FRIEDL IL (1975) Sealing quality of two polycarboxylate cements used as root canal sealers *Journal of Endodontics* **1** 107-111.

BAUMGARTNER WJ, BUSTARD RE & FEIERABEND RF (1963) Marginal leakage of amalgam restorations *Journal of Prosthetic Dentistry* **13** 346-353.

BEN-AMAR A, LIBERMAN R, NORDENBERG D, RENERT H & GORDON M (1985) The effect on marginal microleakage of using a combination of cavity varnishes and calcium hydroxide intermediary bases—an in vitro study *Quintessence International* **12** 821-825.

BOYDE A & KNIGHT PJ (1969) The use of scanning electron microscopy in clinical dental research *British Dental Journal* **127** 313-322.

BRACKET W, GUNNIN TD, JOHNSON WW & CONKIN JE (1995) Microleakage of light-cured glass-ionomer restorative materials *Quintessence International* **26** 583-585.

BRÄNNSTRÖM M (1986) The cause of post-restorative sensitivity and its prevention *Journal of Endodontics* **12** 475-481.

BRÄNNSTRÖM M & NYBORG H (1971) The presence of bacteria in cavities filled with silicate cement and composite resin materials *Svensk Tandlakaretidskrift* **64** 149-155.

BRÄNNSTRÖM M & SOREMARK R (1962) Penetration of Na22 ions around amalgam restorations with and without cavity varnish *Odontologisk Revy* **13** 331-336.

BROWNE RM, TOBIAS RS, CROMBIE IK & PLANT CG (1983) Bacterial microleakage and pulpal inflammation in experimental cavities *International Endodontic Journal* **16** 147-155.

CALLIS PD & PATERSON AJ (1988) Microleakage of root fillings: thermoplastic injection compared with lateral condensation *Journal of Dentistry* **16** 194-197.

CAMP LR & TODD MJ (1983) The effect of dowel preparation on the apical seal of three common obturation techniques *Journal of Prosthetic Dentistry* **50** 664-666.

CANTWELL JC, CANTWELL KL, CLAYCOMB CK & GATEWOOD DC (1959) Study of marginal seal of dental restorations using C14 labelled fructose. Abstract presented at the 37th general meeting *Journal of Dental Research* **38** *Abstracts of Papers* p755 Abstract M16.

CAUSTON BE, BRADEN M, BROWN D, COMBE EC & OTHERS (1984) Dental materials: 1981 literature review, Part 1 *Journal of Dentistry* **12** 1-28.

CHRISTEN AG & MITCHELL DF (1966) A fluorescent dye method for demonstrating leakage around dental restorations *Journal of Dental Research* **45** 1485-1492.

CIUCCHI B, BOUILLAGUET S & HOLZ J (1990) Proximal adaptation and marginal seal of posterior composite resin restorations placed with direct and indirect techniques *Quintessence International* **21** 663-669.

COX CF, FELTON D & BERGENHOLTZ G (1988) Histopathological response of infected cavities treated with Gluma and Scotchbond dentin bonding agents *American Journal of Dentistry* **1** 189-194.

COX CF, KEALL CL, KEALL HJ, OSTRO E & BERGENHOLTZ G (1987) Biocompatability of surface-sealed dental materials against exposed pulps *Journal of Prosthetic Dentistry* **57** 1-8.

CRIM GA (1987) Evaluation of a dental adhesive and cavosurface angle in preventing marginal leakage *New York State Dental Journal* **53** 22-23.

CRIM GA & CHAPMAN KW (1986) Effect of placement techniques on microleakage of a dentin-bonded composite resin *Quintessence International* **17** 21-24.

CRIM GA, ESPOSITO CJ Jr & CHAPMAN KW (1985a) Microleakage with a dentine-bonding agent *General Dentistry* **33** 232-234.

CRIM GA & GARCÍA-GODOY F (1987) Microleakage: the effect of storage and cycling duration *Journal of Prosthetic Dentistry* **57** 574-576.

CRIM GA & MATTINGLY SL (1981) Evaluation of two methods for assessing marginal leakage *Journal of Prosthetic Dentistry* **45** 160-163.

CRIM GA, SWARTZ ML & PHILLIPS RW (1985b) Comparison of four thermocycling techniques *Journal of Prosthetic Dentistry* **53** 50-53.

CRISP S & WILSON AD (1980) Radioactive tracer technique for monitoring of microleakage: an interim report *Journal of Biomedical Materials Research* **14** 373-382.

DARBYSHIRE PA, MESSER LB & DOUGLAS WH (1988) Microleakage in Class II composite restorations bonded to dentin using thermal and load cycling *Journal of Dental Research* **67** 585-587.

DÁVILA JM, GWINNETT AJ & ROBLES JC (1986) Marginal adaptation of composite resins and dental bonding agents *Journal of Dental Research* **65** *Abstracts of Papers* p 238 Abstract 623.

DÁVILA JM, GWINNETT AJ & ROBLES JC (1988) Marginal adaptation of composite resins and dental bonding agents *Journal of Dentistry for Children* **55** 25-28.

DELIVANIS PD & CHAPMAN KA (1982) Comparison and reliability of techniques for measuring leakage and marginal penetration *Oral Surgery, Oral Medicine, Oral Pathology* **53** 410-416.

DOUGLAS WH, CHEW CJ & CRAIG RG (1980) Neutron activation analysis of microleakage around a hydrophobic composite restorative *Journal of Dental Research* **59** 1507-1510.

DOUGLAS WH, FIELDS RP & FUNDINGSLAND J (1989) A comparison between the microleakage of direct and indirect composite restorative systems *Journal of Dentistry* **17** 184-188.

EAKLE WS (1986) Effect of thermal cycling on fracture strength and microleakage in teeth restored with a bonded composite resin *Dental Materials* **2** 114-117.

EL-DEEB ME (1985) The sealing ability of injection-molded thermoplasticized gutta-percha *Journal of Endodontics* **11** 84-86.

ELLIS JM & BROWN LR (1967) Application of an *in vitro* cariogenic technic to study the development of carious lesions around dental restorations *Journal of Dental Research* **46** 403-408.

FAYYAD MA & BALL PC (1987) Bacterial penetration around amalgam restorations *Journal of Prosthetic Dentistry* **57** 571-574.

FAYYAD MA & SHORTALL AC (1987) Microleakage of dentine-bonded posterior composite restorations *Journal of Dentistry* **15** 67-72.

FERRACANE JL, CONDON JR & MITCHEM JC (1992) Evaluation of subsurface defects created during the finishing of composites *Journal of Dental Research* **71** 1628-1632.

FIASCONARO J & SHERMAN HA (1952) Sealing properties of acrylics *New York State of Dental Journal* **18** 189-198.

FOGEL BB (1977) A comparative study of five materials for use in filling root canal spaces *Oral Surgery, Oral Medicine, Oral Pathology* **43** 284-299.

FRASER CJ (1929) A study of the efficiency of dental fillings *Journal of Dental Research* **9** 507-517.

GALAN J Jr, MONDELLI J & CORADAZZI JL (1976) Marginal leakage of two composite restorative systems *Journal of Dental Research* **55** 74-76.

GLYN JONES JC, GRIEVE AR & HARRINGTON E (1979) A machine for thermal cycling in the investigation of marginal leakage *British Dental Journal* **146** 207-211.

GLYN JONES JC, GRIEVE AR & KIDD EAM (1978) An *in vitro* comparsion of marginal leakage associated with three resin based filling materials *British Dental Journal* **145** 299-302.

GLYN JONES JC, GRIEVE AR & YOUNGSON CC (1988) Marginal leakage associated with three posterior restorative materials *Journal of Dentistry* **16** 130-134.

GOING RE (1964) Cavity liners and dentin treatment *Journal of the American Dental Association* **69** 415-422.

GOING RE (1972) Microleakage around dental restorations: a summarizing review *Journal of the American Dental Association* **84** 1349-1357.

GOING RE, MASSLER M & DUTE HL (1960a) Marginal penetration of dental restorations by different radioactive isotopes *Journal of Dental Research* **39** 273-284.

GOING RE, MASSLER M & DUTE HL (1960b) Marginal penetrations of dental restorations as studied by crystal violet dye and I131 *Journal of the American Dental Assocation* **61** 285-300.

GOING RE, MYERS HM & PRUSSIN SG (1968) Quantitative method for studying microleakage in vivo and in vitro *Journal of Dental Research* **47** 1128-1132.

GONZÁLEZ MA (1992) Comparison of four microleakage tests MSD Thesis, University of Indiana, Indianapolis, IN.

GOTTLIEB EW, RETIEF DH & BRADLEY EL (1985) Microleakage of conventional and high-copper amalgam restorations *Journal of Prosthetic Dentistry* **53** 355-361.

GRANATH LE & SVENSSON A (1970) Studies of microleakage with restorative materials. A new air pressure method *Scandinavian Journal of Dental Research* **78** 353-366.

GRIEVE AR (1973) The occurrence of secondary caries-like lesions *in vitro*. The effect of a fluoride cavity liner and a cavity varnish *British Dental Journal* **134** 530-536.

GRIEVE AR & PARKHOLM JDO (1973) The sealing properties of root filling cements. Further studies *British Dental Journal* **135** 327-331.

GRIEVE AR, SAUNDERS WP & ALANI AH (1993) The effects of dentine bonding agents on marginal leakage of composite restorations—long-term studies *Journal of Oral Rehabilitation* **20** 11-18.

GUZMÁN HJ, SWARTZ ML & PHILLIPS RW (1969) Marginal leakage of dental restorations subjected to thermal stress *Journal of Prosthetic Dentistry* **21** 166-175.

HALS E & KVINNSLAND I (1974) Structure of experimental in vitro and in vivo lesions around composite (Addent XV) fillings *Scandinavian Journal of Dental Research* **82** 517-526.

HALS E & NERNAES A (1971) A histopathology of in vitro caries developing around silver amalgam fillings *Caries Research* **5** 58-77.

HAMMESFAHR PD, HUANG CT & SHAFFER SE (1987) Microleakage and bond strength of resin restorations with various bonding agents *Dental Materials* **3** 194-199.

HARPER WE (1912) The character of the adaptation amalgam to the walls of cavities attained by present methods of instrumentation and the use of the best known alloys, as indicated by the air pressure test *Dental Review* **26** 1179-1198.

HARPER RH, SCHNELL RJ, SWARTZ ML & PHILLIPS RW (1980) *In vivo* measurements of thermal diffusion through restorations of various materials *Journal of Prosthetic Dentistry* **43** 180-185.

HATTAB FN, MOK NYC & AGNEW EC (1989) Artificially formed carieslike lesions around restorative materials *Journal of the American Dental Association* **118** 193-197.

HEMBREE JH & ANDREWS JT (1978) Microleakage of several class V anterior restorative materials: a laboratory study *Journal of the American Dental Association* **97** 179-183.

HIRSCH L & WEINREB MM (1958) Marginal fit of direct acrylic restorations *Journal of the American Dental Association* **56** 13-21.

HOLTAN JR, NYSTROM GP, DOUGLAS WH & PHELPS RA 2nd (1990) Microleakage and marginal placement of a glass ionomer liner *Quintessence International* **21** 117-122.

JACOBSEN EL, BERY PF & BEGOLE EA (1985) The effectiveness of apical dentin plugs in sealing endodontically treated teeth *Journal of Endodontics* **11** 289-293.

JACOBSEN PH & VON FRAUNHOFER JA (1975) Assessment of microleakage using a conductimetic technique *Journal of Dental Research* **54** 41-48.

JENSEN ME & CHAN DCN (1985) Polymerization shrinkage and microleakage In *Posterior Composite Resin Dental Restorative Materials* eds Vanherle G & Smith DC pp 243-262 St Paul, MN: 3M Dental Products.

JORGENSEN KD (1970) Some observations on silicate cement *Acta Odontologica Scandinavica* **28** 117-127.

JORGENSEN KD, MATONO R & SHIMOKOBE H (1976) Deformation of cavities and resin fillings in loaded teeth *Scandinavian Journal of Dental Research* **84** 46-50.

KANCA J 3rd (1989) The effect on microleakage of four dentin-enamel bonding systems *Quintessence International* **20** 359-361.

KIDD EAM (1976a) Microleakage: a review *Journal of Dentistry* **4** 199-206.

KIDD EAM (1976b) Microleakage in relation to amalgam and composite restoration. A laboratory study *British Dental Journal* **141** 305-310.

KIDD EAM (1983) The early carious lesion in enamel In *The Prevention of Dental Disease* ed Murray JJ Oxford, England: Oxford University Press pp 192-217.

KIDD EAM, HARRINGTON E & GRIEVE AR (1978) The cavity sealing ability of composite restorations subjected to thermal stress *Journal of Oral Rehabilitation* **5** 279-286.

KING RFH (1874) Blue ink as a test for water-tight fillings *British Journal of Dental Science* **17** 423-425.

KORNFIELD B (1953) Study of clinical behaviour of resins in operative dentistry *Journal of Dental Research* **32** *Abstracts of Papers* p 714 Abstract 208.

KREJCI I, KUSTER M & LUTZ F (1993) Influence of dentinal fluid and stress on marginal adaptation of resin composites *Journal of Dental Research* **72** 490-494.

KWAN EH & HARRINGTON GW (1981) The effect of immediate post preparation on apical seal *Journal of Endodontics* **7** 325-329.

LIM KC (1987) The microleakage of a glass ionomer cement using two methods of moisture protection *Quintessence International* **18** 835-839.

MANDRAS RS, RETIEF DH & RUSSELL CM (1991) The effects of thermal and occlusal stresses on the microleakage of the Scotchbond 2 dentinal bonding system *Dental Materials* **7** 63-67.

MATHIS RS, DEWALD JP, MOODY CR & FERRACANE JL (1990) Marginal leakage in class V composite restorations with glass ionomer liners in vitro *Journal of Prosthetic Dentistry* **63** 522-525.

McWILLIAM EA (1967) Silver in Photography In *Silver: Economics, Metallurgy, and Use*, eds Butts A & Coxe CD Princeton, New Jersey: Van Norstrand, pp 200-217.

MEJÀRE B, MEJÀRE I & EDWARDSSON S (1979) Bacteria beneath composite restorations—a culturing and histobacteriological study *Acta Odontologica Scandinavica* **37** 267-275.

MEYER JM, DENNISON JB & CRAIG RG (1974) Improved method of neutron activation analysis for microleakage studies *Journal of Dental Research* **53** 356-363.

MICHANOWICZ A & CZONSTKOWSKY M (1984) Sealing properties of an injection-thermoplasticized low-temperature (70 °C) Gutta-percha: a preliminary study *Journal of Endodontics* **10** 563-566.

MOLLER B, SCHRODER U & GRANATH L (1983) Effect of IRM on human dental pulp *Scandinavian Journal of Dental Research* **91** 281-287.

MOMOI Y, IWASE H, NAKANO Y, KOHNO A, ASANUMA A & YANAGISAWA A (1990) Gradual increases in marginal leakage of resin composite restorations with thermal stress *Journal of Dental Research* **69** 1659-1663.

MOORE DH & VANN WF (1988) The effect of a cavosurface bevel on microleakage in posterior composite restorations *Journal of Prosthetic Dentistry* **59** 21-24.

MORLEY F & STOCKWELL PB (1977) A simple thermal cycling device for testing dental materials *Journal of Dentistry* **5** 39-41.

MORTENSEN DW, BOUCHER NE & RYGE G (1965) A method of testing for marginal leakage of dental restorations with bacteria *Journal of Dental Research* **44** 58-63.

MUHLEMANN HR (1960) Experimental modifications of the enamel surface *Helvetica Odontologica Acta* **4** 5-24.

MUNKSGAARD EC & IRIE M (1988) Effect of load-cycling on bond between composite fillings and dentin established by Gluma and various resins *Scandinavian Journal of Dental Research* **96** 579-583.

MUNKSGAARD EC, ITOH K & JORGENSEN KD (1985) Dentin-polymer bond in resin fillings tested in vitro by thermo- and load-cycling *Journal of Dental Research* **64** 144-146.

NELSEN RJ, WOLCOTT RB & PAFFENBARGER GC (1952) Fluid exchange at the margins of dental restorations *Journal of the American Dental Association* **44** 288-295.

O'NEILL KJ, PITTS DL & HARRINGTON GW (1983) Evaluation of the apical seal produced by the McSpadden compactor and the lateral condensation with a chloroform-softened primary cone *Journal of Endodontics* **9** 190-197.

PATERSON RC (1976) Bacterial contamination and the exposed pulp *British Dental Journal* **140** 231-236.

PETERSON EA 2nd, PHILLIPS RW & SWARTZ ML (1966) A comparison of the physical properties of four restorative resins *Journal of the American Dental Association* **73** 1324-1336.

PICKARD HM & GAYFORD JL (1965) Leakage at the margins of amalgam restorations *British Dental Journal* **119** 69-77.

POWIS DR, PROSSER HJ, SHORTALL AC & WILSON AD (1988) Long-term monitoring of microleakage of composites. Part I: Radiochemical diffusion technique *Journal of Prosthetic Dentistry* **60** 304-307.

PRATI C, TAO L, SIMPSON M & PASHLEY DH (1994) Permeability and microleakage of Class II resin composite restorations *Journal of Dentistry* **22** 49-56.

PUCKETT AD, FITCHIE JG, BENNETT B & HEMBREE JH (1995) Microleakage and thermal properties of hybrid ionomer restoratives *Quintessence International* **26** 583-585.

RETIEF DH (1989) Dentin bonding agents: a deterrent to microleakage? In *Quality Evaluation of Dental Restorations* Proceedings of the International Symposium on Criteria for Placement and Replacement of Dental Restorations: 19-21 October 1987, Lake Buena Vista, FL, Anusavice KJ ed Chicago: Quintessence Publishing pp 185-195.

ROSS EE, LAI J, WILLIAMS NB & FALCETTI JP (1955) The screening of materials for adhesion to human tooth structure *Journal of Dental Research* **34** 577-588.

ROSSOMANDO KJ & WENDT SL (1995) Thermocycling and dwell times in microleakage evaluation for bonded restorations *Dental Materials* **11** 47-51.

SANDERS SH & DOOLEY RJ (1974) A comparative study of polycarboxylate cement as a root-canal sealer utilizing roughened and non-roughened silver points *Oral Surgery, Oral Medicine, Oral Pathology* **37** 629-640.

SAUNDERS WP, GRIEVE AR, RUSSELL EM & ALANI AH (1990) The effects of dentin bonding agents on marginal leakage of composite restorations *Journal of Oral Rehabilitation* **17** 519-527.

SAUNDERS EM, SAUNDERS WP & RASHID MY (1991) The effect of post space preparation on the apical seal of root fillings using chemically adhesive materials *International Endodontic Journal* **24** 51-57.

SELTZER S (1955) The penetration of microorganisms between the tooth and direct resin fillings *Journal of the American Dental Association* **51** 560-566.

SHORTALL AC (1982) Microleakage, marginal adaptation and composite resin restorations *British Dental Journal* **153** 223-227.

SILVERSTONE LM (1968) The surface zone in caries and in caries-like lesions produced in vitro *British Dental Journal* **125** 145-157.

SILVERSTONE LM & others, eds (1981) *Dental Caries: Etiology, Pathology and Prevention* London: Macmillan pp 133-161.

SÖDERHOLM KJM (1991) Correlation of in vivo and in vitro performance of adhesive restorative materials: report of the ASC MD156 Task Group on Test Methods for the Adhesion of Restorative Materials *Dental Materials* **7** 74-83.

SPANGBERG LS, ACIERNO TG & YONGBUM-CHA B (1989) Influence of entrapped air on the accuracy of leakage studies using dye penetration methods *Journal of Endodontics* **15** 548-551.

TAGGER M, TAMSE A & KATZ A (1983) Efficacy of apical seal of Engine Plugger condensed root canal fillings—leakage to dyes *Oral Surgery, Oral Medicine, Oral Pathology* **56** 641-646.

TAYLOR MJ & LYNCH EL (1992) Microleakage *Journal of Dentistry* **20** 3-10.

TOMES C (1875) Paper to Odontological Society of Great Britain *British Journal of Dental Science* **18** 239-240.

TSUCHIYA T, ZIDÁN O & GÓMEZ-MARÍN O (1986) Marginal gaps in Class V cavities: comparative study of dentinal bonding agents and application techniques *Journal of Dental Research* **65** *Abstracts of Papers* p 765 Abstract 353.

VAN DIJKEN JWV & HORSTED BP (1989) The effects of Gluma and Gluma/Scotchbond on in vivo marginal adaptation of a composite resin to dentin *Dental Materials* **5** 165-167.

VON BARTHELD F (1961) Membrane phenomena in carious dissolution of the teeth *Archives of Oral Biology* **6** 284-303.

WELSH EL & HEMBREE JH Jr (1985) Microleakage at the gingival wall with four Class V anterior restorative materials *Journal of Prosthetic Dentistry* **54** 370-372.

WENDT SL, McINNES PM & DICKINSON GL (1992) The effect of thermocycling in microleakage analysis *Dental Materials* **8** 181-184.

WU W, COBB E, DERMANN K & RUPP NW (1983) Detecting margin leakage of dental composite restorations *Journal of Biomedical Material Research* **17** 37-43.

YOUNGSON CC, GREY NJA & GLYN JONES J (1990) In vitro marginal microleakage: examination of measurements used in assessment *Journal of Dentistry* **18** 142-146.

ZANDER HA (1959) Pulp response to restorative materials *Journal of the American Dental Association* **59** 911-914.

ZIDÁN O, GÓMEZ-MARÍN O & TSUCHIYA T (1987) A comparative study of the effects of dentinal bonding agents and application techniques on marginal gaps in Class V cavities *Journal of Dental Research* **66** 716-721.

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CLINICAL ARTICLE

Modification of a Vinyl Glove into a Dental Dam for Patients Sensitive to Latex Rubber

E J IRELAND

SUMMARY

Dental products containing latex rubber such as rubber dams, gloves, polishing points, prophy cups, blood pressure cuffs, orthodontic elastics, mouth props, intubation tubes, and anesthetic masks have the potential to cause allergic reactions. The clinician should try to identify patients at high risk for latex sensitivity by taking a careful history and, where necessary, using alternative products. This paper describes how a vinyl glove can be easily modified to provide an effective dental dam in patients allergic to latex rubber.

INTRODUCTION

The adoption of universal precautions by dental health care providers, especially through the use of latex rubber gloves, has increased the exposure of patients and workers to proteins found in latex rubber. These proteins have the potential to cause allergic reactions in susceptible individuals, and the U S Food and Drug Administration (1991) issued a medical alert in response to the increasing number of reported cases of latex-related allergic reactions.

Louisiana State University School of Dentistry, Department of Operative Dentistry, 1100 Florida Avenue, New Orleans, LA 70119

Edward J Ireland, DDS, MEd, professor

Additionally, the Council on Dental Materials, Instruments and Equipment (1993) issued warnings and guidelines to dentists regarding latex reactions. In a 1992 study, Berky, Luciano, and James reported a high incidence among dental care providers, and Rankin, Jones, and Rees (1993) reported a 3.7% incidence of latex allergy in an adult dental population and a 15% incidence in dental health care workers. Safadi and others (1996) supported these findings by showing a prevalence rate of 12% among dental professionals. In another report, Rankin and others (1994) warned that patients most likely to have adverse reactions to latex were persons with spina bifida, those who have undergone repeated surgeries that involved extensive contact with rubber tubes, postsurgical drains, or other rubber products. Also at high risk were atopic patients who have histories of other types of allergies. In a similar study, Snyder and Settle (1994) also reported a high incidence (18-40%) of latex sensitivity in spina bifida patients.

Dental health care workers should be aware of the symptoms of rubber protein reactivity, which range from simple irritations to potentially fatal allergic reactions. Rankin and others (1994) reported possible symptoms, which included dermatitis; urticaria; rhinitis; conjunctivitis; swollen lips, mucosa, or eyelids; asthma; dizziness; light-headedness; flushing; tachycardia; sweating; difficulty breathing; hypotension; and anaphylactic shock. March (1988); Smart, Macleod, and Lawrence (1992); and Berky and others (1992) have all reported allergic reactions in dental patients from contact with latex gloves. Blinkhorn and

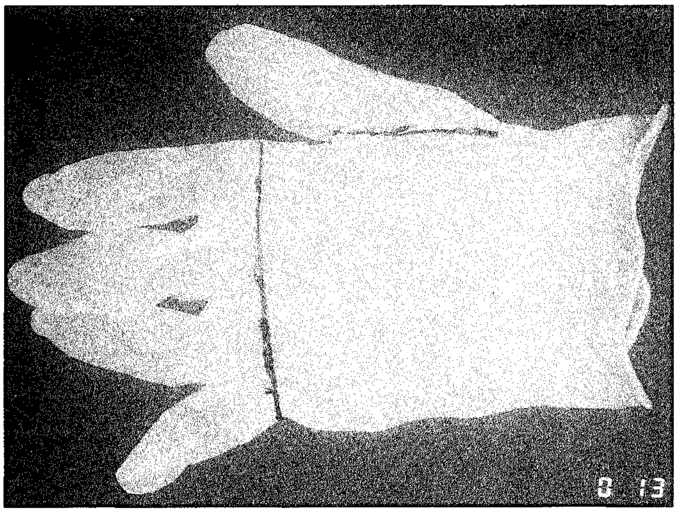

Figure 1. *Black lines show where glove is to be cut.*

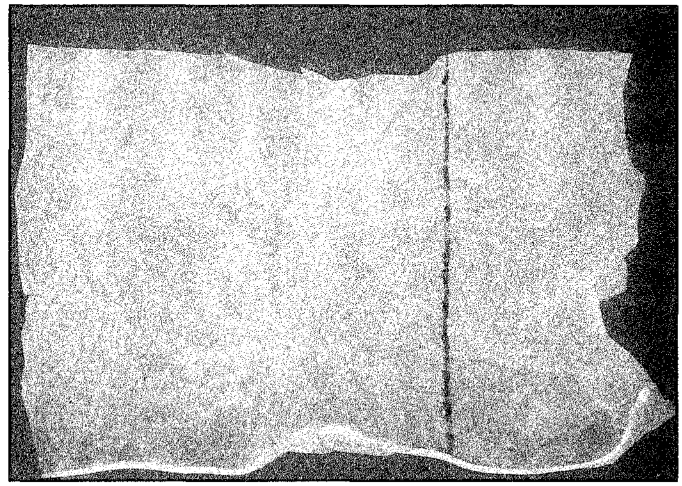

Figure 2. *The opened glove is cut again along the black line to produce an appropriate size dam.*

Leggate (1984) reported a case of angioneurotic edema as a reaction to placement of a rubber dam in a sensitive patient.

The only proper treatment for latex allergy is avoidance, and such patients should be treated using latex-free materials in contact with their skin or mucosa. Setlock, Cotter, and Rosner (1993) reported that premedication with antihistamines or corticosteroids does not protect a sensitized person from having a life-threatening reaction to a latex product.

The placement of a dental dam on such patients requires some innovation. Gallin (1993) suggested using the material from a vinyl headrest cover to fabricate a dental dam in latex-sensitive patients. This method is best limited to isolating a single tooth, because the material permanently deforms when stretched. It is also inconvenient that a heated instrument was recommended to make holes in the material instead of a punch. Since the isolation of a quadrant or more is often necessary, the purpose of this paper is to describe an easy method for converting a vinyl glove into a satisfactory dam for the isolation of multiple teeth in patients allergic to latex.

TECHNIQUE

A large size vinyl glove (Baxter Healthcare Corporation, Valencia, CA 91355-8900) is laid out flat and modified by cutting away the four fingers and thumb (Figure 1). A cut is also made through the cuff of the glove beginning below the thumb to open up the glove. Once the glove is opened up, the vinyl is laid out and the excess material is trimmed away so that the dam is a suitable size of about 5 1/2 x 5 1/2 inches (14 x 14 cm) (Figure 2). The material is rinsed off to remove any residual powder. The vinyl dam is very durable, but it lacks the elasticity of its latex counterpart, so some modifications must be made in punching the holes. The hole that is to receive the clamp must be punched larger than usual to allow it to stretch when the clamp is expanded over the tooth. The easiest method is to employ an ordinary business office paper punch (Gem Paper Punch 1/4-inch round, McGill Inc, Marengo, IL 66052) to create this hole (Figure 3). If this is not available, a regular dam punch set to its largest size can be used to punch the hole for the clamp, and four overlapping holes are

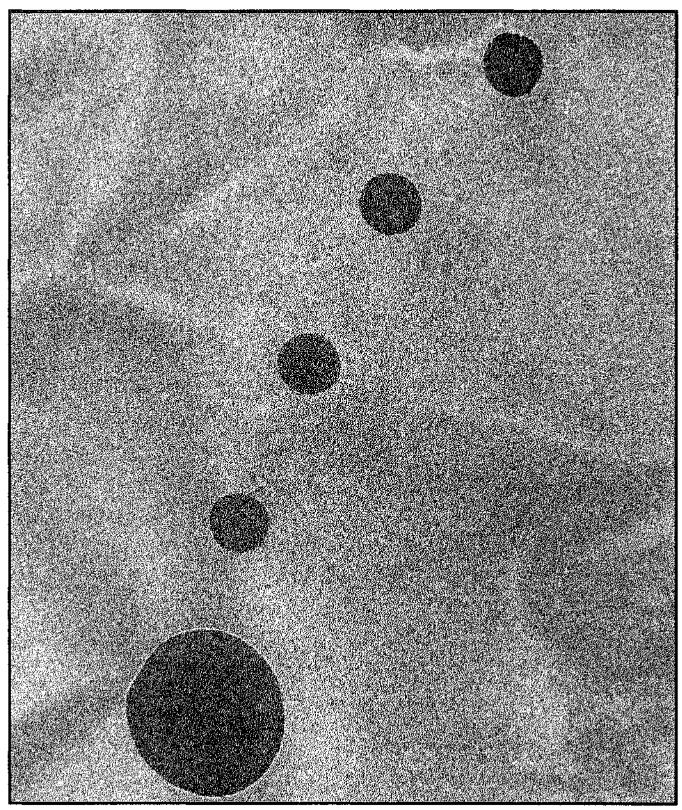

Figure 3. *The hole accommodating the clamp is made with a paper punch.*

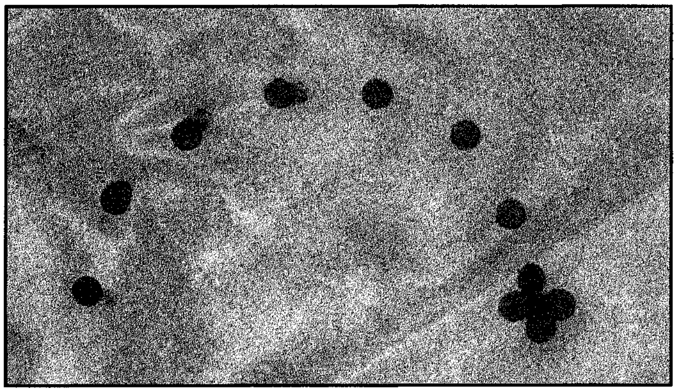

Figure 4. *Alternatively, a large opening can be made by punching one center hole and four circumferential holes.*

made circumferentially to allow the dam to stretch without tearing (Figure 4). Holes to isolate additional teeth may be punched one size larger and 0.5 mm farther apart than usual to compensate for the decreased elasticity of the vinyl (Figure 5). The vinyl dam is then applied in the usual manner (Figure 6). To save time, this vinyl material can be cut from gloves ahead of time but should not be stored in proximity to latex dam material or handled by operators wearing latex gloves.

DISCUSSION

Prior to treatment, a careful medical history should detail any known allergies, occupational exposure to latex, and any surgeries in childhood. Additionally, the patients should be asked if they have ever had a rash or itching after inflating a balloon or after contact with rubber swimming caps or condoms.

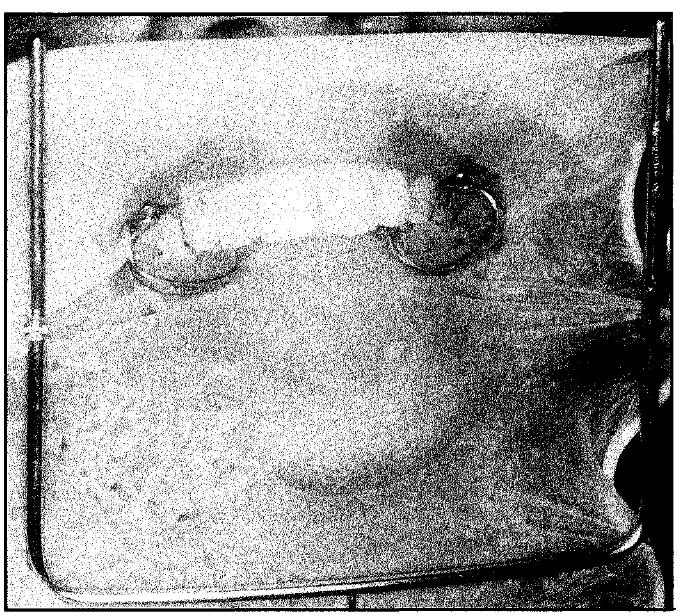

Figure 6. *Vinyl dam in place*

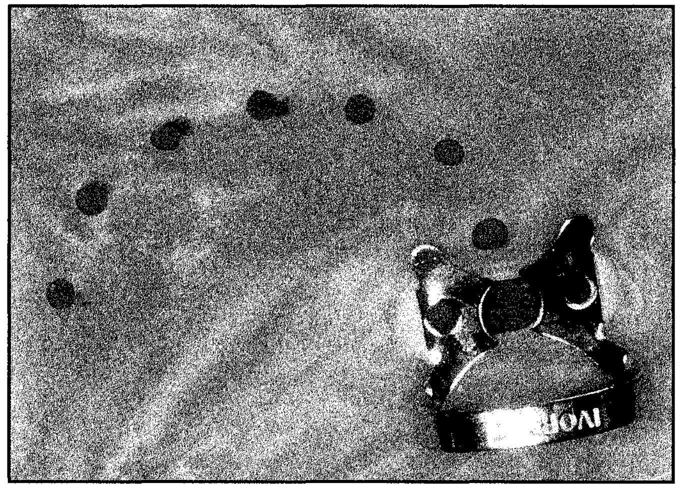

Figure 5. *Remaining holes may be punched one size larger and 0.5 mm farther apart than usual.*

Besides latex gloves and dam material, there are other rubber items commonly found in the dental office that may also pose a hazard to patients at risk. Included in this list are rubber polishing points and wheels, prophy cups, orthodontic elastics, blood pressure cuffs, mouth props, intubation tubes, and anesthesia masks. Snyder and Settle (1994) reported that gloves labeled "hypoallergenic" merely have a reduction in processing chemicals that are irritating to the skin but are not suitable for use in patients sensitive to rubber proteins.

Once identified, sensitive patients should be treated by strictly avoiding contact with these and any other latex products. Safadi and others (1996) even recommend scheduling patients with latex allergy in the first appointment slot of the day to minimize their inadvertent exposure to airborne latex particles that can be carried by the powder applied to latex gloves. Finally, the clinician should be alert to the signs and symptoms of allergic reactions and be prepared to provide emergency supportive care if such symptoms arise.

CONCLUSIONS

The dental health care provider should be aware that 3.7% of one dental population reported sensitivity or allergic reactions to latex rubber products (Rankin & others, 1993) and that there have been increasing reports of latex-related sensitivity. Patients who are dental health care providers themselves, spina bifida patients, and others who fall into high-risk groups exhibit latex-related allergies far above that found in the general population. Nonlatex products such as vinyl gloves and dental dams made from these gloves offer an alternative method for treating such patients.

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References

BERKY ZT, LUCIANO WJ & JAMES WD (1992) Latex glove allergy. A survey of the US Army Dental Corps *Journal of the American Medical Association* **268** 2695-2697.

BLINKHORN AS & LEGGATE EM (1984) An allergic reaction to rubber dam *British Dental Journal* **156** 402-403.

COUNCIL ON DENTAL MATERIALS, INSTRUMENTS AND EQUIPMENT; COUNCIL ON DENTAL THERAPEUTICS; COUNCIL ON DENTAL RESEARCH (1993) Reactions to latex in health care setting: dealing with patient/worker concerns *Journal of the American Dental Association* **124** 91-92.

GALLIN DM (1993) Use of a headrest cover to isolate teeth in patients allergic to latex *New York State Dental Journal* **59** 46-47.

MARCH PJ (1988) An allergic reaction to latex rubber gloves *Journal of the American Dental Association* **117** 590-591.

RANKIN KV, JONES DL & REES TD (1993) Incidence of latex reactions in an adult dental population *Journal of Dental Research* **72** *Abstracts of Papers* p 202 Abstract 786.

RANKIN KV, SEALE NS, JONES DL & REES TD (1994) Reported latex sensitivity in pediatric dental patients from hospital- and dental school-based populations *Pediatric Dentistry* **16** 117-120.

SAFADI GS, SAFADI TJ, TEREZHALMY GT, TAYLOR JS, BATTISTO JR & MELTON AL Jr (1996) Latex hypersensitivity: its prevalence among dental professionals *Journal of the American Dental Association* **127** 83-88.

SETLOCK MA, COTTER TP & ROSNER D (1993) Latex allergy: failure of prophylaxis to prevent severe reaction *Anesthesia and Analgesia* **76** 650-652.

SMART ER, MACLEOD RI & LAWRENCE CM (1992) Allergic reactions to rubber gloves in dental patients: report of three cases *British Dental Journal* **172** 445-447.

SNYDER HA & SETTLE S (1994) The rise in latex allergy: implications for the dentist *Journal of the American Dental Association* **125** 1089-1097.

U S DEPARTMENT OF HEALTH, EDUCATION AND WELFARE, FOOD AND DRUG ADMINISTRATION (1991) Medical Alert issued March 29, Rockville, MD.

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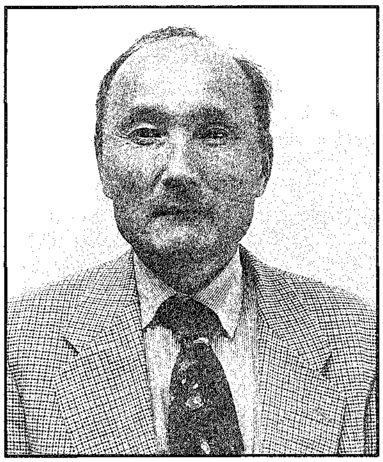

Nubuo Nakabayashi

The Hollenback Memorial Prize is awarded in memory of the late Dr George M Hollenback for his many years of distinguished research and leadership benefiting the quality of dental practice. This year's recipient, Dr Nubuo Nakabayashi, is acknowledged internationally as an author and leader in dental materials research.

Dr Nakabayashi received his PhD in 1964, with a thesis entitled "Preparation of Reactive Polymers." Today he is a professor and the director of the Institute for Medical and Dental Engineering of the Tokyo Medical and Dental University, Tokyo, Japan.

Dr Nakabayashi has published over 230 scientific papers and 120 review articles. He is the co-author of 25 textbooks. Besides his work in dental materials, he has conducted extensive work on blood-compatible polymers, adhesive membranes, and artificial organs. Dr Nakabayashi has been given many awards for his research over the years, including the Wilmer Souder Award, as well as awards from the Japanese Society for Biomaterials and the Japanese Society for Dental Materials and Devices. His work on dental adhesives led to the identification of the hybrid layer and its crucial function in bonding and to the development of commercial dentin adhesive systems. In turn this research has given the profession many new treatment options, allowing us to provide our patients with greater esthetic and higher-quality restorative dentistry.

Although it is unusual to conduct research in different disciplines, Dr Nakabayashi has successfully

crossed the professional lines, and dentistry is most grateful for his remarkable dedication and significant contributions. The Academy is honored to present the 1997 Hollenback Memorial Prize to Dr Nubuo Nakabayashi.

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