OPERATIVE DENTISTRY

january-february 1999 • volume 24 • number 1 • 1-64

(ISSN 0361-7734)

OPERATIVE DENTISTRY

JANUARY-FEBRUARY 1999 • VOLUME 24 • NUMBER 1 • 1-64

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

OPERATIVE DENTISTRY (ISSN0361-7734) is published bimonthly for $60.00 per year in the USA (all other countries $70.00 per year) by University of Washington, Operative Dentistry, Health Sciences Bldg, Rm D-775, Seattle, WA 98195-7457. Periodicals postage paid at Seattle, WA, and additional mailing offices. **POSTMASTER:** Send address changes to: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

Subscriptions
Yearly subscription in USA is $60.00; all other countries, $70.00 (sent by air where appropriate); dental students, $25.00 in USA and Canada; other countries, $34.00; single copy in USA and Canada, $14.00; other countries, $17.00. For back issue prices, write the journal office for quotations. Make remittances payable (in US dollars only) to OPERATIVE DENTISTRY and send to the above address. Credit card payment (Visa, MasterCard, or JCB--Japanese equivalent) is also accepted by providing card type, card number, expiration date, and name as it appears on the card.

Contributions
Contributors should study the instructions for their guidance printed inside the back cover and should follow them carefully.

Permission
For permission to reproduce material from *Operative Dentistry* please apply to Operative Dentistry at the above address.

The views expressed in *Operative Dentistry* do not necessarily represent those of the Academies or of the Editors.

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/

Subscription Manager: Judy Valela

©OPERATIVE DENTISTRY, 1999, 24, 1

EDITORIAL

Diversity: A Blessing or a Curse?

Basic dental education is becoming more variable among dental schools than ever before. Some schools still cling to traditional concepts of teaching, while others are exploring or have explored "self-paced" learning, the team approach to patient treatment, problem-based learning from the start of dental school, and/or comprehensive patient treatment without the structure of clinical requirements. Certain schools no longer teach partial coverage restorations. Other schools are graduating students whose only experience preparing fixed bridges occurred in preclinic lab. At least one school graduates students with only five or six units of fixed bridgework completed during their clinical education. Schools have also looked seriously at giving dual medical-dental degrees. A new twist in education is being introduced where dental students take the same courses as medical students for their first two years except for a 3-hour period each week for dental courses. Preclinic lab courses necessary for preparing those students to treat patients will, by necessity, be integrated with clinical teaching during the last two years of dental school. This situation sounds like on-the-job training and may be the first step towards the closing of another dental school.

In 1998, in an effort to work with this diversity, the Accreditation Standards for Dental Education Programs was modified to enable schools to establish their own, individual educational outcomes. Each school will be required to develop assessment methods for measuring only those outcomes they deem necessary for graduation. These standards state that "graduates must be competent in providing oral health care within the scope of general dentistry, as defined by the school." With such ambiguous guidelines over what students should be taught, dental education is truly at the crossroads without direction and may be going down the wrong road. From now on, when the accreditation team visits a dental school, the emphasis will be on whether that school is achieving the goals it set for itself. If a goal is difficult to measure or reach by students, you can be sure that the school will have eliminated it from its educational outcomes long before the inspection team arrives. Competency will be defined individually by each school. If fixed bridges are difficult to find for all students, that criteria will not be included. It may come down to outcomes as general as treating a certain number of patients, which could easily be measured. There will be no reason to have commonality among schools. Every dental school will be doing its own thing. Excellence, or reaching for higher goals, is still being presented as the ultimate goal for dental education, but is really just smoke and mirrors. These new guidelines offer little incentive to establish higher goals for students to push them towards excellence. The Commission realized this situation, so included a statement in its introduction encouraging institutions to extend the scope of their curriculum "to include instruction beyond the scope of the minimum requirements." Those of us who have been involved with undergraduate education know that students strive to accomplish requirements at whatever level is set. Few strive for a higher level. Therefore, if the education outcomes are set at a minimally acceptable level to ensure passing accreditation, that will be the level which the majority of students will strive to achieve and will be considered excellence by them. From this editor's perspective, the intensifying diversity in dental education is a dangerous situation. Let's all hope that our administrators and national leaders don't get so hung up on doing their own thing that they forget that the new dentist needs to know and strive for excellence in order to be a viable part of society. Unfortunately, only the future will be able to tell us the rest of the story: Is diversity in dental education a blessing or a curse?

RICHARD B McCOY
Editor

©OPERATIVE DENTISTRY, 1999, 24, 2-8

ORIGINAL ARTICLES

Mechanical Properties of Compomer Restorative Materials

I H EL-KALLA • F GARCÍA-GODOY

Clinical Relevance
Results of compressive strength, flexural strength, and microhardness testing revealed the following ranking of tested materials: resin-modified glass ionomer (Vitremer) < compomers (Compoglass, Dyract, and Hytac) < resin composite (Z100).

SUMMARY

The purpose of this study was to measure the compressive strength, flexural strength, microhardness, and surface roughness of three compomers (Compoglass, Dyract, and Hytac) and compare the values to the ones obtained for a resin-modified glass-ionomer cement (Vitremer) and a resin composite (Z100). All materials were handled according to the manufacturers' instructions. There was a significant difference ($P < 0.01$) among Vitremer, Hytac and Z100 composite with regard to yield strength. Vitremer values were lower than for Hytac, which were lower than for Z100. The yield strength values for Compoglass and Dyract were significantly lower than for Hytac and Z100 composite and significantly higher than for Vitremer ($P < 0.01$). There was no significant difference in the strain at yield among Vitremer, Hytac, and Z100, but their values were significantly higher than for Compoglass and Dyract ($P < 0.01$). The flexural strength data displayed a significant difference between Vitremer and Hytac ($P < 0.05$). Z100 was significantly stronger than the other products tested. The values of strain at break for Vitremer, Hytac, and Z100 were significantly lower than for Compoglass and Dyract ($P < 0.01$). The compressive strength results showed significantly higher values for Dyract, Compoglass, and Hytac than for Vitremer ($P < 0.01$). Z100 displayed higher values than the other products tested ($P < 0.01$). Hytac strength was significantly higher than for Dyract ($P < 0.01$). The microhardness of Compoglass and Dyract was not significantly different ($P < 0.05$). Hytac displayed microhardness values higher than for Vitremer, Compoglass, and Dyract ($P < 0.01$). However, all products tested showed values significantly lower than for Z100 ($P < 0.01$). The surface roughness values for Compoglass, Dyract, Hytac, and Z100 were not significantly different. Vitremer displayed a significantly higher value than Dyract, Hytac, and Z100 ($P < 0.05$).

University of Texas Health Science Center at San Antonio, Department of Restorative Dentistry, 7703 Floyd Curl Drive, San Antonio, TX 78284-7888

Ibrahim H El-Kalla, BChD, MS, DDSc, associate professor, Mansoura University, Department of Pediatric Dentistry, Mansoura, Egypt

Franklin García-Godoy, DDS, MS, professor and director, Clinical Materials Research

INTRODUCTION

Glass-ionomer cements have gained widespread acceptance as dental restorative materials, especially for cervical erosion/abrasion lesions and restoration of primary teeth (Knibbs, 1987; Van de Voorde, Gerdts & Murchison, 1988; Wilson & McLean, 1988; Geiger, 1990; Croll, 1992; Donly, Kanellis & Segura, 1997; Qvist and others, 1997; Abdalla & Alhadainy, 1997; Abdalla, Alhadainy & García-Godoy, 1997). This wide acceptance is mainly due to their fluoride release (Forsten, 1977; DeSchepper & others, 1990; Swift, Bailey & Hansen, 1990; García-Godoy & Chan, 1991; García-Godoy & others, 1990) and their antimicrobial action, especially against *Streptococcus mutans* (McComb & Erikson, 1987; Loyola-Rodríguez, García-Godoy & Lindquist, 1994). Glass-ionomer cements have also shown reduced microleakage when used both as liners and restorative materials (García-Godoy, 1988a,b; García-Godoy & Malone, 1988; García-Godoy, Marshall & Mount, 1988a; García-Godoy & others, 1988b; Manders, García-Godoy & Barnwell, 1990; Hallett & García-Godoy, 1993).

Fluoride release from dental materials is considered an adjunctive property to reduce secondary caries around restorations (Hicks, Flaitz & Silverstone, 1986; García-Godoy & Jensen, 1990; Griffin, Donly & Erickson, 1992; Marcushamer, García-Godoy & Chan, 1993; Souto & Donly, 1994; Ten Cate & Van Duinen, 1995; Segua, Donly & Stratmann, 1997).

New restorative materials that combine the chemistry of both glass-ionomer cement and light-activated resin composite have been recently developed to improve toughness of conventional glass-ionomer cement materials, while retaining their favorable physical properties. McLean, Nicholson, and Wilson (1994) described two additional categories of materials to help classify the similarities and differences in currently available light-cured glass-ionomer cement products. In addition to the traditional glass-ionomer cements, they recommended that one category be referred to as resin-modified glass ionomers, which have a significant acid-base reaction in the setting reaction and will set without exposure to visible light. Materials that do not have an acid-base reaction and will not set unless exposed to a visible light source are referred to as polyacid-modified resin composites (compomers).

Compomer materials have gained acceptance among practitioners due to their handling properties, esthetics, and fluoride release. They are used for restoring primary teeth and nonstress-bearing cavities in permanent teeth (Abdalla & others, 1997; García-Godoy, 1997; Peters, Roeters & Frankenmolen, 1996; van Dijken, 1996).

Because compomers have properties of both glass ionomers and resin composites, the purpose of this study was to compare mechanical properties of compomers, a resin-modified glass ionomer, and a resin composite.

Table 1. Materials Used

Material	Code	Batch #	Composition	Manufacturer
Vitremer	Vitremer	551 546	Powder: fluoroaluminosilicate glass Liquid: light-sensitive modified polyalkenoic acid	3M Dental Products, St Paul, MN 55144
Compoglass	Compoglass	340-24	Propoxylated BIS-GMA, urethane dimethacrylate, tetraethylene glycol dimethacrylate, cycloaliphatic dicarboxylic acid dimethacrylate, silanized spheroidal mixed oxide, yterbium trifluoride, silanized Ba-fluorosilicate glass	Ivoclar-Vivadent, Amherst, NY 14228
Dyract	Dyract	9510154	Fluorosilicate glass, acidic polymerizable monomers and other light-curing polymers	Dentsply/Caulk, Milford, DE 19963
Hytac Aplitip	Hytac	009	Bis (meth) acrylates, Ca-Al-fluoroglass, silicic acid, ytrium fluoride, complex fluoride, amine, camphoroquinone	ESPE, Seefeld/Oberbay, Germany
Z100	Z100	5905	Zircona/silica filler, BIS-GMA, TEGDMA resin	3M Dental Products

METHODS AND MATERIALS

Five restorative materials were tested in this study (Table 1). These materials included three compomers, a resin-modified glass ionomer, and a resin composite. The resin-modified glass ionomer and the resin composite were used as controls. Handling of the materials was done according to the manufacturers' instructions. The materials were cured for four 40-second periods with an Optilux 400 (Demetron Research Corp, Danbury, CT 06810) curing light. The light-curing unit was calibrated with a curing radiometer after every five specimens.

Compressive Strength

The specimens were prepared in split cylindrical Teflon molds 9 mm in height and 4 mm in diameter. The molds were placed on glass slabs and the material injected directly from the capsule. Vitremer was hand mixed (powder/liquid ratio 1:1), applied using the delivery tips with the dispenser provided, until the mold was slightly overfilled, then another glass slab was pressed on it and cured for four 40-second periods, one from the top and one from the bottom before removal from the mold, and from both sides after removal from the mold. The glossing agent was not used. The compressive tests were done in an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021) at a crosshead speed of 5 mm/minute.

Flexural Three-Point Bending

Ten test bars (22 x 2 x 2 mm) for each material were prepared in a split brass mold. The molds were supported on a glass slab, packed with the test material, and compressed from the top with another glass slab. The specimens were light cured through the glass slab, first in the center and then on both ends with overlapping irradiation. Three-point bending tests were carried out on the test bar at a span of 18 mm and a crosshead speed of 5 mm/minute using the Instron machine.

The specimens were stored in room-temperature water for 48 hours before mechanical testing. Vitremer specimens were covered with the gloss provided by the manufacturer for protection from water at the initial setting stage. The setting reaction of Vitremer and composite was found to be established at 24 hours (Swift & others, 1995; Atmadja & Bryant, 1990; Leung, Fan & Johnston, 1983; Swartz, Phillips & Rhodes, 1983). The specimen sides were ground flat in order to remove excess flash and prevent edge fracture during testing. The dimensions of the samples were measured with an electronic digital caliper accurate to ± 10 μm. The dimensions of the specimens were input into the series IX Automated testing system software of an IBM PC computer, which interfaced with the Instron.

Microhardness

Five circular disks of each material were prepared (2 mm thick and 10 mm in diameter) in a stainless steel mold on a celluloid matrix supported with a glass slab on the top and bottom.

Microhardness was measured on the top and bottom surfaces with a Buehler Micromet (Buehler, Lake Bluff, IL 60044) equipped with a Vickers indentor at a rate of 50 μm/seconds with a load of 25 gm. The length of the diagonal of each indentation was measured directly from the graduated eye lens. Six indentations for every surface were made, and means calculated and converted to Vicker's hardness numbers (VHN) from catalogued data.

Surface Roughness (Ra)

The specimens used for microhardness were utilized for Ra before hardness measurement. Profilometric analyses were carried out using the Surtonic 3 (Rank Organization, Leicester, England). Five tracings were made at different locations on each surface using a tracing length and a cut-off value of 2-5 mm. The Ra values are the mathematical mean values of the departure of the roughness profile from the mean line calculated by the machine.

The data were analyzed by ANOVA. A Student-Newman-Keuls test was used at 0.05 and 0.01 significance levels for comparisons among products.

Table 2. Compressive Strength

Material	Compressive Strength (MPa ± SD)	Strain at Maximum
Vitremer	142.0 ± 24.0	6.2 ± 1.1 aCE
Compoglass	228.0 ± 27.0 AB	6.9 ± 1.0 aC D
Dyract	202.0 ± 16.0 B	7.9 ± 1.7 D
Hytac	256.0 ± 17.0 A	5.5 ± 0.4 CE
Z100	296.0 ± 52.0	5.0 ± 0.9 E

Means with the same small and capital letters are not significantly different at $P < 0.05$ and $P < 0.01$ respectively.

Table 3. Flexural Strength (Three-Point Bend)

Material	Yield Strength (MPa ± SD)	Strain at Maximum	Flexural Strength (MPa ± SD)	Strain at Break
Vitremer	33.1 ± 5.4	0.0057 ± 0.0021C	24.9 ± 06.4 bD	0.0059 ± 0.0021 F
Compoglass	61.3 ± 23.9	0.0179 ± 0.0071B	39.0 ± 27.5 abD	0.0182 ± 0.0072E
Dyract	64.3 ± 16.1	0.0199 ± 0.0066B	43.8 ± 19.7 abD	0.0202 ± 0.0066E
Hytac	97.9 ± 22.3	0.0112 ± 0.0030C	59.1 ± 20.7 a D	0.0114 ± 0.0031 F
Z100	135.6 ± 15.4	0.0104 ± 0.0019C	92.3 ± 20.1	0.0106 ± 0.0019 F

Means with the same small and capital letters are not significantly different at $P < 0.05$ and $P < 0.01$ respectively.

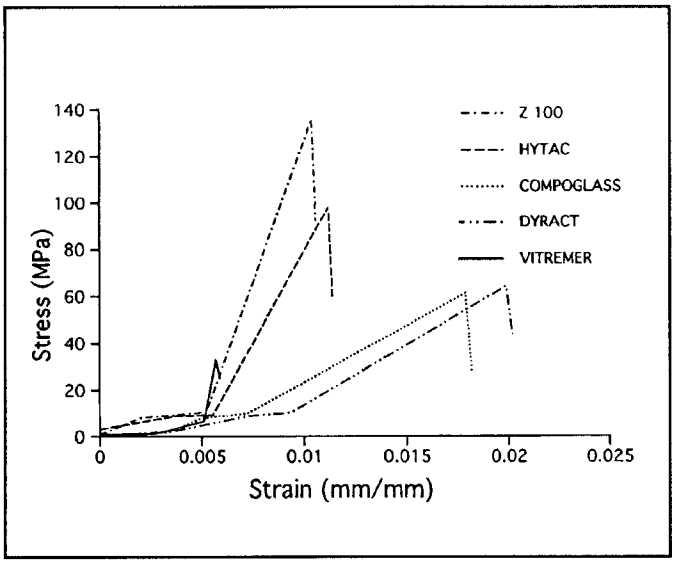
RESULTS

Compressive Strength

The data of the compressive tests are summarized in Table 2. These data showed significantly higher values for Dyract, Compoglass, and Hytac than for Vitremer ($P < 0.01$). Z100 composite displayed higher values than the other products tested ($P < 0.01$). Hytac strength was significantly higher than Dyract ($P < 0.01$). Strain under compression data showed higher values for Compoglass and Dyract than for Z100 composite and a higher value for Dyract than for Hytac and Vitremer ($P < 0.01$).

Flexural Three-Point Bending

The results of the flexure strength tests are presented in Table 3 and in the figure. There was a significant difference ($P < 0.01$) among Vitremer, Hytac, and Z100 composite with regard to yield strength. The strength of Vitremer was less than for Hytac, which was less than for Z100 composite. The yield strength values for Compoglass and Dyract were significantly less than for Hytac and Z100 composite and significantly higher than for Vitremer ($P < 0.01$). There was no significant difference in the strain at yield among Vitremer, Hytac, and Z100, but their values were significantly higher than for Compoglass and Dyract ($P < 0.01$). The flexural strength data displayed a significant difference between Vitremer and Hytac ($P < 0.05$). Z100 composite was significantly stronger than all the other products tested. The values of strain at break for Vitremer, Hytac, and Z100 were significantly less than for Compoglass and Dyract ($P < 0.01$).



Flexural strength data

Microhardness

Microhardness and surface roughness data are shown in Table 4. The microhardness values of

Table 4. Microhardness and Surface Roughness

Material	Microhardness (VHN)	Surface Roughness (μm ± SD)
Vitremer	41.0 ± 4.5 A	1.03 ± 0.38 b
Compoglass	33.0 ± 11.3 aA	0.83 ± 0.34 bc
Dyract	31.0 ± 8.2 aA	0.61 ± 0.35 c
Hytac	51.0 ± 10.0	0.63 ± 0.22 c
Z100	97.0 ± 7.8	0.67 ± 0.36 c

Means with the same small and capital letters are not significantly different at $P < 0.05$ and $P < 0.01$ respectively.

Compoglass and Dyract were not significantly different ($P < 0.05$). Hytac displayed microhardness values higher than Vitremer, Compoglass, and Dyract ($P < 0.01$). All products tested showed values significantly less than for Z100 ($P < 0.01$).

Surface Roughness

The surface roughness values of Compoglass, Dyract, Hytac, and Z100 were not significantly different. Vitremer displayed a significantly higher value than Dyract, Hytac, and Z100 ($P < 0.05$).

DISCUSSION

A linear relationship between flexural strength values and modulus of resilience and clinical wear has been reported (Peutzfeldt & Asmussen, 1992). Our results showed that the materials tested partially confirmed this statement, as they displayed the same arrangement of strength in both stages of the three-point bending test, the yield and flexure strength. The weakest material was Vitremer (a resin-modified glass ionomer), then Compoglass, Dyract, and Hytac (compomers = polyacid-modified resin composites), with the strongest being Z100 (composite). This arrangement suggests placement of the compomer restorative materials between the resin-modified glass-ionomer cement and the resin composite tested in this research project.

The explanation for the variable strength of compomers may depend on the degree to which each material has been modified with resin-like components or polyacid-like components. For instance, the manufacturers could replace only a small percentage of the carboxylic acid groups on the polyacrylic acid with methylmethacrylate groups resulting in a small amount of covalent (resin-like) crosslinking in the polymerization. A material of this type would consist of a matrix largely cross-linked by ionic bonding and would exhibit properties similar to a traditional glass ionomer. If a large percentage of carboxylic groups were substituted with methyl methacrylate groups, the material would polymerize largely as a resin by formation of free radicals and subsequent crosslinking by formation of covalent bonds (Kovarik & Muncy, 1995). Compoglass contains propoxylated BIS-GMA with other dimethacrylates. Dyract contains light-curing polymers with polymerizable monomers, and Hytac contains Bis (meth) acrylate. The addition of these resins may be the reason for the behavior of these materials being close to resin composites (Peutzfeldt, García-Godoy & Asmussen, 1997).

Vitremer displayed a small amount of strain in flexural testing. This reflected the brittle nature of the glass-ionomer cements. The set glass-ionomer cement has a particulate-filled composite structure with crosslinked polymeric matrix (Wilson & McLean, 1988). Mueller (1990) reported that the fracturing process of glass ionomers was mainly decohesive rupture of debonding glass particles and cleavage of several isolated layer-sized cement particles.

Our results showed that the materials tested had the same ranking in compression as in flexural testing, which supported the mentioned finding that compomers fall between the glass ionomer and the composite.

There was no significant difference among Vitremer, Compoglass, and Dyract hardness. This may be attributed to the fluorosilicate glass incorporated in the three materials, while Hytac contained Ca-Al-fluoroglass.

Our study was designed to compare the Ra of the materials without the effect of finishing. In this study there was no significant difference in the measured Ra values of Compoglass, Dyract, Hytac, and Z100, which were 0.61-0.83 μm. This is equivalent to Ra at the occlusal enamel contact (0.64 ± 0.25 μm), which is considered to be the standard with which to compare the Ra value for a restorative material (Lambrechts, Braem & Vanherle, 1988; Willems & others, 1991). This finding showed that hand-mixing of the powder and liquid may not produce the same surface as the material provided originally in paste form, such as the compomers and resin composites. Based on the results of this study, the resin composite Z100 would be the material of choice for use over the compomers and glass ionomer, Vitremer, when high compressive strength is desired. The compomers Hytac and Z100 could best be used when flexural strength is deemed important and/or microhardness is needed for restoration success.

CONCLUSION

The results showed that the flexural and compressive strengths and microhardness of the three compomers tested, Compoglass, Dyract, and Hytac, were higher than for Vitremer but less than for Z100. The Hytac compomer had the best mechanical properties in the compomer group. Surface roughness of the three compomers and composite was not significantly different.

(Received 24 July 1997)

References

ABDALLA A & ALHADAINY H (1997) Clinical evaluation of glass ionomer in erosion/abrasion lesions *Quintessence International* **28** 245-248.

ABDALLA A, ALHADAINY H & GARCÍA-GODOY F (1997) Clinical evaluation of glass ionomers and compomers in Class V carious lesions *American Journal of Dentistry* **10** 18-20.

ATMADJA G & BRYANT RW (1990) Some factors influencing the depth of cure of visible light-activated composite resins *Australian Dental Journal* **35** 213-218.

CROLL TP (1992) Glass ionomers and esthetic dentistry: what the new properties mean to dentistry *Journal of the American Dental Association* **123** 51-54.

DeSCHEPPER EJ, BERRY EA, CAILLETEAU JG & TATE WH (1990) Fluoride release from light-cured liners *American Journal of Dentistry* **3** 97-100.

DONLY KJ, KANELLIS R & SEGURA A (1997) Glass ionomer restoration in primary molars: three-year clinical results *Journal of Dental Research* **76** *Abstracts of Papers* p 41 Abstract 223.

FORSTEN L (1977) Fluoride release from a glass ionomer cement *Scandinavian Journal of Dental Research* **85** 503-504.

GARCÍA-GODOY F (1988a) Microleakage of preventive glass-ionomer restorations *Compendium* **9** 88-94.

GARCÍA-GODOY F (1988b) Microleakage of a posterior composite resin lined with glass ionomer *General Dentistry* **36** 514-516.

GARCÍA-GODOY F (1998) Clinical evaluation of Compoglass in primary molars *American Journal of Dentistry* (In press).

GARCÍA-GODOY F & CHAN DC (1991) Long-term fluoride release from glass ionomer-lined amalgam restorations *American Journal of Dentistry* **4** 223-225.

GARCÍA-GODOY F, DRAHEIM RN, TITUS HW & CHIESA D (1988a) Microleakage of composite restorations with etched and non-etched glass ionomer bases *American Journal of Dentistry* **1** 159-162.

GARCÍA-GODOY F & JENSEN ME (1990) Artificial recurrent caries in glass ionomer-lined amalgam restorations *American Journal of Dentistry* **3** 89-93.

GARCÍA-GODOY F & MALONE WF (1988) Microleakage of posterior composite resins using glass ionomer cement bases *Quintessence International* **19** 13-17.

GARCÍA-GODOY F, MARSHALL TD & MOUNT GJ (1988b) Microleakage of glass ionomer tunnel restorations *American Journal of Dentistry* **1** 53-56.

GARCÍA-GODOY F, OLSEN B T, MARSHALL TD & BARNWELL GM (1990) Fluoride release from amalgam restorations lined with a silver-reinforced glass ionomer *American Journal of Dentistry* **3** 94-96.

GEIGER S (1990) Glass ionomer and its various clinical applications: A critical review *Refuat-Hashinayim* **8** 19-23.

GRIFFIN F, DONLY KJ & ERICKSON RL (1992) Caries inhibition of fluoride-releasing liners *American Journal of Dentistry* **5** 293-295.

HALLETT KB & GARCÍA-GODOY F (1993) Microleakage of resin-modified glass ionomer cement restorations: an *in vitro* study *Dental Materials* **9** 306-311.

HICKS MJ, FLAITZ CM & SILVERSTONE LM (1986) Secondary caries formation *in vitro* around glass ionomer restorations *Quintessence International* **17** 527-532.

KNIBBS PJ (1987) A clinical report on the use of a glass ionomer cement to restore cervical margin lesions *Journal of Oral Rehabilitation* **14** 105-109.

KOVARIK RE & MUNCY MV (1995) Fracture toughness of resin-modified glass ionomers *American Journal of Dentistry* **8** 145-148.

LAMBRECHTS P, BRAEM M & VANHERLE G (1988) Roughness of human enamel as additional acceptance standard for posterior composites *Journal of Dental Research* **67** *Abstracts of Papers* p 262 Abstract 1192.

LEUNG RL, FAN PL & JOHNSTON WM (1983) Post irradiation polymerization of visible light activated composite resin *Journal of Dental Research* **62** 363-365.

LOYOLA-RODRÍGUEZ JP, GARCÍA-GODOY F & LINDQUIST R (1994) Growth inhibition of glass ionomer cements on mutans streptococci *Pediatric Dentistry* **16** 346-349.

MANDERS CA, GARCÍA-GODOY F & BARNWELL GM (1990) Effect of a copal varnish, ZOE or glass ionomer cement bases on microleakage of amalgam restorations *American Journal of Dentistry* **3** 63-66.

MARCUSHAMER M, GARCÍA-GODOY F & CHAN DC (1993) Caries protection after orthodontic band cementation with glass ionomer *Journal of Dentistry for Children* **60** 300-303.

McCOMB D & ERIKSON D (1987) Antimicrobial action of new, proprietary lining cements *Journal of Dental Research* **66** 1025-1028.

McLEAN JW, NICHOLSON JW & WILSON AD (1994) Proposed nomenclature for glass-ionomer dental cements and related materials *Quintessence International* **25** 587-589.

MUELLER HJ (1990) Fracture toughness and fractography of dental cements, lining, build-up, and filling materials *Scanning Microscopy* **4** 297-307.

PETERS TCRB, ROETERS JJM & FRANKENMOLEN FWA (1996) Clinical evaluation of Dyract in primary molars: 1-year results *American Journal of Dentistry* **9** 83-88.

PEUTZFELDT A & ASMUSSEN E (1992) Modulus of resilience as predictor for clinical wear of restorative resin *Dental Materials* **8** 146-148.

PEUTZFELDT A, GARCÍA-GODOY F & ASMUSSEN E (1997) Surface hardness and wear of glass ionomers and compomers *American Journal of Dentistry* **10** 15-17.

QVIST V, LAURBERG L, POULSEN A & TEGLERS PT (1997) Glass ionomer and amalgam restorations in primary teeth 4 - 4 1/2 yr results *Journal of Dental Research* **76** *Abstracts of Papers* p 41 Abstract 224.

SEGURA A, DONLY KJ & STRATMANN RG (1997) Enamel remineralization on teeth adjacent to Class II glass ionomer restorations *American Journal of Dentistry* **10** 247-250.

SOUTO M & DONLY KJ (1994) Caries inhibition of glass ionomers *American Journal of Dentistry* 7 122-124.

SWARTZ ML, PHILLIPS RW & RHODES B (1983) Visible light-activated resins—depth of cure *Journal of American Dental Association* **106** 634-637.

SWIFT EJ Jr, BAILEY SJ & HANSEN SE (1990) Fluoride release from fast-setting glass ionomer restorative materials *American Journal of Dentistry* **3** 101-103.

SWIFT EJ, PAWLUS MA, VARGAS MA & FORTIN D (1995) Depth of cure of resin-modified glass-ionomer restoratives *Journal of Dental Research* **74** *Abstracts of Papers* p 38 Abstract 212.

TEN CATE JM & VAN DUINENE RN (1995) Hypermineralization of dentinal lesions adjacent to glass-ionomer cement restorations *Journal of Dental Research* **74** 1266-1271.

VAN DE VOORDE A, GERDTS GJ & MURCHISON DF (1988) Clinical use of glass ionomer cement: a literature review *Quintessence International* **9** 53-61.

VAN DIJKEN JW (1996) 3-year clinical evaluation of a compomer, a resin-modified glass ionomer, and a resin composite in Class III restorations *American Journal of Dentistry* **9** 195-198.

WILLEMS G, LAMBRECHTS P, BRAEM M, VUYKSTEKE-WAUTERS M & VANHERLE G (1991) The surface roughness of enamel-to-enamel contact areas compared with the intrinsic roughness of dental resin composites *Journal of Dental Research* **70** 1299-1305.

WILSON AD & McLEAN JW (1988) *Glass-Ionomer Cement*, 1st ed, Chicago: Quintessence Publishing Co Inc.

©OPERATIVE DENTISTRY, 1999, 24, 9-13

Two-Year Clinical Performance of a Resin-modified Glass-Ionomer Restorative Material

W W BRACKETT • R O GILPATRICK
W D BROWNING • P N GREGORY

Clinical Relevance
A resin-modified glass-ionomer restorative material was an effective restoration of cervical abrasion/abfraction lesions and was approximately equal in clinical performance to its chemically cured predecessor.

SUMMARY

This study was a 2-year clinical evaluation of a conventional and a resin-modified glass-ionomer restorative material. Thirty-four restorations each of Ketac-Fil and Photac-Fil were placed without tooth preparation in cervical abrasion/abfraction lesions, primarily in premolar teeth. Patients ranged in age from 30 to 73 years, with a median age of 45 years. Isolation for the restorations was accomplished with cotton rolls. Restorations of both materials were retained at the rate of 93%, and both were comparable in appearance, receiving Alfa ratings for more than 85% of the restorations. One occurrence of secondary caries was observed for each material. No significant difference between the materials was observed for any evaluation category (exact binomial test, $P > 0.05$).

University of Tennessee—Memphis, College of Dentistry, Department of General Dentistry, 875 Union Avenue, Memphis, TN 38163

William W Brackett, DDS, MSD, assistant professor, Division of Operative Dentistry

Russell O Gilpatrick, DDS, professor and chair

William D Browning, DDS, MS, Medical College of Georgia, School of Dentistry, Department of Oral Rehabilitation, Augusta, GA 30912

Paul N Gregory, DDS, assistant professor, coordinator of patient care, Department of Biologic and Diagnostic Sciences, Division of Oral Diagnosis

INTRODUCTION

Glass-ionomer restorative materials, which were introduced in the late 1970s, are well proven as adhesive restorations for nonretentive cervical cavities. A 10-year clinical study (Matis, Cochran & Carlson, 1996) reported retention of approximately 80% of glass-ionomer restorations of unprepared cervical abrasion/abfraction lesions, with no incidence of secondary caries.

Acceptance of these materials has been limited, however, because of inconvenient setting characteristics and a less-than-ideal appearance. Recently, these limitations have been addressed through the introduction of resin-modified glass ionomers, which can be light cured and which have an improved appearance after placement (Brackett & others, 1996). Clinical trials of resin-modified glass-

ionomer restorations of cervical abrasion/abfraction lesions have shown retention rates near 100%, with no secondary caries (Maneenut & Tyas, 1995; Abdalla & Alhadainy, 1997). Relatively few products of this type have been clinically evaluated, and no clinical trial has compared conventional and resin-modified glass-ionomer restorative materials.

The purpose of this 2-year study was to compare the clinical performance of a resin-modified glass ionomer with its chemically cured predecessor in restorations of unprepared cervical abrasion/abfraction lesions.

METHODS AND MATERIALS

The resin-modified restorative material chosen for this study was Photac-Fil (ESPE GmbH, Seefeld-Oberbay, Germany), while the chemically cured material chosen was Ketac-Fil (ESPE GmbH). The study was conducted according to the protocol for clinical studies set forth in the American Dental Association acceptance program for dentin and enamel adhesive materials.

Thirty-four pairs of equivalent-sized cervical abrasion/abfraction lesions, primarily in premolar teeth, were identified in 29 healthy patients presenting for treatment at the student clinics of the University of Tennessee College of Dentistry. The median age of these patients was 45 years, while the age range was 30 to 73 years. Each pair of cervical abrasion/abfraction lesions received one restoration of each material, assigned randomly. No patient received more than two pairs of restorations. Included in the study were pairs of lesions of varied size and axial depth (Table 1). One investigator (WWB) placed all restorations. Isolation was accomplished using cotton rolls, and no mechanical preparation or any abrasion of tooth surfaces was done. Instead, tooth surfaces were scrubbed with a cotton pellet saturated with 20% polyacrylic acid (Ketac Conditioner, ESPE GmbH).

Closely adapted metal cervical matrices (Cervical Matrix Forms, Premier Dental Products Co, Norristown, PA 19401) were used to contour the Ketac-Fil during placement. These were sealed at the edges with unfilled resin (Ketac-Glaze, ESPE GmbH) to prevent dehydration or water contamination of the material and were left in place throughout the required 7-minute delay prior to finishing. Photac-Fil restorations were shaped with a plastic instrument prior to light curing.

Restorations of both materials were contoured and finished with wet abrasive disks (Sof-Flex XT, 3M Dental Products, St Paul, MN 55144), and were lightly air dried and glazed with unfilled resin (Ketac-Glaze) after finishing. Because both restorative materials were mechanically mixed in predosed capsules, no shade blending was possible. Teeth were restored with the shade selected as the closest match using the manufacturer's shade guide for Ketac-Fil and a Vita shade guide (Vita-Zahnfabrik, Bad Säckingen, Germany) for Photac-Fil.

At baseline, and at 6-, 12-, 18-, and 24-month intervals, the restorations were clinically evaluated by two other investigators (ROG and WDB), using a modification of clinical evaluation criteria described by Cvar and Ryge (1971), which is listed in Table 2. The evaluators were unaware of which material had been used in any given restoration, and any discrepancy between evaluators was resolved before the patient was dismissed.

Table 1. Distribution of Materials to Teeth Restored; Axial Depth and Preoperative Sensitivity of Abrasion/Abfraction Lesions

PHOTAC-FIL

	Canines					Premolars					
		s	o	a	b	c		s	o	a	b	c
Maxillary	9	3	6	6	3		13	4	9	5	7	1
Mandibular	1		1		1		6	3	3	4	2	

KETAC-FIL

	Canines					Premolars					
		s	o	a	b	c		s	o	a	b	c
Maxillary	1	1		1			18	6	12	9	8	1
Mandibular	0						10	4	6	5	5	

s = sensitive to air
o = insensitive to air

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

RESULTS

At the end of the study period, 29 pairs of restorations were available for evaluation, a recall rate of 85%. Restorations of both materials were 93% retained (Table 3) over 24 months. The appearance of both materials was also acceptable (figure), with 86-88% of the restorations receiving Alfa ratings (Table 2). Secondary caries of two restorations, one of each material, were observed on adjacent teeth in one patient. In both of these restorations, caries progressing into dentin occurred at the enamel/glass-ionomer interface. Both required cavity preparation and replacement restorations. All teeth sensitive to air prior

to restoration remained free of sensitivity throughout the study.

The two restorations receiving Charlie ratings for color match were Photac-Fil, although both were placed in patients who were smokers. Although Photac-Fil restorations showed a greater incidence of Bravo scores for marginal adaptation and marginal discoloration than Ketac-Fil restorations (Table 2), a pairwise comparison showed no significant difference between restorations made with the two materials for any evaluation category (exact binomial test, $P > 0.05$).

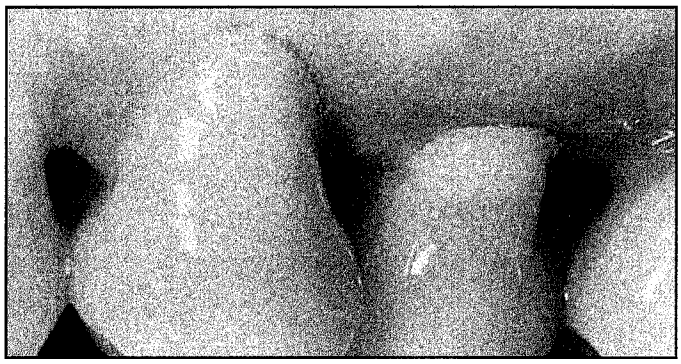
DISCUSSION

The authors elected use of cotton rolls rather than rubber dam isolation for this study to lessen the need for local anesthesia and to lessen trauma to patients' gingiva. Although it was not evident in this group of patients, gingival bleeding or exudate was considered cause for exclusion from the study. The clinical performance of both materials in this study is comparable to other studies conducted with similar materials over the same time interval, regardless of the isolation method employed.

The authors believe that abrasion of abfracted tooth surfaces with diamond burs prior to restorations of this type, as is advocated by some clinicians, is not conservative of noncarious tooth structure and is contraindicated. In the absence of stain, some authors believe abrasion of the abraded/abfracted tooth surface with pumice to be unnecessary (Brackett,1989; Mount, 1994). Given the retention rate for restorations in the study, the isolation method and surface treatment employed seemed to be effective for these two restorative materials.

Table 2. Modified USPHS Rating System

CATEGORY	SCORE	CRITERIA
Retention	Alfa	No loss of restorative material
	Charlie	Any loss of restorative material
Color Match	Alfa	Matches tooth
	Bravo	Acceptable mismatch
	Charlie	Unacceptable mismatch
Marginal Discoloration	Alfa	No discoloration
	Bravo	Discoloration without axial penetration
	Charlie	Discoloration with axial penetration
Secondary Caries	Alfa	No caries present
	Charlie	Caries present
Anatomic Form	Alfa	Continuous
	Bravo	Slight discontinuity, clinically acceptable
	Charlie	Discontinuous, failure
Marginal Adaptation	Alfa	Closely adapted, no detectable margin
	Bravo	Detectable margin, clinically acceptable
	Charlie	Mariginal crevice, clinical failure



Representative 2-year-old restorations of Ketac-Fil (tooth #13) and Photac-Fil (tooth #12) (original magnification X1.5)

The thickness of restorative material may have influenced retention in this study, as the four restorations lost had been placed in lesions scored as less than 1 mm in axial depth. It is possible that a minimum thickness of 1 mm is necessary to assure retention of a glass-ionomer restoration in an abrasion/abfraction lesion.

Given the fluoride content of these restorative materials, secondary caries was unexpected. Both failed restorations, in the mandibular right premolars of one patient, had been judged to be clinically acceptable for marginal adaptation at the 18-month recall. This patient exhibited generalized root caries, and the failure of these restorations appears attributable to factors beyond the scope of this study. There is no apparent explanation for the occurrence of secondary caries at the glass-ionomer/enamel interface, like there is at the glass-ionomer/dentin interface in these two restorations.

The higher incidence of Bravo scores for marginal adaptation and marginal discoloration in Photac-Fil restorations relative to Ketac-Fil, although the restorations were not clinical failures, is of concern. The only obvious difference between the two materials is the resin content of Photac-Fil, which may undergo sufficient polymerization shrinkage to produce the observed margin discrepancies (Attin & others, 1995). The Bravo scores for marginal adaptation observed early in the study were detectable restoration margins, while Bravo scores in the same category found at the end of the study were usually detectable margins of tooth structure. It is likely that

Table 3. Results of Clinical Evaluation for Resin-modified and Conventional Glass-Ionomer Restorations

PHOTAC-FIL

	Retention			Color Match				Marg Disc	
	n*	Alfa	Charlie	n*	Alfa	Bravo	Charlie	Alfa	Bravo
baseline	34	100	0	34	91	9	0	97	3
6 months	34	100	0	34	85	15	0	97	3
12 months	30	97	3	29	90	3	7	83	17
18 months	30	97	3	29	94	3	3	79	21
24 months	29**	93	7	27**	86	7	7	78	22

	Sec Caries			Anat Form		Marg Adapt		
	n*	Alfa	Charlie	Alfa	Bravo	Alfa	Bravo	Charlie
baseline	34	100	0	79	21	65	35	0
6 months	34	100	0	82	18	88	12	0
12 months	29	100	0	72	28	79	21	0
18 months	29	100	0	100	0	48	52	0
24 months	27***	96	4	96	4	33	63	4***

KETAC-FIL

	Retention			Color Match				Marg Disc	
	n*	Alfa	Charlie	n*	Alfa	Bravo	Charlie	Alfa	Bravo
baseline	34	100	0	34	68	32	0	100	0
6 months	34	100	0	34	82	18	0	100	0
12 months	30	100	0	30	73	27	0	93	7
18 months	30	93	7	28	89	11	0	100	0
24 months	28**	93	7	26**	88	12	0	88	12

	Sec Caries			Anat Form		Marg Adapt		
	n*	Alfa	Charlie	Alfa	Bravo	Alfa	Bravo	Charlie
baseline	34	100	0	82	18	76	24	0
6 months	34	100	0	88	12	88	12	0
12 months	30	100	0	80	17	77	23	0
18 months	28	100	0	100	0	61	39	0
24 months	26**	96	4	92	8	54	42	4***

*Sample size larger for retention than for other criteria because lost restorations unavailable for evaluation

**Sample size larger for Photac-Fil at 24 months due to loss of one Ketac-Fil restoration from study due to tooth fracture

***Charlie score due to secondary caries

the former occurred due to cautious finishing and the lack of a distinct tooth margin in many of the abrasion/abfraction lesions, while the latter resulted from wear of the restorations.

The purported advantages of improved appearance and faster application of the resin-modified material were not as evident as expected. Although Photac-Fil restorations were judged to have a better color match early in the study, little difference was observed between the two materials after 24 months. Because finishing of the Ketac-Fil restorations had to be delayed, but required little time, the immediate finishing possible with resin-modified restorations was of little advantage as long as the 7-minute finishing delay for Ketac-Fil was employed to place successive restorations or to finish previously placed ones.

Although clear matrix forms are available, these cannot be closely adapted to all teeth, and were excluded from this study so that all of the Photac-Fil restorations could be placed by the same method. Shaping the restorations free-hand increased the time actually spent in finishing, relative to use of metal matrix forms. It is unlikely that shaping the Photac-Fil restorations by hand affected the study, because only marginal adaptation differed between the materials, and this became evident primarily later in the study.

The selective discoloration of two Photac-Fil restorations probably occurred because the patients were smokers and because these were maxillary restorations, more anterior than the Ketac-Fil restorations. Glass-ionomer restorations may be subject to discoloration in the anterior maxilla of patients who smoke.

CONCLUSIONS

The resin-modified glass-ionomer restorative material evaluated in this study appeared to be equivalent in clinical performance to its chemically cured predecessor. The rate of success observed in restorations of both materials in this study would be sufficient for full acceptance in the clinical portion of the ADA acceptance program for enamel and dentin adhesive materials.

Acknowledgments

The authors gratefully acknowledge the administrative support for this study provided by Ms Betty J Eason, and the financial support of the University of Tennessee College of Dentistry Alumni Foundation.

(Received 29 July 1997)

References

ABDALLA AI & AL HADAINY HA (1997) Clinical evaluation of hybrid ionomer restoratives in Class V abrasion lesions: two-year results *Quintessence International* **28** 255-258.

ATTIN T, BUCHALLA W, KIELBASSA AM & HELLWIG E (1995) Curing shrinkage and volumetric changes of resin-modified glass ionomer restorative materials *Dental Materials* **11** 359-362.

BRACKETT WW (1989) Restoration of cervical erosion lesions with glass ionomer cements *Ohio Dental Journal* **63** 4-7.

BRACKETT WW, GILPATRICK RO, BROWNING WD, GREGORY PN & EASON BJ (1996) Clinical esthetics of a light-cured and a chemically cured glass ionomer restorative material *Journal of the Tennessee Dental Assocation* **76** 30-31.

CVAR JF & RYGE G (1971) *Criteria for the Clinical Evaluation of Dental Restorative Materials* US Public Health Service Pub No 790-244, San Francisco: Government Printing Office.

MANEENUT C & TYAS MJ (1995) Clinical evaluation of resin-modified glass-ionomer restorative cements in cervical 'abrasion' lesions: one-year results *Quintessence International* **26** 739-743.

MATIS BA, COCHRAN M & CARLSON T (1996) Longevity of glass-ionomer restorative materials: results of a 10-year evaluation *Quintessence International* **27** 373-382.

MOUNT GJ (1994) Personal communication.

©OPERATIVE DENTISTRY, 1999, 24, 14-19

Fluoride Release from Some Dental Materials in Different Solutions

A S CARVALHO • J A CURY

Clinical Relevance
The cariostatic potential of dental materials that release fluoride can change depending on the media used to evaluate them.

SUMMARY

Most of the data reported on release of fluoride from dental materials are based upon measurements made in deionized water and artificial saliva, which do not simulate the dynamics of caries development. So, the purpose of this study was to determine the level of fluoride released from different restorative materials in storage solutions, considering the caries process (pH-cycling). Six cylindrical samples of each material (Chelon-Fil, Dyract, Variglass, Vitremer, and Tetric) were prepared and suspended individually in 2.0 mL of each studied solution. The studied media were deionized water, artificial saliva, and solutions for pH-cycling (demineralizing solution—pH 4.3 and remineralizing solution—pH 7.0). All solutions were changed daily over 15 days. Fluoride release was determined after buffering the solutions with an equal volume of TISAB. The fluoride release was higher in pH-cycling than in the other solutions ($P < 0.05$), and changes of the rank order of fluoride release from the studied materials occurred when the different media were considered ($P < 0.05$). The data suggest that the comparison of fluoride released from dental materials is dependent on the medium used in the evaluation.

University of Campinas, Piracicaba School of Dentistry, Av Limeira, 901-CEP 13414-900, Piracicaba, São Paulo, Brazil

Adriana S Carvalho, DDS, MS, graduate student

Jaime A Cury, DDS, MS, PhD, professor

INTRODUCTION

Cury, Saad, and Rodrigues (1993) have suggested that the in vitro fluoride evaluation of dental materials has been made in conditions that do not simulate the caries development and the effect of fluoride. Deionized water, which does not represent the oral fluid, has been the medium frequently used to evaluate fluoride release (Cranfield, Kuhn & Winter, 1982; Meryon & Smith, 1984; El-Mallakh & Sarkar, 1990; Hörsted-Bindslev & Larsen, 1990; Rawls, 1991). According to Cranfield and others (1982) some studies have used artificial saliva. Although this medium is more appropriate, it does not simulate the caries process. In addition, when the fluoride released from different materials was compared using deionized water or saliva, reversal results were found by El-Mallakh and Sarkar (1990). Considering that dental caries depends on the equilibrium between demineralization and remineralization, during the pH-cycling into dental plaque, as Featherstone and others (1986), Ten Cate (1990), and Cury (1993) explained, the laboratory models to evaluate fluoride should simulate these conditions.

Therefore, the purpose of this study was to compare fluoride release from glass-ionomer cements, polyacid-modified resins, and a composite in

Table 1. Restorative Materials Used

Material	Manufacturer	Nomenclature McLean & others (1994)	Code
Chelon-Fil Batch # 0031/0042	ESPE GmbH Seefeld/Oberbay, Germany	glass-ionomer cement	CHE
Vitremer Batch # 312/322	3M Dental Products St Paul, MN 55144	resin-modified glass ionomer	VIT
Variglass Batch # 920602/587010	DeTrey/Dentsply Weybridge, England	polyacid-modified resin	VAR
Dyract Batch # 9311627	DeTrey/Dentsply Weybridge, England	polyacid-modified resin	DYR
Tetric Batch # 560385	Vivadent Schaan, Liechtenstein	composite	TET

conventional solutions (deionized water and artificial saliva) and in a pH-cycling model (demineralizing and remineralizing solutions).

METHODS AND MATERIALS

The materials tested are listed in Table 1.

A pilot study was conducted revealing that a sample size of six specimens displayed a standard deviation no greater than 10%. Therefore, 18 samples of each material (six for each medium) were prepared as thin disks with a diameter of 8.6 mm and a thickness of 1.65 mm, at room temperature (23 ± 1.0 °C and 50 ± 5% relative humidity), according to ISO #7489 specification, using disk-shaped plastic molds. The materials were mixed according to the manufacturers' recommendations, placed in the molds, and pressed between two glass plates. Paraffin dental floss was incorporated into the cements during setting to suspend the samples in the test medium. The materials VIT, VAR, DYR, and TET were light cured for 40 seconds each, and CHE was cured by chemical reaction. After hardening, the specimens were superficially protected with an appropriate varnish (Vidrion V, S S White, Lakewood, NJ 08701) and stored in an oven (37 °C, 100% relative humidity) for 24 hours, simulating the oral environment. Each surface of the specimens was then polished using Sof-Lex disks (3M Dental Products) with water refrigeration. Six specimens of each material were suspended individually in 2.0 mL of each studied solution (Table 2) in polyethylene tubes for up to 15 days. The specimens were agitated on circular shaker equipment at room temperature (23.5 °C). The storage media were changed daily to fresh ones as follows: deionized water—changed every 24 hours; artificial saliva—changed every 24 hours; pH-cycling system—the specimens were immersed 6 hours in demineralizing solution (pH 4.3) and 18 hours in remineralizing solution (pH 7.0). According to Featherstone and others (1986) this in vitro evaluation over 15 days represents an in vivo situation of high caries challenge.

After the prescribed immersion time, the disks were removed from the solutions. The fluoride ion concentration in the solutions was measured using an Orion fluoride ion electrode (model 96-09) and an Orion digital ion-analyzer (model EA-940) (Orion Research Inc, Boston, MA 02129). For the analysis of the released fluoride ion, the same volume of the samples and TISAB (acetate buffer 1.0 M, pH 5.0, containing NaCL 1.0 M and 1,2-cyclohexanediaminetetraacetic 0.4%) were mixed. The results found in the demineralizing and remineralizing solutions were added. The fluoride electrode was previously calibrated with a series of standard solutions (0.5 to 5.0 or 1.0 to 10.0 µg F/ml in

Table 2. Immersion Media Used

I: deionized water (**H_2O**)

II: artificial saliva (**AS**): Ca 1.5 mM, PO_4 0.9 mM, KCL 150 mM and Tris buffer 20 mM, pH 7.0, containing NaN_3 0.02%

III: pH-cycling system--demineralizing (De) and remineralizing (Re) solutions (**De-Re**):
De: Ca 2.0 mM, PO_4 2.0 mM and acetate buffer 75 mM, pH 4.3, containing NaN_3 0.02%
Re: the same as artificial saliva

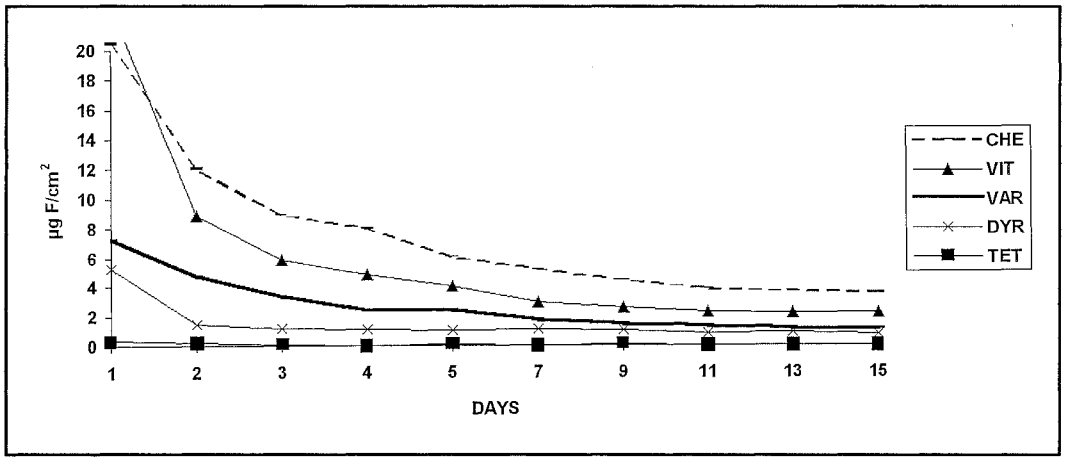


Figure 1. *Mean fluoride released from the materials in deionized water*

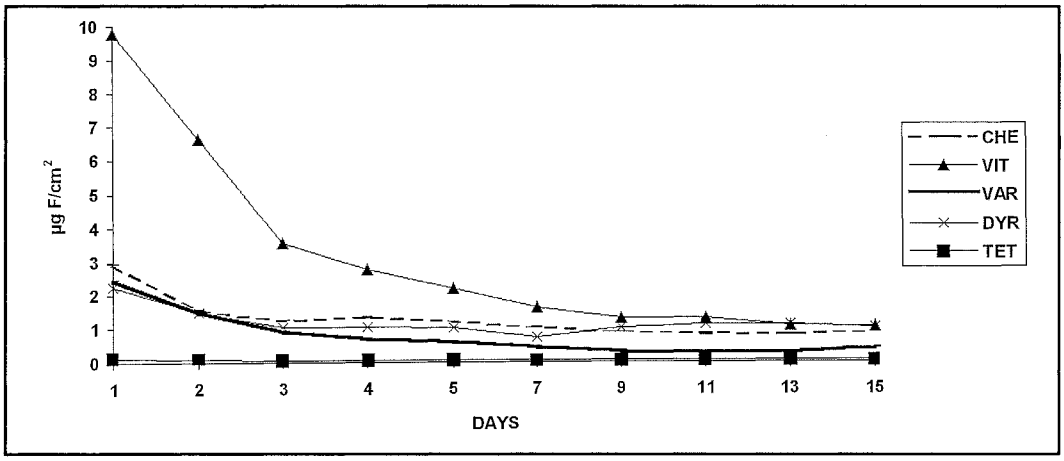


Figure 2. *Mean fluoride released from the materials in artificial saliva*

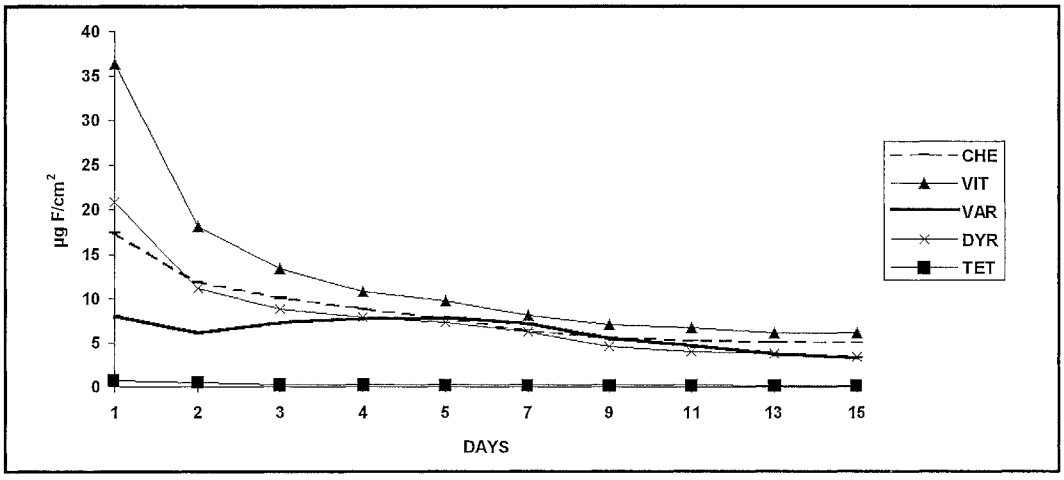


Figure 3. *Mean fluoride released from the materials in pH-cycling solutions*

TISAB) according to the fluoride concentration in the samples. The results of fluoride concentration in the solutions were transformed into released quantity of fluoride per material area (µg F/cm²).

The results were analyzed statistically by ANOVA and the differences between the treatments by Tukey test ($P < 0.05$).

RESULTS

The results of ANOVA were statistically significant for material ($P < 0.00001$), medium ($P < 0.00001$), time ($P < 0.00001$), and for interactions material x medium ($P < 0.00001$), material x time ($P < 0.00001$), medium x time ($P < 0.00001$), material x time x medium ($P < 0.00001$). Then the differences were analyzed by Tukey test ($P < 0.05$).

The fluoride released (µg F/cm²) during the 15 days from glass-ionomer cements and composites in the three studied solutions is shown in Figures 1, 2, and 3. The qualitative pattern of fluoride release was similar for all five materials.

The greatest amount of fluoride was released in the pH-cycling solutions (µg F/cm²) and the lowest in artificial saliva (Table 3) when storage media was considered.

The comparison of fluoride released (µg F/cm²) among the materials in each medium is shown in Table 4. In the artificial saliva and pH-cycling system, the highest total fluoride-released rate was from VIT, followed by CHE, DYR, VAR, and TET. However, changes in the rank order of fluoride release by the various materials was noted when the data in water were compared: CHE

Table 3. Fluoride Released (Mean ± Standard Error) from Each Material (μg F/cm²) Considering the Media

	MATERIALS				
MEDIA	**CHE**	**VIT**	**VAR**	**DYR**	**TET**
DE-RE	8.35 ± 0.51 A	12.27 ± 1.16 A	6.17 ± 0.24 A	7.82 ± 0.65 A	0.28 ± 0.020 A
H_2O	7.62 ± 0.73 B	5.91 ± 0.79 B	2.71 ± 0.25 B	1.50 ± 0.17 B	0.14 ± 0.020 A
AS	1.26 ± 0.08 C	3.13 ± 0.36 C	0.80 ± 0.10 C	1.20 ± 0.05 B	0.07 ± 0.003 A

Means followed by the same letter do not differ statistically (Tukey, $P < 0.05$).

released the greatest quantity, followed by VIT, VAR, DYR, and TET.

DISCUSSION

The results (Figures 1-3) showed that all five materials in each medium had the same qualitative fluoride release pattern during the 15 experimental days. The concentration of fluoride released was higher during the first 24 hours, declined sharply on the second day, then gradually diminished to a nearly constant level for each material. These results are in agreement with Forsten (1977); Derkson, Poon, and Richardson (1982); Meryon and Smith (1984); Cooley, Sandoval, and Barnwell (1988); Muzynski and others (1988); Swift (1989); Tay and Braden (1988); Hörsted-Bindslev and Larsen (1990); Forsten (1991); Verbeeck and others (1993); De Araujo and others (1996); Rasmussen, Hollis, and Christensen (1996); Glockmann and others (1997); Braverman and Hatibovic-Kofman (1997); and Shaw and McCabe (1997), who have evaluated the fluoride released from glass-ionomer cements and composites. The pattern of fluoride release from glass-ionomer cements in this study was also in agreement with Tay and Braden (1988), who explained that it occurred possibly because two processes were involved: a rapid surface elution followed by a slower continuous bulk diffusion of fluoride ions. This sharp decrease in fluoride released from the composite and polyacid-modified resins was in agreement with Dijkman and Arends (1994), who concluded that fluoride must be extracted from deeper parts within the matrix. Although the pattern of fluoride release in all media was the same, the highest values for each material were found ($P < 0.05$) in pH-cycling. Forss and Seppä (1990) showed that in acidic pH more fluoride is released.

Fluoride release was consistently higher in pH-cycling than in water, and the lowest value was observed in artificial saliva, statistically significant for all materials (Table 3), except for TET (very low concentrations, in the limit of electrode sensitivity). Glockman and others (1997) also showed that glass-ionomer cements released more fluoride in water than in artificial saliva. Meryon and Smith (1984) explained that a wide variety of methods were used to study fluoride release from dental materials containing fluoride; in most tests a sample of set material was suspended in water and, in some tests, artificial saliva was used (Meryon & Smith,1984; El-Mallakh & Sarkar, 1990). El-Mallakh and Sarkar (1990) showed that the values of fluoride release in water and in artificial saliva were consistently different, the highest values noted in the first medium, caused by the presence of cations and anions in artificial saliva, with an ionic effect on the solubility. In the present study, demineralizing and remineralizing solutions were used to reproduce a dynamic situation, because according to Cury (1993), dental caries represented a process of alternating demineralization and

Table 4. Fluoride Released (Means ± Standard Error) in Each Medium Considering the Materials (μg F/cm²)

	MEDIA		
MATERIALS	**H_2O**	**AS**	**DE-RE**
CHE	7.62 ± 0.73 A	1.26 ± 0.080 B	8.35 ± 0.51 B
VIT	5.91 ± 0.79 B	3.13 ± 0.360 A	12.27 ± 1.16 A
VAR	2.71 ± 0.25 C	0.80 ± 0.100 C	6.17 ± 0.24 D
DYR	1.50 ± 0.17 D	1.20 ± 0.050 B	7.82 ± 0.65 C
TET	0.14 ± 0.02 E	0.07 ± 0.003 D	0.28 ± 0.02 E

Means followed by the same letter do not differ statistically (Tukey, $P < 0.05$).

remineralization phenomena that were a direct function of conditions that maintain a critical pH in the mouth. In addition, the present model, suggested by Featherstone and others (1986), showed correlation with the development of in vivo caries in situations of high cariogenic challenge.

The results of the present study are in agreement with Forss and Seppä (1990), who observed that the acidic conditions during the daily demineralization period probably increased the release of fluoride through chemical erosion. These authors explained that low pH resulted in greater release of fluoride. Rezk-Lega, Ogaard, and Rolla (1990) showed that fluoride release from glass ionomer was a pH-controlled process, and a higher release in demineralizing solution than in remineralizing solution was shown by Martins and others (1991) and Modesto and others (1997). This could be the primary cariostatic mechanism for the studied materials. When the localized plaque pH dropped due to a cariogenic challenge (sugar intake), fluoride was released in that area by the restorative material. The increase in fluoride concentration changed the mineral saturation level favoring fluorapatite formation and reduced the effect of hydroxyapatite dissolution from enamel by the acid produced in dental plaque (Larsen, 1990). Secondarily, when the plaque pH returned to the original level, the restorative material still released fluoride, which would enhance the remineralization of the enamel induced by salivary calcium and phosphate (Benelli & others, 1993).

Further, when means of fluoride released during the 15 days were compared in water, artificial saliva, and the pH-cycling system, changes were noted (Table 4) in the rank order of fluoride release from the various materials (water versus artificial saliva and water versus pH-cycling). El-Mallakh and Sarkar (1990) also observed a reversal behavior in fluoride release from glass ionomer in artificial saliva and deionized water, showing the necessity to consider the media used. So, if deionized water was considered, Chelon-Fil would be the best material for fluoride release. However, in artificial saliva and during cycling in demineralizing-remineralizing solutions, Vitremer had the best performance. While Chelon-Fil released 6.6 times more fluoride during pH-cycling than in saliva, Vitremer released 3.9 times more (Table 3). Furthermore, while Chelon-Fil released in deionized water 5.1 times more fluoride than Dyract, in demineralizing-remineralizing solutions the difference was only 1.1 times higher. The findings showed the relevance for considering the media used to evaluate the fluoride-release property of dental materials and the consequent comparative anticariogenic potential. This is important, because when different materials are compared, the performance of a glass-ionomer cement could be better or worse than a resin-modified glass ionomer or polyacid-modified resin according to the media used to evaluate them. These results have clinical significance when other properties of the materials are considered.

On the other hand, the rank order of fluoride release was not different when the materials were immersed in artificial saliva or pH-cycling solutions. However, the fluoride release between Chelon-Fil and Dyract was not statistically different in saliva, but in pH-cycling solutions there was a statistical difference (Table 4). In addition, while Vitremer released 2.6 times more fluoride than Dyract in saliva, in the de-remineralizing solutions the difference was lower (1.5 times).

Ten Cate (1990) affirmed that laboratory evaluation could simulate the oral environment. According to Ten Cate (1990), Cury (1993), and Cury and others (1993), caries was a dynamic process, and fluoride worked by inhibiting demineralization while enhancing the remineralization of teeth. So, in vitro evaluation of dental materials that release fluoride should take into account the pH-cycling in dental plaque. Thus, deionized water does not seem to be the most appropriate medium to compare the fluoride release from dental materials. In addition, changes occurred in the rank order of fluoride release from the various materials when other media were used. Although artificial saliva represents the oral environment, pH-cycling solutions would be preferable to evaluate the anticariogenic potential of dental materials, because they better represent the dynamic process of caries.

CONCLUSION

The data suggest that the rank of fluoride release from different dental materials changes when different media are used.

Acknowledgments

The authors thank Professor Rosana Cristina Pereira Parente, University of Amazonas, for the statistical analysis; Miss Mariza de Jesús Carlos Soares and Mr Waldomiro Vieira Filho, Laboratory of Biochemistry, Faculty of Dentistry of Piracicaba, for the technical assistance; Dr Cinthia Pereira Machado Tabchoury for English correction. This publication was based on a thesis submitted, by the first author, to the Faculty of Dentistry of Piracicaba, University of Campinas, in partial fulfillment of the requirements for an MS degree in dental materials.

(Received 29 July 1997)

References

BENELLI EM, SERRA MC, RODRIGUES AL Jr & CURY JA (1993) *In situ* anticariogenic potential of glass ionomer cement *Caries Research* **27** 280-284.

BRAVERMAN I & HATIBOVIC-KOFMAN S (1997) Microleakage and fluoride release from glass ionomer, compomer and amalgam restorative materials *Journal of Dental Research* **76** *Abstracts of Papers* p19 Abstract 41.

COOLEY RL, SANDOVAL VA & BARNWELL SE (1988) Fluoride release and color stability of a fluoride-containing composite resin *Quintessence International* **19** 899-904.

CRANFIELD M, KUHN AT & WINTER GB (1982) Factors relating to the rate fluoride-ion release from glass-ionomer cement *Journal of Dentistry* **10** 333-341.

CURY JA (1993) Fluoride therapy In *Advanced Operative Dentistry* São Paulo: Quintessence pp 43-67.

CURY JA, SAAD JRC & RODRIGUES AL Jr (1993) Fluoride release from sealant in water, saliva and demineralizing-remineralizing solutions *Revista Gaúcha de Odontologia* **41** 273-275 (in Portuguese).

De ARAUJO FB, GARCÍA-GODOY F, CURY JA & CONCEIÇÃO EN (1996) Fluoride release from fluoride-containing materials *Operative Dentistry* **21** 185-190.

DERKSON GD, POON PJ & RICHARDSON AS (1982) Fluoride release from a silicophosphate cement with added fluoride *Journal of Dental Research* **61** 660-664.

DIJKMAN GEHM & ARENDS J (1994) Fluoride release from composites; a correlation with *in situ* data *Journal of Dental Research* **74** *Abstracts of Papers* p 950 Abstract 90.

EL-MALLAKH BF & SARKAR NK (1990) Fluoride release from glass-ionomer cements in de-ionized water and artificial saliva *Dental Materials* **6** 118-122.

FEATHERSTONE JDB, O'REILLY MM, SHARIATI M & BRUGLER S (1986) Enhancement of remineralization *in vitro* and *in vivo* In *Factors Relating to Demineralization and Remineralization of the Teeth* Oxford: IRL Press pp 23-34.

FORSS H & SEPPÄ L (1990) Prevention of enamel demineralization adjacent to glass ionomer filling materials *Scandinavian Journal of Dental Research* **98** 173-178.

FORSTEN L (1977) Fluoride release from a glass ionomer cement *Scandinavian Journal of Dental Research* **85** 503-504.

FORSTEN L (1991) Fluoride release uptake by glass ionomers *Scandinavian Journal of Dental Research* **99** 241-245.

GLOCKMAN E, SIGLISH B, GEHROLDT C & TRIEMER K (1997) Fluoride release of different types of glass ionomer cements *Journal of Dental Research* **76** *Abstracts of Papers* p 316 Abstract 2421.

HÖRSTED-BINDSLEV P & LARSEN MJ (1990) Release of fluoride from conventional and metal-reinforced glass-ionomer cements *Scandinavian Journal of Dental Research* **98** 451-455.

LARSEN MJ (1990) Chemical events during tooth demineralization *Journal of Dental Research* **69** 575-580.

MARTINS LRM, SERRA MC, FRANCISCHONE CE & CURY JA (1991) Fluoride release from glass-ionomer cements subjected to demineralization-remineralization cycles *Journal of Dental Research* **70** *Abstracts of Papers* p 638 Abstract 20.

McLEAN JW, NICHOLSON JW & WILSON AD (1994) Proposed nomenclature for glass-ionomer dental cements and related materials *Quintessence International* **25** 587-589.

MERYON SD & SMITH AJ (1984) A comparison of fluoride release from three glass ionomer cements and a polycarboxylate cement *International Endodontic Journal* **17** 16-24.

MODESTO A, CHEVITARESE O, CURY JA & VIEIRA AR (1997) Variglass fluoride release and uptake by an adjacent tooth *American Journal of Dentistry* **10** 123-127.

MUZYNSKI BL, GREENER E, JAMESON L & MALONE WF (1988) Fluoride release from glass ionomers used as luting agents *Journal of Prosthodontic Dentistry* **60** 41-44.

RASMUSSEN TE, HOLLIS RA & CHRISTENSEN RP (1996) Fluoride release from glass ionomer resins and composites *Journal of Dental Research* **75** *Abstracts of Papers* p 179 Abstract 1290.

RAWLS HR (1991) Preventive dental materials: sustained delivery of fluoride and other therapeutic agents *Advances in Dental Research* **5** 50-55.

REZK-LEGA F, OGARD B & ROLLA G (1991) Availability of fluoride from a glass-ionomer luting cements in human saliva *Scandinavian Journal of Dental Research* **99** 60-63.

SHAW AJ & McCABE JF (1997) Fluoride release from glass ionomer and compomer restorative materials *Journal of Dental Research* **76** *Abstracts of Papers* p 39 Abstract 203.

SWIFT EJ Jr (1989) Fluoride release from two composite resins *Quintessence International* **20** 895-897.

TAY WM & BRADEN M (1988) Fluoride ion diffusion from polyalkenoate (glass ionomer) cement *Biomaterials* **9** 454-456.

TEN CATE JM (1990) *In vitro* studies on the effect of fluoride on de- and remineralization *Journal of Dental Research* **69** 614-619

VERBEECK RM, de MOOR RJG, Van EVEN DF & MARTENS LC (1993) The short-term fluoride release of a hand-mixed vs capsulated system of a restorative glass-ionomer cement *Journal of Dental Research* **72** 577-581.

©OPERATIVE DENTISTRY, 1999, 24, 20-25

Radiopacity of Compomers, Flowable and Conventional Resin Composites for Posterior Restorations

M R BOUSCHLICHER • D S COBB • D B BOYER

Clinical Relevance
Utilization of materials ranked more radiopaque than enamel would enable clinicians to distinguish the initial increment of a posterior resin composite restoration from tooth structure.

SUMMARY

The objective of this study was to densitometrically determine the relative radiopacity (aluminum [Al]-equivalent values) of dentin, enamel, and 20 resin composite materials currently used for posterior restorations. Specimens 5 mm in diameter and 2 mm thick were fabricated from 20 materials (n = 7) for a total of 140 specimens. Human molars were longitudinally sectioned 2.0 mm thick to include both enamel and dentin. The optical densities of enamel, dentin, restorative materials, lead, and an aluminum step wedge were obtained from radiographic images, using a transmission photodensitometer. The Al equivalent (mm) for each material was calculated from the linear regression equation of the log of normalized optical density and Al mm thickness obtained from the step wedge.

A linear regression of the logarithm of normalized optical density and Al mm thickness was plotted (r^2 = 0.9953), and the relative radiopacities, expressed as equivalent thickness of Al, were ranked ordinally. All materials tested, with the exception of an unfilled resin adhesive, complied with ISO Standard 4049, being at least as radiopaque as a 2.0 mm thickness of 99.6% pure Al. Four of six flowable composites had radiopacity values that fell between that of dentin and enamel, while two materials were more radiopaque than enamel. The three compomers tested had radiopacities greater than enamel. In addition, all traditional light- and chemical-cure resin composite materials tested were more radiopaque than enamel.

All materials tested, with the exception of one adhesive resin, were at least as radiopaque as dentin and complied with ISO Standard 4049. Clinicians should be able to distinguish these restorative materials radiographically from recurrent decay, voids, gaps, or other defects that lead to clinical failure. Utilization of materials ranked more radiopaque than enamel would enable clinicians to distinguish the restorative material from tooth structure.

University of Iowa, Department of Operative Dentistry, S-245 Dental Science Building, Iowa City, IA 52242-1001

Murray R Bouschlicher, DDS, MS, assistant professor

Deborah S Cobb, DDS, MS, assistant professor

Daniel B Boyer, DDS, PhD, professor

INTRODUCTION

The use of posterior resin composite restorations as an alternative to amalgam has increased substantially over the past few years. This is due in part to a growing public demand for esthetic restorations, concerns about mercury-containing alloys, and improvements in resin composite materials (Leinfelder, 1991).

To assess the adequacy of posterior composite restorations both at baseline and recall examinations, it is important that composite materials used in class 2 and class 1 restorations be sufficiently radiopaque to be easily distinguished from tooth structure on a radiograph. Inadequate radiopacity decreases x-ray diagnostic information and can be a contributing factor in faulty interpretation, making it difficult to assess cavity wall adaptation, marginal gaps, voids, and recurrent decay. Adequate radiopacity also permits assessment of interproximal contour, contact point adequacy, and overhangs (Akerboom & others, 1993; Curtis, von Fraunhofer & Farman, 1990; Prevost & others, 1990).

While a composite with a radiopacity greater than dentin meets ISO standard 4049, several studies have indicated that a radiopacity equal to or greater than enamel is desirable (Curtis & others, 1990; Goshima & Goshima, 1990; Lutz & others 1984; Omer, Wilson & Watts, 1986). However, too high a level of radiopacity, such as with amalgam or cast metal restorations, may interfere with the diagnosis of recurrent decay and other defects (Espelid & others, 1991; Curtis & others, 1990; Stanford & others, 1987; Tveit & Espelid, 1986)

Historically, resin restorative materials used in posterior teeth have demonstrated a wide range of radiopacities (Abou-Tabl, Tidy & Combe, 1979; Cook, 1981; Stanford & others, 1987). While manufacturers state that their materials are radiopaque, there is no clear agreement on the degree of radiopacity that provides the best conditions for radiographic detection of caries and defects adjacent to restorations (Cook, 1981; Tveit & Espelid, 1986).

Requirements for the radiopacity of dental resins for use in class 1 and class 2 restorations have been established by the International Organization for Standardization (1988). ISO Standard 4049 specifies that the transmission densitometer reading of an x-ray image of a resin restorative specimen 2.0 mm-thick should be less than that of a 2.0 mm-thick 99.6% pure Al standard. Alternatively stated, a resin restorative specimen 2.0 mm thick should have a radiopacity, expressed in Al equivalent (mm) or % Al, that exceeds that of a 2.0 mm-thick 99.6% pure Al standard. Prior studies have found this Al standard to be comparable in radiopacity to an equivalent thickness of dentin (Curtis & others, 1990; El-Mowafy & Benmergui, 1994; Abou-Tabl & others, 1979; Stanford & others, 1987).

The clinical success of posterior composite restorations depends upon the integrity of the bond and marginal adaptation to tooth structure. In spite of improvements in adhesive systems and composite materials, polymerization shrinkage remains a significant problem associated with adhesive resin composite restorations. Stresses from polymerization shrinkage are a primary cause of marginal separation between a restoration and tooth (Feilzer, de Gee & Davidson, 1987). Marginal gaps and resultant microleakage can lead to tooth sensitivity, staining, and recurrent caries (Eick & Welch, 1986). Since the gingival margins of class 2 composites are particularly vulnerable to microleakage and subsequent secondary caries, it is crucial that the first increment of resin restorative material placed in the approximal box of a posterior class 2 be sufficiently radiopaque to facilitate evaluation of the tooth-restoration interface.

Resins with a high elastic modulus (stiffer) or faster rates of polymerization increase shrinkage stresses, making restorations more prone to marginal gap formation. Flowable composites, compomers, and chemical-cure composites have been advocated to reduce the adverse effects of polymerization shrinkage. Flowable composites with a low modulus and increased flexibility are believed to ameliorate the stresses of polymerization shrinkage and better preserve the integrity of the bond to tooth structure. In addition, their rheological properties or "flowability," compared to conventional composites, may improve adaptation to the cavity preparation and decrease the possibility of air entrapment during placement. Chemical-cure resin composites have a reduced rate of polymerization, which allows an extended viscous flow period, which allows for a reduction of polymerization shrinkage stresses compared to their light-cured counterparts (Feilzer, de Gee & Davidson, 1993; Bouschlicher, Vargas & Boyer, 1997).

Prior studies have found a wide range of radiopacities for posterior resin composite materials. The radiopacity of these contemporary materials is clinically relevant in establishing their appropriateness for use in the technique-sensitive initial increment of class 2 restorations, where evaluation of the tooth restorative interface is critical.

The principal aim of this study was to determine the relative radiopacities, expressed in Al equivalent (mm) or % Al, of 20 posterior resin restorative materials, and compare them to enamel and dentin.

METHODS AND MATERIALS

Using a split metal mold, specimens measuring 5.0 mm in diameter and 2.0 mm thick were made

Table 1. Restorative Materials and Manufacturers

Material	Type	Manufacturer
Dentin		
Enamel		
All-Bond 2 D/E Resin	Unfilled adhesive resin	Bisco Dental Products, Itasca, IL 60143
OptiBond FL Adhesive	Filled adhesive resin	Kerr Corp, Orange, CA 92557
AeliteFlo	Flowable composite	Bisco Dental Products
FloRestore	Flowable composite	Den-Mat Corp, Santa Maria, CA 93456
Flow-It	Flowable composite	Jeneric/Pentron Inc, Wallingford, CT 06492
Revolution	Flowable composite	E&D Dental Products Inc, Somerset, NJ 08873
Tetric-Flow	Flowable composite	Ivoclar-Vivadent, Amherst, NY 14228
Ultraseal XT	Flowable composite	Ultradent Products Inc, South Jordan, UT 84095
Compoglass	Compomer	Ivoclar-Vivadent
Dyract	Compomer	L D Caulk/Dentsply, Milford, DE 19963
Hytac Aplitip	Compomer	ESPE America, Norristown, PA 19404
Bis-Fil-2B	Chemical-cure composite	Bisco Dental Products
Heliomolar RO	Microfill composite	Ivoclar-Vivadent
Charisma	Hybrid composite	Heraeus Kulzer Inc, Irvine, CA 92718
Herculite XRV Dentin	Hybrid composite	Kerr Corp
Herculite XRV Enamel	Hybrid composite	Kerr Corp
Restorative Z-100	Hybrid composite	3M Dental Products, St Paul, MN 55144
TPH	Hybrid composite	L D Caulk/Dentsply
Pertac II	Hybrid composite	ESPE America
Prodigy	Hybrid composite	Kerr Corp

from a group of materials used in direct posterior resin composite restorations (Table 1). Two adhesive resins, nine posterior resin composites, three compomers, and six "flowable" or "low-modulus" resin composite materials were included in this evaluation. The latter two categories of materials were included for comparison as they have been advocated for use in the initial increment(s) of class 2 and class 1 posterior restorations. Seven samples were prepared for each resin material and polymerized 40 seconds using a Elipar II curing light (ESPE America, Norristown, PA 19404) with a power density > 500 mW/cm^2. Enamel and dentin specimens were obtained from 2.0 mm-thick longitudinal sections of recently extracted human third molars. Specimen thickness was measured with a micrometer, and specimens were sanded using #320 carbide paper to 2.0 mm (± 10 μm).

Radiographs were made including one specimen from each of the 20 materials, dentin, enamel, and an aluminum step wedge, using Eastman Kodak Ektaspeed E occlusal film (Eastman Kodak Co, Rochester, NY 14650). Films were exposed for 0.4 seconds at 70 kV, 10 mA, and a 400 mm target film distance with a Gendex Model 1000 (certified unit ± 5 % for kV and mA and time interval) x-ray machine (Gendex Dental Division of Dentsply International, Milwaukee, WI 53207). Films were developed in a Dent-X Model 9000 film processor using fresh chemicals (Dent-X, Elmsford, NY 10523).

An aluminum step wedge, which included a lead specimen, provided nine increments of aluminum thickness and served as the internal standard for each sample exposure. The lead specimen included in the top step of the aluminum step wedge was used as a correction for inherent film fog.

The optical density of each radiographic image was measured using an X-Rite Model 331 B/W Transmission Densitometer with a 1 mm aperture (X-Rite, Inc, Grandville, MI 49418). Three readings were taken from each specimen's radiographic image. Each radiograph included 20 resins or resin composites, enamel, dentin, lead, and nine steps of the aluminum step wedge (33 specimens x 3 readings each). Three densitometer readings of an area without a specimen image were recorded to provide an optical density value for zero specimen thickness. The optical density value for each specimen in a sample (individual film) was the arithmetic mean of the three readings. The mean and standard deviation of the independent samples were calculated for each of the

34 densitometer readings enumerated. The log of the mean optical density of the specimen's radiographic image corrected for inherent film fog ($D_t - D_{Pb}$) divided by the mean optical density of zero sample thickness corrected for inherent film fog ($D_0 - D_{Pb}$) was plotted on the y-axis and the corresponding thickness of mm Al standard was plotted on the x-axis according to Beer's law: $ln(I / I_0) = -kt$, where I_0 is the incident energy, I is the transmitted energy, k is the absorption coefficient of the material and t is the sample thickness. Substituting the densitometer readings, corrected for inherent film fog, resulted in the following equation:

$$ln\left(\frac{D_t - D_{Pb}}{D_0 - D_{Pb}}\right) = -kt \text{ or alternatively } \left(\frac{D_t - D_{Pb}}{D_0 - D_{Pb}}\right) = e^{-kt}$$

Aluminum equivalent (mm) and % Al for each material as well as enamel and dentin were calculated from the linear regression equation $D_t = D_{Pb} + (D_0 - D_{Pb})\, e^{-kt}$.

RESULTS

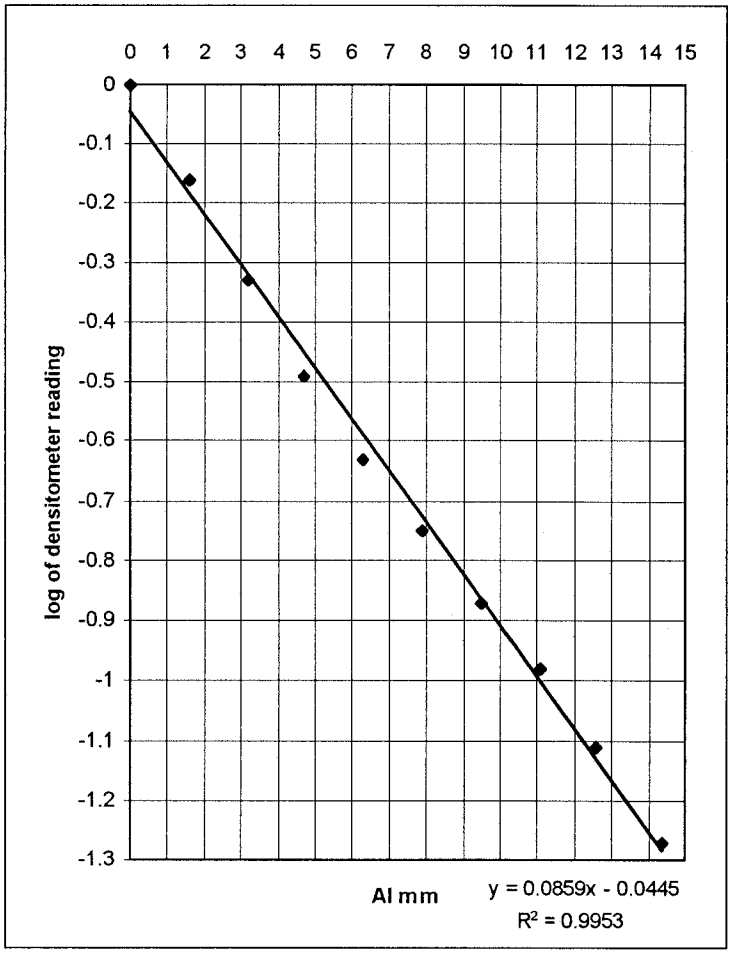
The linear regression plot of the logarithm of normalized optical density and Al mm thickness is plotted in the figure. The regression equation $y = -0.085x - 0.1049$ had a linear correlation (r^2) value of 0.9953. All resin composites evaluated in this study complied with ISO Standard 4049 and had radiopacities ≥ that of dentin. Ordinal rankings of radiopacity expressed as Al equivalent (mm) and % Al of each of the restorative materials, as well as enamel and dentin, are listed in Table 2. Al equivalent (mm) and % Al are directly related to degree of radiopacity, while densitometer readings are inversely related to radiopacity. Al 100% means that a sample with a thickness of 2 mm has the same radiopacity (optical density) as 2 mm of Al. If a restorative material has radiopacity greater than 100% Al or an optical density less than an equivalent thickness of Al, the material complies with ISO Standard 4049.

The unfilled adhesive resin evaluated in this study was radiolucent, while the filled adhesive, Opti-Bond FL, was similar in radiopacity to dentin. Three of the flowable composites (FloRestore, AeliteFlo, and Revolution) had radiopacities that fell between those of dentin and enamel. The mean radiopacity of Ultraseal XT was statistically equivalent to dentin. Two flowable composites (Flow-It and Tetric Flow) had radiopacities greater than enamel. All compomers tested (Hytac Aplitip, Dyract, and Compoglass) were more radiopaque than enamel. In addition, the chemical-cure composite, Bis-Fil-2B, and all of the traditional light-cure materials evaluated (Charisma, Heliomolar, HXRV Enamel, HXRV Dentin, Z-100, TPH, and Pertac II) had radiopacity values that exceeded that of enamel.

DISCUSSION

The results of this study indicated that all materials tested, with the exception of one unfilled adhesive resin, had radiopacities equal to or greater than dentin (compliance with ISO standard 4049). Fourteen of the 20 materials tested were more radiopaque than enamel.

The radiopacity values reported in this study (dentin = 1.99 mm Al or 100% Al; enamel = 3.29 mm Al or 165% Al) were similar to those reported by El-Mowafy and Benmergui (1994) (dentin = 116% Al; enamel = 184%), Williams and Billington (1987) (dentin = 100% Al; enamel = 210% Al), and Stanford and others (1987) (dentin =79% Al; enamel = 222% Al). ISO Standard 4049 includes recommendations for sample thickness, exposure time, film speed, target to film distance, kV, and mA. Studies conducted prior to the publication of the ISO standard had variable methods that make direct comparisons from study to study difficult. While interstudy comparisons are hazardous, the ordinal rankings of materials



Regression equation: densitometer readings vs Al (mm)

Table 2. Aluminum Equivalent (mm) of Resin, Composite, Enamel, and Dentin (2 mm Sample Thickness) and % Al Listed in Ascending Order of Radiopacity

Material	Densitometer Reading (SD)	Al Equivalent (mm)	% Al
All-Bond 2 D/E Resin	3.05 (0.07)	0.30	15
OptiBond FL Adhesive	2.34 (0.29)	1.88	94
Ultraseal XT	2.31 (0.07)	1.96	98
DENTIN	2.30 (0.07)	1.99	100
FloRestore	2.17 (0.07)	2.35	118
AeliteFlo	2.12 (0.07)	2.49	125
Revolution	2.08 (0.07)	2.61	131
ENAMEL	1.87 (0.05)	3.29	165
Bis-Fil-2B	1.80 (0.05)	3.54	177
Charisma	1.78 (0.04)	3.61	181
Heliomolar	1.75 (0.04)	3.73	187
Hytac Aplitip	1.73 (0.03)	3.80	190
Flow-It	1.70 (0.06)	3.92	196
Herculite XRV Dentin	1.63 (0.06)	4.20	210
Prodigy	1.63 (0.04)	4.20	210
Herculite XRV Enamel	1.59 (0.06)	4.37	219
Restorative Z-100	1.53 (0.04)	4.63	232
Dyract	1.52 (0.04)	4.68	234
Compoglass	1.50 (0.04)	4.77	239
TPH	1.48 (0.03)	4.86	243
Tetric-Flow	1.39 (0.04)	5.31	266
Pertac II	1.25 (0.04)	6.09	305

within individual studies relative to enamel, dentin, and Al standards should not be affected.

The degree of radiopacity required for optimal clinical radiographic evaluation in composite resins has been established by prior studies (Stanford & others, 1987; Tveit & Espelid, 1986). The ordinal ranking of the radiopacity of posterior composite materials established by this study should be used in conjunction with prior recommendations of optimal radiopacity. Materials that are less radiopaque than enamel may not be sufficiently radiopaque for use as an initial increment in posterior composite restorations. Four of the six flowable composites tested complied with ISO Standard 4049, but were less radiopaque than enamel (165% Al in this study). If "acceptable radiopacity" is defined as greater than enamel, then two flowable composites, Flow-It and Tetric Flow, demonstrated adequate radiopacity. If the initial increment of posterior restoration has a radiopacity ≅ dentin (100 % Al in this study) it may not be possible to detect the extent of the restoration, a small defect, or an overhang. Three compomers, a chemical-cure composite, and the eight light-cured composites tested had radiopacities greater than enamel.

The unfilled adhesive resin in this study was found to be radiolucent (15% Al). This could be problematic when trying to differentiate between a marginal gap, with potential for secondary caries, from a thick layer of bonding resin that has been applied too liberally. Optibond FL, a filled bonding resin, had a radiopacity similar to that of dentin and may be of value in radiographically assessing resin adaptation to the gingival seat or pulpal floor of a cavity preparation.

CONCLUSIONS

Assuming that composite materials should have a radiopacity similar to or greater than that of enamel for optimal radiographic diagnosis, two flowable composites (Flow-It and Tetric Flow), all the compomers (Hytac Aplitip, Dyract, and Compoglass), the chemical cure (Bis-Fil 2B) and all eight light-cured composites tested were found to be suitable for class 1 and class 2 posterior composite resin restorations.

Acknowledgments

The authors would like to thank Bisco, Inc; Den-Mat Corp; E & D Dental Products; Jeneric Pentron,

Inc; Ultradent Products, Inc; ESPE America, Inc; Kerr Corp; and Ivoclar-Vivadent/Ivoclar North America, Inc for supplying materials used in this study.

(Received 12 August 1997)

References

ABOU-TABL ZM, TIDY DC & COMBE EC (1979) Radiopacity of composite restorative materials *British Dental Journal* **147** 187-188.

AKERBOOM HB, KREULEN CM, VAN AMERONGEN WE & MOL A (1993) Radiopacity of posterior composite resins, composite resin luting cements, and glass ionomer lining cements *Journal of Prosthetic Dentistry* **70** 351-355.

BOUSCHLICHER MR, VARGAS MA & BOYER DB (1997) Effect of composite type, light intensity, configuration factor and laser polymerization on polymerization contraction forces *American Journal of Dentistry* **10** 88-96.

COOK WD (1981) An investigation of the radiopacity of composite restorative materials *Australian Dental Journal* **26** 105-112.

CURTIS PM, Jr, VON FRAUNHOFER JA & FARMAN AG (1990) The radiographic density of composite restorative resins *Oral Surgery, Oral Medicine, Oral Pathology* **70** 226-230.

EICK JD & WELCH FH (1986) Polymerization shrinkage of posterior composite resins and its possible influence on postoperative sensitivity *Quintessence International* **17** 103-111.

EL-MOWAFY OM & BENMERGUI C (1994) Radiopacity of resin-based inlay luting cements *Operative Denistry* **19** 11-15.

ESPELID I, TVEIT AB, ERICKSON RL, KECK SC & GLASSPOOLE EA (1991) Radiopacity of restorations and detection of secondary caries *Dental Materials* **7** 114-117.

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

FEILZER AJ, de GEE AJ & DAVIDSON CL (1993) Setting stresses in composites for two different curing modes *Dental Materials* **9** 2-5.

GOSHIMA T & GOSHIMA Y (1990) Radiographic detection of recurrent carious lesions associated with composite restorations *Oral Surgery, Oral Medicine, Oral Pathology* **70** 236-239.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (1988) *ISO Standard 4049: Dentistry–Resin-based Filling Materials 7.11.1-4* Geneva, Switzerland: International Organization for Standardization.

LEINFELDER KF (1991) Using composite resin as a posterior restorative material *Journal of the American Dental Association* **122** 65-70.

LUTZ F, PHILLIPS RW, ROULET JF & SETCOS JC (1984) *In vivo* and *in vitro* wear of potential posterior composites *Journal of Dental Research* **63** 914-920.

OMER OE, WILSON NHF & WATTS DC (1986) Radiopacity of posterior composites *Journal of Dentistry* **14** 178-179.

PREVOST AP, FOREST D, TANGUAY R & DeGRANDMONT P (1990) Radiopacity of glass ionomer dental materials *Oral Surgery, Oral Medicine, Oral Pathology* **70** 231-235.

STANFORD CM, FAN PL, SCHOENFELD CM, KNOEPPEL R & STANFORD JW (1987) Radiopacity of light-cured posterior composite resins *Journal of the American Dental Association* **115** 722-724.

TVEIT AB & ESPELID I (1986) Radiographic diagnosis of caries and marginal defects in connection with radiopaque composite fillings *Dental Materials* **2** 159-162.

WILLIAMS JA & BILLINGTON RW (1987) A new technique for measuring the radiopacity of natural tooth substance and restorative materials *Journal of Oral Rehabilitation* **14** 267-269.

©OPERATIVE DENTISTRY, 1999, 24, 26-30

Retention of Microfilled and Hybrid Resin-based Composite in Noncarious Class 5 Lesions: A Double-blind, Randomized Clinical Trial

W D BROWNING • W W BRACKETT • R O GILPATRICK

Clinical Relevance
At 12 months no difference was found in the proportion of restorations retained between two groups of subjects, one group whose restorations were placed using a microfilled composite and the other a small-particle hybrid composite.

SUMMARY

This double-blind clinical trial was undertaken to compare the retention rate of restorative materials with contrasting stiffness in noncarious class 5 lesions. All restorations were placed using retraction cord and cotton roll isolation to more closely mimic the general practice setting. Thirty subjects with at least two lesions were recruited to participate in the study. Each subject received one restoration using Silux Plus and one using Z100. The assignment of material was randomized, and the subjects were unaware of which tooth had received which material. All restorations were placed with a fourth-generation adhesive liner, Scotchbond Multi-Purpose. Evaluations were performed at baseline, 6, and 12 months by two independent examiners unaware of the restoration's group identity. The restorations were evaluated using criteria developed by Cvar and Ryge in a forced-consensus model. Despite the fact that the two materials have widely different elastic modulus values, after 12 months no difference between the retention rates for the two groups was found, and both groups of restorations performed very well.

Medical College of Georgia, School of Dentistry, Department of Oral Rehabilitation, Augusta, GA 30912-1260

William D Browning, DDS, MS, assistant professor

William W Brackett, DDS, MS, assistant professor, University of Tennessee, College of Dentistry, Department of General Dentistry, Section of Operative Dentistry, Memphis, TN 38163

Russell O Gilpatrick, DDS, chair, University of Tennessee, College of Dentistry, Department of General Dentistry, Memphis, TN 38163

INTRODUCTION

Noncarious cervical lesions represent a significant dental health problem in America. The prevalence of these noncarious lesions has been estimated at between 31% and 56%, with 85% of the population showing some loss of tooth structure at the cervical (Levitch & others, 1994). The problem will become an increasingly significant one, because the mean

age of our population is increasing and our citizens are retaining more of their teeth.

A decision to restore this type of lesion is complicated by several factors. First is lack of understanding of the natural history of this type of lesion. The profession lacks knowledge of how rapidly or slowly these lesions develop, and what the potential sequelae are for unrestored lesions. These issues make it difficult for us to establish criteria about which lesions should be restored.

A second consideration is that we do not have a sound understanding of the etiology of these lesions. Traditionally they have been described as erosion and abrasion lesions, and more recently as abfraction lesions, citing tooth flexure as a possible cause. The possibility that these lesions develop from a multiplicity of causes has not been fully investigated (Bader & others, 1993). The terms presently used to describe these lesions all imply a known etiology, but since it is not possible at this time to consistently determine the etiology of any given lesion, the terms are probably more misleading than helpful. The inability to identify a specific etiology may make it more difficult for clinicians to provide restorations that will provide patients with long-term clinical success. Lesions caused by flexure may require techniques and materials different than those caused by abrasion, erosion, or by a combination of causes. Indeed, dentists use a variety of materials and techniques when restoring this type of lesion.

Finally, the position of a typical lesion makes access and mechanical retention difficult to obtain, and often places the axial wall in close proximity to the pulp. Perhaps for all these reasons, secondary caries is common around this type of restoration (Baum, Phillips & Lund, 1985), and the longevity of class 5 resin-based composite restorations has been shown to compare poorly to that of other classes of composite restorations (Browning & Dennison, 1996).

Amalgam, resin-based composite, and glass ionomers have all been used to restore these lesions with some success, but the question of which material(s) and which technique(s) are best suited has not been definitively answered (Bader & others, 1993; Iacopino & Wathen, 1993; Kaplan & others, 1993; Powell, Johnson & Gordon, 1995; Van Meerbeek & others, 1993). While Van Meerbeek and others (1993) achieved a 99% retention rate over 2 years with Scotchbond 2 and Silux Plus, Powell and others (1995) found the retention rate achieved with these same two materials to be only 87%. In the same study the authors also found that a glass-ionomer restorative (Ketac-Fil, ESPE/Premier, Norristown, PA 19404) and a resin-based composite restorative utilizing a dentin bonding agent and with a glass-ionomer liner (Silux Plus with Scotchbond 2 and Vitrebond, 3M Dental Products, St Paul, MN 55144) had a retention rate that was statistically superior to Silux Plus and Scotchbond 2. The authors theorized that, relative to the resin-based composite restorations placed with a dentin bonding agent, the superior retention of the glass-ionomer restorations may have resulted from their (1) greater flexibility, (2) decreased dependence on etching dentin, (3) ability to bond with the extra calcium ions available in these areas of sclerosed dentin, and (4) ability to tolerate the presence of moisture.

This project was undertaken to investigate the role that the stiffness of resin-based composite restorations, as measured by the elastic modulus, has on the clinical success of restorations placed in noncarious class 5 lesions. It was part of an ongoing effort to compare glass-ionomer restorative materials, resin-based composites, and compomer materials. In this particular phase we were comparing the retention rates of two groups of restorations placed in noncarious cervical lesions utilizing a fourth-generation dentin bonding agent (Scotchbond Multi-Purpose). One group consisted of restorations placed using a microfilled, resin-based composite (Silux Plus), while the other group was placed using a small-particle-hybrid resin-based composite (Z100, 3M Dental Products). The hypothesis that the proportion of restorations retained would be different for the two groups was tested against the hypothesis that there is no difference at a 5% significance level. In addition, the restorations were evaluated for color match, marginal discoloration, secondary caries, anatomic form, and marginal adaptation using the criteria developed by Cvar and Ryge (Cvar & Ryge, 1971). These observations are reported as well.

METHODS AND MATERIALS

A random sample of 30 patients with at least two noncarious cervical lesions were recruited from the health sciences campus and the surrounding community. These subjects were from 40 to 75 years old, were in good health, and were known to be available for follow-up at baseline, 6, 12, 18, and 24 months. No restrictions were placed on either the size or position of the lesion, and a wide variety of lesions were restored. One of the two teeth received a restoration placed with Silux Plus, while the other was restored with Z100. The assignment of materials was made randomly, and the patient was unaware of which tooth received which restoration. All restorations were placed by one operator.

After the patient's informed consent was received, the patient was offered the option of being anesthetized, and the operator proceeded according to the patient's desires. All teeth were isolated with

Table 1. Retention

		Silux Plus	
		Alfa	Charlie
Z			
1	Alfa	27	1
0			
0	Charlie	1	0

N = 29 pairs; $P > 0.05$ (matched pairs chi-square using exact binomial test).

Table 2. Secondary Caries

		Silux Plus	
		Alfa	Charlie
Z			
1	Alfa	27	1
0			
0	Charlie	0	0

N = 28 pairs.

retraction cord, cotton rolls, and Dri-angles (Dental Health Products, Youngstown, NY 14174). The tooth was cleansed with flour of pumice and water and rinsed thoroughly. A small bevel was placed on the incisal margin using a fine diamond (Brasseler USA, Savannah, GA 31419). No attempt to place mechanical retention on the gingival margin was made. Teeth were etched using 37% phosporic acid (Ultraetch, Ultradent Products Inc, South Jordan, UT 84095) for 15 - 20 seconds, rinsed thoroughly, and dried for 1 - 2 seconds with a gentle stream of air to avoid overdrying the dentin. Scotchbond Multi-Purpose primer and adhesive were placed according to the manufacturer's directions. All restorations were placed with a minimum of two increments, which were light cured for 40 seconds each. Finishing and polishing was accomplished with extra-fine diamonds (Brasseler USA).

After completion of the restoration, two independent examiners evaluated the restorations for color match, retention, marginal discoloration, secondary caries, anatomic form, and marginal adaptation according to the criteria developed by Cvar and Ryge (Cvar & Ryge, 1971). The examiners were unaware of which material had been used, thus creating a double-blind study. A forced-consensus model was used to determine a final rating when there was disagreement between examiners. The same evaluation procedures were repeated at 6 and 12 months, and color photographs were made at each evaluation.

The results were analyzed using a chi-square analysis for matched pairs. Since some cells in the two-by-two table contained less than five observations, an exact binomial test was used.

RESULTS

Ninety-seven percent of both the Silux Plus and the Z100 restorations were retained after 12 months (Table 1). One Silux Plus and one Z100 restoration

Table 3. Comparison of the Two Groups at Baseline

Category	Silux Plus*		Z100**	
Color Match	27	Alfa	29	Alfa
	3	Bravo	1	Bravo
	0	Charlie	0	Charlie
Marginal Discoloration	29	Alfa	28	Alfa
	1	Bravo	2	Bravo
	0	Charlie	0	Charlie
Anatomic Form	30	Alfa	29	Alfa
	0	Bravo	1	Bravo
	0	Charlie	0	Charlie
Marginal Adaptation	25	Alfa	28	Alfa
	5	Bravo	2	Bravo
	0	Charlie	0	Charlie

*Silux Plus: N = 30; **Z100: N = 30.

Table 4. Comparison of the Two Groups at 12 Months

Category	Silux Plus*		Z100**	
Color Match	20	Alfa	29	Alfa
	8	Bravo	1	Bravo
	0	Charlie	0	Charlie
Marginal Discoloration	24	Alfa	28	Alfa
	4	Bravo	2	Bravo
	0	Charlie	0	Charlie
Anatomic Form	28	Alfa	29	Alfa
	0	Bravo	1	Bravo
	0	Charlie	0	Charlie
Marginal Adaptation	24	Alfa	28	Alfa
	4	Bravo	2	Bravo
	0	Charlie	0	Charlie

*Silux Plus: N = 28 (1 restoration lost and 1 with secondary caries; **Z100: N = 29 (1 restoration lost).

had been lost. The number of pairs in which both restorations rated Alfa for retention was 27. There was one pair where the Z100 restoration rated Alfa while the Silux Plus restoration rated Charlie, and one pair of restorations where the Silux Plus restoration rated Alfa while the Z100 restoration rated Charlie. There were no pairs where both restorations rated Charlie for retention. There was no statistically significant difference between the two groups in terms of the proportion of restorations retained at 12 months. In addition, in one pair of restorations the Silux Plus restoration developed secondary caries, while the Z100 restoration rated Alfa for secondary caries. In 26 pairs both restorations were rated Alfa, and there were no pairs of restorations where the Z100 restoration was rated Charlie and the Silux Plus restoration Alfa (Table 2). Thus 97% of the Z100 restorations and 93% of the Silux Plus restorations were clinically successful after 12 months.

Comparisons between the two groups for color match, marginal discoloration, anatomic form, and marginal adaptation can be found in Tables 3 and 4. The groups are comparable for each evaluation criteria with the exception of color match. It would appear that the color match obtained with Z100 is superior to that of Silux Plus. The number of Z100 restorations rated Alfa for color match was 28, while for Silux Plus it was 20. The number rated Bravo was 1 and 8 for Z100 and Silux Plus respectively. Of the eight Silux Plus restorations rated Bravo for color match, three were rated Bravo at baseline and five other restorations originallv rated Alfa were rated Bravo at 12 months. The changes in ratings from baseline to 12 months for all categories can be seen in Table 5. The Silux Plus restorations were seen to change most from their baseline rating in the categories of color match and marginal discoloration, while for the Z100 restorations the changes were seen in the categories of marginal discoloration and marginal adaptation. No restorations in either group exhibited any change in anatomic form from baseline to 12 months.

Table 5. Changes in Ratings from Baseline to 12 Months

Category	Silux Plus*		Z100*	
Color Match	5	Alfa to Bravo	0	Alfa to Bravo
	0	Bravo to Charlie	0	Bravo to Charlie
Marginal Discoloration	3	Alfa to Bravo	5	Alfa to Bravo
	0	Bravo to Charlie	0	Bravo to Charlie
Anatomic Form	0	Alfa to Bravo	0	Alfa to Bravo
	0	Bravo to Charlie	0	Bravo to Charlie
Marginal Adaptation	0	Alfa to Bravo	5	Alfa to Bravo
	0	Bravo to Charlie	0	Bravo to Charlie

*Number of restorations in which the rating changed

DISCUSSION

If the ability of the restorative material to flex is critical to success in these noncarious class 5 lesions, one would expect to find that the Silux Plus group had a superior retention rate, since Z100 is substantially more stiff than Silux Plus: the elastic modulus of Z100 is 9.5 GPa and Silux Plus 21.0 GPa (Willems & others, 1992). Instead we see that the restorations in both groups have performed very well. The percentage of class 5 resin-based composite restorations that fail relatively quickly (Browning & Dennison, 1996) is surprisingly high, so 12 months, although it may not seem very long, should be a long-enough period to begin to observe evidence of a difference between these two groups if a significant difference exists. The ADA's revision of its acceptance program guidelines for dentin and enamel adhesive materials, which allows provisional acceptance after 6 months and full acceptance after 18 months, is further evidence to indicate that 12 months is a reasonable length of time in which to see some meaningful results. While Powell and others (1995) hypothesized that the superior performance of the glass-ionomer materials relative to Silux Plus was because of their greater flexibility, the elastic modulus for Ketac-Fil is very similar: 10.8 GPa (Beatty & Pidaparti, 1993).

It is also interesting to note that, while a fourth-generation bonding agent was used in this study, the results obtained thus far are on a par with those seen by Van Meerbeek and others (1993) and Powell and others (1995). The 3M Company estimated the bond strength to dentin obtained with Scotchbond 2 to be approximately 18 MPa and that for Scotchbond Multi-Purpose to be 30 MPa, a substantial improvement. The present findings make it reasonable to suspect that factors other than just the strength of the bond to dentin and the restorative material's ability to flex with the surrounding tooth are important to the retention of these restorations.

One such factor may be the ability of the restorative material to flow during setting, thus compensating for the stresses caused by polymerization shrinkage. Davidson, de Gee, and Feilzer (1984) noted that the shrinkage stress was particularly a problem in class 5 restorations because such a large proportion of the restorative material was in contact with tooth,

leaving a smaller free surface capable of flowing and compensating for this stress. Feilzer, de Gee, and Davidson (1988) also noted that the relatively slow development of shrinkage in glass ionomers may be an advantage when compared with resin-based composite. This seems to explain the difference in performance between Silux Plus and glass ionomers seen by Powell and others (1995) better than would a difference in the flexibility of the two materials.

Examining the data on the color match for the two groups, Silux Plus had more Bravo ratings (Table 3) and more changes in rating from baseline to 12 months. The operator in this study found less consistency between the color indicated by the shade guide and that obtained in the restoration for Silux Plus than for Z100. The shade obtained generally tended to be lighter than that indicated by the shade guide. The operator's clinical impression was that the change in ratings for the Silux Plus restorations (Table 5) resulted from a darkening of the tooth combined with a less-than-optimum color match at baseline rather than a lack of color stability in the material. The other apparent contrast between the two groups of restorations was in marginal adaptation. The Z100 group had more restorations change from an Alfa rating to a Bravo rating than the Silux Plus group (Table 5). One possible reason for this difference between the two groups might be that the brittleness of Z100 relative to Silux Plus could be expected to result in more chip fractures at the margin. Another possibility for this change in rating for marginal adaptation may be the re-establishment of a non-carious cervical lesion above the apical margin of the restoration. The clinical impression drawn from this project was that this was indeed the case. If this impression is true, one would have to wonder why this would occur more frequently with the hybrid composite rather than the microfill.

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

CONCLUSIONS

At 12 months there was no difference between the number of restorations retained in the two groups. Both groups of restorations performed well clinically.

(Received 19 August 1997)

References

BADER JD, LEVITCH LC, SHUGARS DA, HEYMANN HO & McCLURE F (1993) How dentists classified and treated non-carious cervical lesions *Journal of the American Dental Association* **124** 46-54.

BAUM LG, PHILLIPS RW & LUND MR (1985) *Textbook of Operative Dentistry*, 2nd edition, Philadelphia: Saunders p 282.

BEATTY MW & PIDAPARTI RVM (1993) Elastic and fracture properties of dental direct filling materials *Biomaterials* **14** 999-1002.

BROWNING WD & DENNISON JB (1996) A survey of failure modes in composite resin restorations *Operative Dentistry* **21** 160-166.

CVAR JF & RYGE G (1971) *Criteria for the Clinical Evaluation of Dental Restorative Materials, US Public Health Service Publication No 790-244* San Francisco: Government Printing Office.

DAVIDSON CL, de GEE AJ & FEILZER A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63** 1396-1399.

FEILZER AJ, de GEE AJ & DAVIDSON CL (1988) Curing contraction of composites and glass-ionomer cements *Journal of Prosthetic Dentistry* **59** 297-300.

IACOPINO AM & WATHEN WF (1993) Geriatric prosthodontics: An overview. Part II. Treatment considerations *Quintessence International* **24** 353-361.

JOYNT RB, DAVIS EL & SCHREIER PJ (1989) Rubber dam usage among practicing dentists *Operative Dentistry* **14** 176-181.

KAPLAN I, HARRIS EF, MINCER HH & GILPATRICK RO (1993) Microleakage of glass ionomer and composite resin restorations in cut non-retentive preparations and pre-existing cervical erosion/abrasion lesion *Journal of the Tennessee Dental Association* **73** 24-28.

LEVITCH LC, BADER JD, SHUGARS DA & HEYMANN HO (1994) Non-carious cervical lesions *Journal of Dentistry* **22** 195-207.

POWELL LV, JOHNSON GH & GORDON GE (1995) Factors associated with clinical success of cervical abrasion/erosion restorations *Operative Dentistry* **20** 7-13.

VAN MEERBEEK B, BRAEM M, LAMBRECHTS P & VANHERLE G (1993) Evaluation of two dentin adhesives in cervical lesions *Journal of Prosthetic Dentistry* **70** 308-314.

WILLEMS G, LAMBRECHTS P, BRAEM M, CELIS JP & VANHERLE G (1992) A classification of dental composites according to their morphological and mechanical characteristics *Dental Materials* **8** 310-319.

OPERATIVE DENTISTRY, 1999, 24, 31-37

Effect of Curing-Tip Diameter on the Accuracy of Dental Radiometers

D L LEONARD • D G CHARLTON • T J HILTON

Clinical Relevance
Some commercially available radiometers are poor indicators of the actual irradiance generated by visible-light polymerization units.

SUMMARY

The purpose of this study was to determine the accuracy of four commercially available radiometers when curing tips of different diameters were used. A visible-light curing unit (Optilux 500) with a new 80-watt quartz-halogen bulb (OptiBulb) was used as the light source for all measurements. The unit's irradiance value was measured using three hand-held radiometers (Demetron model #100, Cure-Rite model # 644726, and Coltolux Light Meter) and a built-in visible-light curing unit radiometer (Optilux 500). Measurements were made with four curing tips of diameters 4 mm, 7.5 mm, 10.5 mm, and 12 mm. For each tip, trials were made with five radiometers of each model. Student's *t*-tests at the 0.05 level of significance were used to compare the mean irradiance measured by each model of radiometer to the irradiance value measured by a laboratory-grade power meter. A one-way analysis of variance at the 0.05 level of significance was used to compare the irradiance values among the five samples of each commercially available radiometer model.

Except for the Optilux 500 built-in radiometer with the 10.5-mm tip, all the commercially available radiometers exhibited irradiance values significantly different from those of the laboratory-grade power meter. There were no statistically significant differences among the five samples of each commercially available radiometer model.

USAF Dental Investigations Service, Brooks AFB, TX 78235-5117

Daniel L Leonard, Lt Col, USAF, DC, Officer-in-Charge, Equipment Evaluation

Daniel G Charlton, Lt Col, USAF, DC, Officer-in-Charge, Materials Evaluation

Thomas J Hilton, Colonel, USAF, DC, Chief

INTRODUCTION

Visible-light curing units are indispensable in the practice of dentistry. They are commonly used to cure restorative materials such as composite resin, resin-reinforced glass ionomers, polyacid-modified composite resins, and pit-and-fissure sealants. In addition, visible-light curing units are required for

most bonding systems, an increasing number of bases and liners, various luting agents, and some provisional restorations. Adequate polymerization of these materials depends on the light-source intensity (irradiance), wavelength, and curing time. Unless all three are adequate, the materials will incompletely polymerize and exhibit poor physical properties that may lead to early failure (Rueggeberg, Caughman & Curtis, 1994; Cook, 1982).

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

Degradation of individual components and disinfection/sterilization procedures can adversely affect the output of light units. The output of curing lights has been shown to diminish over time due to degradation of the light bulb and reflector (Friedman, 1989), autoclaving of the light wand (Rueggeberg, Caughman & Comer, 1996), and exposure of the wand to at least one brand of glutaraldehyde disinfectant (Dugan & Hartleb, 1989). In addition, decreased line voltage has been shown to adversely affect the intensity of curing lights (Fan & others, 1987). The breakage and crazing of the optical fibers of the curing tip and damage to internal filters (e g, blistering, cracking) all have a detrimental effect on irradiance (Barghi, Berry & Hatton, 1994). For these reasons, periodic evaluation of the light's output is indicated.

There are a number of methods that can determine the adequacy of curing lights. Some of these include simple scrape tests (Leung, Kahn & Fan, 1984), incremental surface hardness evaluations (Denyer & Shaw, 1982), and Fourier Transform Infrared Analysis (FTIR) (Ruyter & Gyorosi, 1976; Ruyter & Svendsen, 1978; Asmussen, 1982; Ferracane & Greener, 1984). The scrape test, while easily performed in the dental office, gives no indication of the quality of cure, especially in the deeper levels adjacent to the soft resin that is removed (Leung & others, 1984; Yearn, 1985). Incremental surface hardness tests and FTIR require laboratory testing equipment and are therefore not practical for the routine clinical testing of irradiance.

The easiest method for determining adequate irradiance is the commercially available radiometer. Several studies have determined that simple, hand-held, dental radiometers provide an accurate means of correlating irradiance and depth of cure (Pires & others, 1993; Lee & others, 1993; Fowler, Swartz & Moore, 1994; Shortall, Harrington & Wilson, 1995; Rueggeberg, 1993).

Early curing lights were provided with a single curing tip. These were usually approximately 7 to 8 mm in diameter. Because light units are being used for a broader range of clinical applications, manufacturers have developed additional tip sizes and shapes. The commercially available hand-held radiometers have a fixed-diameter aperture and a detector that calculates irradiance based on the area of the fixed aperture. The irradiance values measured by these fixed-aperture radiometers may be inaccurate when larger- or smaller-diameter curing tips are used, because irradiance is a measure of power divided by the area of the light source. The purpose of this study was to determine the accuracy of four commercially available radiometers when curing tips of different diameters were used.

METHODS AND MATERIALS

Three commercial hand-held radiometers (Demetron model # 100, Demetron Research Corporation, Danbury, CT 06810; Caulk Cure-Rite model # 644726, L D Caulk, Milford, DE 19963; Coltolux Light Meter, Coltene/Whaledent Inc, Mahwah, NJ 07430) and a built-in visible-light curing unit radiometer (Demetron Optilux 500, Demetron) were used in this study. Five of each model of radiometer were measured. The irradiance values measured by the commercially available radiometers were compared to the values determined by a laboratory-grade power meter (PowerMax 500D with PM10 Probe, Molectron Detector, Inc, Portland, OR 97224).

A Demetron Optilux 500 visible-light curing unit (Demetron) with a new 80-watt quartz-halogen Demetron OptiBulb (Demetron) was used as the light source for all measurements. The bulb was "burned-in" intermittently (20 minutes on and 5 minutes off) for 3 hours until the intensity stabilized as measured with the PowerMax 500D meter. The filtering system in the Optilux 500 was scanned using a Cary 5G UV-VIS-NIR Spectrophotometer (Varian Associates, Sugarland, TX 77478) and found to restrict the passage of light to wavelengths between 400 and 520 nm. The spectral radiance of the Demetron

Table 1. Measured Irradiance (mW/cm²)

	4 mm Tip	7.5 mm Tip	10.5 mm Tip	12 mm Tip
PowerMax 500D	2574 ± 49	893 ± 6	749 ±12	547 ± 7
Coltolux	789 ± 18	1030 ± 8	1237 ± 21	1086 ± 23
Cure-Rite	890 ± 16	876 ± 22	861 ± 35	715 ± 23
Demetron Model 100	713 ± 33	812 ± 25	834 ± 35	690 ± 20
Demetron Built-In	684 ± 34	738 ± 28	752 ± 12	618 ± 27

Mean +/- one standard deviation; n = 5.

Optilux 500 was determined by an Optronic Laboratories Model OL 754 Spectroradiometer (Optronic Laboratories, Orlando, FL 32811) and found to range from 400 nm to 520 nm with the peak wavelength at 492 nm. According to individual manufacturer specifications, the Demetron radiometers are reported to be sensitive to wavelengths between 400 nm and 520 nm and the Caulk and Coltolux radiometers are sensitive to wavelengths between 400 nm and 525 nm. The wavelengths of light from the Demetron Optilux 500 fell within the range of all the commercial radiometers. Although the PowerMax 500D meter is sensitive to a much broader wavelength range (190 nm to 11 microns), it was restricted in this study from detecting wavelengths outside the 400 nm to 520 nm wavelength. Therefore, because the commercial radiometers and the PowerMax 500D meter were measuring the same light source and wavelengths, the laboratory-grade power meter could be used to evaluate the accuracy of the commercial radiometers.

Power to the Demetron Optilux 500 light was routed through a Powerstat variable autotransformer (Superior Electric Company, Bristol, CT 06010), which maintained a constant line voltage by negating the effect of transient line voltage fluctuations on light intensity (Fan & others, 1987). The voltage to the Demetron Optilux 500 was maintained at 110 volts and confirmed with a Fluke 87 Multimeter (John Fluke Manufacturing, Everett, WA 98201).

The irradiance was measured by five separate units of each model of commercial radiometer and the PowerMax 500D meter for each of four Demetron curing tips with diameters of 4 mm, 7.5 mm, 10.5 mm, and 12 mm. For the commercial radiometers, the curing tip was placed in contact with the aperture window as per the manufacturer's instructions. Irradiance measurements with the laser power meter were made with the curing tip 1 mm from the detector to prevent damage to the detector. Three 60-second exposures of the curing unit, spaced 1 second apart, were performed before any measurements were made to eliminate the possibility of intensity variations resulting from a cool bulb (Rueggeberg, 1993). After this warm-up sequence, the light-intensity measurements were made 20 seconds into a 40-second exposure. The bulb was allowed to cool for 5 minutes after every 20 minutes of use to prevent any possibility of damage to the bulb or filter from prolonged continuous use.

A set rotation of individual radiometer/curing tip diameter combinations was used to facilitate five separate tests of each individual radiometer/curing tip diameter combination. Each test consisted of the mean of three intensity measurements taken in succession. The rotation was designed to equally distribute the order of measurements taken by all individual radiometer/curing tip diameter combinations to negate the effect of any intensity variations due to the source light.

The means and standard deviations of these five tests were calculated for each individual radiometer/curing tip diameter combination. For each model radiometer/curing-tip diameter combination, a Student's *t*-test at the 0.05 level of significance was used to compare the irradiance measured by each model of radiometer to the irradiance measured by the PowerMax 500D. A one-way analysis of variance at the 0.05 level of significance was used to compare the irradiance values among the five samples of each commercially available radiometer model.

RESULTS

The data are reported in Tables 1 and 2 and depicted graphically in Figures 1- 4. Table 1 presents the mean

Table 2. Percentage Error Compared to PowerMax 500D (n =5)

	4 mm Tip	7.5 mm Tip	10.5 mm Tip	12 mm Tip
Coltolux	226% ↓	13% ↑	39% ↑	50% ↑
Cure-Rite	186% ↓	2% ↓	13% ↑	23% ↑
Demetron Model 100	261% ↓	10% ↓	10% ↑	21% ↑
Demetron Built-In	276% ↓	21% ↓	0%	11% ↑

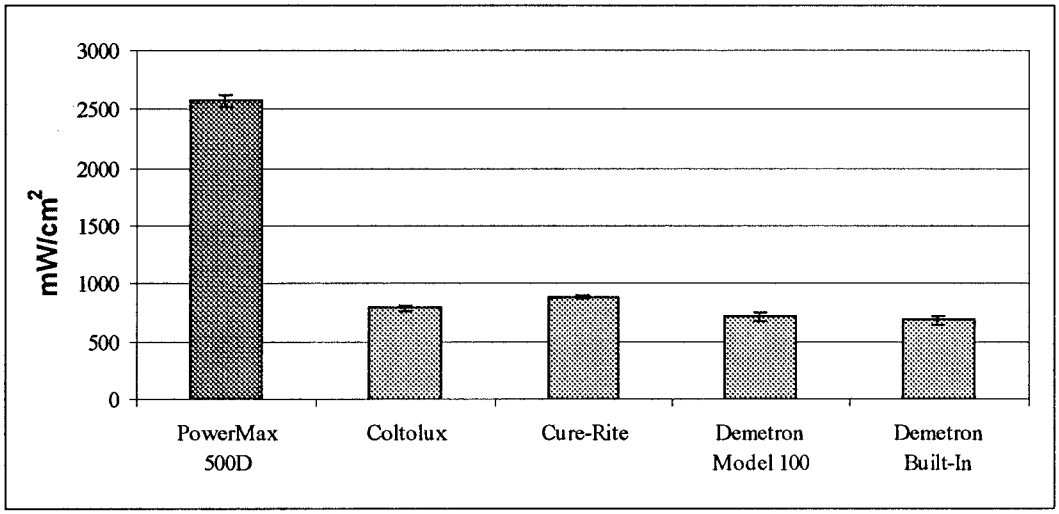


Figure 1. *Irradiance values measured with 4 mm tip. Brackets indicate +/- one standard deviation. All experimental groups statistically different from PowerMax 500D at* $P < 0.05$.

irradiance values measured by each brand of radiometer and the PowerMax 500D. Table 2 reports the percentage error for each brand of radiometer either above or below the correct irradiance as measured by the PowerMax 500D. Except for the Demetron built-in radiometer with the 10.5-mm tip, all the commercially available radiometers exhibited irradiance values significantly different from those of the PowerMax 500D. There were no statistically significant differences among the five samples of each commercially available radiometer model.

DISCUSSION

Because of the large number of light-activated dental materials, visible-light curing units have become a common piece of equipment in dental offices. Their proper performance is crucial to optimizing the physical properties of light-activated materials. An accurate method is needed to detect decreases in light output due to degradation of the light from sterilization/disinfection, voltage fluctuations, or lack of periodic maintenance. The hand-held dental radiometer is a relatively inexpensive and simple means of monitoring light performance. Unfortunately, little has been published on the accuracy of the measurements provided by commercial radiometers.

The accuracy of the commercially available radiometers used in this study varied widely depending on the diameter of the curing tip. This is essentially due to the fact that irradiance is a function of power per unit area. A curing light, therefore, exhibits different irradiance values when tested with different diameter tips. For example, in this study irradiance values of the same curing light ranged from 547 mW/cm² for the 12 mm tip to 2574 mW/cm² for the 4 mm tip when measured with the laboratory-grade laser power meter. In general, given the same light source, larger-diameter tips provide lower irradiance (mW/cm²) values than smaller-diameter tips. Because of their lower irradiance values, larger-diameter tips may be less effective than smaller-diameter tips in polymerizing light-activated materials. Liberman and others (1990) found that the degree of composite resin polymerization was significantly greater when a tip with a smaller surface area was used than a tip with a larger surface area.

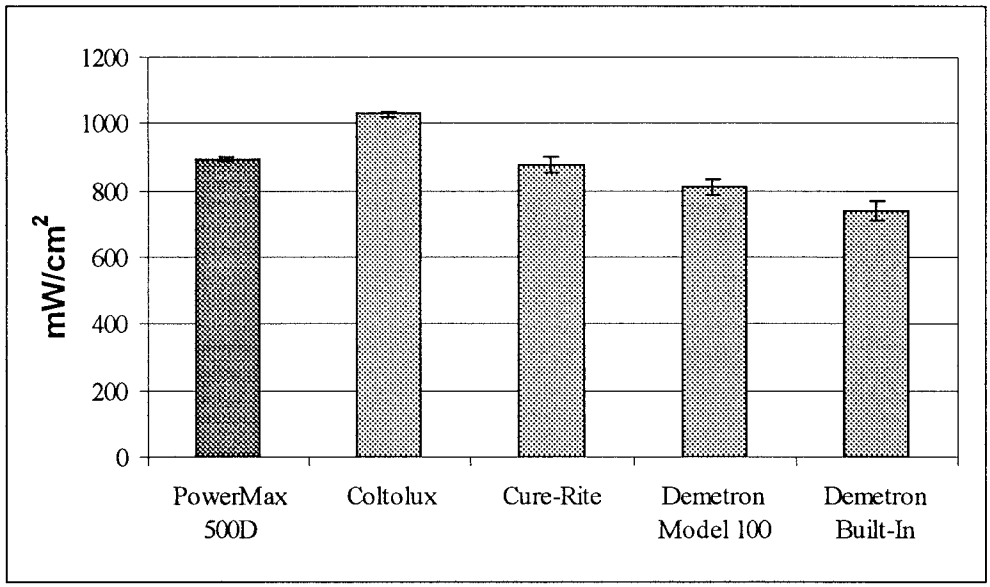


Figure 2. *Irradiance values measured with 7.5 mm tip. Brackets indicate +/- one standard deviation. All experimental groups statistically different from PowerMax 500D at* $P < 0.05$.

Inadequate polymerization has been associated with inferior physical properties, higher solubility, retention failures, and adverse pulpal responses due to unpolymerized monomers (Council on Dental Materials, 1985; Blankenau & others, 1991).

Perhaps the more important finding of this study is that some commercially available radiometers are inaccurate. This occurs, in large part, because commercial radiometers have fixed apertures. While the PowerMax 500D measures all the light intensity from the curing tip regardless of the diameter, the commercial radiometers have fixed apertures and measure light restricted to the size of the aperture. These instruments have been calibrated to take the intensity and calculate irradiance based on the area of their fixed aperture independent of the source tip diameter. As a result, these radiometers do not differentiate between tips of different diameters.

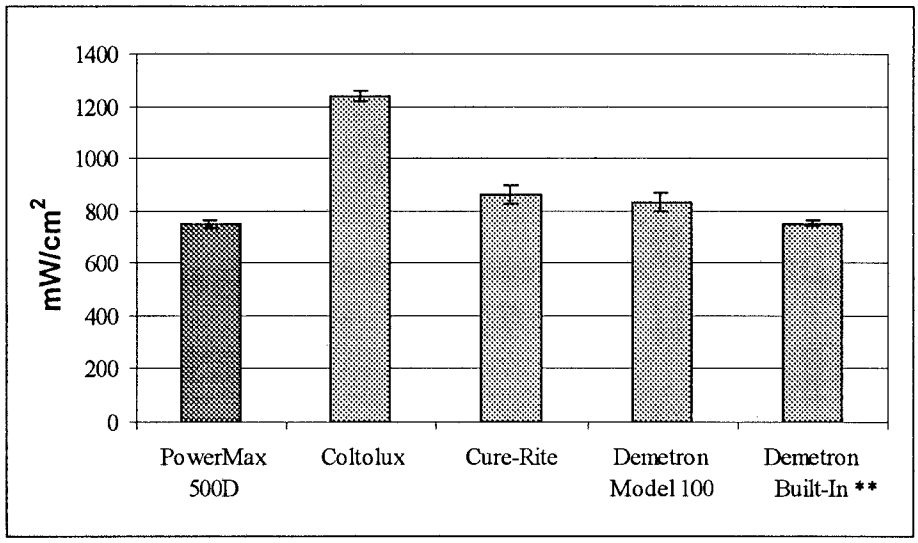


Figure 3. *Irradiance values measured with 10.5 mm tip.* ***Not statistically different from PowerMax 500D at* $P < 0.05$.

The data from this study indicate that fixed-aperture radiometers (i e, commercially available units) overestimate irradiance from larger-diameter tips and underestimate irradiance from smaller-diameter tips. These inaccuracies occur because the commercial radiometers calculate irradiance as if the light is coming from the same-diameter tip regardless of tip size. All the commercial radiometers in this study have an aperture diameter larger than the 4 mm tip and all gave irradiance values much less than actually existed. The commercial radiometers consistently reported greater irradiance values than actually existed when the 12 mm tip was used. For the 7.5 mm tip, the commercial radiometers gave lower readings than actually existed with the exception of the Coltolux meter, which reported higher irradiances than expected. With a 10.5-mm tip, overestimation of the actual irradiance occurred for all commercial radiometers with the exception of the built-in Demetron radiometer, which reported the correct irradiance.

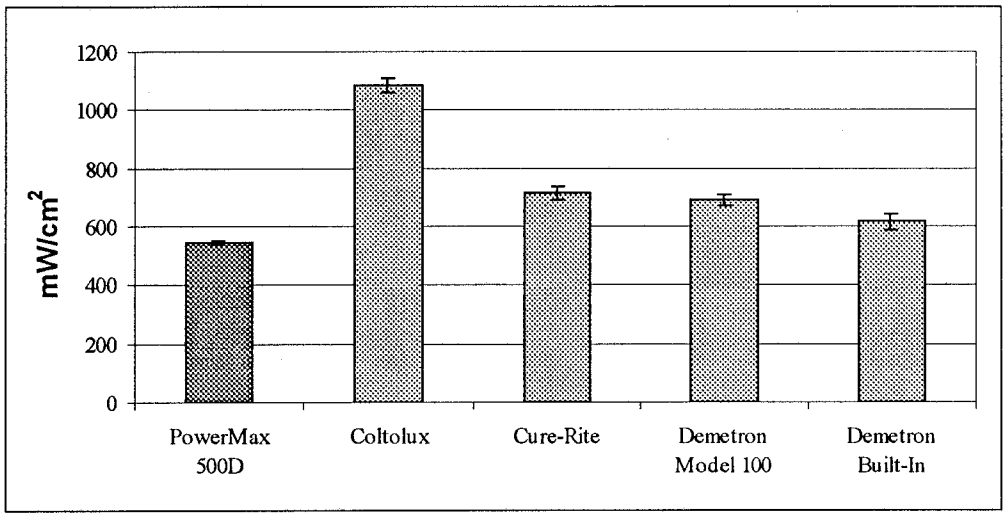


Figure 4. *Irradiance values measured with 12 mm tip. Brackets indicate +/- one standard deviation. All experimental groups statistically different from PowerMax 500D at* $P < 0.05$.

The data indicate that, depending on the combination of radiometer and tip size, radiometer irradiance measurements may vary from the actual, true value by up to 276%. More importantly, inaccurately high radiometer readings of up to 50% were recorded using various radiometer tip combinations. If this inaccuracy holds true throughout the irradiance range of the visible-light curing unit, the impact of this on clinical procedures could be substantial. If light units are being measured that have irradiance values close to the minimally acceptable value (i e, $\approx$ 300 mW/cm^2), the actual light output would be inadequate for curing purposes.

Some clinicians believe that the ultimate test of their radiometer's accuracy (and, therefore, their light unit's adequacy) is a tactile examination of the dental material's surface hardness following polymerization. Studies have shown, however, that surface hardness alone is a poor indicator of the degree of polymerization in the deeper areas of composite resins (Fowler & others, 1994; Rueggeberg & Jordan, 1993; Myers, Caughman & Rueggeberg, 1994; Pires & others, 1993). The clinician would be unaware of the decreased polymerization because surface hardness would appear clinically acceptable even with the lower irradiance. At the composite surface a sufficient number of photons are available, even at reduced irradiance values, to initiate polymerization. However, at deeper layers, adequate irradiance is a much more important factor, because the overlying composite resin at the surface causes photon scattering and absorption, which adversely affects the degree of polymerization (Rueggeberg & Jordan, 1993).

To ensure that clinicians obtain the most accurate readings from their radiometers, they should carefully read and follow the manufacturer's instructions. A cursory review of the operating instructions often leaves the user with the impression that tip diameter is unimportant and that as long as the curing light's irradiance is at least 300 mW/cm^2 it is operating adequately. In fact, all the manufacturers recommend readings be taken with the same-diameter tip when comparing light output of the curing light over time. Demetron states their radiometers can accommodate tip diameters of 8 mm to 13 mm but qualifies the statement by mentioning that some curing lights display lower readings for larger (11 mm-in-diameter) tips than for smaller (8 mm-in-diameter) tips. Coltolux claims their radiometer is accurate as long as an 8 mm-in-diameter tip is used.

Analysis of the data in this study revealed that units of the same model by a manufacturer consistently gave similar irradiance values. This indicates good manufacturing practices and quality control. However, when comparing different manufacturers' radiometers, significantly different values were obtained. For example, with the 12 mm tip, the Demetron built-in radiometer measured 618 mW/cm^2 while the Coltolux radiometer measured 1086 mW/cm^2. Similar differences were noted for tips with other diameters. Generally, the Coltolux radiometer gave much higher irradiance values than the other three hand-held radiometers.

CONCLUSIONS

The effect of different-diameter curing tips on the accuracy of four commercially available radiometers was evaluated by comparing them to a laboratory-grade laser power meter. The results indicate that the commercially available radiometers used in this study are poor indicators of the actual irradiance generated by visible-light polymerization units. The degree of inaccuracy of their values also varied based on the diameter of the tip being measured. The commercial radiometers generally gave irradiance values that were from 11% to 50% higher than actually existed for the 12 mm-in-diameter tip and gave irradiance values that were from 186% to 276% lower than actually existed for the 4 mm-in-diameter tips. The commercial radiometers tended to be more accurate when measuring irradiance with 7.5 mm and 10.5 mm tips. The irradiance values of different brands of radiometers varied; however, values from model to model within the brands, while inaccurate, were consistent.

Commercial radiometers, despite their limitations, are still a valuable tool for the practitioner to monitor curing lights. If used correctly, they provide a quick and relatively inexpensive means of assessing curing-light performance. Initial baseline irradiance with a new bulb should be compared to subsequent irradiance values over time using the same-diameter tip. Their use should be limited to this function only, and the irradiance values obtained should not be considered absolute.

Acknowledgment

We thank L D Caulk, Coltolux/Whaledent, and Kerr/Demetron for supplying the radiometers used in this study.

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

(Received 19 August 1997)

References

ASMUSSEN E (1982) Factors affecting the quantity of remaining double bonds in restorative resin polymers *Scandinavian Journal of Dental Research* **90** 490-496.

BARGHI N, BERRY T & HATTON C (1994) Evaluating intensity output of curing lights in private dental offices *Journal of the American Dental Association* **125** 992-996.

BAYNE SC & TAYLOR DF (1995) Dental materials In *The Art and Science of Operative Dentistry* St Louis: Mosby p 260.

BLANKENAU RJ, KELSEY WP, POWELL GL, SHEARER GO, BARKMEIER WW & CAVEL WT (1991) Degree of composite resin polymerization with visible light and argon laser *American Journal of Dentistry* **4** 40-42.

COOK WD (1982) Spectral distributions of dental photopolymerization sources *Journal of Dental Research* **61** 1436-1438.

COUNCIL ON DENTAL MATERIALS (1985) Visible light-cured and activating units *Journal of the American Dental Association* **110** 100-103.

DENYER R & SHAW DJ (1982) Cure evaluation of visible light composites by Knoop hardness measurement *Journal of Dental Research* **61** *Abstracts of Papers* p 272 Abstract 833.

DUGAN WT & HARTLEB JH (1989) Influence of a glutaraldehyde disinfecting solution on curing light effectiveness *General Dentistry* **37** 40-43.

FAN PL, WOZNIAK WT, REYES WD & STANFORD JW (1987) Irradiance of visible light-curing units and voltage variation effects *Journal of the American Dental Association* **115** 442-445.

FERRACANE JL & GREENER EH (1984) Fourier transform infrared analysis of degree of polymerization in unfilled resins—methods comparison *Journal of Dental Research* **63** 1093-1095.

FOWLER CS, SWARTZ ML & MOORE BK (1994) Efficacy testing of visible-light-curing units *Operative Dentistry* **19** 47-52.

FRIEDMAN J (1989) Variability of lamp characteristics in dental curing lights *Journal of Esthetic Dentistry* **1** 189-190.

LEE SY, CHIU CH, BOGHOSIAN A & GREENER EH (1993) Radiometric and spectroradiometric comparison of power outputs of five visible light-curing units *Journal of Dentistry* **21** 373-377.

LEUNG RL, KAHN RL & FAN PL (1984) Comparison of depth of polymerization evaluation methods for photo-activated composites *Journal of Dental Research* **63** *Abstracts of Papers* p 292 Abstract 1095.

LIBERMAN R, BEN-AMAR A, URSTEIN M & JUDES H (1990) The photocure attachment lens: its effect on polymerization of visible-light-cure resin composite. *Dental Materials* **6** 10-12.

McCABE JF & CARNICK TE (1989) Output from visible-light activation units and depth of cure of light-activated composites *Journal of Dental Research* **68** 1534-1539.

MYERS ML, CAUGHMAN WF & RUEGGEBERG FA (1994) Effect of restoration composition, shade, and thickness on the cure of a photoactivated resin cement *Journal of Prosthodontics* **3** 149-157.

PIRES JA, CVITKO E, DENEHY GE & SWIFT EJ Jr (1993) Effects of curing tip distance on light intensity and composite resin microhardness *Quintessence International* **24** 517-521.

RUEGGEBERG FA (1993) Precision of hand-held dental radiometers *Quintessence International* **24** 391-396.

RUEGGEBERG FA, CAUGHMAN WF & COMER RW (1996) The effect of autoclaving on energy transmission through light-curing tips *Journal of the American Dental Association* **127** 1183-1187.

RUEGGEBERG FA, CAUGHMAN WF & CURTIS JW Jr (1994) Effect of light intensity and exposure duration on cure of resin composite *Operative Dentistry* **19** 26-32.

RUEGGEBERG FA & JORDAN DM (1993) Effect of light-tip distance on polymerization of resin composite *International Journal of Prosthodontics* **6** 364-370.

RUYTER IE & GYOROSI PP (1976) An infrared spectroscopic study of sealants *Scandinavian Journal of Dental Research* **84** 396-400.

RUYTER IE & SVENDSEN SA (1978) Remaining methacrylate groups in composite restorative materials *Acta Odontologica Scandinavica* **36** 75-82.

SHORTALL AC, HARRINGTON E & WILSON HJ (1995) Light curing unit effectiveness assessed by dental radiometers *Journal of Dentistry* **23** 227-232.

YEARN JA (1985) Factors affecting cure of visible light activated composites *International Dental Journal* **35** 218-225.

©OPERATIVE DENTISTRY, 1999, 24, 38-44

Hardening of New Resin Cements Cured through a Ceramic Inlay

O M EL-MOWAFY • M H RUBO • W A EL-BADRAWY

Clinical Relevance
Among a group of eight dual-cure resin cements, some had hardness values obtained through self-curing less than 50% of those obtained through dual-curing. Ceramic inlay thickness of more than 2 mm inhibited maximum hardening of a number of the cements.

SUMMARY

This study investigated the degree of hardening achieved through self-curing only and through dual-curing a group of eight new resin-based cements. In addition, the effect of ceramic inlay thickness on cement hardness was determined. Disk specimens measuring 6 mm in diameter and 2.5 mm thick were prepared from eight cements: Adherence, Choice, Duolink, Enforce, Lute-It, Nexus, Resinomer, and Variolink. Eight specimens were prepared from each material; half were self-cured, while the remainder were dual-cured. Knoop hardness measurements were then made at 1-hour, 1-day, and 1-week intervals. In addition 12 specimens of the same dimensions were prepared from each cement and were dual-cured through ceramic spacers of varying thickness (1 - 6 mm). Hardness measurements were made as above. ANOVA showed significant differences in hardness of self-cured versus dual-cured specimens for all cements ($P < 0.0001$). Significant differences were also found in the hardness of specimens dual-cured through ceramic spacers 2-3 mm in thickness or more compared with those that were dual-cured without spacer. It is concluded that for some materials self-curing alone was not adequate to achieve sufficient hardening; cement hardness was significantly reduced when ceramic inlay thickness was 2-3 mm or more.

University of Toronto, Faculty of Dentistry, Department of Restorative Dentistry, 124 Edward Street, Toronto, Ontario M5G 1G6, Canada

Omar M El-Mowafy, BDS, PhD, FADM, associate professor

Marcia H Rubo, DDS, MSc, former graduate student

Wafa A El-Badrawy, BDS, MSc, assistant professor

INTRODUCTION

Applications of resin cements have increased considerably over the last few years. They are the materials of choice for cementation of ceramic inlay and onlay restorations, indirect resin composite

restorations, ceramic crowns, as well as porcelain veneers. They can also be used for cementation of posts, both cast and prefabricated, as well as cast metal restorations and crown and bridge work. According to their method of polymerization, resin cements can be classified into three main categories: self-cured cements, used mostly for cementation of metallic restorations and posts; light-cured cements, used for cementation of porcelain veneers; and dual-cured cements, used for cementation of ceramic inlay and onlay restorations, indirect resin composite restorations, and ceramic crowns.

With increasing public concern about mercury-containing amalgam restorations, dentists are now forced to use alternative restorative materials, particularly the ones that are esthetic. These include ceramic inlays and onlays. Dual-cure cements, which are typically used for cementation of such restorations, polymerize chemically upon mixing of a base and catalyst components (self-curing) and also when subjected to light from a light-curing unit. During cementation of an inlay restoration, the peripheral parts of the cement interface, mainly at the occlusal aspect, are about the only parts that can benefit largely from both self- and light-curing, as they are readily accessible to the curing light. Polymerization of the more remote parts of the cement, for example at the gingival floor of the cavity, rely more extensively on the self-curing component of the polymerization system. Studies have indicated that self-curing alone was insufficient for dual-cure cements to achieve maximum hardening (Darr & Jacobson, 1995; El-Badrawy & El-Mowafy, 1995; Linden & others, 1991). In one recent study that investigated seven different dual-cured cements (El-Badrawy & El-Mowafy, 1995), one of the cements completely failed to harden when self-curing only was used. Other studies reported adverse effects of increasing ceramic inlay thickness on hardening of light-cured and dual-cured resin cements (Blackman, Barghi & Duke, 1990; Chan & Boyer, 1989; El-Badrawy & El-Mowafy, 1995; Uctasli, Hasanreisoglu & Wilson, 1994). Furthermore, Hasegawa, Boyer, and Chan (1991), who studied the hardening of three dual-cured cements under resin composite inlays, reported that self-curing alone did not completely harden the cements when light was attenuated by tooth and restorative material. Thus, it is important for newly manufactured dual-cure cements to be formulated in such a way so that they are capable of achieving a sufficient degree of hardening with or without light-curing.

This study evaluated the hardening of a group of eight new dual-cure inlay resin cements when self-cured only and when dual-cured. Also, the effect of ceramic inlay thickness on the hardening of the cements was investigated.

Table 1. The Eight Dual-Cure Resin-based Cements Examined in This Study

Material	Manufacturer	Shade(s) Used
Adherence M[5]	Confi-Dental Products Louisville, CO 80027	Light yellow/ light gray
Choice	Bisco, Inc Itasca, IL 60143	A1 / B1
Duolink	Bisco, Inc	One shade provided
Enforce	Dentsply/Caulk Milford, DE 19963	A2 / C2
Lute-It	Jeneric/Pentron Inc Wallingford, CT 06492	Light/dark
Nexus	Kerr USA Orange, CA 92667	Neutral/dark
Resinomer	Bisco, Inc	One shade provided
Variolink	Vivadent Schaan, Liechtenstein	Yellow/brown

METHODS AND MATERIALS

Eight dual-cure resin-based cements were examined in this study (Table 1), one of which was a polyacid-modified resin cement (Resinomer). Following manufacturers' instructions for proportioning and mixing, four disk specimens measuring 2.5 mm thick and 6 mm in diameter were prepared from each cement using steel rings. When a selection of cement shades was available in the provided kit, middle-range shades were selected (Table 1). Each ring was placed on a glass plate lined with a Mylar strip, filled with the mixed cement, and covered with another Mylar strip-lined glass plate. The two glass plates were pressed together with a clamp and were maintained in darkness in a box at 37° C without light-curing. Another set of four specimens were prepared from each cement in the same manner as above; however, these were subjected to light from a light-curing unit for 60 seconds from one surface only. Prepared specimens were stored at 37 °C until testing. Using a Tukon 300 microhardness tester (Acco Industries Inc, Wilson Instrument Division, Bridgeport, CT 06602) with a Knoop indenter and 30 g weight, the surface microhardness of each specimen was determined at 1-hour, 1-day, and 1-week intervals. Five readings were obtained from each specimen at each test interval. Mean Knoop

Table 2. Means and Standard Deviations, in Parentheses, of KHNs Obtained from Self-cured Specimens of the Examined Cements at the Three Test Intervals

Material	1-Hour	1-Day	1-Week
Enforce	32.1 (1.3)	42.0 (1.8)	42.9 (2.9)
Nexus	29.2 (1.9)	38.5 (1.8)	38.5 (1.3)
Choice	26.1 (2.2)	39.2 (3.8)	39.7 (2.8)
Lute-It	25.6 (4.6)	32.4 (6.4)	34.6 (6.4)
Duolink	15.9 (1.5)	20.7 (1.8)	21.2 (2.3)
Resinomer	15.6 (1.2)	30.0 (2.1)	32.3 (2.5)
Adherence M[5]	11.5 (3.4)	16.0 (4.0)	16.2 (4.7)
Variolink	7.7 (1.1)	9.3 (0.8)	10.0 (1.7)

Vertical bars indicate mean KHNs that were not significantly different ($P > 0.05$).

Table 3. Means and Standard Deviations, in Parentheses, of KHNs Obtained from Dual-cured Specimens of the Examined Cements at the Three Test Intervals

Material	1-Hour	1-Day	1-Week
Duolink	47.4 (2.2)	55.9 (2.6)	57.1 (3.0)
Lute-It	47.4 (2.2)	57.0 (1.9)	57.5 (2.6)
Nexus	45.4 (1.9)	50.8 (2.1)	52.1 (1.8)
Enforce	44.1 (2.0)	51.4 (2.5)	52.1 (2.4)
Variolink	44.5 (2.6)	50.1 (2.4)	53.8 (2.4)
Resionomer	33.1 (1.7)	44.3 (1.1)	44.6 (1.8)
Adherence M[5]	36.5 (1.6)	44.1 (2.2)	44.8 (2.4)
Choice	36.2 (1.9)	45.8 (2.6)	48.4 (3.8)

Vertical bars indicate mean KHNs that were not significantly different ($P > 0.05$).

hardness numbers (KHNs) were calculated for each material at the three test intervals. Data were analyzed statistically using three-way ANOVA and Duncan's tests.

The effect of inlay thickness on the degree of cement hardening was assessed in a second part of this investigation. This procedure was carried out by applying the light through ceramic spacers of varying thickness (1 through 6 mm) during specimen preparation. A set of six ceramic spacers were cut from Cerec Vita Blocks (Vita Zahnfabrik, Bad Säckingen, Germany) shade A2C. These were used during the preparation of 12 specimens from each cement material in the manner described above; however, prior to light application a ceramic spacer was placed between the top surface of the specimen and the curing light source. For each cement material two specimens were prepared using one spacer thickness at a time. Specimens were stored at 37 °C until testing. Knoop hardness measurements were made in the same manner as above. Mean KHNs were calculated and data analyzed statistically using three-way ANOVA and Duncan's tests.

Using a light radiometer (Cure Rite, model # 8000, EFOS Inc, Williamsville, NY 14221), the curing light intensity was measured directly and through the six ceramic spacers in order to determine the degree of light attenuation as it passed through the different spacers.

RESULTS

Tables 2 and 3 record mean KHNs and standard deviation values of self-cured and dual-cured specimens of all examined cements at the three test intervals. Generally, KHNs were lower when self-curing alone was used compared to dual-curing. At 1 hour, Variolink's mean KHN from self-cured specimens was less than 25% of that from dual-cured ones; while for Adherence, Duolink, and Resinomer, mean KHNs from self-cured specimens were less than 50% of those from dual-cured specimens. All cements, however, showed increases in hardness with time for both curing methods. For one cement (Resinomer), the mean KHN from self-cured specimens increased to 68% of the value from dual-cured specimens at 1 day and to 72% at 1 week. ANOVA revealed significant differences in KHNs among the cements ($P < 0.0001$) and also significant difference in KHNs between self- and dual-curing ($P < 0.0001$). At the three test intervals, Lute-It and Duolink had the highest KHNs when the specimens were dual cured (Table 3), while Enforce had the significantly highest KHN for the self-cured specimens (Table 2). In contrast, at 1 hour Resinomer had the significantly lowest KHN (33.1) when the specimens were dual-cured , and Resinomer and Adherence had the significantly lowest KHNs when the specimens were dual cured at 1 day and 1 week.

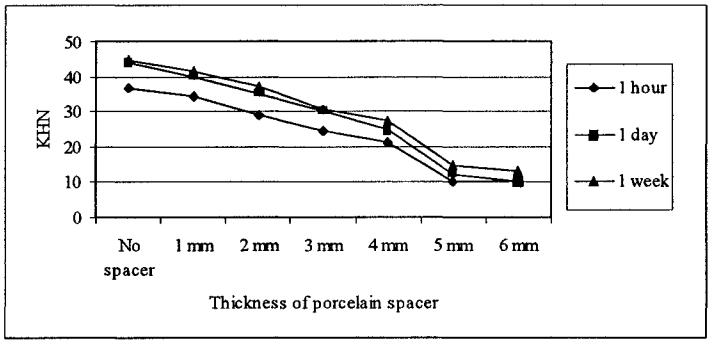


Figure 1. *Mean KHNs for Adherence obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

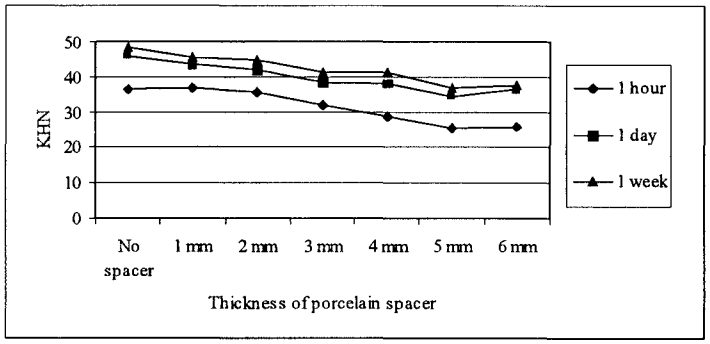


Figure 2. *Mean KHNs for Choice obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

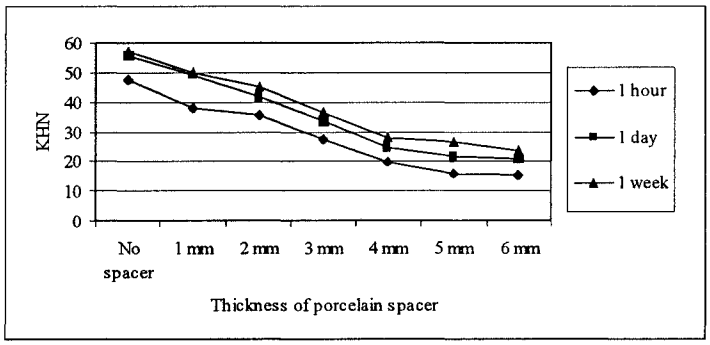


Figure 3. *Mean KHNs for Duolink obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

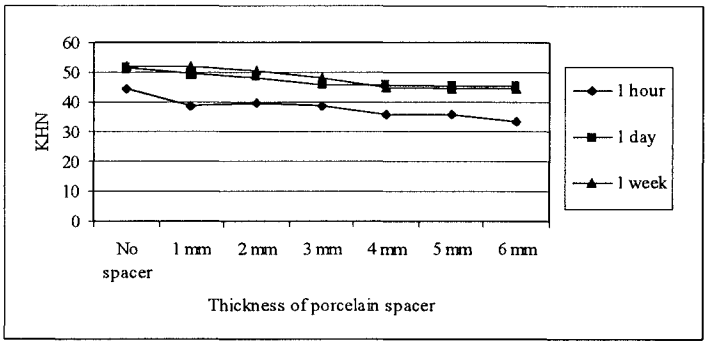


Figure 4. *Mean KHNs for Enforce obtained with the six ceramic spacers at the three test intervals. Mean KHNs without spacer were included for comparison.*

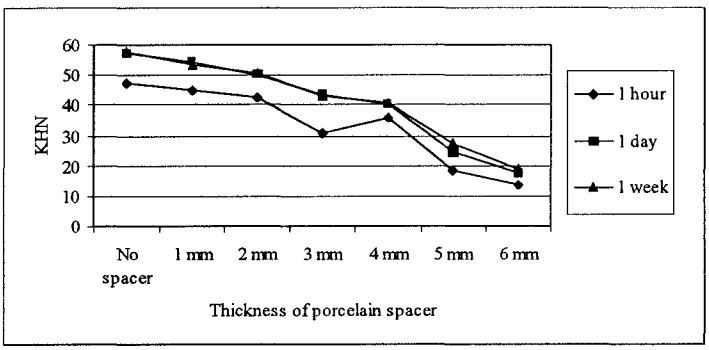


Figure 5. *Mean KHNs for Lute-It obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

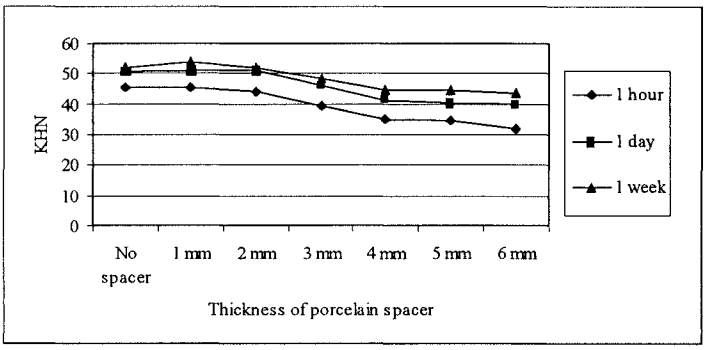


Figure 6. *Mean KHNs for Nexus obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

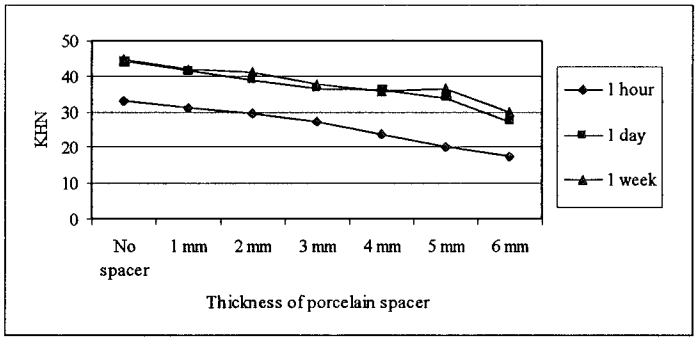


Figure 7. *Mean KHNs for Resinomer obtained with the six ceramic spacers at the three test intervals. Mean KHNs without spacer were included for comparison.*

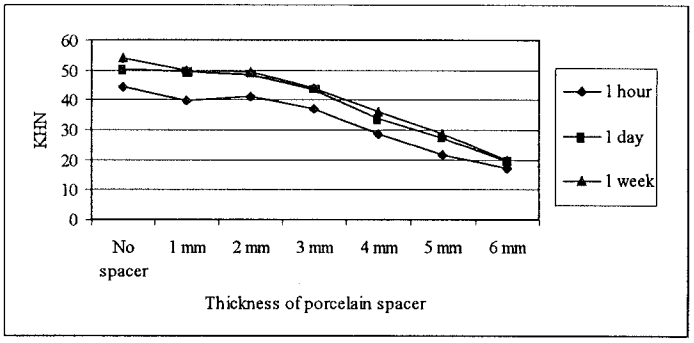


Figure 8. *Mean KHNs for Variolink obtained with the six ceramic spacers at the three test intervals. Mean KHNs obtained without spacer were included for comparison.*

Variolink had the significantly lowest KHNs when the specimens were only self-cured at the three test intervals. For four cements there was no significant difference in KHNs obtained at 1 day and 1 week (Adherence, Duolink, Enforce, and Nexus).

In the second part of this study when specimens were cured through ceramic spacers, there was a tendency for hardness to decrease gradually with increasing thickness of the spacer. However, the degree of decrease varied among the eight cements (Figures 1-8). ANOVA revealed significant differences in KHNs among the materials ($P < 0.0001$) and among different spacer thicknesses ($P < 0.0001$). For Adherence, decreases in KHN ranging from 69 to 74% occurred when spacer thickness was increased from 1 mm to 6 mm at the three test intervals (Figure 1). Mean KHNs for Adherence with the six spacers were significantly different at the three test intervals with the exception of KHNs at 5 and 6 mm spacers, while for Choice, decreases in KHN ranging from only 16 to 29% occurred when spacer thickness increased from 1 to 6 mm at the three test intervals (Figure 2). Significant decreases in KHNs of Choice occurred when spacer thickness was more than 2 mm for the three test intervals. For Duolink, KHNs decreases ranging from 54 to 59% occurred when spacer thickness increased from 1 to 6 mm at the three test intervals (Figure 3). Significant decreases in KHNs of Duolink occurred when spacer thickness was 2 mm or more for the three test intervals. In contrast, Enforce had decreases in KHNs ranging from only 9 to 14% when spacer thickness increased from 1 to 6 mm at the three test intervals (Figure 4). Enforce's KHNs decreased significantly when spacer thickness was 3 mm or more at 1 day and 1 week. For Lute-It, decreases in KHNs ranging from 66 to 69% occurred when spacer thickness increased from 1 to 6 mm at the three test intervals (Figure 5). All KHNs obtained for this cement were significantly different at the three test intervals. In contrast, Nexus had decreases in KHNs ranging from only 18 to 29% when spacer thickness increased from 1 to 6 mm at the three test intervals (Figure 6). KHNs for Nexus decreased significantly when spacer thickness was 3 mm or more. For Resinomer, mean KHNs decreased when spacer thickness increased from 1 to 6 mm by 29 - 45% at the three test intervals (Figure 7). KHNs for Resinomer decreased significantly when spacer thickness was more than 2 mm at 1 hour and 1 week. Variolink's mean KHNs deceased by 61 to 66% when the spacer thickness increased from 1 to 6 mm (Figure 8). Significant decreases in KHNs of Variolink occurred when the spacer thickness was more than 2 mm.

Figure 9 gives radiometer readings of light intensity of the light-curing unit when it was measured with and without spacers. Through only 1 mm ceramic spacer there was a decrease in light intensity of about 75%. Beyond 1 mm, light intensity continued to decrease gradually with increasing thickness of the ceramic spacer until light was totally obstructed at 6 mm.

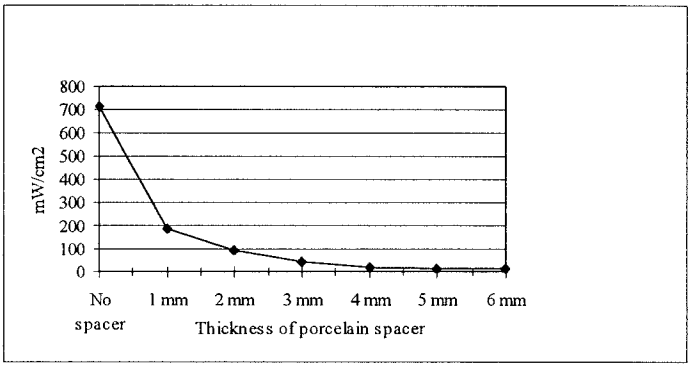


Figure 9. *Curing-light intensity measurements made with and without ceramic spacers. Note the significant drop in light intensity with merely 1 mm ceramic spacer.*

DISCUSSION

Ideally, dual-cure resin cements should be capable of achieving a degree of hardening through self-curing similar to or not much lower than that achieved through dual-curing. This is to ensure adequate polymerization of the cement in those areas underneath inlay/onlay restorations that are inaccessible to the curing light. Despite the fact that the majority of the examined cements were recently made available on the market, their degree of hardening, which is an indicator of extent of polymerization, continued to be significantly lower when only self-curing was used than their degree of hardening when dual-curing was used. This finding is in agreement with findings of previous reports (Hasegawa & others, 1991; Rueggeberg & Caughman, 1993; Watts & others, 1994; and El-Badrawy & El-Mowafy, 1995). However, there was variability among the cements regarding the amount of hardening achieved through self-curing alone. For one material (Enforce), a mean KHN of 42 was achieved through self-curing compared with a mean KHN of 51.4 achieved through dual-curing at 1 day. For another (Variolink), a mean KHN of merely 9.3 was achieved through self-curing compared with a mean KHN of 50.1 achieved through dual-curing, also at 1 day. Mean KHNs of the remaining materials fell somewhere between these two extremes. The reason for this variability is most likely due to the way these cements were formulated. When a sufficient amount of self-curing chemical is incorporated in the material, this allows the cement to achieve an adequate amount of hardening in the absence of light activation, while if the self-curing element is deficient, maximum cement hardness cannot be achieved. Insufficient hardening of the cement may predispose to postoperative sensitivity due to wash out of the unset cement material with subsequent microleakage and recurrent caries.

The significant increase in KHN of Resinomer with time (Table 2) must be attributed to a slow polymerization reaction. The mean KHN for this material increased from 15.6 at 1 hour to 32.3 at 1 week for the self-cured specimens and from 33.1 at 1 hour to 44.6 at 1 week for the dual-cured ones.

According to Ash (1984), the cervico-occlusal length of premolar teeth ranges from 8 to 8.5 mm and from 7 to 7.5 mm for permanent molars. Thus, the range of spacer thickness used in this study (1 - 6 mm) realistically represented the clinical situation, assuming that the gingival margin of a bonded inlay/onlay restoration ideally should remain on enamel, i e, above the cementoenamel junction, and bearing in mind that the tip of the light-curing rod remains at or above the level of the cusp tip during curing.

For the majority of examined cements, there was little difference in KHNs obtained with the 5 and 6 mm spacers. This can be easily explained by reference to Figure 9, which indicates little difference in light attenuation between these two spacers. Basically at this depth the cements were dependent mostly on their self-curing capabilities for polymerization, as penetration of light was almost totally obstructed. For spacers 1 - 4 mm thick, the effect of light attenuation varied among the cements. For some of them the decrease in KHNs was small (such as Enforce, Nexus, and Resinomer), while for others more abrupt decreases in KHNs took place between 1 and 4 mm spacers (e g, Adherence, Duolink). In the former case, the presence of a potent self-curing component compensated for light attenuation even with the thicker spacer, while in the latter case a less-potent self-curing component can be blamed.

In a clinical situation where an inlay/onlay restoration with deep gingival seat(s) is being cemented, the operator should apply the curing light from the buccal and lingual aspects of the restoration as well as through the occlusal aspect in order to maximize the amount of curing light that reaches the cement in the gingival seat areas. In the meantime, manufacturers should modify their dual-cured resin cement formulations to optimize the efficiency of the self-curing component. This has to be done with great care to avoid incorporation of an excessive amount of the chemical-curing component, which can lead to significant shortening of the working time of the cement with subsequent problems in insertion of the inlay/onlay restorations.

CONCLUSIONS

1. For three of the examined cements (Adherence, Duolink, and Variolink), self-curing alone was found to result in hardness values less than 50% of those obtained when dual-curing was used, even after 1 week of storage.
2. For many of the examined cements, there were significantly lower hardness values beyond 2-3 mm of ceramic inlay thickness.
3. Enforce cement exhibited highest hardness values when specimens were self-cured at the three test intervals (32, 42, and 43 KHN). This was sustained best through up to 6 mm of ceramic inlay material among the eight examined cements, with hardness ranging from 50 KHN at 1 mm to 45 KHN at 6 mm for the 1-day test interval.

Acknowledgment

The authors would like to thank the various dental product companies who generously donated sufficient quantities of the cement materials examined in this study.

(Received 27 August 1997)

References

ASH MM Jr, ed (1984) *Wheeler's Dental Anatomy, Physiology, and Occlusion,* 6th edition, Philadelphia: Saunders.

BLACKMAN R, BARGHI N & DUKE E (1990) Influence of ceramic thickness on the polymerization of light-cured resin cement *Journal of Prosthetic Dentistry* **63** 295-300.

CHAN KC & BOYER DB (1989) Curing light-activated composite cement through porcelain *Journal of Dental Research* **68** 476-480.

DARR AH & JACOBSON PH (1995) Conversion of dual cure luting cements *Journal of Oral Rehabilitation* **22** 43-47.

EL-BADRAWY WA & El-MOWAFY OM (1995) Chemical versus dual curing of resin inlay cements *Journal of Prosthetic Dentistry* **73** 515-524.

HASEGAWA EA, BOYER DB & CHAN DCN (1991) Hardening of dual-cured cements under composite resin inlays *Journal of Prosthetic Dentistry* **66** 187-192.

LINDEN JJ, SWIFT EJ Jr, BOYER DB & DAVIS BK (1991) Photo-activation of resin cements through porcelain veneers *Journal of Dental Research* **70** 154-157.

RUEGGEBERG FA & CAUGHMAN WF (1993) The influence of light exposure on polymerization of dual-cure resin cements *Operative Dentistry* **18** 48-55.

UCTASLI S, HASANREISOGLU U & WILSON HJ (1994) The attenuation of radiation by porcelain and its effect on polymerization of resin cements *Journal of Oral Rehabilitation* **21** 565 -575.

WATTS DC, CASH AJ, CHAUHAN J & RATHORE S (1994) Variables influencing hardness development in dual-cure composite luting materials *Journal of Dental Research* **73** *Abstracts of Papers* p 801 Abstract 115.

OPERATIVE DENTISTRY, 1999, 24, 45-50

Fracture Strength of Class 2 Amalgams with Various Cavity-lining Materials

A E PALMER • R D DAVIS
D F MURCHISON • R B COHEN

Clinical Relevance
The fracture resistance of class 2 amalgam restorations is not affected by the presence of a 0.5 mm-thick material lining the approximal box of a cavity preparation when a 3 mm-thick bulk of amalgam remains over the material.

SUMMARY

This in vitro study compared the fracture resistance of class 2 amalgam restorations placed over seven materials: three resin-modified glass-ionomer cements (Fuji II LC, Vitrebond, and Vitremer), one polyacid-modified composite resin (VariGlass VLC), two conventional glass-ionomer cements (Ketac-Bond and GlasIonomer Cement), and one calcium-hydroxide material (Dycal). Eighty maxillary molars with flattened occlusal surfaces were divided into 14 experimental groups and two control (no liner) groups. One standardized class 2 amalgam cavity preparation was completed per tooth. Lining materials standardized at a thickness of 0.5 mm were placed in the approximal box portion of 10 test specimens per experimental group. Spherical amalgam was hand condensed into each cavity preparation. At 1 hour and again at 7 days, five samples from each group were fractured in compression using an Instron Universal Testing Machine. The force was directed at 10^0 to the long axis of the tooth, 2.0 mm inside the approximal portion of the restoration. Results were analyzed using a two-way ANOVA for time and material. No statistically significant differences were found among the materials and controls at either time interval tested ($P > 0.05$). A statistically significant difference was found ($P < 0.05$) when comparing 1-hour and 7-day strengths. The 7-day specimens were more resistant to fracture than the 1-hour specimens. Conclusion: the fracture resistance of

81st Dental Squadron/SGD, 606 Fisher St, Keesler AFB, MS 39534

Alan E Palmer, DDS, Lt Col, USAF, DC, comprehensive dentist, FE Warren AFB, WY 82005

RD Davis, DDS, Col, USAF, DC, director of research and dental materials, general dentistry residency, Keesler AFB, MS 39534

DF Murchison, DDS, Col, USAF, DC, director of research and dental materials, general dentistry residency, Lackland AFB, TX 78236

RB Cohen, DMD, senior tutor, Harvard School of Dental Medicine, Harvard University, 188 Longwood Avenue, Boston, MA 02115

amalgam restorations was not affected by the presence of a material 0.5 mm thick placed in the approximal box when 3 mm of bulk of amalgam remained over it.

INTRODUCTION

Traditionally, bases have been used beneath amalgam restorations for the purpose of thermal insulation (Voth, Phillips & Swartz, 1966; Piperno & others, 1982). Alternatively, liners have been used primarily for their sealing abilities. Fluoride release was added to the beneficial properties available when glass-ionomer materials were introduced in the 1980s. The fluoride released from glass ionomers was found to inhibit the demineralization of tooth structure, and the early glass ionomers were well received by the dental profession for their hypothesized potential to inhibit secondary caries (Swartz, Phillips & Clark, 1984; Maldonado, Swartz & Phillips, 1978).

Resin-modified glass ionomers were introduced in the 1980s. In addition to their purported caries-inhibitory effect, these materials provided clinicians with the advantage of a command set through the incorporation of a light-activated resinous component (Tam, McComb & Pulver, 1991; Jensen, García-Godoy & Wefel, 1990). A concern with the use of these light-activated materials is the risk of fracture in the overlying amalgam restoration due to the effect of the resin on the modulus of elasticity of the liner. The modulus of elasticity of the resin-modified glass-ionomer lining materials (1.1 to 2.4 GPa) is significantly less than that of zinc phosphate (22.8 GPa), chemically cured glass-ionomer liners (9.8 GPa), and dentin (18.6 GPa) (Tam & others, 1991; Craig, O'Brien & Powers, 1992).

A number of studies have investigated the effect of bases on the fracture strength of amalgam and found that the modulus of elasticity of the base has a significant influence on the resistance of the amalgam to fracture under compressive load (Hormati & Fuller, 1980; Farah, Hood & Craig, 1975; Farah & others, 1981, 1983; Pierpont & others, 1994). Hormati and Fuller (1980) found a diminished resistance to fracture in amalgam restorations placed over a base with a low modulus of elasticity (Cavitec) as compared to those placed over a base with a higher modulus of elasticity (zinc-phosphate cement). This research confirmed earlier findings by Farah and others (1975) that the strength of an amalgam restoration varied as a function of the modulus of elasticity of the base more so than the compressive strength of the base. Farah and others (1981, 1983) demonstrated that a modulus of elasticity of the base material approaching that of dentin resulted in a minimal decrease in fracture resistance, while lower modulus bases significantly decreased the amalgam restoration's resistance to fracture.

Pierpont and others (1994) found that the fracture resistance of amalgam restorations placed over high-modulus materials, such as zinc phosphate, was similar to the control (no liner) and to chemically cured glass ionomer, and was greater than the fracture resistance of amalgam restorations placed over resin-modified glass-ionomer liners. Pierpont's investigation used metal dies, and no studies have investigated the effects of resin-modified glass-ionomer lining materials on the fracture resistance of amalgam placed in human teeth. In addition, no studies have investigated the effects of a lining material on the fracture resistance of amalgam when the liner has been confined to the approximal box of class 2 restorations.

The purpose of this in vitro study was to determine the compressive fracture resistance of class 2 amalgam restorations placed over seven 0.5 mm-thick materials confined to the approximal box of the cavity preparation. The materials used were two conventional glass ionomers, three resin-modified glass-ionomer liners, one polyacid-modified composite resin, and one calcium-hydroxide lining material.

METHODS AND MATERIALS

Eighty extracted maxillary molars were collected and stored in a 10% formalin solution. Each tooth was embedded to the level of the cementoenamel junction (CEJ) in polymethyl methacrylate resin (Dental Acrylic Resin, Plastodent Inc, Bronx, NY 10461) inside a metal ring. The occlusal surfaces were ground flat approximately 5 mm above the CEJ.

The teeth were randomly divided into fourteen experimental groups and two control groups with each group containing five specimens. One standardized class 2 rectangular-shaped preparation (MO or

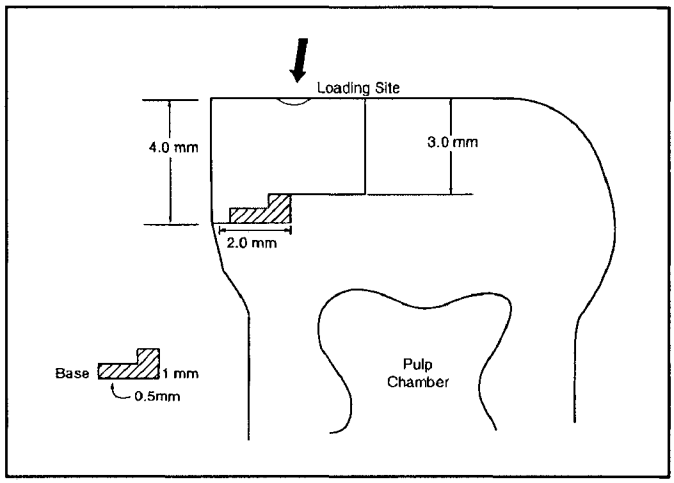


Figure 1. *Cross section schematic of class 2 amalgam preparation*

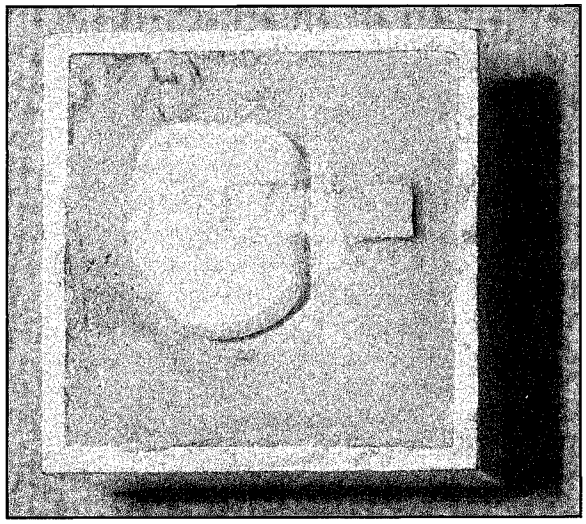


Figure 2. *Completed translucent template*

DO) was placed in each tooth using a mounted high-speed air turbine handpiece (Midwest Tradition-L High Speed, Midwest Dental Products, Des Plaines, IL 60018-1884) and a #557 carbide bur (Brasseler USA, Savannah, GA 31419). The occlusal portion of the preparations was 3.0 mm deep and 3.0 mm wide. The box preparations were 4.0 mm in height, 3.0 mm in width, and 2.0 mm in axial depth (Figure 1).

Lining materials were placed in the experimental groups using a custom-designed template to standardize thickness. The template was fabricated by making a translucent polyvinylsiloxane impression (Occlusal Matrix Material, Kerr Mfg Co, Romulus, MI 48174) of each class 2 preparation at box dimensions of 3.5 mm in height, 3.0 mm in width, and 1.5 mm in axial depth. After template fabrication, the box preparation in the experimental groups was enlarged such that the gingival depth of the box was increased to 4 mm and the axial depth was 2 mm. A completed template is shown in Figure 2. Replacement of the template into the preparation left an unoccupied 0.5 mm space at the gingival and axial depth of the box. The lining material was injected into this space under the template, resulting in a standard 0.5 mm thickness of liner along the axial and gingival portions of the box. The seven materials tested are listed in Table 1.

Light-cured materials were polymerized with a Max curing unit (LD Caulk, Milford, DE 19963) through the impression template for the time recommended by the material's manufacturer. The template was removed and the lining material was again cured for the recommended time and the excess trimmed with hand instruments to approximately 0.75 mm from the gingival cavosurface margin. A Tofflemire matrix (Tofflemire Matrix Bands, No 1 Ultrathin, Teledyne Getz, Elk Grove Village, IL 60007) was applied to each preparation, and a high-copper single-composition spherical amalgam (Tytin Spherical Amalgam, Kerr Mfg Co) was placed and condensed using hand condensers. The amalgam was carved flush with the cavosurface margin. Excess amalgam was removed and a depression was carved 0.5 mm deep into the amalgam above the approximal box using a self-limiting hand-held bur (8 Round SH Carbide Bur, Brasseler). The depression was centered

Table 1. Lining Materials Listed

Product	Manufacturer	Description
GlasIonomer Base Cement	Shofu Inc Kyoto, Japan	autocured glass ionomer
Ketac-Bond	ESPE-Premier Norristown, PA 19404	autocured glass ionomer
Dycal	L D Caulk Milford, DE 19963	calcium hydroxide
Vitremer	3M Dental Products St Paul, MN 55144	resin-modified glass ionomer
Fuji II LC	GC America Chicago, IL 60658	resin-modified glass ionomer
Vitrebond	3M Dental Products	resin-modified glass ionomer
VariGlass VLC	L D Caulk	polyacid-modified composite resin

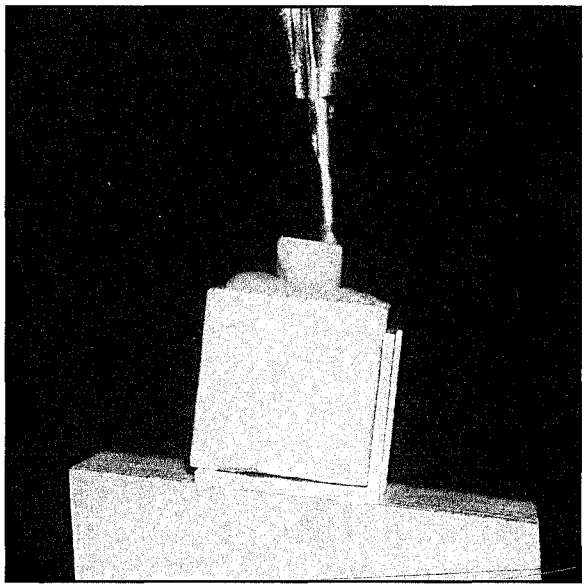


Figure 3. *Application of compressive load with Instron Universal Testing Machine*

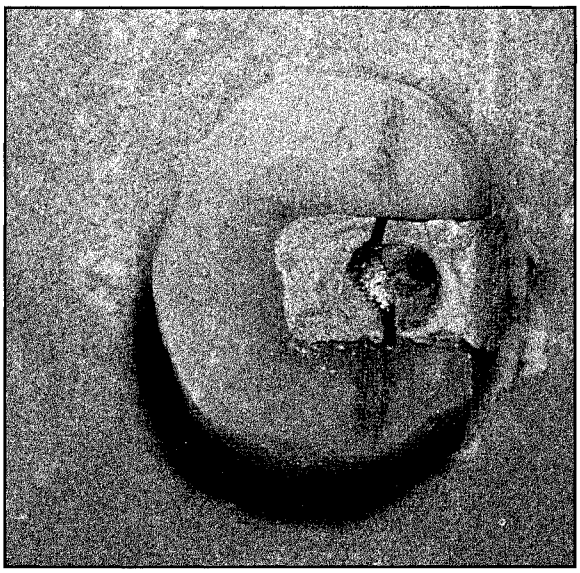


Figure 4. *Fractured specimen indicating typical fracture pattern*

buccolingually and was located 2.0 mm inside (in a mesiodistal direction) the approximal line angle of the restoration. All test specimens were stored in 100% humidity at 37 °C.

At 1 hour and again at 7 days, five samples per group were fractured in compression (Figure 3) with an Instron Universal Testing Machine (Instron Corp, Canton, MA 02021) at a strain rate of 3 mm/min using a loading device designed to fit the previously carved 0.5 mm depression in the amalgam restoration. The loading force was directed toward the approximal at an angle of 10° to the long axis of the tooth, contacting only amalgam. The initial deflection of the stress-strain line on the Instron recorder device was defined as amalgam fracture. Amalgam fracture was confirmed visually by gross inspection and microscopic examination with a Bausch/Lomb microscope (Bausch/Lomb Inc, Rochester, NY 11602) at X20 magnification. Figure 4 demonstrates a fractured specimen.

Fracture-resistance data were analyzed using a two-way analysis of variance (ANOVA) with time and materials as the independent variables. Post hoc comparisons among groups were accomplished by applying a Student-Neuman-Keuls test ($\alpha = 0.05$).

Data were evaluated to determine whether fracture planes were contiguous with the axiopulpal line angle. Groups were separated into high-, intermediate-, and low-elastic modulus categories based upon the average elastic moduli attributed to these classes of materials by Tam and others (1989, 1991) and Craig and others (1992). The control group (no lining material) constituted the high-modulus group, since the support of the overlying amalgam was dentin. Ketac-Bond and GlasIonomer Base Cement constituted the intermediate-modulus group. Dycal and those materials containing a resinous component (Vitremer, Fuji II LC, Vitrebond, and VariGlass VLC) constituted the low-modulus group. Fracture-location data were analyzed using a chi-square analysis (X^2, α=0.05) to determine whether differences in fracture-plane location varied according to modulus of elasticity.

RESULTS

The mean compressive fracture loads for the control and experimental groups are reported in Table 2. There were no statistically significant differences found among the materials and controls at either time interval tested. A statistically significant difference was found ($P < 0.05$) when comparing 1-hour and 7-day strengths, with the 7-day specimens being

Table 2. Mean Fracture Strength, in Newtons (SD), of Control and Lined Amalgam Groups

Testing Time	Lining Material							
	Control (no liner)	GlasIon	KetacBond	Dycal	Vitremer	Fuji II LC	Vitrebond	VariGlass
1-hour	973 (49)	892 (216)	1156 (361)	1103 (298)	1249 (180)	1246 (251)	863 (153)	904 (134)
7-day	1212 (169)	1078 (334)	1254 (142)	1135 (328)	1243 (372)	1147 (118)	1154 (161)	1097 (216)

Statistical analysis: two-way ANOVA.
No statistically significant differences were found among the groups (by material) at either time interval ($P > 0.05$).
A statistically significant difference was found between the 1-hour and 7-day groups ($P < 0.05$).
n = five per group.

more resistant to fracture than the 1-hour specimens.

Table 3 depicts the fracture distribution among high-, intermediate-, and low-elastic modulus groups. No significant difference was found among the high-, intermediate-, and low-elastic modulus groups with respect to fracture location ($P > 0.05$). Fractures were associated with the axiopulpal line angle according to the following distribution: all restorations 57% (45/79), nonlined restorations 50% (5/10), conventional glass-ionomer lined restorations 70% (14/20), and restorations with Dycal and resin-containing liners 53% (26/49).

DISCUSSION

Farah and others (1975, 1981, 1983) reported that the modulus of elasticity of a base is a critical factor in determining the fracture resistance of the overlying amalgam restoration. This is in contrast to the findings of the present study, which suggested that the elastic moduli of the lining materials did not affect the fracture resistance of the overlying amalgam restoration. The present results also contrast those of Pierpont and others (1994), who found a lower mean fracture resistance in amalgams supported by low-modulus resin-modified glass-ionomer cement bases as compared to restorations supported by higher-modulus materials.

There are several possible explanations for these differing results. The relative percentage of the cavity floor covered with the material would likely influence the fracture resistance of the restoration. In two studies by Farah and others (1981, 1983) utilizing extracted teeth, and in the investigation by Pierpont and others (1994) utilizing aluminum dies, a compressive load was applied perpendicular to the amalgam restorations. In these studies the lining materials completely covered the pulpal floor and exclusively supported the overlying amalgam restorations. In the present study, a lining material was used to cover only the approximal portion of the preparation floor. Clinically, this is a more frequently encountered situation than is the situation in which the entire pulpal floor is covered by a liner.

In contrast to the studies of Farah and others (1981, 1983) and Pierpont and others (1994), the load in the present investigation was directed to the area of the restoration supported by the lining material at a 10^0 angle from the long axis of the tooth. Since the test material was confined to the approximal box and the load was placed over the box area with the stress concentrated at the axiopulpal line angle, the amount of the restoration supported by the material was proportionally small compared to that supported by dentin, which may have made the restoration less sensitive to the effects of the lining material.

It has been hypothesized that if the elastic modulus of the material were low, one would expect amalgam restorations to exhibit a lower fracture resistance and demonstrate a significantly greater incidence of fracture above the lining material and axiopulpal line angle compared to the controls. The present investigation found no significant difference in fracture location among the various groups that were categorized by their modulus of elasticity. The clinical implication of these findings is that when a small area of the cavity floor is covered with a lining material, as in the present study, the presence of this material has no significant influence on the amalgam restoration's fracture resistance or fracture location.

The results of this investigation do not imply that low-modulus lining materials may not adversely affect fracture strength when a large portion of the amalgam restoration is supported by the lining material. Results might also differ when amalgam restorations include retention and resistance features in the approximal box area.

CONCLUSION

Amalgam restorations are not significantly weakened by the presence of a 0.5 mm-thick material placed in the approximal box of class 2 amalgams when a 3 mm bulk of amalgam remains over it.

Table 3. Comparison of Amalgam Fracture Sites among Lining Materials

Categories	Lining Materials	A	B
High-elastic modulus	Control: no liner	5	5
Intermediate-elastic modulus	Ketac-Bond, GlasIonomer	14	6
Low-elastic modulus	Dycal, Vitremer, Fuji II LC, Vitrebond, VariGlass VLC	26	23

Statistical analysis: chi-square df = 2.
No statistically significant differences were found among group ($P = 0.3889$).
Amalgam fracture sites: A = fracture contiguous with axiopulpal line angle; B = fracture not contiguous with axiopulpal line angle.

(Received 26 August 1997)

References

CRAIG RG, O'BRIEN WJ & POWERS JM (1992) *Dental Materials: Properties and Manipulation* St Louis: Mosby-Year Book Inc, 5th edition, p 21.

FARAH JW, CLARK AE, MOHSEIN M & THOMAS PA (1983) Effect of cement base thicknesses on MOD amalgam restorations *Journal of Dental Research* **62** 109-111.

FARAH JW, CLARK AE, THOMAS PA & BORKOW I (1981) Cement bases under amalgam restorations: effect of thickness *Operative Dentistry* **6** 82-89.

FARAH JW, HOOD JA & CRAIG RG (1975) Effects of cement bases on the stresses in amalgam restorations *Journal of Dental Research* **54** 10-15.

HORMATI AA & FULLER JL (1980) The fracture strength of amalgam overlying base materials *Journal Prosthetic Dentistry* **43** 52-57.

JENSEN ME, GARCÍA-GODOY F & WEFEL JS (1990) Artificial root caries in amalgam restorations: effect of light-cured fluoride releasing liners *American Journal of Dentistry* **3** 295-298.

MALDONADO A, SWARTZ ML & PHILLIPS RW (1978) An in vitro study of certain properties of a glass ionomer cement *Journal of the American Dental Association* **96** 785-791.

PIERPONT WF, GRAY SE, HERMESCH CB & HILTON TJ (1994) The effect of various bases on the fracture resistance of amalgam *Operative Dentistry* **19** 211-216.

PIPERNO S, BAROUCH E, HIRSCH SM & KAIM JM (1982) Thermal discomfort of teeth related to presence or absence of cement bases under amalgam restorations *Operative Dentistry* **7** 92-96.

SWARTZ ML, PHILLIPS RW & CLARK HE (1984) Long-term F release from glass ionomer cements *Journal of Dental Research* **63** 158-160.

TAM LE, McCOMB D & PULVER F (1991) Physical properties of proprietary light-cured lining materials *Operative Dentistry* **16** 210-217.

TAM LE, PULVER E, McCOMB D & SMITH DC (1989) Physical properties of calcium hydroxide and glass-ionomer base and lining materials *Dental Materials* **5** 145-149.

VOTH ED, PHILLIPS RW & SWARTZ ML (1966) Thermal diffusion through amalgam and various liners *Journal of Dental Research* **45** 1184-1190.

©OPERATIVE DENTISTRY, 1999, 24, 51-56

Bond Strength of Composite to Enamel and Dentin Using Prime & Bond 2.1

W W BARKMEIER • P D HAMMESFAHR
M A LATTA

Clinical Relevance
High bond strengths of composite to enamel and dentin can be achieved using one-component adhesive systems.

SUMMARY

A laboratory study was conducted to determine the bond strength of composite to enamel and dentin using a one-component dental adhesive system (Prime & Bond 2.1) with three application regimens ranging from four to seven procedural steps. In addition, the effect of acid conditioning of dentin on bond strength was evaluated. Enamel bond strengths ranged from 29.2 to 29.8 MPa, and dentin bond strengths ranged from 18.6 to 21.3 MPa. Enamel bond strengths were significantly higher ($P = 0.000$) than dentin values. There was no significant difference ($P > 0.05$) among the bond strengths in either the enamel or dentin groups using the three application regimens. Nor did acid conditioning of dentin increase bond strengths ($P = 0.683$).

Creighton University School of Dentistry, Departments of Operative Dentistry and Comprehensive Dental Care, Omaha, NE 68178

Wayne W Barkmeier, DDS, MS, dean and professor

Paul D Hammesfahr, PhD, director of technical research, Dentsply/Caulk, Milford, DE 19963

Mark A Latta, DMD, MS, associate dean for research and continuing education, associate professor

INTRODUCTION

In recent years dental manufacturers have developed dental adhesive systems that require fewer procedural steps when compared with earlier-generation systems. One of the first adhesive systems that combined the primer and bonding resin into a single component system was Dyract PSA (Dentsply/DeTrey, Konstanz, Germany). This system used an acetone solvent with PENTA (dipentaerythritolpentacrylate phosphoric acid ester) as the primary adhesion promoter. This adhesive was later introduced in the United States as Prime & Bond (Dentsply/Caulk, Milford, DE 19963).

The directions for Dyract PSA and Prime & Bond included using the one-component primer/adhesive on enamel and dentin. The first application of the primer/adhesive was applied to the tooth surfaces

and left on the surface for 30 seconds followed by air drying. This application was visible light cured for 10 seconds. A second application of the primer/adhesive was applied and then immediately air dried. The second application was also light cured for 10 seconds.

Prime & Bond 2.0 was later introduced in Europe and Asia (Dentsply/DeTrey). Elastomeric resins were added to form a combination of relatively rigid and relatively flexible molecules. More recently, Prime & Bond 2.1 was introduced worldwide (Dentsply/Caulk & Dentsply/DeTrey). The Prime & Bond 2.1 adhesive system uses the elastomeric resin of Prime & Bond 2.0 plus the addition of cetylamine hydrofluoride, which provides release of fluoride ions.

The directions were also changed with the introduction of Prime & Bond 2.1. The first application time was reduced from 30 seconds to 20 seconds. In the product directions from Dentsply/Caulk, the curing step for the second application was eliminated. The Dentsply/DeTrey directions maintained the curing step for the second application of the primer/adhesive.

The purpose of this laboratory study was to determine the bond strengths of composite to enamel and dentin using Prime & Bond 2.1 with various application techniques and curing sequences.

METHODS AND MATERIALS

Specimen Preparation

Enamel and dentin bonding sites were prepared on the buccal surfaces of 90 human molar teeth (60 dentin sites and 30 enamel sites). The bonding sites were prepared by wet grinding on a water-cooled abrasive wheel to 600-grit using silicon carbide paper (Ecomet III Grinder, Buehler Ltd, Lake Bluff, IL 60044). The teeth were then divided into groups of 10 teeth each.

Table 1. Directions for Dyract PSA and Prime & Bond (Bonding Technique: PB 30 Seconds/LC/PB/LC)

1) Thoroughly wet enamel and dentin surfaces with primer/adhesive.
2) Leave on surface for 30 seconds.
3) Remove excess solvent by air drying.
4) Visible light cure for 10 seconds.
5) Apply second coat of primer/adhesive.
6) Immediately remove excess solvent by air drying.
7) Visible light cure for 10 seconds.

Table 2. Directions for Prime & Bond 2.1 (Bonding Technique: PB 20 Seconds/LC/PB)

1) Thoroughly wet enamel and dentin surfaces with primer/adhesive.
2) Leave on surface for 20 seconds.
3) Remove excess solvent by air drying.
4) Visible light cure for 10 seconds.
5) Apply second coat of primer/adhesive.
6) Immediately remove excess solvent by air drying.

Bonding Techniques

The primary categories of evaluation in this study included three bonding regimens with varying treatment times and primer application sequences, and acid conditioning of dentin versus no acid treatment.

The first treatment regimen (Table 1) followed was the original directions for Dyract PSA and Prime & Bond. The second regimen (Table 2) represents the current directions for Prime & Bond 2.1. The third regimen was an experimental group that did not include a second application of the primer/adhesive (Table 3). The bonding regimens are summarized in Table 4.

In the three enamel bonding groups (10 teeth each) the only variable was the treatment regimen for the primer/adhesive (Tables 1-3). The enamel surfaces were acid conditioned with 37% phosphoric acid (Caulk Tooth Conditioner Gel, Dentsply/Caulk) for 15 seconds. The acid conditioner was washed from the surface with an air-water spray for 15 seconds and the surface was gently air dried.

There were two variables in the dentin treatment groups, treatment regimen and acid conditioning of dentin versus no acid treatment. A "moist" bonding technique was used for the dentin groups. The dentin surfaces (30 teeth: 10 for each bonding regimen) were acid conditioned for 15 seconds, washed with an air-water spray and excess water removed by blot drying (Kimwipes, Kimberly-Clark Corp, Roswell, GA 30076),

Table 3. Experimental Treatment Regimen for Prime & Bond 2.1 (Bonding Technique: PB 20 Seconds/LC)

1) Thoroughly wet enamel and dentin surfaces with primer/adhesive.
2) Leave on surface for 20 seconds.
3) Remove excess solvent by air drying.
4) Visible light cure for 10 seconds.

Table 4. Summary of Bonding Procedures

Group	Surface	Acid Conditioned	Adhesive (First Coat)	VLC	Adhesive (Second Coat)	VLC
1A	Enamel	Yes	P&B 2.1 (30 seconds)	10 seconds	Yes	10 seconds
2A	Enamel	Yes	P&B 2.1 (20 seconds)	10 seconds	Yes	No
3A	Enamel	Yes	P&B 2.1 (20 seconds)	10 seconds	No	NA
1B	Dentin	Yes	P&B 2.1 (30 seconds)	10 seconds	Yes	10 seconds
2B	Dentin	Yes	P&B 2.1 (20 seconds)	10 seconds	Yes	No
3B	Dentin	Yes	P&B 2.1 (20 seconds)	10 seconds	No	NA
1C	Dentin	No	P&B 2.1 (30 seconds)	10 seconds	Yes	10 seconds
2C	Dentin	No	P&B 2.1 (20 seconds)	10 seconds	Yes	No
3C	Dentin	No	P&B 2.1 (20 seconds)	10 seconds	No	NA

VLC = visible light cured.

leaving a visibly moist surface. The dentin bonding surfaces on the 30 other specimens (10 teeth for each bonding regimen) were not acid conditioned and the bonding surfaces were washed with an air-water spray and blot dried.

Following the bonding procedures, a restorative material (Prisma TPH Spectrum, Dentsply/Caulk) was applied using a No 5 gelatin capsule (Torpac Inc, Fairfield, NJ 07004) to form a cylinder of restorative material. The gelatin capsules were preloaded with the restorative material, approximately two-thirds full, and cured for 1 minute in a Triad 2000 unit (Dentsply Trubyte, York, PA 17405). Additional material was then added to fill the capsules and they were positioned onto the bonding site and cured using three 20-second curing sequences around the circumference of the cylinder (total visible light curing time of 60 seconds). The diameter of the restorative cylinders formed with the No 5 gelatin capsules was 4.5 mm.

The specimens were stored for 24 hours at 37 °C in distilled water for the 24 hours. Following water storage, the specimens were thermocycled for 24 hours between water baths of 5 ± 2 °C and 55 ± 2 °C (dwell time 1 minute: 640 cycles). Shear bond strengths were determined using a chisel-shaped rod in an Instron with a crosshead speed of 5 mm per minute.

A three-way ANOVA was used for data analysis of all groups. The factors were: (1) Surface, 1 = dentin and 2 = enamel; (2) Acid, 1 = acid conditioning and 2 = no acid treatment; (3) Technique, 1 = PB 30 seconds/LC/PB/LC (Table 1), 2 = PB 20 seconds/LC/PB (Table 2), and 3 = PB 20 seconds/LC (Table 3). A two-way ANOVA was also conducted on the dentin groups. Factors were (1) Acid, 1 = acid conditioning and 2 = no acid treatment and (2) Technique, 1 = PB 30 seconds/LC/PB/LC, 2 = PB 20 seconds/LC/PB, and 3 = PB 20 seconds/LC. Post hoc comparisons were made using Tukey's test.

RESULTS

The three-way ANOVA of all groups revealed a significant effect ($P = 0.000$) for the individual factor of surface. Enamel bond strengths were significantly greater than dentin bond strengths. There was not a significant effect for the individual factors of acid conditioning ($P = 0.635$) or the treatment regimens ($P = 0.918$).

The two-way ANOVA of the dentin groups also did not show a difference ($P = 0.683$) in bond strengths when acid conditioning was compared to no acid treatment. Additionally, there was not a significant difference ($P = 0.776$) in bond strengths among the three treatment regimens.

Table 5. Rank Order of Composite to Enamel Bond Strengths

Group	Acid Conditioned	Treatment Regimen	MPa ± SD	Percent Cohesive Failures*
2A	Yes	PB 20 seconds/LC/PB	29.8 ± 5.0	100
1A	Yes	PB 30 seconds/LC/PB/LC	29.3 ± 5.6	90
3A	Yes	PB 20 seconds/LC	29.2 ± 5.4	90

*Cohesive failures in enamel.
Groups connected by line are not different at the 5% significance level.

The enamel bond strengths ranged from 29.2 ± 5.4 MPa to 29.8 ± 5.0 MPa (Table 5). There was not a significant difference ($P > 0.05$) in bond strengths among the three enamel groups. The percentage of cohesive failures in enamel ranged from 90% to 100% (Table 5).

Bond strengths to dentin ranged from 18.6 ± 3.3 MPa to 21.3 ± 4.2 MPa (Table 6). There was not a significant difference ($P > 0.05$) in bond strengths among the six treatment groups. The percentage of cohesive failures in dentin ranged from 0% to 40% (Table 6).

DISCUSSION

Bonding of resin dental materials to enamel has been a long-standing predictable procedure. Buonocore (1955) introduced a simple procedure for attaining high bond strengths of resin materials to enamel. The procedure typically involved (1) phosphoric acid conditioning the enamel surface and (2) application of a bonding resin. Phosphoric acids in the range of 32% to 40% have been the material of choice for enamel acid conditioning. Initially, a 60-second acid-conditioning time was used for enamel bonding (Young & others, 1975; Silverstone, 1975). Studies have shown that a reduced conditioning time of 15 seconds yielded bond strengths equivalent to a 60-second time (Barkmeier, Shaffer & Gwinnett, 1986; Glasspoole & Erickson, 1986). Scanning electron microscopy (SEM) studies have also shown a similar etch pattern on enamel that is conditioned for either 15 or 60 seconds (Nordenvall, Brännström & Malmgren, 1980; Barkmeier & others, 1986). The reduction of enamel conditioning time has further simplified enamel bonding.

Enamel bond strengths have routinely been reported in the range of 16 to 24 MPa (Craig, 1989; Barkmeier & Cooley, 1992). A BIS-GMA (bisphenyl-A glycidyl methacrylate) resin bonding agent was typically used in earlier studies. These earlier bonding agents were generally viscous in nature. Newer-generation adhesive bonding agents are now more hydrophilic and use solvent systems that allow better wetting of the enamel surface, resulting in even higher bond strengths (Ruyter, 1992). The bond strengths of composite to enamel reported in this study were consistently over 29 MPa. The Prime & Bond 2.1 system uses an acetone solvent that allows excellent wetting of the conditioned enamel surface and results in much higher bond strengths than earlier BIS-GMA resin bonding materials (Barkmeier & others, 1986; Barkmeier & Cooley, 1992).

Dentin bonding has traditionally involved more steps that enamel bonding. Adhesive systems marketed for dentin adhesion have typically used three steps: (1) acid conditioning the dentin surface, (2) priming the conditioned surface, and (3) application of a resin adhesive agent. Depending on the system, the priming and/or application of the adhesive resin may also require several applications.

Attaining high bond strengths to dentin has continued to be a challenge when compared to enamel

Table 6. Rank Order of Composite to Dentin Bond Strengths

Group	Acid Conditioned	Treatment Regimen	MPa ± SD	Percent Cohesive Failures*
3C	No	PB 20 seconds/LC	21.3 ± 4.2	40
1C	No	PB 30 seconds/LC/PB/LC	21.2 ± 5.7	20
2B	Yes	PB 20 seconds/LC/PB	20.9 ± 3.7	0
1B	Yes	PB 30 seconds/LC/PB/LC	20.0 ± 3.4	30
2C	No	PB 20 seconds/LC/PB	18.6 ± 3.2	40
3B	Yes	PB 30 seconds/LC	18.6 ± 3.3	0

*Cohesive failures in dentin.
Groups connected by line are not different at the 5% significance level.

Table 7. Dyract PSA Prime/Adhesive Mean Shear Bond Strength to Dentin

Surface Condition	Restorative	MPa	SD
Dry dentin	Dyract	21.4	1.8
Moist dentin	Dyract	20.6	2.0
36% phosphoric acid/ dry dentin	Dyract	15.2	3.4
36% phosphoric acid/ moist dentin	Dyract	25.4	2.3

Table 8. Prime & Bond 2.0 Mean Shear Bond Strength to Dentin

Surface Condition	Restorative	MPa	SD
Dry dentin	Prisma TPH	20.2	3.7
Moist dentin	Prisma TPH	24.0	3.2
36% phosphoric acid/ dry dentin	Prisma TPH	14.6	7.0
36% phosphoric acid/ moist dentin	Prisma TPH	25.3	2.4

bonding (Barkmeier & Erickson, 1994). The early systems (first-generation) yielded bond strengths in the range of 1 to 3 MPa (Huget, Denniston & Vilca, 1979; Solomon & Beech, 1983; Barkmeier & Cooley, 1991, 1992). The bond strengths for second-generation systems were in the range of 6 to 13 MPa (Barkmeier & Cooley, 1989, 1992; Erickson, 1992). As adhesive systems have evolved, bond strengths to dentin now approach or even equal previously reported enamel bond values (Barkmeier & Erickson, 1994; Los & Barkmeier, 1994; Triolo, Swift & Barkmeier, 1995).

In efforts to simplify dentin bonding, manufacturers have recently introduced systems that combine the primer and adhesive agent. These systems have generally been referred to as "one-component systems." However, several of these newer systems still require multiple application and curing sequences, and thus are not single-procedure systems. Tay, Gwinnett, and Wei (1996) have also suggested that one-component systems have a narrow "window of opportunity" for optimum bonding, which is dependent on residual surface moisture.

The present study compared several technique variables using a one-component system, Prime & Bond 2.1. Three application regimes, ranging from seven steps to four procedural steps, were evaluated (Tables 1-3). While enamel bond strengths were higher than dentin values, there was no difference ($P > 0.05$) in bond strengths among the enamel or dentin groups using the three application regimens. The dentin bond values found in this study were high compared with other newer-generation adhesive systems (Los & Barkmeier, 1994; Triolo & others, 1995; Swift & others, 1997). Additionally, this study found that acid conditioning of dentin did not improve the bond-strength values for Prime & Bond 2.1.

Studies have generally shown that acetone-based primers are more effective on moist dentin surfaces when compared to dried dentin (Kanca, 1992; Gwinnett, 1992; Gwinnett & Kanca, 1992). Earlier studies conducted at Creighton University School of Dentistry showed similar bond strengths to dentin for Dyract PSA and Prime & Bond 2.0 when bonding to nonacid-conditioned moist dentin or dry dentin (Tables 7 and 8). Acid conditioning of dentin and blot drying of the surface (moist dentin) yielded higher bond strengths than bonding to unconditioned moist or dry dentin. However, when an acid-conditioned dentin surface was air dried, the bond values were markedly lower for both Dyract PSA and Prime & Bond 2.0.

The Prime & Bond series of adhesive agents has shown the ability to bond to unconditioned dry dentin surfaces. It is postulated that the PENTA, which has a low pH, acts as a "self-etching" agent when in contact with the dentin surface. The Prime & Bond products have generated high bond values to both moist and dry dentin and also to moist acid-conditioned dentin. However, the results of earlier studies (Table 7 and 8) clearly showed that an acid-conditioned dentin surface should not be air dried before the application of the Prime & Bond.

CONCLUSIONS

High bond strengths of composite to enamel and dentin were obtained using the Prime & Bond 2.1 adhesive system. Enamel bond strengths were significantly greater ($P = 0.000$) than dentin bond strengths. Phosphoric acid conditioning of dentin did not improve bond strengths to moist dentin using Prime & Bond 2.1. There was no difference among enamel or dentin bond strengths using three different treatment application and visible light curing regimens.

(Received 14 October 1997)

References

BARKMEIER WW & COOLEY RL (1989) Resin adhesive systems: in vitro evaluation of dentin bond strength and marginal microleakage *Journal of Esthetic Dentistry* **1** 67-72.

BARKMEIER WW & COOLEY RL (1991) Current status of adhesive resin systems *Journal of the American College of Dentists* **58** 36-39.

BARKMEIER WW & COOLEY RL (1992) Laboratory evaluation of adhesive systems *Operative Dentistry* **Supplement 5** 50-61.

BARKMEIER WW & ERICKSON RL (1994) Shear bond strength of composite to enamel and dentin using Scotchbond Multi-Purpose *American Journal of Dentistry* **7** 175-179.

BARKMEIER WW, SHAFFER SE & GWINNETT AJ (1986) Effects of 15 vs 60 second enamel acid conditioning on adhesion and morphology *Operative Dentistry* **11** 111-116.

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

CRAIG RG (1989) *Restorative Dental Materials*, 8th edition, St Louis: Mosby p 262.

ERICKSON RL (1992) Surface interactions of dentin adhesive materials *Operative Dentistry* **Supplement 5** 81-94.

GLASSPOOLE EA & ERICKSON RL (1986) Effect of acid etching and rinsing times on composite to enamel bond strengths *Journal of Dental Research* **65** *Abstracts of Papers* p 285 Abstract 1046.

GWINNETT AJ (1992) Moist versus dry dentin: its effect on shear bond strength *American Journal of Dentistry* **5** 127-129.

GWINNETT AJ & KANCA JA 3rd (1992) Micromorphology of the bonded dentin interface and its relationship to bond strength *American Journal of Dentistry* **5** 73-77.

HUGET EF, DENNISTON JC & VILCA JM (1979) Dentin adhesives: a perspective *Military Medicine* **144** 619-620.

KANCA J 3rd (1992) Effect of resin primer solvents and surface wetness on resin composite bond strength to dentin *American Journal of Dentistry* **5** 213-215.

LOS SA & BARKMEIER WW (1994) Shear bond strength of composite to dentin using newer generation dental adhesive systems *Esthetic Dentistry Update* **5** 46-49.

NORDENVALL K-J, BRÄNNSTRÖM M & MALMGREN O (1980) Etching of deciduous teeth and young and old permanent teeth. A comparison between 15 and 60 seconds of etching *American Journal of Orthodontics* **78** 99-108.

RUYTER IE (1992) The chemistry of adhesive agents *Operative Dentistry* **Supplement 5** 32-43.

SILVERSTONE LM (1975) The acid etch technique: in vitro studies with special reference to the enamel surface and the enamel-resin interface In *Proceedings of an International Symposium on the Acid Etch Technique* St Paul, MN: North Central Publishing Co pp 13-39.

SOLOMON A & BEECH DR (1983) Bond strengths of composite to dentine using primers *Journal of Dental Research* **62** *Abstract of Papers* p 677 Abstract 253.

SWIFT EJ Jr, WILDER AD Jr, MAY KN Jr & WADDELL SL (1997) Shear bond strengths of one-bottle dentin adhesives using multiple applications *Operative Dentistry* **22** 194-199.

TAY FR, GWINNETT AJ & WEI SH (1996) Micromorphological spectrum from overdrying to overwetting acid-conditioned dentin in water-free acetone-based, single-bottle primer/adhesives *Dental Materials* **12** 236-244.

TRIOLO PT Jr, SWIFT EJ Jr & BARKMEIER WW (1995) Shear bond strengths of composite to dentin using six dental adhesive systems *Operative Dentistry* **20** 46-50.

YOUNG KC, HUSSEY M, GILLESPIE FC & STEPHEN KE (1975) In vitro studies of physical factors affecting adhesion of fissure sealant to enamel In *Proceedings of an International Symposium on the Acid Etch Technique*, St Paul, MN: North Central Publishing Co pp 50-62.

DEPARTMENTS

ABSTRACTS

The editor wishes to thank the second-year General Dentistry residents at Wilford Hall United States Air Force Medical Center at Lackland AFB, Texas, for their assistance in the preparation of these abstracts.

The effect of recementation on crown retention. *Ayad MF, Rosenstiel SF & Woelfel JB (1998) *International Journal of Prosthodontics* 11 177-182.

(*University of Tanta College of Dentistry, Section of Restorative Dentistry, Prosthodontics, and Endodontics, Tanta, Egypt)

Displaced or loose castings are commonly encountered in clinical practice. Where adequate retention and resistance form exist and caries has not undermined the preparation, recementation may be indicated. The aim of this in vitro study was to evaluate the retentive properties of three luting cements upon cementation and after recementation of complete cast crowns. Thirty extracted intact human molar teeth were cleaned and mounted in epoxy resin cylinders. Using a milling machine like a hardware store key cutter, replica crown preparations were created from a stylized metal master die. All axial and occlusal surfaces of the preparations were in dentin. Base metal alloy crowns were produced by the indirect method and a passive fit of the castings to the dies achieved. Cast crowns and corresponding teeth were randomly assigned to three groups (n=10) for each luting cement. Group I crowns were cemented with zinc phosphate cement (Fleck's, Mizzy). Group II crowns were cemented with adhesive resin cement (Panavia-EX, J Morita). Group III groups were cemented with glass-ionomer cement (Ketac-Cem Applicap, ESPE-Premier). Crowns were cemented, excess cement removed, and specimens were thermocycled 1500 cycles. Retention was measured by testing the crowns under tensile load aligned with the long axis of the tooth. Subsequently, tooth preparations were scraped clean and polished with prophylaxis paste, the fitting surfaces of the crowns ultrasonically cleaned and air abraded, and the crowns recemented. Thermocycling and tensile retesting followed. Panavia-EX and Ketac-Cem yielded both the highest initial and second cementation retentive strengths. There was no significant difference between Panavia-EX and Ketac-Cem on initial cementation nor between initial and recementation values for either cement. Retention values were almost 32% higher than those obtained with zinc phosphate cement during initial cementation and 59% higher than values obtained after recementation.

Conclusion: In clinical situations where recementation is indicated, glass-ionomer or adhesive resin cements appear to offer a significant advantage in retention over zinc phosphate.

A comparison of a hybrid light-cured glass-ionomer base and liner vs a light-cured resin tooth fragment attachment. *Dean JA, Minutillo AL & Moore BK (1998) *American Academy of Pediatric Dentistry* 20(1) 49-52.

(*Indiana University School of Dentistry, Department of Oral Facial Development, Indianapolis, IN 46202)

The purpose of this in vitro study was to measure the amount of force required to cause separation of reattached tooth fragments and types of fractures when using either a hybrid light-cured glass ionomer or a light-cured composite resin for reattachment. The majority of dental trauma to children and adolescents is from falls, contact sports, and automobile accidents. Use of the acid-etched composite resins has been an overall success in treatment of these injuries, although they tend to wear and stain. Reattaching the tooth fragment onto the tooth has proven to be successful with composite resins. Recent reports have shown the use of glass ionomers to be beneficial due to their ability to bond to dentin, fluoride release, and decreased microleakage properties. Seventy-five bovine incisors were fractured from the labial with a blunt chisel to cause either an Ellis class 2 or a small Ellis class 3 fracture. These teeth were randomly divided into three groups. Group A used a light-cured bonding agent and composite resin (Caulk Prisma-Fil Universal Bonding Agent and TPH Composite Resin). Following the manufacturer's directions, both segments were etched, bonded, and gently meshed together. Any small areas of lost enamel were replaced with the composite resin. Group B was restored with Dentsply VariGlass VLC Base and Group C with VariGlass VLC Liner following the manufacturer's instructions. A bonding agent (Dentsply Universal

Bonding Agent) was placed on any exposed glass ionomer in Groups B and C. All samples were thermocycled and then tested for force required for dislodgement by placing a loading pin 1 mm incisal to the repaired fracture at a perpendicular angle with an Instron Universal Testing Machine with a crosshead rate of 0.5 mm/min. A one-way ANOVA was performed as a statistical analysis. There was no statistically significant difference ($P < 0.05$) in dislodgement strength among the three groups (range = 5.0 to 116.6 kg). Fracture type was designated as cohesive, adhesive, or mixed using a light microscope. The type of fracture for the majority of the dislodgements was cohesive (73%). The authors believe that there should be further studies comparing (1) etching vs nonetching when reattaching tooth fragments using glass ionomer and (2) the relationship of surface area to dislodgement strengths. Conclusions reached from this study included the following: (1) no statistically significant difference was noted in dislodgement strength between the glass-ionomer base, the glass-ionomer liner, and the VLC composite resin, and (2) there were no statistically significant differences in fracture types for the three products, with cohesive fractures occurring 73% of the time.

Reviewer's Note: VariGlass is presently termed a "polyacid-modified composite resin," and the performance of other "true" glass-ionomer materials cannot be inferred from this study.

The effect of amalgam bonding on resistance form of class II amalgam restorations. Della Bona A & *Summitt JB (1998) *Quintessence International* 29 95-101.

(*University of Texas Health Sciences Center, 7703 Floyd Curl Drive, San Antonio, TX 78284)

Amalgam possesses excellent physical properties, but it is not adhesive and has traditionally relied on mechanical undercuts for retention in cavity preparations. If amalgam could be effectively bonded to tooth structure, tooth preparations could be greatly simplified and would require the removal of much less tooth structure. The purpose of this study was to evaluate the effect of amalgam bonding on resistance and retention form of class 2 amalgam restorations. Five groups of 12 maxillary molars were mounted. Class 2 mesio-occlusal preparations were cut. Group 1 had extension through the central groove. Group 2 had approximal slot preparation without retention grooves. Groups 3 and 5 had slot preparations with long facial and lingual retention grooves. Group 4 had slot preparations without grooves with unsupported enamel allowed to remain. Groups 1-4 were restored using Amalgambond and Valiant amalgam. Group 5 was restored without amalgam bonding. After restoration, the specimens were stored in water for 24 hours and thermocycled for 100 cycles. The amalgam restorations were loaded in compression on the marginal ridge using an Instron Universal Testing Machine. The mean (SD) failure loads in newtons were: Group 1--281 (77); Group 2--246 (101); Group 3--238 (84); Group 4--254 (100); Group 5--191 (66). There was no significant difference among the groups in which Amalgambond was used, regardless of the preparation design. There was no difference between any of the groups of restorations placed with Amalgambond and the group placed with grooves but without Amalgambond. However, the results of this study suggest that there was a trend toward greater resistance to dislodgment or fracture when Amalgambond was used. Both grooves and Amalgambond provided a significant level of resistance to dislodgment for class 2 approximal-only amalgam restorations. Preparations without undercuts, with Amalgambond, provided resistance to fracture similar to that imparted by retention grooves. Amalgam bonding materials may provide retention for at least a short time period in class 2 slot amalgam restorations similar to that provided by undercut retention.

Bonding amalgam to dentin: bond strength, marginal adaptation, and micromorphology of the coupling zone. *Fritz UB & Werner JF (1998) *American Journal of Dentistry* 11(2) 61-66.

(*University of Cologne, Dental School, Department of Operative Dentistry, Köln, Germany)

Amalgam has been successfully used as a restorative material for over 100 years. It is easy to handle and place, is relatively inexpensive, and has acceptable longevity. The life span has been reported as 10 years for 40% of all amalgam restorations. One of the shortcomings of amalgam restorations is microleakage, which may result in incomplete adaptation, marginal breakdown, secondary decay, sensitivity, and pulpal inflammation. The alloy used, trituration variables, and the condensation technique all affect the severity of microleakage. Spherical alloys such as Tytin display greater microleakage when compared to

admixed alloys like Dispersalloy. Varnishes have been used for many years in an attempt to control microleakage. The long-term results of sealing restorations against leakage using varnishes have been convincing. Improvements in the area of enamel/dentin bonding have resulted in bonding systems designed to adhesively bond amalgam restorations. This study evaluated the effect of bonding amalgam to dentin by investigation of the bond strength, marginal adaptation, and micromorphology of the coupling zone between amalgam, bonding agent, and dentin. The adhesive systems evaluated included two commercially available systems and three experimental one-bottle-type resin adhesive systems. The commercial systems were Amalgambond and All-Bond 2. The experimental resins were EX1, an acetone-based one-bottle adhesive containing UDMA, HEMA, and 4-META as a light-activated resin; EX2, a combination of EX1 and a dual-cure resin; and EX3, the adhesive EX1 without the 4-META component.

The shear bond strength of each of the systems was compared by bonding Dispersalloy cylinders to extracted and prepared human molar teeth. Five teeth per system were prepared for each system. The specimens were shear loaded with a metal rod parallel to the bonding surface. A crosshead speed of 1 mm/minute was used. The shear bond strength was calculated as the ratio of debonding force and bonding area. The marginal adaptation in dentin cavities was tested by cutting preparations in mechanically exposed dentin of extracted molars. For each of the five systems, six restorations of Dispersalloy and six restorations using Tytin alloy were prepared. The cavity margins were examined at X500 using light microscopy. The maximum width of a detected marginal gap was measured using an ocular screw micrometer. The coupling zone between dentin and amalgam was investigated using SEM. One Dispersalloy sample from each of the five bonding groups was randomly selected and examined at X500 using the SEM to identify morphological characteristics at the bonding site.

The results of the study indicate that All-Bond 2, Amalgambond, and the experimental resins containing 4-META can adequately bond amalgam to dentin in vitro. The 4-META-free experimental resin was significantly less effective, not only in shear bond strength, but in marginal adaptation with both Dispersalloy and Tytin. Bonding of Tytin overall was generally less effective. SEM examination for specimens from each of the systems demonstrated the formation of a hybrid layer as the coupling zone on the dentin side. SEM analysis also revealed interfacial debonding between the adhesive resins and amalgam; however, the authors feel that this is an artifact from SEM preparation rather than from setting or thermal contraction stresses.

In vitro caries inhibition by polyacid-modified composite resins ('compomers'). *Millar BJ, Abiden F & Nicholson JW (1998) *Journal of Dentistry* 26 133-136.

(*The King's Dental Institute, Department of Conservative Dentistry, Caldecot Road, London, SE5 9RW, UK)

Polyacid-modified composite resin (PMCR) is an esthetic restorative option toward the composite resin fringe of the esthetic directly placed restorative materials continuum, as previously described by Burgess. Fluoride release by and reuptake or recharging of PMCRs have been shown to be inferior to resin-modified glass-ionomer cement (RMGIC) and conventional glass-ionomer restorative materials (GIC). Manufacturers claim that PMCR is an easy-to-handle, cariostatic restorative option. The authors investigated the relative caries inhibitory effect in vitro of two PMCR materials (Dyract and Compoglass) and one GIC (Chemfil II). Standardized restorations were placed in extracted human permanent molars and subjected to an artificial caries/lactic acid gel submersion protocol. Subsequent dehydration, resin embedding, and sectioning permitted light microscopic evaluation and quantitative analysis of surface enamel and dentin lesion depths, as well as wall lesions. While enamel and dentin surface lesion depth was similar for each of the materials, GIC prevented the formation of wall lesions. Wall lesions were observed with each of the PMCRs, indicating potentially less caries inhibition. GIC also exhibited a zone of inhibition related to the cavity wall that was not observed with either of the PMCRs. Dunne (1996) demonstrated a RMGIC (Fuji II LC) to provide similar in vitro caries inhibition compared to the same GIC (Chemfil II) used in this study. The authors concluded that PMCR provided inferior anticaries efficacy to that attainable with use of a RMGIC or GIC.

The effect of the bleaching agent sodium perborate on macrophage adhesions in vitro: implications in external cervical root resorption. *Jiménez-Rubio A & Segura J (1998) *Journal of Endodontics* 24(4) 229-232.

(*University of Seville, School of Medicine and Dentistry, Seville, Spain)

External cervical root resorption after internal bleaching of nonvital teeth is a possible risk. There are various materials available used for treating discolored pulpless teeth, and some of these agents

are capable of inducing an inflammatory process in the attachment apparatus. Macrophages and osteoclasts (macrophage-derived cells) play a key role in the pathogenesis of external cervical root resorption. Adherence is the first step in the phagocytic process of inflammatory macrophages. Most reported cases of bleach-related root resorption are associated with the use of 30% hydrogen peroxide and heat during treatment. A previous study by Holmstrup and others found no signs of cervical root resorption in teeth bleached with sodium perborate and water after 3 years of follow-up. The effect of sodium perborate on inflammatory macrophages and the phagocytic process has not been investigated. Therefore, the purpose of this study was to examine the in vitro effect of sodium perborate on substrate adherence capacity of macrophages. Peritoneal macrophages were collected from Wistar rats and resuspended in a medium where the adherence capacity of macrophages to a plastic surface was determined. Adherence assays were performed in Eppendorf tubes for 15 minutes of incubation at 37 °C in a humidified atmosphere of 5% CO_2. Dilutions of sodium perborate of 1:1000, 1:100, and 1:10 were analyzed at 5, 15, and 30 minutes. Results showed that sodium perborate was effective in a dose-dependent manner, and the adherence index of rat peritoneal macrophages decreased significantly ($P < 0.05$). Sodium perborate was less potent than sodium hypochlorite and eugenol in inhibiting macrophage adhesion. This article concluded that the inhibitory effect of sodium perborate on macrophage adhesion interrupted the phagocytic function of macrophages, thus reducing the risk of external cervical root resorption. The authors recommended sodium perborate as the agent of choice when nonvital bleaching is indicated.

Effect of sequential versus continuous irradiation of a light-cured resin composite on shrinkage, viscosity, adhesion, and degree of polymerization. *Koran P & Kurschner R (1998) *American Journal of Dentistry* 11 17-22.

(*ESPE Dental Medizin GmbH & Co, KG, D-82229, Seefeld/Oberbay, Germany)

Recent studies have suggested that marginal adaptation of composite resins may be improved by polymerizing the material at a reduced rate. The theory is that slower rates of conversion allow for better flow of the material, which in turn reduces contraction stress and results in better marginal adaptation.

The purpose of this study was to evaluate the effect of a two-phase approach to light curing, beginning with a period of low-intensity light followed by one of high intensity. Five different tests were performed to compare variable irradiation with continuous irradiation. All test specimens used a hybrid composite (Pertac).

Surface hardness, shrinkage, and residual monomer content were no different when compared to the conventional curing approach as long as the total irradiation was high enough to permit complete polymerization. For this composite, a minimum value of 17,000 mW/cm^2 was required. How the total dose was delivered in terms of a sequential versus a continuous approach had no bearing upon the final hardness results. Viscosity tests suggested that polymerization at low intensity progressed more slowly than the higher-intensity curing, but the final viscosity changes were the same regardless of which method was used. Adhesion values to stainless steel surfaces pretreated with Rocatec and silanated with ESPE Sil were lowest with continuous irradiation. The best adhesion values were achieved using a two-step approach of 10 seconds with 150 mW/cm^2 followed by 30 seconds of 700 mW/cm^2. The lowest adhesion results were produced from a continuous irradiation for 40 seconds at 700 mW/cm^2. The results of this study appear to support the theory that marginal adhesion is weakened by very fast polymerization and may be improved with a low-intensity pre-polymerization.

Rigidity and retention of root canal posts. *Purton D, Chandler N & Love R (1998) *British Dental Journal* 184(6) 294-296.

(*University of Otago School of Dentistry, Department of Oral Rehabilitation, Box 647, Dunedin, New Zealand)

Failure of fixed restorations using post and cores in nonvital teeth can result from loss of post retention, root fracture, core fracture, bending, or fracture of the post. Prefabricated posts have been designed around retention, strength, corrosion resistance, and passive fit on cementation. Past research has shown threaded posts to have the best retention but to cause high stresses, while serrated parallel-sided posts show good retention and low stress to the dentin. The purpose of this in vitro study was to test the rigidity and retention of prefabricated parallel-sided root canal posts. The standard 1.25 mm-in-diameter Parapost (stainless steel, parallel sided, serrated) was used as the control. Two newer post systems were tested. The AccessPost is a 1.1 mm two-tiered, parallel-sided,

hollow, stainless steel post; and the Masterpost is a 1.2 mm titanium, parallel-sided, spiral-vented post. Ten of each post system were subjected to a three-point bending test to find the elastic limit as a measure of rigidity. The Parapost was found to be significantly more rigid than the other two types of posts. There was no significant difference between the AccessPost and Masterpost. The retention testing was accomplished by cementing 10 samples of each post into extracted human teeth. The canals were prepared 9 mm deep with a Gates Glidden drill followed by the manufacturers' post hole drill. The posts were cemented with Flexi-Flow Natural, a resin cement. The samples were stored in water for 2 weeks with no thermocycling. The posts were subjected to tensile force until dislodged. The Parapost showed significantly greater retention than the other two systems. The Masterpost showed greater retention than the AccessPost. The authors conclude that the stainless steel serrated Parapost was superior to the other two post systems in rigidity and retention and that coupled with the Parapost's record of clinical success it remains the first choice in prefabricated posts.

In-Ceram fixed partial dentures: three year clinical trial results. *Sorensen JA, Kong S-K, Torres TJ & Knode H (1998) *Journal of the California Dental Association* 26 207-214.

(*Oregon Health Sciences University, School of Dentistry, Portland, OR 97201-3097)

The two purposes of this prospective clinical trial were to push the limits of In-Ceram fixed partial dentures using both anterior and posterior application, and to evaluate the variables that contributed to any failures. In-Ceram is a sintered, high-alumina-content, glass-infiltrated ceramic core. Since In-Ceram gains its high strength from the core material, its manufacturers state that it may be cemented like a metal ceramic restoration. It is stable after repeated veneer porcelain firings in the porcelain oven. The authors list the advantages of the In-Ceram restoration as improved esthetics with light transmittance; reduced thermal conductivity; recurrent caries detection due to its radiolucent property; smooth surfaces resulting in less plaque accumulation; better contours when compared to overcontoured metal ceramic crown margins; and elimination of base metal alloys, which decreases casting and finishing exposure to dental laboratory personnel. A total of 61 fixed partial dentures were placed with approximately a third divided among anterior, premolar, and molar pontic areas. The margin design was a shoulder configuration with a rounded axiogingival line angle. Study evaluation consisted of intraoral photographs, polyvinylsiloxane impressions of the fixed partial dentures and antagonist teeth, and direct clinical measurements. The study found no anterior fractures at 3 years, 11% failure for the premolar pontics and 24% failure for the molar pontics. Fixed partial denture fractures occurred through the connector within the first year of placement. In the discussion, the authors attributed failure to inadequate connector height, bruxism, and flaws at the interface of the tissue surface of the connector. Veneer porcelain placed on the tissue side of the connector was not necessary due to possible voids. Glass-ionomer cement, the only cement used in this 3-year study, was predictably used to cement In-Ceram fixed partial dentures with few clinical side effects.

Conclusion: The authors felt that In-Ceram alumina can be reliably used for anterior fixed partial dentures, but cannot be reliably used for posterior fixed partial dentures.

Effect of etching on leakage of sealants placed after air abrasion. *Zyskind D, Zyskind K, Hirschfeld Z & Fuks A (1998) *American Academy of Pediatric Dentistry* 20(1) 25-27.

(*Hebrew University, Hadassah School of Dental Medicine, Department of Restorative Dentistry, Jerusalem, Israel)

The purpose of this study was to assess microleakage of pit and fissure sealants in: (1) air-abraded molars with and without etching, and (2) preventive resin restorations (PRR) prepared with air abrasion or with a bur. Forty extracted molars were divided into four groups. Prior to placement of Helioseal, treatments were: Group A—air abrasion only; Group B—air abrasion with 20 seconds of etch (PRRs); Group C—air abrasion preparation, 20 seconds of etch, Scotchbond Multi-Purpose, Z100; and Group D—bur preparation, 20 seconds of etch, Scotchbond Multi-Purpose, Z100. The teeth were thermocycled and following storage were immersed in dye. Dye penetration was measured as absolute and also as a percentage of the sealant-tooth interface. Both methods showed comparable results. The group with air abrasion only (A) showed significant microleakage compared with all other groups. There was no significant difference between air abrasion and bur preparation for microleakage with PRRs.

Conclusion: The results indicated acid etching is necessary before sealant placement. The use of air abrasion or bur preparation is equally successful prior to PRR placement with the addition of acid etching.

BOOK REVIEWS

CAD/CIM IN AESTHETIC DENTISTRY: CEREC 10-YEAR ANNIVERSARY SYMPOSIUM

Edited by Werner H Mormann

Published by Quintessence Publishing Co, Inc, Berlin, Germany, 1996. 663 pages, 400 illustrations. $68.00, softbound.

This text is based on the proceedings of the Cerec 10-Year Anniversary Symposium held in Zurich, Switzerland in 1995. This symposium provided a venue for the exchange of scientific information and practical experiences involving CEREC-computer restorations. As co-developer of the Cerec system and a well-recognized expert in the field, Werner Mormann is highly qualified to edit this book. This collection of articles by different authors forms an extensive overview of the present state of the art of CAD/CIM in dentistry, materials used, along with clinical experience and expertise involved with this new technology. This text primarily focuses on the CEREC system, with presentations covering its development and improvements, including the introduction of the Cerec 2 system, materials and techniques used in the fabrication of Cerec inlay/onlays and long-term clinical studies.

The editor has divided the book into three chapters: "Oral Presentations," "Poster Presentations," and "Contributions from Private Practices," with the sequence of publication following the order of presentation during the symposium. The "Oral Presentations" section consists of papers from 35 authors. The first five articles cover the evolution and state of the art of CAD/CIM tooth-colored restorations utilizing adhesive dentistry, provide a summary and comparison of current systems, and address esthetic and soft tissue considerations in treatment planning.

The next group of presentations focused on the Cerec system. Detailed information is provided on the scope of the Cerec 2 system's clinical applications, including cavity and restoration design, operational procedures, fabrication, and cementation of the various restorations. The step-by-step description for the design and computer machining of porcelain veneers includes a thorough section on optimizing esthetics of laminate veneers fabricated with the Cerec 2 system. Generation of full-coverage crowns and occlusal morphology using the new Cerec 2 system is also discussed in detail. Current ceramic materials are briefly reviewed and compared. In addition, the physical properties and clinical performance of CAD/CIM restorations are covered in depth and compared to other laboratory-processed inlay/onlay systems.

The second chapter, "Poster Presentations," consists of eight presentations covering such topics as clinical evaluation, comparisons of polishing methods, adaptation, and marginal fit.

The final chapter, "Contributions from Private Practice," deals with the clinical use of the Cerec system by private practitioners: marketing, patient satisfaction, clinical tips, practitioners' point of view, and implications of integrating the Cerec system in their practices.

This book is the most comprehensive and current resource for the Cerec system. It provides practitioners with background, detail in technical research, and rationale for the use of this system. There is relevant background information emphasizing clinical significance along with sufficient detail of the clinical procedures for a practitioner to apply the information in a clinical setting. Illustrations and photographs help the readers to better understand the concepts and technical procedures described.

The organization of the text, however, following the sequence of presentations, interferes with the flow of information and makes it more difficult for the reader to search for a particular topic.

This text accomplishes the editor's goal of being a thorough review of the Cerec 10-year anniversary symposium. The text is directed to owners of the Cerec system, or those dentists interested in incorporating CAD/CIM restorations into their clinical practice, specifically Cerec restorations. It is a good resource book for professionals and educators that want detailed information on the Cerec system.

MARCOS A VARGAS, DDS, MS
Assistant Professor
Department of Operative Dentistry
College of Dentistry
The University of Iowa
229 Dental Science S
Iowa City, IA 52242-1001

UNDERSTANDING ORTHODONTICS

Harold T Perry and David P Forbes

Published by Quintessence Publishing Co, Inc, Chicago, 1997. 52 Pages, 32 color illustrations. $28.00.

This beautifully presented book of illustrations aims to help young prospective orthodontic patients and their families answer many common questions

concerning the nature and origins of their orthodontic problems and guides them along the treatment process in an easy-to-follow format. By answering very basic questions such as "Why are my teeth crooked ?" and "What can I expect from orthodontic treatment ?" the authors help explain in easy-to-understand terminology and with excellent illustrations the underlying causes of malocclusion. In sections that follow, the reader is taken through a number of the appliances and techniques that could be used in the correction of different orthodontic problems. An oral hygiene section gives some pointers for good brushing and flossing and maintaining the level of health needed during treatment, and a section of frequently asked questions can help a patient get answers to some basic questions about orthodontic treatment.

This text works very well as a waiting room educational tool or as a chair-side reference. Its excellent illustrations deserve a place in both the general and specialty practice. In an orthodontic practice this text, with its clear and concise presentation, could fit in at a number of places during the course of diagnosing, planning, and treating an orthodontic patient.

JEFF ABOLOFIA, DDS
Associate Professor
Department of Restorative Dentistry
School of Dentistry
University of Washington
Box 357456
Seattle, WA 98195-7456

DRAGON TEETH AND PARROT BEAKS

Almute Grohmann

Published by Quintessence Publishing Co, Inc, Chicago, 1997. 32 pages, 14 color illustrations. $18.50.

Dragon Teeth and Parrot Beaks would be an excellent addition to any reception area library made available to children. The interest level is at about ages 4 to 9, although many adults will enjoy it as well. The author skillfully educates his young audience by disguising the familiar hygiene lessons in a comical, animated story. He describes how various animals properly or improperly care for their teeth, which alleviates any guilt trip or sense of lecturing a tutorial approach would take. This hardback book is beautifully illustrated and fun to read.

DIANTHA J BERG, DDS
1216 NE 65th Street
Seattle, WA 98115

LETTER

BASES AND LINERS

Twenty years ago when I attended dental school, we were taught to place some form of nonmetallic bases and liners under all of our amalgam restorations. Since that time the pendulum has swung the other direction, so that now many clinicians are telling us that the placement of bases is not only unnecessary, but may in fact be harmful. Current thinking in operative dentistry is that liners not only wash out, leaving voids under amalgam restorations, but also thick bases can contribute to early amalgam fracture. The more current thought is that dentinal bonding agents reduce dentinal tubule flow, thereby reducing dentinal sensitivity without the previously mentioned disadvantages. Although there is enough in vitro as well as clinically anecdotal evidence in microleakage reduction to justify routine use of these agents under amalgam restorations, I contend their ability to eliminate thermal transmission is questionable. My contention in based upon the observation that numerous teeth with moderate-to-deep amalgam restorations (no liner) often remain sensitive for a prolonged period of time. Certainly we do not need to place bases/liners under all amalgam restorations, and if we do place a base it doesn't need to be to ideal depth. But we still need some bases under our medium-to-deep amalgam restorations, and these bases can be of minimal thickness. Lastly, we as clinicians tend to forget how the pulp, with its minimal ability to heal itself, is so often insulted by bacteria and numerous dental procedures. We should make sure that any potential chronic thermal trauma is eliminated, and I feel that dentinal bonding agents alone are not enough.

JAMES E NEWMAN, Jr, DDS
4518 NE Arlington
Lawton, OK 73507

ANNOUNCEMENTS

28th ANNUAL MEETING of the ACADEMY OF OPERATIVE DENTISTRY

17-19 February 1999
FAIRMONT HOTEL
CHICAGO, ILLINOIS

The 28th annual meeting of the Academy of Operative Dentistry will be held in a new meeting hotel (the Fairmont), which offers the additional room needed for our expanding attendance. Thursday will feature Dr Richard Blankenau ("Laser Treatments as a Part of Operative Dentisty: Why and When"), Dr Beatrice Gandara ("Dental Erosion: Diagnosis and Management"), Dr E Steven Duke (Buonocore Memorial Lecture), Dr Rella Christensen ("Interesting and Controversial New Products"), and Dr John Osborne ("Amalgam: I Heard You Had Died!"). Friday's essayists include Dr John Burgess ("Fluoride-releasing Materials: Fact and Fiction"), Dr James B Summitt ("Responding to Advantages of Adhesive Dentistry: Cavity Preparations Are Different Today"), and Dr Michael A Cochran ("Management of the Cervical Lesions: the Nonglamorous Side of Restorative Dentistry"). Besides these exciting and outstanding speakers, an excellent Table Clinic session will be held on Friday afternoon. In addition there are always fun "companion activity" events, which include a get-acquainted breakfast at the Fairmont hotel on Thursday and a tour, "Chicago from the River," given by Joan Lindsay on Friday.

For meeting information please contact Dr Gregory Smith, P O Box 14996, Gainesville, FL 32604-2996; FAX (352) 371-4882.

CREDIT CARD PAYMENT

Operative Dentistry now accepts Visa, MasterCard, or JCB (Japanese equivalent to Visa or MasterCard) payment for subscriptions and other services. We will need the usual information: type of credit card, credit card number, expiration date, and name as it appears on the card.

OPERATIVE DENTISTRY HOME PAGE

There is an abundance of information available by accessing our internet Home Page, where we have nine folders to support your needs. Our address is:

http://weber.u.washington.edu/~opdent

Within the **Subscribe** folder, you will find change of address forms, request forms for information about the AOD, AAGFO, and/or the ESAOD, and a subscription form for *Operative Dentistry*. Within this same folder, subscription rates and back issue rates are provided for you.

A **Message** folder contains articles in the queue for publication in the future. The author, title, and clinical relevance statement are provided for each article.

The **Index** folder contains contents of all the Journal articles since Volume 1, 1976.

The **Search** folder offers you the ability to search for articles of interest within any of the previous issues. A key word or words will facilitate the search process.

Recent **Editorials** are included for those interested in returning to one published in the past.

The **News** folder contains meeting announcements and University faculty position advertisements submitted to *Operative Dentistry* for publication.

The **Reviewers** folder is provided for the Editorial Board to submit reviews of manuscripts to the Editor.

The **Pearls** folder includes operative pearls submitted by subscribers so that all the helpful hints will be contained in one place for easy reference.

So, all in all, your Journal's Home Page contains an abundance of information for your convenience.

NOTE: It is highly recommended that Academy interest, change of address, and subscription forms be downloaded and used by anyone wishing to contact us. It really is a convenience available to anyone in the world!

BOUND ISSUES OF *OPERATIVE DENTISTRY* AVAILABLE

Volume 22 of *Operative Dentistry* (1997, six issues) has been bound and is available for purchase from the Editorial Office in Seattle. Individual volumes sell for $35.00 each plus postage. The entire set of 22 volumes sells for $510.00 plus postage. Checks or money orders should be made payable to Operative Dentistry. Credit card payment requires the type of credit card, credit card number, expiration date, and name as it appears on the card. Send orders to: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

INSTRUCTIONS TO CONTRIBUTORS

Correspondence

Send manuscripts and correspondence regarding manuscripts to the Editor, Richard B McCoy, at the editorial office: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457; (206) 543-5913, FAX (206) 543-7783; e-mail: rmccoy@u.washington.edu; URL: http://weber.u.washington.edu/~opdent/.

Exclusive Publication

It is assumed that all material submitted for publication is submitted exclusively to *Operative Dentistry.*

Manuscripts

Submit the original manuscript and one copy; authors should keep another copy for reference. Type double spaced, including references, and leave margins of at least 3 cm (1 inch). Supply a short title for running headlines and a FAX number for the corresponding author. Spelling should conform to *American Heritage Dictionary of the English Language,* 3rd ed, 1992. Nomenclature used in descriptive human anatomy should conform to *Nomina Anatomica,* 6th ed, 1989. The terms *canine* and *premolar* are preferred; the terms *vestibular*, *buccal*, *facial*, and *lingual* are all acceptable. SI (Système International) units are preferred for scientific measurement, but traditional units are acceptable. **Proprietary names of equipment, instruments, and materials should be followed in parentheses by the name and address, including ZIP code, of the source or manufacturer.** The editor reserves the right to make literary corrections. Research (original) papers must include a one-sentence **Clinical Relevance** statement, as well as **Summary**, **Introduction**, **Methods and Materials**, **Results**, **Discussion**, and **Conclusion** sections. Clinical papers should contain at least the following: **Purpose**, **Description of Technique** or **Solution** along with materials and potential problems, and a **Brief Summary** outlining advantages and disadvantages.

Authors who prepare their manuscripts on a word processor are to submit a computer disk of the manuscript (3½ - or 5¼-inch) in addition to the original typed manuscript. Identification of the operating system (Macintosh or IBM-compatible) and the word processing program used is necessary. Authors should also retain an additional manuscript copy on disk to facilitate altering the paper in response to comments by referees.

Illustrations

Submit four copies of each illustration. **Line drawings** should be in india ink or its equivalent on heavy white paper, card, or tracing vellum. All lettering must be of professional quality, be legible against its background, and remain proportionally legible if reduced. Type legends on separate sheets. **Graphs** are to be submitted with any lettering proportional to their size as indicated for illustrations, and with their horizontal and vertical axes values **as well as all values used to create the graphs**. **Photographs** should be on glossy paper with a maximum size of 15x20 cm (6x8 inches). For best reproduction a print should be one-third larger than its reproduced size. Only black-and-white photographs will normally be accepted. On the back of each illustration, near the edge, indicate lightly in pencil the top, the author's name, and the number of the figure. Where relevant, state staining technique(s) and the magnification of prints. Obtain written consent from holders of copyright to republish any illustrations published elsewhere. Photographs become the property of *Operative Dentistry.*

Tables

Submit two copies of tables typed on sheets separate from the text. Number the tables with arabic numerals.

References

Arrange references in alphabetical order of the authors' names at the end of the article, the year of publication being placed in parentheses immediately after the author's name. Do not abbreviate titles of journals; write them out in full. Give full subject titles and first and last pages. In the text cite references by giving the author, and, in parentheses, the date: Smith (1975) found...; or, by placing both name and date in parentheses: It was found ... (Smith & Brown, 1975; Jones, 1974). When an article cited has three authors, include the names of all of the authors the first time the article is cited; subsequently, use the form (Brown & others, 1975). Four or more authors should always be cited in the text thus: (Jones & others, 1975), but in the list of references list all the authors. If reference is made to more than one article by the same author and published in the same year, the articles should be identified by a letter (a, b) following the date, both in the text and in the list of references. Titles of books should be followed by the name of the place of publication and the name of the publisher.

Reprints

Reprints of any article, report, or letter can be ordered through the Seattle office.

JANUARY-FEBRUARY 1999 • VOLUME 24 • NUMBER 1 • 1-64

EDITORIAL

Diversity: A Blessing or a Curse?	1	RICHARD B McCOY

ORIGINAL ARTICLES

Mechanical Properties of Compomer Restorative Materials	2	I H EL-KALLA F GARCÍA-GODOY
Two-Year Clinical Performance of a Resin-modified Glass-Ionomer Restorative Material	9	W W BRACKETT • R O GILPATRICK W D BROWNING • P N GREGORY
Fluoride Release from Some Dental Materials in Different Solutions	14	A S CARVALHO J A CURY
Radiopacity of Compomers, Flowable and Conventional Resin Composites for Posterior Restorations	20	M R BOUSCHLICHER D S COBB D B BOYER
Retention of Microfilled and Hybrid Resin-based Composite in Noncarious Class 5 Lesions: A Double-blind, Randomized Clinical Trial	26	W D BROWNING W W BRACKETT R O GILPATRICK
Effect of Curing-Tip Diameter on the Accuracy of Dental Radiometers	31	D L LEONARD • D G CHARLTON T J HILTON
Hardening of New Resin Cements Cured through a Ceramic Inlay	38	O M EL-MOWAFY • M H RUBO W A EL-BADRAWY
Fracture Strength of Class 2 Amalgams with Various Cavity-lining Materials	45	A E PALMER • R D DAVIS D F MURCHISON • R B COHEN
Bond Strength of Composite to Enamel and Dentin Using Prime & Bond 2.1	51	W W BARKMEIER P D HAMMESFAHR • M A LATTA

DEPARTMENTS

Abstracts	57
Book Reviews	62
Letter	63
Announcements	64

10-9385
University of Washington
OPERATIVE DENTISTRY
Box 357457
Seattle, WA 98195-7457 USA

Periodicals