# OPERATIVE DENTISTRY

AMERICAN ACADEMY OF GOLD FOIL OPERATORS

ACADEMY OF OPERATIVE DENTISTRY

july-august 1996 • volume 21 • number 4 • 133-180

(ISSN 0361-7734)

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JULY-AUGUST 1996 • VOLUME 21 • NUMBER 4 • 133-180

**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 also are published.

*OPERATIVE DENTISTRY* (ISSN 0361-7734) is published bimonthly for $55.00 per year in the US and Canada (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 other selected points. **POSTMASTER:** Send address changes to: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457.

**CHANGE OF ADDRESS: University of Washington, OPERATIVE DENTISTRY, Box 357457, Seattle, WA 98195-7457 USA.**

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Yearly subscription in USA and Canada, $55.00; other countries, $70.00 (sent air mail printed matter); dental students, $25.00 in USA and Canada; other countries, $34.00; single copy in USA and Canada, $15.00; other countries, $18.00. 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.

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# EDITORIAL

# Dental Economics and Its Effect on the Quality of Care

"May you live in interesting times." This old Chinese curse is certainly a reality for dentistry today. Changes in techniques are occurring at a rapid pace, and to keep up with them, dentists need to spend practically all their time in study clubs. Insurance salespeople and financial planners tell us that 95% of dentists reach retirement age without being financially independent, and practice management people tell us that independent practice of dentistry is a thing of the past, that within a few years we will all belong to the PPOs and HMOs. They say that the demise of our delivery system is imminent, because the insurance industry sees dentistry as its next great profit center.

There is one thing that these practice management Malthusians are correct about: The motivation of the insurance industry's corporate executives is the bottom line. I do not say that critically, because that is their responsibility. And that is the difference between being an insurance executive and being a dentist; that's what makes us a profession. I differ from some in our profession in that I don't believe that insurance executives are evil people. They are doing what they are supposed to do, i e, increase their market share and profits. These executives will and should do this in any manner that is legal. They have no responsibility to do what is dentally best for the public, because they don't know what that might be. The public doesn't either. So that leaves the responsibility to protect the public's interest with us, the dental profession. We are the last and only barrier to protect the public from the insurance industry. It is our sacred responsibility; it is what makes us a profession. Granted, this is a most difficult task. Have you ever met two dentists who would agree on a specific treatment plan? Each of us has to make these difficult decisions based on what is in the best interest of the patient. It is still our responsibility, because no one else has the knowledge. Insurance executives would be the first to agree that they do not set the standards of care. But if we tell them that bat guano is an acceptable restorative material, then they would rightly say that "If the dental profession says this is an acceptable treatment, then that is the treatment that we will pay for, and we will pay for nothing more expensive." The insurance company would set the quality of care to the lowest common denominator that we will allow them. Unfortunately, I have heard dentists discuss managed care from the prospective of how it might influence their personal income. Ironically, this is the <u>only</u> position that would likely cause us to lose our freedom of independent practice. But if we claim the high ground of what is truly in the interest of the patient, then we have nothing to fear. If we act out of principal regardless of the consequences, we will always control our destiny. It is unlikely that we could ever be coerced to join groups that discriminate against one group in favor of another, i e, that charge one group of people less than another for the same service. This is grossly unfair. We should charge the same fee for the same service regardless of who the patients may be.

It is important for us, as dentists, to remember that this is the same profession that promoted fluoride in the drinking water, that turned the American public into flossers, that has taken the position that it is unethical to recommend the removal of mercury-silver amalgam, because removal was only supported by anecdotal evidence and not substantiated by scientific evidence. It was certainly not in our economic interest to take any of these positions, but we did, because it was in the patients' best interest. We can be very proud of our past record, and we should use it to good advantage in promoting the preservation of a delivery system that allows for a continued improvement in the dental health of the public. The public, the government, and the insurance industry need to be vigorously reminded of our past record when we take a position that might make the cynical person think we are acting out of self-interest. It just turns out that in this case our own self-interest and the patients' self-interest are the same. Our current delivery system allows great flexibility. Within this system we can look forward to treating our patients with an even higher standard of care over the next 5 to 10 years. But if we are all forced into the straight jacket of PPOs and managed care, the quality of care will spiral downward because of an inflexible bureaucratic system that only values cost containment.

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*OPERATIVE DENTISTRY, 1996,* **21**,*134-146*

# REVIEW OF LITERATURE

# Cavity Sealers, Liners, and Bases: Current Philosophies and Indications for Use

T J HILTON

**Clinical Relevance**
Understanding the properties of currently available materials and how they interact with pulpal tissues can help the practitioner decide when to use bases and liners and which products to choose.

## SUMMARY

**Traditional dental education has recommended the generous use of bases and liners under amalgam restorations, primarily to prevent postoperative sensitivity. However, new developments in bases and liners, as well as a better understanding of pulp biology, have changed the indications for the use of these materials. Understanding the properties of currently available materials and how they interact with pulpal tissues can help the practitioner decide when to use bases and liners and which products to choose.**

## INTRODUCTION

Prior to placing or cementing a restoration into a cavity preparation, the clinician must decide if a protective sealer, liner, or base should be placed on the cavity walls. While seemingly simple, this decision has been complicated by an ever increasing number of products. The purpose of this review article is to discuss how the various protective materials interact with and provide protection for the pulp, review the properties of the current products, and make recommendations for their use based on the current scientific knowledge.

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## PULPAL CONSIDERATIONS

The physiology of the pulp is influenced by several factors that form the basis for the decision to use a base and/or liner.

### Remaining Dentin Thickness

There is no artificial material that can be placed into a tooth that provides better protection for the pulp than dentin. Basing or lining materials have not demonstrated properties that ideally duplicate those of dentin. The remaining dentin thickness from the pulpal extent of the cavity preparation to the pulp is the single most important factor in protecting the pulp from insult (Stanley, 1981b). In vitro studies have shown that a 0.5 mm thickness of dentin reduces the toxicity level of a material by 75%, and a 1 mm thickness of dentin by 90% (Meryon, 1988). Little if any pulpal reaction occurs with 2 mm of remaining dentin thickness (Stanley, 1981c). Dentin has excellent buffering capability to neutralize the effects of cariogenic acid production (Stanley, 1981a). Conservation of remaining tooth structure is more important to pulpal health than replacement of lost tooth structure with a cavity liner or base.

### Causes of Pulpal Inflammation

As with other soft tissues in the body, the pulp reacts to irritants with inflammation (Weine, 1982a). It was believed for a number of years that the primary causes of pulpal inflammation were direct toxic effects from dental materials (Stanley, 1990; Stanley, Going & Chauncey,1975). More recent evidence, however, has demonstrated that pulpal inflammation resulting from dental materials is mild and transitory, with adverse pulpal reactions only occurring as the result of pulpal invasion by bacteria or their toxins (Brännström, 1984; Cox & others, 1987; Watts & Paterson, 1987; Browne & others, 1983). When this occurs, severe inflammation or necrosis of the pulp is frequently observed (Watts & Patterson, 1987). The outward flow of fluid through dentin tubules does not prevent either bacteria or their toxins from reaching the pulp and initiating pulpal inflammation (Vojinović, Nyborg & Brännström, 1973).

When bacterial contamination is prevented, favorable pulpal responses have been found with restorations of amalgam, zinc phosphate cement, light-activated composite, silicate (Cox & others, 1987), glass ionomer, autocure composite (Nordenvall, Brännström & Torstenson, 1979), and acrylic resin (Brännström & Vojinović, 1976). Acid etching of dentin has long been considered detrimental to the pulp, but recent animal studies have indicated that the pulp can readily tolerate the effects of low pH if bacterial invasion is prevented (Nordenvall & others, 1979; Kurosaki & others, 1990; Brännström & Nordenvall, 1978). A multicenter clinical trial being conducted by the University of Texas/San Antonio School of Dentistry and the U S Air Force, evaluating the use of the total etch technique to restore noncarious class 5 lesions, has shown no adverse pulpal effects after 2 years.

### Causes of Pulpal Pain

While not fully understood, the causes of pulpal pain are becoming better explained. Increased intrapulpal pressure on nerve endings secondary to an inflammatory response is one mechanism that has been put forth to explain pain due to bacterial invasion (Stanley, 1981d). However, this interpretation fails to account for sensitivity that occurs in the absence of inflammation. Although alternative theories have been proposed, the one that is most accepted is the hydrodynamic theory. In a vital tooth with exposed dentin, there is a constant slow movement of fluid outward through dentin tubules (Brännström, 1984). The hydrodynamic theory proposes that when a stimulus causes the slow fluid movement to become more rapid, nerve endings in the pulp are deformed, which is interpreted as pain. Stimuli, such as tooth preparation, drying with an air syringe, or application of cold, have been suggested to cause this sudden rapid fluid movement (Brännström, 1984). Chiseling or scraping with an explorer can also cause sudden movement by mechanically pressing out fluid from the dentinal tubules (Brännström, 1982).

## THERMAL SENSITIVITY

Prevention of postoperative thermal sensitivity following restoration has long been a rationale for placement of a base underneath a restoration, but in vivo research documenting the frequency of postoperative discomfort is sparse and poorly controlled. Although one study showed that patients seemed to benefit from placement of thick cement bases (Miller & Charbeneau, 1984), another demonstrated that after 6 months few patients had thermal sensitivity regardless of whether a base had been utilized or not (Piperno & others, 1982). Fifty percent of patients surveyed 24 hours after restoration placement noted some thermal discomfort in the restored tooth. However, 78% of these patients described the discomfort as mild and fleeting (Silvestri, Cohen & Wetz, 1977). Any discussion of the need for protection against postoperative thermal sensitivity must be tempered by the prospect that the prevalence and magnitude of this problem may be overestimated.

There are two theories dealing with the cause of thermal sensitivity (usually to cold) following restoration placement and, therefore, two philosophies addressing the problem. The first philosophy is that sensitivity is the result of direct thermal shock to the pulp via temperature changes transferred from the oral cavity through the restorative material (Going, 1964), especially when remaining dentin is thin. Protection from this insult would then be provided for by an adequate thickness of an insulating material with low thermal diffusivity (Harper & others, 1980). It has been noted that composite exhibits such low thermal diffusivity that a thermal insulating base is unnecessary in conjunction with these restorations (Harper & others, 1980; Drummond & others, 1993). An insulating base for thermal protection purposes is therefore limited to use under metallic restorative materials that exhibit higher rates of temperature transfer.

When utilizing a base to provide insulation to counter thermal sensitivity, caution must be exercised to minimize the thickness of basing material utilized. Research has clearly shown that as the thickness of the base increases, the fracture resistance of the overlying amalgam decreases (Farah & others, 1983; Hormati & Fuller, 1980). Since temperature diffusion through amalgam to the floor of the cavity preparation is effectively reduced by 0.5-0.75 mm of basing material, thickness should be restricted to this dimension (Harper & others, 1980). Modulus of elasticity (MOE) (stiff = high modulus of elasticity; flexible = low modulus of elasticity) is the key property predicting how effectively a base will support an amalgam restoration. As the MOE of a material decreases, the resistance to fracture of an amalgam decreases (Farah & others, 1983; Hormati & Fuller, 1980; Pierpont & others, 1994).

The second philosophy holds that temperature sensitivity is based on pulpal hydrodynamics. Most restorations have a gap between the wall of the preparation and the restorative material that allows the slow outward movement of dentinal fluid. Cold causes a sudden contraction of this fluid, resulting in a rapid increase in the flow, which is perceived by the patient as pain (Brännström, 1984). As dentin nears the pulp, tubule density and diameter increase (Stanley, 1990), as does permeability (Pashley, 1990), thus increasing both the volume and flow of pulpal fluid susceptible to the hydrodynamic effects of cold. Resistance to such fluid movement is proportional to dentin thickness or tubule length (Pashley, 1991). This could explain why deeper restorations are associated with more sensitivity problems. According to this theory, if the tubules can be occluded, fluid flow is prevented and cold cannot induce pain. The operative factor in reducing temperature sensitivity thus becomes not a specific thickness of insulating material, but effective sealing of dentin tubules (Brännström, 1984). Credence is lent to this theory by scanning electron microscope observations that demonstrate significantly more open tubule orifices in hypersensitive dentin (Duke & Lindemuth, 1991; Yoshiyama & others, 1989). Additionally, human research has related pain response to hydrostatic pressures applied to prepared dentinal cavities following removal of the smear layer (Ahlquist & others, 1994).

## CATEGORIES OF BASES AND LINERS

This section summarizes the properties of the currently available materials for use as bases, liners, or sealers. Knowledge of the properties and indications for use within each category will aid the practitioner when faced with a decision regarding specific brands.

**CAVITY SEALERS** provide a protective coating for freshly cut tooth structure of the prepared cavity.

A **Varnish** is a natural gum, such as copal or rosin, or a synthetic resin dissolved in an organic solvent such as acetone, chloroform, or ether, which evaporates and leaves a protective film behind.

Copal varnish has been utilized for many years to seal the amalgam-tooth interface until corrosion products form to eliminate the gap (Andrews & Hembree, 1980; Lin, Marshall & Marshall, 1983; Craig, 1993), and to provide a barrier against the passage of irritants from cements (Craig, 1993). Two applications have been shown to be most effective (Pashley & others, 1985). Copal varnish is capable of reducing dentin permeability by 69% (Pashley, Livingston & Outhwaite, 1977), and to significantly reduce microleakage for 6 months (Ben-Amar & others, 1990). Since the layer of varnish is so thin, little or no thermal insulation is provided (Craig, 1989a). It is commonly used under amalgam restorations and prior to cementation of indirect restorations with zinc phosphate cement. Placement of copal varnish prior to crown cementation with zinc phosphate does not have a detrimental effect on retention (Felton, Kaney & White, 1987).

### Dentin Bonding Agents

The most recent materials to be used as cavity sealers are those that have a demonstrated multisubstrate bonding ability to bond the restorative material to the tooth. Examples include resin cements, glass ionomers, and dentin bonding agents. The benefits of utilizing these materials to bond composite to tooth structure is a well-documented and accepted procedure. However, employing them in conjunction with amalgam restorations is more controversial. The proposed benefits for using adhesive liners under amalgams are to decrease microleakage and temperature sensitivity, and to provide improved retention and strengthening of adjacent tooth structure.

Researchers have sought to find a cavity sealer that could provide improved performance over varnish. Studies have revealed that varnishes reduce but do not eliminate microleakage around amalgam restorations (Pashley & Depew, 1986; Fitchie & others, 1990; Sneed, Hembree & Welsh, 1984), while others have shown no benefit or even increased microleakage (Wright & others, 1992; Mazer, Rehfeld & Leinfelder, 1988). Although some studies have not demonstrated a decrease in marginal microleakage using dentin bonding agents when compared to varnish (Dutton & others, 1993), others have shown a significant reduction (Saiku, St Germain & Meiers, 1993; Ben-Amar & others, 1990). In addition, improved sealing of dentin tubules compared to varnish has been demonstrated by dentin bonding agents

(Saiku & others, 1993) and a primer/liner (Pashley & others, 1985). Additionally, animal research has demonstrated that dentin primers alone or in conjunction with dentin adhesives can significantly reduce dentin sensitivity (Watanabe & others, 1991) and have good pulpal compatibility (Suzuki, Cox & White, 1994; White & others, 1994).

Modern adhesives continue to exhibit significant leakage when cavity margins are on cementum (Strydom & others, 1995; Pameijer & Wendt, 1995; Tay & others, 1995). It is important to note that most in vitro research on dentin bonding agents' use with amalgam restorations is of short-term duration. When evaluated over a longer period of time, the seal at both the restoration interface (Saiku & others, 1993) and over the dentinal tubules breaks down significantly (Warren & others, 1995). An ongoing multicenter clinical trial of class 5 composites being conducted by the University of Texas/San Antonio School of Dentistry and the U S Air Force has shown a loss of marginal seal as evidenced by a steady increase in dentin marginal discoloration.

Given these facts, there are some concerns about the use of dentin bonding agents under amalgam restorations. The insoluble adhesive layer may act as a barrier to prevent amalgam corrosion products from ultimately sealing that gap. The dentin bonding agents may potentially put the patient at greater risk in the long term for marginal leakage and recurrent caries. In addition, use of dentin bonding agents is much more technique sensitive than varnish (Tay & others, 1995; Hilton & Schwartz, 1995), as well as being more expensive and time consuming (Christensen, 1994). Finally, controlled clinical trials have failed to demonstrate a decrease in postoperative sensitivity with the use of adhesive agents under amalgam restorations when compared to using either varnish or no cavity liner at all (Mazer, Leinfelder & Barnette, 1995; Mahler, Engle & Adey, 1995).

The other proposed benefits of using dentin bonding agents in conjunction with amalgam restorations are improved retention and strengthening of adjacent tooth structure. Research results are equivocal, with some in vitro studies demonstrating these advantages (Eakle, Staninec & Lacy, 1992; Temple-Smithson, Causton & Marshall, 1992; Boyer & Roth,1994), while others have not (Joynt & others, 1989; Santos & Meiers, 1994; Larsen & others, 1995). In addition, loss of the bond between the adhesive agent and amalgam with aging has been demonstrated (Saiku & others, 1993; Warren & others, 1995), as has the bond of adhesive to tooth (Watanabe & Nakabayashi, 1993). Because the attachment mechanism between bonding agent and amalgam is achieved by intermingling unset bonding agent with unset amalgam (McComb, Brown & Forman, 1995), consideration of the possible effects of bonding procedures on the physical properties of amalgam is warranted, since incorporation of adhesive agents may have detrimental consequences (Charlton, Murchison & Moore, 1991; Hadavi & others, 1991). Use of bonded composite restorations has failed to reinforce in vivo tooth structure over the long term (Hansen, 1988), and clinical studies have not shown any improvement in amalgam marginal breakdown compared to using varnish or no cavity liner (Mazer & others, 1995; Mahler & others, 1995). The clinician should also keep in mind that amalgam restorations utilizing conventional resistance and retention form have demonstrated capability for long-term clinical success (Robbins & Summitt, 1988; Smales, 1991), whereas substituting adhesive agents and retaining weakened tooth structure in lieu of the more traditional cavity preparation principles have not.

Clearly, research results concerning the use of dentin bonding agents are promising. But it is just as certain when reviewing the literature that the data are often equivocal, rarely definitive, and lack long-term clinical documentation. It is the author's opinion that wholesale endorsement of their use under amalgam restorations is premature, and caution should be exercised until controlled clinical studies can document both their effectiveness and long-term sequela.

**CAVITY LINERS** placed with minimal thickness, usually less than 0.5 mm, act as cavity sealers and provide expanded beneficial functions, such as fluoride release, adhesion to tooth structure, and/or antibacterial action that promotes the health of the pulp (McCoy, 1995).

### Calcium Hydroxide ($Ca[OH]_2$)

Calcium hydroxide has long been used as a base/liner because of its pulpal compatibility and purported ability to stimulate reparative dentin formation with direct pulpal contact (Stanley, 1981e). However, research has shown that not all formulations of $Ca(OH)_2$ have a stimulatory effect on human pulpoblasts (Hanks, Bergenholtz & Kim, 1983). There is a growing belief that reparative dentin formation is assisted, rather than stimulated, because $Ca(OH)_2$ has antibacterial activity that prevents bacteria from entering the pulp and inducing inflammation (Brännström, 1984; Cox & others, 1987; Watts & Paterson, 1987). Conventional formulations of $Ca(OH)_2$ demonstrate poor physical properties (Farah & others, 1983; Craig, 1989b). High solubility may result in contamination of bonding agents and increased marginal leakage (Krejci & Lutz, 1990), as well as softening or material loss under poorly sealed restorations (Brännström, 1984; Pereira, Manfio & Franco, 1990). Visible-light-activated calcium hydroxide overcomes most of these deficiencies and exhibits improved physical properties (Tam & others, 1989) and significantly reduced solubility (Craig, 1989b). While modulus of elasticity has been shown to be increased relative to conventional $Ca(OH)_2$ in one study (Lewis, Burgess & Gray, 1992), in another it was lower (Tam & others, 1989), with a subsequent reduced ability to support an overlying amalgam restoration (Pierpont & others, 1994). These unfavorable properties restrict $Ca(OH)_2$ use to application over the least area needed to aid in the formation of reparative dentin when a known or suspected pulp exposure exists.

### Glass Ionomer

Glass ionomer has been utilized as a cavity liner in an attempt to take advantage of two highly desirable properties: chemical bond to tooth structure and fluoride release (Craig, 1989e). Although fluoride release from glass ionomer decreases with time (Olsen & others, 1989), sustained release has been demonstrated (Mitra, 1991) with corresponding uptake into adjacent tooth structure (Geiger & Weiner, 1993). This is thought to aid in anticariogenic activity (García-Godoy & Jensen, 1990). Similar to $ZnPO_4$, glass ionomer is quite acidic upon initial mixing, but tends to neutralize within 24 hours (Charlton, Moore & Swartz, 1991). Pulpal response to both visible-light-activated and conventional glass-ionomer formulations has been shown to be quite favorable (Nordenvall & others, 1979; Hosada & others, 1991; Gaintantzopoulou, Willis & Kafrawy, 1994; Heys & Fitzgerald, 1991), probably due to glass ionomer's ability to decrease bacterial penetration (Heys & Fitzgerald, 1991). The exact mechanism by which glass ionomer reduces bacterial invasion is uncertain, but it may be due to one or more of the following: fluoride release, initial low pH (DeSchepper, Thrasher & Thurmond, 1989), chemical bond to tooth structure physically excluding bacteria (Heys & Fitzgerald, 1991), or release of a metal cation (Meryon & Jakeman, 1986; Scherer, Lippman & Kaim, 1989). Both visible-light-activated and conventional glass ionomers exhibit good physical properties, with the conventional version exhibiting a higher modulus of elasticity (Burgess & others, 1993), and subsequently improved support for amalgam restorations (Pierpont & others, 1994). In addition, glass ionomer has been shown to reduce microleakage when placed under amalgam restorations (Arcoria, Fisher & Wagner, 1991). Conventional glass ionomers are relatively soluble in an acidic environment and are susceptible to rapid surface deterioration when subjected to acid etching (Smith, 1988). Visible-light-activated glass ionomers show improved resistance to acid solubility (Tam & others, 1989) while maintaining fluoride release and bond to tooth structure (Burgess & others, 1993). Therefore, the visible-light-activated formulations are more desirable for use with composite restorations.

**CAVITY BASES** are dentin replacement materials, allowing less bulk of restorative material or blocking out undercuts for indirect restorations (McCoy, 1995).

### Zinc Oxide-Eugenol

Zinc oxide-eugenol is obtundent when placed in close proximity with the pulp (Craig, 1989b). While normally considered an advantage, this effect may also mask pathologic symptoms. In addition, direct pulpal contact with the eugenol from zinc oxide-eugenol can interfere with cellular respiration, resulting in necrosis (Cox, 1987). Zinc oxide-eugenol provides an effective seal against biological leakage (Cox & others, 1987); this is probably due more to its antibacterial properties than to its ability to effectively prevent fluid ingress at the cavity interface (Pameijer & Wendt, 1995). Zinc oxide-eugenol bases and liners provide excellent thermal insulation (Peters & Augsberger, 1981), but tend to exhibit poor physical properties (Farah & others, 1983; Hormati & Fuller, 1980; Craig, 1989b), inhibit composite polymerization (Craig, 1989b), and increase microleakage under amalgam restorations (Manders, García-Godoy & Barnwell, 1990). Because of these latter significant drawbacks, zinc oxide-eugenol use should be limited to that of a temporary restorative material or luting agent.

### Zinc Phosphate ($ZnPO_4$)

Zinc phosphate is very acidic shortly after being mixed (Craig, 1989c), and this property has traditionally been blamed for pulpal inflammation following its use. However, it is now known that zinc phosphate's poor sealing properties and subsequent bacterial invasion are the primary reasons for adverse pulpal reactions from $ZnPO_4$ (Cox & others, 1987). However, $ZnPO_4$ is inexpensive, readily available in most dental offices, exhibits excellent thermal insulation (Harper & others, 1980), physical properties (Craig, 1989d), and support for overlying restorations (Pierpont & others, 1994). Because of its poor sealing abilities and lack of anticariogenic properties, however, its use would be best limited to patients with a low caries index, in which dentin needs to be replaced prior to restoration placement.

### Glass Ionomer

As previously mentioned, glass ionomer has excellent physical properties, with the conventional version offering excellent modulus of elasticity and ability to support restorations. As a result, glass ionomer can be used as a cavity base as well as a cavity liner.

## MINIMUM BASING CONCEPT

Regardless of the clinician's rationale for using a base under a restoration, the limitations of currently available basing materials must be kept in mind. The best possible base for any restoration is sound tooth structure. The following are guidelines for the placement of bases:

1. Do not remove sound tooth structure to provide space for a base. This will maximize sound tooth structure for restoration support and remaining dentin thickness for pulpal protection.
2. Minimize the extent of the base. Basing a preparation to "ideal" depth and outline form is contraindicated (Robbins, 1986). This leads to decreased bulk of restorative material and increased potential for restoration fracture.
3. Use the minimum thickness necessary to achieve the desired result. This should not exceed 0.5-0.75 mm under amalgam restorations (Eames & Scrabeck, 1980).
4. Currently, there is not yet any convincing evidence for the routine use of dentin bonding agents under metallic restorations.

## DIRECT AND INDIRECT PULP CAPS

### General Considerations

There are several requirements when considering a direct or indirect pulp cap. The tooth must be vital and have no history of spontaneous pain (Baume & Holz, 1981). Pain elicited during pulp testing with hot or cold should not linger when the stimulus is removed. A periapical radiograph should show no evidence of a periradicular lesion of endodontic origin. Because success with either procedure is uncertain, pulpal health should be monitored for several months in teeth that have been pulp capped and are to receive a cast restoration or serve as abutments for fixed or removable partial dentures. If there is uncertainty regarding the pulpal status of a tooth, the clinician should strongly consider endodontics prior to initiating restorative treatment.

### Direct Pulp Cap

While animal studies have demonstrated that direct mechanical pulp exposures can heal normally, a germ-free environment is required (Paterson, 1976). The adverse consequences of bacterial contamination of the pulp have been well documented (Brännström, 1984; Cox & others, 1987; Watts & Paterson, 1987; Nordenvall & others, 1979; Brännström & Vojinović, 1976). Therefore, the only reasonable chance that a direct pulp cap will permit formation of a dentin bridge and maintain pulp vitality is under the most ideal conditions. If the pulp has become contaminated either via caries or exposure to the oral flora, then the likelihood of success is greatly diminished. In addition, aged pulps have increased fibrosis and a decreased blood supply (Bernick & Nedelman, 1975), and thus, a decreased ability to mount an effective response to the invading microorganisms. Direct pulp caps should only be attempted when a small (<0.5mm) mechanical exposure of an otherwise healthy pulp occurs isolated by use of a rubber dam. The exposure should be covered with calcium hydroxide because of its documented ability to provide the highest percentage of success (Weine, 1982b; Baume & Holz, 1981; Fitzgerald & Heys, 1991). It must be possible to restore the tooth with a well-sealed restoration that will prevent later bacterial contamination.

### Indirect Pulp Cap

When performing an indirect pulp cap, all caries is removed except the last portion of firm, leathery dentin immediately overlying the pulp, which might result in pulp exposure if excavated. Placement of calcium hydroxide over this layer of infected dentin has been shown to virtually eliminate all remaining bacteria and render the residual carious dentin operationally sterile (Dumsha & Hovland, 1985; Fairbourn, Charbeneau & Loesche, 1980; Leung, Loesche & Charbeneau, 1980). A well-sealed restoration will deny bacteria substrate for further acid production and arrest the carious lesion (Mertz-Fairhurst & others, 1979), and provide a sound dentin base (Stanley, 1981f). These facts argue against a two-step procedure in which the tooth is reentered for the purpose of excavating the previously carious dentin to confirm reparative dentin formation. This procedure risks creating a pulp exposure and causing further traumatic insult to the pulp (Dumsha & Hovland, 1985).

### Calcium Hydroxide vs Dentin Bonding Agents in Pulp Capping

It has been suggested recently that dentin bonding agents be used for direct and indirect pulp capping (Kanca, 1993; Prager, 1994). The rationale for this is based on the belief that an effective, permanent seal against bacterial invasion is provided and will allow pulpal healing to occur. Animal research has shown good compatibility of mechanically exposed pulps to visible-light-activated composite when bacteria are excluded (Cox & others, 1987). In addition, pulpal compatibility was good when the smear layer was removed prior to dentin adhesive placement in prepped teeth for up to 90 days, showing the ability of the bonding agents to eliminate bacterial invasion for this period of time (Cox & Suzuki, 1994; Suzuki & others, 1994; White & others, 1994). Although many components of dentin bonding agents are directly toxic to pulp cells (Jontell & others, 1995; Hanks & others, 1991; Rathbun & others, 1991), their release is rapid and slows dramatically with time, and is not thought to be a source of chronic exposure to regenerating pulp tissues (Ferracane & Condon, 1990). Clinical success with direct pulp capping for traumatic exposure (Kanca, 1993) and deep carious exposure have been described (Prager, 1994). A clinical study of 64 cases of direct pulp capping with a dentin bonding agent following carious exposure revealed that 60 of the teeth were vital 1 year later. In this same study, six caries-free third molars were intentionally exposed with a bur, pulp capped with a dentin bonding agent, and extracted up to 1 year later for histologic evaluation. All cases revealed dentin bridge formation and no inflammatory changes in the pulp (Kashiwada & Takagi, 1991). In vitro microleakage tests showing imperfect seals with dentin bonding agents have been criticized as not being valid from a biocompatibility standpoint, since many dye tracer molecules are orders of magnitude smaller than the oral bacteria that cause pulpal inflammation (White & others, 1994), and therefore may not be a reliable indicator of the ability of these bacteria to infiltrate towards the pulp. In addition, the outward flow of dentinal fluid in vivo partially opposes the diffusion of toxins into dentin (Vongsavan & Matthews, 1991), and those that do ultimately reach the pulp are diluted and removed by the circulation (Pashley, 1979). Finally, proponents of dentin bonding agent use for pulp capping point to the shortcomings of calcium hydroxide, such as its breakdown when acid etchants are used, dissolution after long-term restoration placement, interfacial failure during amalgam condensation, and the presence of tunnel defects in reparative dentin that remain open from the pulp to the medicament interface, allowing recurring microleakage of bacteria to the pulp (Cox & others, 1996). The ultimate failure of $Ca(OH)_2$ is thought to be its inability to provide a long-term seal against microleakage (Cox & Suzuki, 1994).

The success of dentin bonding agents for pulp capping depends on the quality and durability of the bond, and that their placement has no deleterious effects on the pulp.

## Quality and Durability of the Bond

Improvements in dentin bonding agents have been dramatic since their introduction. However, in vitro research has demonstrated that modern dentin bonding agents leak almost immediately when bonded to superficial dentin (Strydom & others, 1995; Pameijer & Wendt, 1995; Tay & others, 1995). The anatomy of dentin near the pulp can have an even greater adverse impact on bond formation. As dentin nears the pulp, more area is taken up by tubules and less by intertubular dentin (Garberoglio & Brännström, 1976). The collagen of intertubular dentin is required for the formation of a hybrid zone, which is the means by which modern dentin bonding agents adhere to dentin (Nakabayashi, Ashizawa & Nakamura, 1992). In addition, the bond immediately adjacent to dentin tubules is often loose, allowing fluid shift and leakage of substrates due to a cuff of collagen-poor peritubular dentin (Pashley, 1991). The shear bond strengths of dentin bonding agents are directly related to the area of sound dentin minus the area of the tubules (Suzuki & Finger, 1988), since resin tags down the dentin tubules contribute little to the bond strength (Tao & Pashley, 1988). It is therefore not surprising to learn that nearly all dentin bonding agents show a significant loss of bond strength when bonding to deep versus superficial dentin (Tao, Tagami & Pashley, 1991; Tao & Pashley, 1988; Mitchem & Gronas, 1986; Suzuki & Finger, 1988), which degrades with time (Saiku & others, 1993; Watanabe & Nakabayashi, 1993; Warren & others, 1995). This is significant since animal studies of pulpal compatibility are short term (21-90 days) (Cox & others, 1987; Cox & Suzuki, 1994; Suzuki & others, 1994; White & others, 1994) and so do not provide an in vivo evaluation of these materials' ability to provide a long-term barrier to bacterial penetration.

## Effect of Dentin Bonding Agent Application on the Pulp

Modern dentin bonding agents require conditioning that removes the dentinal smear layer, usually through acid etching (Suzuki & others, 1994; White & others, 1994; Nakabayashi & others, 1992; Tay & others, 1995). Opening the dentinal tubules results in increased dentin fluid flow, which can cause fluid contamination, poor bonding, and fluid-filled gaps, which can allow bacterial penetration into dentin (Pashley, 1991). These bacteria and their toxins can progress to the pulp despite the outward flow of dentinal fluid (Vojinović & others, 1973). While acid etching dentin has been demonstrated in multiple animal studies to not cause pulpal problems (Nordenvall & others, 1979; Kurosaki & others, 1990; Brännström & Nordenvall, 1978; Suzuki & others, 1994; White & others, 1994), smear layer removal prior to dentin bonding agent and composite restoration placement significantly increased dentin fluid flow and pulpal nerve firing in dogs compared to leaving the smear layer intact (Hirata & others, 1991). Etching of dentin in humans has been shown to cause massive bacterial invasion down the tubules (Vojinovic & others, 1973), as well as pulpal necrosis and moderate to severe pulpal inflammation that lasted up to 1 year following the placement of a dentin adhesive/composite restoration (Franquin & Brouillet, 1988).

While pathogenic intraoral bacteria are quite small (0.2-0.5 μ) (Pashley, 1991), dye tracers used in leakage tests are significantly smaller, and therefore their usefulness as a model of microbial contamination is questioned (White & others, 1994). However, key components of pulpal inflammation are bacterial products (Bergenholtz & others, 1982), which are of lesser size than the bacteria themselves. Research has shown that dentin permeability is not always directly related to molecular weight (Pashley & others, 1977), and that the nature of the dentin surface may be more important than molecule size on diffusion (Pashley & Livingston, 1978). Lipopolysaccharides, which are of similar structure and size to endotoxins produced by intraoral bacteria, diffused more quickly interfacially under cast crowns than a smaller dextran molecule (Coleman, 1995). Acid etching to remove the smear layer increases dentin permeability 4-9 times, with the greater increase being for the larger molecules (Pashley & Livingston, 1978). It would seem reasonable to assume that if dyes can penetrate between dentin and the bonding agent, this would indicate an imperfect seal, which would ultimately lead to bacterial penetration, especially as the size of the interfacial gap and subsequent leakage is exacerbated by thermal stress (Bullard, Leinfelder & Russell, 1988).

Many components of modern dentin bonding agents are directly toxic to cells (Hanks & others, 1991; Rathbun & others, 1991). Although the concentration at which they reach the pulp is unknown (Hanks & others, 1991), it would seem reasonable to presume that the concentration would be greater in cases of pulp capping, where there is little or no remaining dentin thickness. The inward diffusion of these components is not prevented by intrapulpal pressure, even at a level used to simulate an inflamed pulp (Gerzina & Hume, 1995). More importantly, at certain concentrations most resin components in dentin bonding agents inhibit pulp T-lymphocytes, leading to speculation that immunosuppression of pulpal immunocompetent cells may enhance potential for bacterial injury to pulp tissue (Jontell & others, 1995).

Visible-light-activated induced temperature increases within the pulp can produce significant adverse consequences. An intrapulpal temperature increase above 20 °F (11.2 °C) has been shown in vivo to cause virtually all pulps to be irreversibly damaged (Zach & Cohen, 1965). A recent study investigating the temperature rise associated with curing a dentin adhesive found an increase of 18.2 °C with a 10-second cure, and 25.2 °C with a 20-second cure (Puckett & others, 1995). Since pulp capping implies little or no remaining dentin between the adhesive and the pulp, the pulp could be exposed to dangerous heat levels during light curing of visible-light-activated dentin bonding agents.

### Use of Dentin Bonding Agents for Indirect Pulp Capping

Many of the points regarding direct pulp capping apply to indirect pulp capping as well. However, there are some additional concerns regarding an indirect pulp cap with dentin bonding agents. A recent study found a significant loss of bond strength to human carious dentin versus sound dentin (Nakajima & others, 1995), leading one to question even further the integrity of the bond and subsequent ability to prevent bacterial invasion of a carious substrate. In addition, it would seem prudent to be cautious transferring results of pulp compatibility studies to humans from short-duration animal studies that utilize a noncarious model (Cox & others, 1987; Suzuki & others, 1994; White & others, 1994).

## CONCLUSION

While the most significant drawback of calcium hydroxide is purported to be its inability to provide a permanent seal against bacterial invasion, the integrity and durability of the bond achieved with dentin adhesives can be questioned as well. Although clinical success has been reported for pulp capping with dentin bonding agents (Kashiwada & Takagi, 1991), most of these results are empirical and with a sample size of one case (Kanca, 1993; Prager, 1994). In an animal study comparing pulp capping with conventional and visible-light-activated calcium hydroxide to a dentin bonding agent, dentin bridges formed in almost all teeth capped with $Ca(OH)_2$, whereas less than 25% of dentin bonding agent-capped teeth did (Pitt Ford & Roberts, 1991). Although showing promise and offering a distinct future possible treatment modality, the lack of long-term documentation of clinical success for pulp capping with dentin bonding agents in controlled clinical trials should be weighed against literature that demonstrates 75-90% success for up to 12 years with calcium hydroxide (Fitzgerald & Heys, 1991; Haskell & others, 1978; Baume & Holz, 1981). Many of the other drawbacks reported for the use of $Ca(OH)_2$, such as dissolution with acid etching or after long-term placement and interfacial failure during amalgam condensation, can be overcome by using a visible-light-activated form of calcium hydroxide. Pending the results of controlled clinical trials that demonstrate the long-term efficacy of using dentin bonding agents for pulp capping, an alternate option would be the following: utilize visible-light-activated $Ca(OH)_2$ to cover the area of known or suspected exposure only and apply a glass ionomer lining material to the dentin immediately surrounding the $Ca(OH)_2$. This protocol provides a combination of clinically proven materials that have been associated with clinical success in pulp capping ($Ca[OH]_2$), are antibacterial and have good physical properties (both materials), and provide fluoride release and chemical adhesion to tooth structure (glass ionomer).

## Acknowledgment

The author wishes to sincerely thank the following individuals for their thoughtful insight and generous assistance: Dr Jack L Ferracane, Dr Charles B Hermesch, Dr Richard Schwartz, and Dr James B Summitt.

*(Received 28 February 1995)*

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# ORIGINAL ARTICLES

# Bond Strength of Composites to Hybrid Ionomers

W H TATE • K-H FRIEDL • J M POWERS

**Clinical Relevance**
Composites were found to have high tensile bond strength when bonded to hybrid ionomers.


## SUMMARY

**Tensile bond strengths among three different hybrid ionomers and two different hybrid composites were evaluated. With one exception, bond strength to a high-modulus composite (Z-100) was higher than that to a low-modulus composite (Charisma). Thermocycling lowered the bond strength of Charisma, whereas storage for 3 months increased the bond strength of Z-100 compared to storage for 24 hours. Etching the hybrid ionomers with phosphoric acid had no effect on bond strength.**



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## INTRODUCTION

Glass-ionomer restorative materials have been an important advance in restorative dentistry. They bond to tooth structure, are tissue compatible, release fluoride over time, are tooth colored, inhibit demineralization, are radiopaque, and contribute to remineralization of adjacent dentin (Crim, 1993a; DeSchepper & others, 1990). However, first-generation glass-ionomer restorative materials were plagued with several undesirable characteristics, such as a prolonged setting time that prohibited timely finishing, moisture sensitivity during initial setting, dehydration, rough surface texture, and opaqueness (Crim, 1993a).

Resin-modified hybrid ionomers have resolved many of the problems associated with traditional glass ionomers. They have improved setting characteristics, can be finished immediately after curing, have a superior finish to traditional glass ionomers, have reduced water sensitivity, and have enhanced mechanical properties (Crim, 1993a; Mount, 1993; Wilson, 1990). Adhesion to dentin also has improved (Hinoura, Miyazaki & Onose, 1991; Lin, McIntyre & Davidson, 1992; Mason & Ferrari, 1994) as well as a reduction in microleakage (Crim 1993a,b). Due to their enhanced properties, resin-modified hybrid ionomers provide a suitable alternative to silver amalgam (Croll, 1993) in children and small class 1 restorations. Further, hybrid ionomers have the advantage of directly bonding to composite (Wilson, 1990). A "sandwich"-type restoration, similar to Mount's (1989a) suggestion of a "sandwich" of dentin to glass-ionomer cement to composite restoration, recently has been suggested using a dual-cured, light-activated glass ionomer-composite technique (Knight, 1994). Knight (1994) has shown that these restorations have a clinical performance similar to conventional composite restorations. Furthermore, they have the advantage of fluoride release (Creanor & others, 1994). Others have examined the shear strength between glass-ionomer cement and composites (Sneed & Looper, 1985), the tensile strength between glass-ionomer cements and composites (Mount, 1989b), and the effects of acid etching and bonding agent on glass ionomer and composite bond strength (Hinoura, Moore & Phillips, 1987; Suliman & others, 1989).

The enhanced properties of hybrid ionomers make this material an innovative restorative alternative as seen with hybrid ionomer-composite "sandwich"-type restorations. To investigate the clinical viability of this type of restoration, bonding between the hybrid ionomer and composite needs to be considered. In this study, the tensile bond strength between three hybrid glass ionomers and two hybrid composites was investigated. This interaction was examined as a function of several clinically relevant physical parameters: 24-hour and 3-month storage, thermocycling, and with and without hybrid ionomer acid etching.

*Table 1. Products, Lot Numbers, and Manufacturers*

| Product/Shade | Lot # | Manufacturer |
|---|---|---|
| **Low-Modulus Composite** | | |
| Charisma/A20 | | Heraeus Kulzer Inc, USA, Irvine, CA 92718 |
| **High-Modulus Composite** | | |
| Z-100/A3 | 19940209 | 3M Dental Products, St Paul, MN 55144 |
| **Hybrid Ionomers** | | |
| Fuji II LC Capsules/A2 | 190731 | G-C America Inc, Chicago, IL 60658 |
| Photac-Fil Aplicap/A3 | | ESPE-America, Norristown, PA 19404 |
| Vitremer/A3 | | 3M Dental Products |
| liquid | 19940119 | |
| powder | 19940124 | |
| **Etchant** | | |
| Uni-Etch | | Bisco Inc, Itasca, IL 60143 |

## METHODS AND MATERIALS

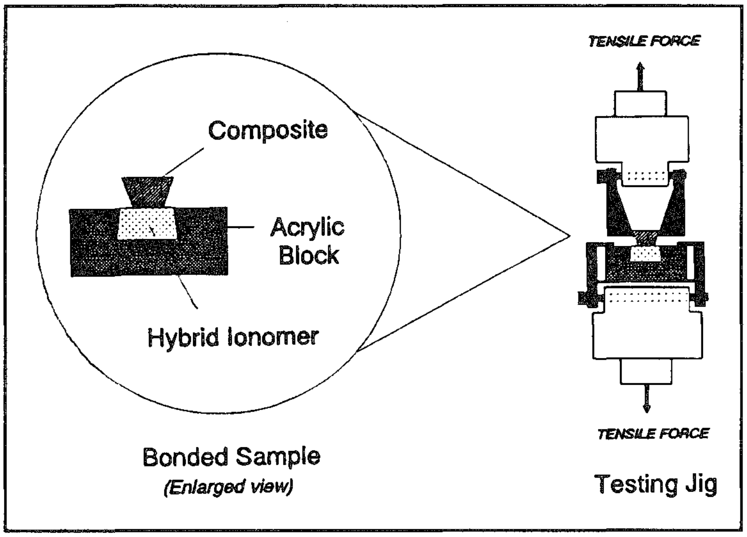
This study evaluated tensile bond strength using a four-factor (3x2x3x2) completely randomized design. The factors were: hybrid ionomers (Fuji II LC, Photac-Fil, Vitremer), composite (low modulus, Charisma; high modulus, Z-100), storage condition (24-hour, thermocycled, 3-month), and surface treatment (etched versus nonetched). Manufacturers and batch numbers of products tested are listed in Table 1.

The hybrid ionomers were prepared according to the manufacturers' directions in acrylic wells measuring 6 mm in diameter and 3 mm in depth and cured with a curing light (Max Light, L D Caulk/Dentsply, Milford, DE 19963). The intensity of the curing light was monitored with a light meter (L D Caulk/Dentsply). Sixty samples were fabricated per hybrid ionomer for a total of 180 samples. After curing, the samples were surfaced with 600-grit silicon carbide paper (3M Dental Products, St Paul, MN 55144) on a polisher (Buehler Polimet I Polisher, Buehler Ltd, Lake Bluff, IL 60044).

The 60 samples of each hybrid ionomer were divided into two groups of 30, to which one of the two composites was bonded. The groups of 30 were further divided into three groups of 10, one group for each of the three storage conditions. Half of each group of 10 were treated with 32% phosphoric acid (Bisco, Inc, Itasca, IL 60143) for 30 seconds, and the other half were not treated. The acid-treated surfaces were rinsed with water for 20 seconds and air-dried for 5 seconds.

The hybrid ionomer samples were placed in a bonding apparatus within 2 hours after fabrication with storage in air. A polytetrafluoroethylene mold in the shape of an inverted truncated cone, with a diameter of 5 mm tapering to a diameter of 3 mm at a height of 4 mm, was positioned over the block in such a manner that the 3 mm-in-diameter hole coincided with the prepared hybrid ionomer surface. A clamp was used to hold the block and mold in position. The composites were placed in the mold and cured according to the manufacturers' recommendations, forming a truncated cone of composite with the smaller diameter of the cone bonded to the hybrid ionomer. No bonding resin between the hybrid ionomer and composite was used in this experiment. The composite-ionomer assembly is shown in the figure.

The samples were subjected to one of three storage conditions: storage for 24 hours in distilled water at 37 °C, 3-month storage in distilled water at 37 °C, and thermocycling (1000 cycles over 24 hours, low temperature: 8 °C, high temperature: 55 °C, dwell




*Schematic of testing apparatus*

time: 30 seconds). After storage, the acrylic blocks were attached to a testing machine (Model 8501, Instron Corp, Canton, MA 02021). The cone-shaped composite was placed into a jig with an internal taper that corresponded to the shape of the sample (figure). The block and jig were loaded in tension at a cross-head speed of 0.05 cm/min until fracture occurred. Bond strength was calculated in MegaPascals (MPa). Bond failure sites were observed visually under magnification of X4.5 and recorded.

Modulus of elasticity of the two composites was measured in compression on cylindrical samples (8 mm height and 4 mm in diameter) on a testing machine (Model 8501, Instron Corp). Strain was measured using a tension-compression extensiometer (Instron Corp) with corrections made for deformation of the steel platens of the loading jig. Five samples were measured for each composite.

Bond strength data were analyzed initially by four-way analysis of variance (SuperANOVA, Abacus Concepts, Inc, Berkeley, CA 94704) with five replications per condition using a factorial design that included two composites, three hybrid ionomers, three storage conditions, and etched versus nonetched samples. Subsequently, the etched and nonetched data were combined and analyzed again using a three-way analysis of variance with 10 replications per condition. Tukey-Kramer intervals (SuperANOVA) were determined at a 0.05 significance level for comparisons of means. Differences between two means that were greater than the appropriate Tukey-Kramer interval were considered statistically significant. Bond failure data were not analyzed statistically.

*Table 2. Effect of Storage Conditions on Bond Strength of Composites to Hybrid Ionomers*

| Ionomer | C: 24 Hours | C: Therm | C: 3 Months |
|---|---|---|---|
| Fuji II LC | 15.7 (4.2)a | 10.5 (2.6)b | 8.5 (2.4)e,f |
| Photac-Fil | 15.4 (4.5)a | 9.2 (1.8)b,c | 7.1 (2.8)f |
| Vitremer | 15.9 (3.3)a | 8.1 (1.6)c,d | 9.6 (3.1)d,e |
| **Ionomer** | **Z: 24 Hours** | **Z: Therm** | **Z: 3 Months** |
| Fuji II LC | 17.2 (2.9)g,h | 15.9 (2.8)h,i | 23.3 (4.8) |
| Photac-Fil | 16.5 (5.6)g | 18.1 (2.9)j | 12.7 (5.2) |
| Vitremer | 14.3 (4.0) | 16.6 (3.9)i,j | 19.6 (3.5) |

C = Charisma; Z = Z-100; Therm = thermocycled. Mean bond strengths and standard deviations (n=10) are listed. Data were analyzed by ANOVA. Tukey-Kramer intervals at a 0.05 significance level for comparisons among three ionomers and three storage conditions and between two composites were 1.5, 1,5, and 1.0 MPa respectively. Means with the same letters are not statistically different.

## RESULTS

Based on the four-way analysis of variance, treating the hybrid ionomers with phosphoric acid had no statistical effect on bond strength ($P = 0.26$). Further, none of the interactions involving etching was significant, with $P$ values ranging from 0.13 to 0.77. As a result, bond strength observations for etched and nonetched samples for each hybrid ionomer were combined for further statistical analysis.

The mean values and standard deviations of bond strengths (n=10) are listed in Table 2. Results of the three-way analysis of variance are listed in Table 3. The main effects and all but one interaction (composite-ionomer interaction, $P = 0.27$) were significant. Tukey-Kramer intervals among the three ionomers and the three storage conditions and between the two composites were 1.5, 1.5, and 1.0 MPa respectively. Means that are not statistically different are indicated with similar letters in Table 2. The modulus of elasticity of Charisma was found to be 7.8 (0.5) GigaPascals (GPa) and that of Z-100 was 10.6 (0.8) GPa.

At 24 hours, Fuji II LC, Photac-Fil, and Vitremer had similar bond strengths with Charisma; bond strengths of Fuji II LC and Photac-Fil were higher than that of Vitremer for Z-100. With one exception, bond strength to the high modulus composite, Z-100, was higher than that to the low-modulus composite, Charisma, under similar storage conditions.

Thermocycling and 3-month storage lowered the bond strength of Charisma for all three hybrid ionomers. Bond strength to Z-100 increased after storage for 3 months when compared to 24-hour

*Table 3. Results of Three-Way Analysis of Variance of Bond Strength*

| Source | df | Sum of Squares | Mean Square | *F*-Value | *P*-Value |
|---|---|---|---|---|---|
| ionomer | 2 | 121.45 | 60.72 | 4.66 | 0.0108 |
| composite | 1 | 1629.74 | 1629.74 | 124.95 | 0.0001 |
| condition* | 2 | 265.14 | 132.57 | 10.16 | 0.0001 |
| ionomer*composite | 2 | 34.38 | 17.19 | 1.32 | 0.2705 |
| ionomer*condition | 4 | 315.47 | 78.87 | 6.05 | 0.0001 |
| composite*condition | 2 | 762.70 | 381.35 | 29.24 | 0.0001 |
| ionomer*composite*condition | 4 | 247.12 | 61.78 | 4.74 | 0.0012 |
| residual | 162 | 2112.99 | 13.04 | --- | --- |

*storage condition (24 hours, thermocycle, 3 months)

storage for Fuji II LC and Vitremer but decreased for Photac-Fil.

All bond failures were adhesive except for those samples stored for 3 months. As shown in Table 4, more cohesive failures, either in the composite or hybrid ionomer, were observed with 3-month storage of Z100/hybrid ionomer (nine failures in the ionomer and 12 failures in the composite out of 30 samples) than with 3-month storage with Charisma/hybrid ionomer (one failure in the ionomer out of 30 samples).

## DISCUSSION

Many of the undesirable characteristics encountered with early glass-ionomer cements have been reduced or eliminated with the development of resin-modified hybrid ionomers (Crim, 1993a; Mount, 1993; Wilson, 1990). Although hybrid ionomers do adhere chemically better than conventional glass-ionomer cements (Friedl, Powers, & Hiller, 1994) to underlying tooth structure, they still do not bond as well to dentin as composite used with most of the newer dentin/enamel bonding systems (Kanca, 1992; Lin & others, 1992).

*Table 4. Sites of Bond Failures after 3-Month Storage*

| | A | B | C |
|---|---|---|---|
| Z-100/Fuji II LC | 3 | 2 | 5 |
| Z-100/Photac-Fil | 3 | 6 | 1 |
| Z-100/Vitremer | 3 | 1 | 6 |
| Charisma/Fuji II LC | 10 | 0 | 0 |
| Charisma/Photac-Fil | 9 | 1 | 0 |
| Charisma/Vitremer | 10 | 0 | 0 |

A=adhesive failure; B=cohesive failure in the ionomer; C=cohesive failure in the composite.

In general, acid etching improves the bond strength of composites to conventional glass ionomers (Hinoura & others, 1987; Sneed & Lopers, 1985; Suliman & others, 1989); however, in this study it was observed that etching the hybrid ionomers with phosphoric acid had no statistical effect on bond strength. Speculation is that the resin-modified hybrid ionomers are not susceptible to acid etching due to the high resin content.

With one exception, bond strengths to the hybrid ionomers were greatest using Z-100, which had a higher modulus of elasticity than Charisma. Clinically, Charisma would probably be best suited for class 5-type lesions or for any location where a small amount of flexibility within the composite would be of benefit.

Overall, composite/hybrid ionomer failures were adhesive. Cohesive failures occurred mainly with Z-100/hybrid ionomer, stored for 3 months. In these groups, Vitremer and Fuji II LC bonded to Z-100 produced more cohesive failures in the composite, while Photac-Fil and Z-100 failed cohesively in the hybrid ionomer. Cohesive failure after 3 months of storage of Z-100 and the hybrid ionomers indicate stability within the bond as well as an increase in bond strength as the cement ages (Wilson, 1990).

Some hybrid ionomer cements stored in water become progressively weaker with time (Nicholson, Anstice & McLean, 1992). Physical properties of these light-activated cements change dramatically when exposed to moisture. Water enters the cement and acts as a plasticizer, making the cement more plastic than brittle. In these cases, the photochemical polymerization leaves a structure that contains a high proportion of hydrophilic functional groups. This structure is similar to a synthetic hydrogel. Hydrogel strength is related to the amount of water uptake: the greater the uptake, the weaker the enlarged hydrogel. Perhaps the low bond strength found with water storage of the low-modulus Charisma bonded to the hybrid ionomers is related to water uptake of the hybrid ionomer and the polymerization shrinkage of the Charisma. The bond interface may stretch within the composite, creating excess strain within the bond. Z-100 (66% by volume) is more highly filled than Charisma (60% by volume) (Farah & Powers, 1994). Polymerization shrinkage decreases and bond strength to dentin increases as filler content increases (Miyazaki & others, 1991). The initial bond of Z-100 to hybrid ionomer may be under less of an initial strain due to lower polymerization shrinkage than that of Charisma.

Despite lower bond strengths than most bonded composites, studies have not detected any measurable microleakage at the hybrid ionomer/tooth structure interface (Chandwani, L'Herault, & Nathanson, 1993; Crim, 1993a,b; Mason & Ferrari, 1994). Some authors have suggested including undercut retention form within the preparation, stating that the hybrid ionomer/tooth structure bond is probably more important in maximizing marginal integrity and the release of fluoride ions rather than providing enough strength to withstand occlusal stresses (Croll, 1993). Of additional interest is a report describing considerable variations in the chemical composition and behavior of some new light-activated hybrid ionomers (Forss, 1993). These observations stress the need for further evaluation. Regardless, the bonding of composite to hybrid ionomers observed in this study, as well as the overall improved physical characteristics of light-cured hybrid ionomers, suggest that "sandwich"-type restorations using hybrid ionomers and composites are viable restorative alternatives.

## CONCLUSIONS

With one exception, bond strength of Z-100 to the hybrid ionomers was higher than that of Charisma under similar storage conditions. Thermocycling lowered the bond strength of Charisma to the hybrid ionomers, whereas storage for 3 months increased the bond strength of Z-100 to Fuji II LC and Vitremer compared to storage for 24 hours. Surface treating the hybrid ionomers with phosphoric acid had no statistical effect on bond strength.

### Acknowledgments

The authors thank Mr David Ladd for technical assistance and the manufacturers for providing commercial products. This study was supported in part by ESPE America and 3M Dental Products.

*(Received 23 May 1995)*

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# Cavity Disinfectants and Dentin Bonding

J C MEIERS • J C KRESIN

**Clinical Relevance**
The use of cavity disinfectants with composite resin restorations appears to be material specific regarding their interactions with various dentin bonding systems' ability to seal dentin.

## SUMMARY

**The purpose of this study was to examine the effect on microleakage of two disinfectants, one chlorhexidine based and the other $I_2$-KI/$CuSO_4$ based, used as cavity washes prior to the application of the dentin bonding systems Tenure and Syntac in class 5 composite restorations. Class 5 cavity preparations were placed on extracted molars with occlusal margins in enamel and gingival margins in cementum. Preparations were treated with either Syntac or Tenure, combinations of one of the two disinfectant washes with Syntac or Tenure, or with one of the disinfectants only and filled with Tetric composite. Samples were thermocycled, stained, and sectioned to evaluate dye penetration. The chlorhexidine-based wash did not significantly affect microleakage when compared to the Tenure and Syntac controls, while the $I_2$-KI/$CuSO_4$-based wash resulted in significantly higher gingival microleakage when used with Syntac. The use of cavity disinfectants with composite resin restorations appears to be material specific regarding their interactions with various dentin bonding systems' ability to seal dentin.**

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## INTRODUCTION

An inherent problem of any restorative material is microleakage, defined as the passage of bacteria, fluids, chemical substances, molecules, and ions between the tooth and its restoration (Bauer & Henson, 1984). Microleakage has been demonstrated as a factor in hypersensitivity and secondary caries (Chan & Glynn Jones, 1992). To date no restorative material has consistently been shown to seal and adhere to dentin. Brännström (1986) has demonstrated that bacteria from the oral cavity are able to enter contraction gaps produced by the polymerization shrinkage of composite resins.

The problems associated with microleakage can be magnified by incomplete sterilization of the preparation from failure to mechanically remove infected tooth structure. Besic (1943) showed that bacteria left in cavity preparations can survive for longer than 1 year, while Leung, Loesche, and Charbeneau (1980) found the number of residual bacteria in cavity preparations were able to double within 1 month of the restoration being placed. Bacteria can remain in the smear layer or in dentinal tubules and can multiply to fill a fluid space. Brännström (1986) stated that residual bacteria have been shown to proliferate from the smear layer even in the presence of a good seal from the oral cavity, allowing toxins to diffuse to the pulp, resulting in irritation and inflammation of pulpal tissue.

In an effort to provide objective criteria on removal of bacteria-laden dentin, various dyes have been tested. Anderson and Charbeneau (1985) applied a solution of 0.5% basic fuchsin in propylene glycol as a caries-disclosing dye and found 59% of the teeth that had passed as clinically sound stained with the dye. These results were duplicated (57% still infected) in a study by Kidd and others (1989), using a dye of 1% acid red in propylene glycol. However, the use of a caries-disclosing dye does not necessarily result in detection of all bacteria. Boston and Graver (1989) found 25% of the cases they examined still contained low numbers of bacteria in the dentinal tubules after the removal of dye-stained caries.

To reduce the potential for residual caries and sensitivity, an antibacterial solution that could be placed after cavity preparation and have the ability to disinfect the dentin would be valuable. A study by Meiers and Schachtele (1984) showed that the disinfectant ORA-5, a commercially available iodine-based oral disinfectant, will dramatically reduce the *Streptococcus mutans* found in fissures. Studies using the disinfectant chlorhexidine were found to be effective in reducing the levels of *S mutans* located on exposed carious root surfaces (Fure & Emilson, 1990; Schaeken, Keltjens & Van Der Hoeven, 1991; Caufield & others, 1981).

A potential problem for use of a disinfectant with dentin bonding agents is the possibility of altering the ability of the hydrophilic resin to seal the dentin. Salivary contamination has been reported to have mixed effects on the ability of some current dentin bonding systems to adequately bond to dentin (Johnson & others, 1993; Aasen & Fundingsland, 1993).

Perdigao, Denehy, and Swift (1994) found that using chlorhexidine as a cavity cleaner after etching dentin did not reduce the shear bond strength of All-Bond 2 dentin/enamel bonding resin. Similar conclusions were reached by Filler and others (1994) after a study of composite bonded to chlorhexidine-treated enamel.

The purpose of this study was to evaluate the effect of two dentin disinfectants, one chlorhexidine based and the other iodine/potassium iodide based, on the dentin sealing ability of two dentin bonding systems, Tenure and Syntac.

## METHODS AND MATERIALS

Forty noncarious extracted human third molars stored in normal saline with 0.2% sodium azide were used in this study. The teeth were scraped of any residual tissue tags and thoroughly rinsed under running tap water for 15 minutes to remove any residual sodium azide. The facial and lingual surfaces were cleaned with pumice. Class 5 facial and lingual cavities were placed on each tooth using a #35 high-speed bur (Brasseler, Savannah, GA 31419) that was changed after preparation of every five teeth. Each cavity was approximately 2 mm wide, 1.5 mm deep, and 6 mm long, paralleling the cementoenamel junction. The gingival half of the preparations extended 0.5 mm below the CEJ. Cavosurface walls were then finished with a #56 slow-speed bur (Brasseler) to a butt joint. Each preparation was rinsed for 20 seconds with distilled water and dried with compressed air for 20 seconds. Using a random number table the teeth were assigned to eight treatment groups (n=10) as indicated in Table 1. Groups 1 and 2 served as the negative controls and groups 7 and 8 as the positive controls. The dentin disinfectant, dentin bond application, and composite placement were as follows: In the appropriate test groups the cavity wash Bisco Cavity Cleanser (Bisco Dental Products, Itasca, IL 60143), which contains 2% chlorhexidine digluconate (CHG), or ORA-5, a 0.11% iodine/potassium iodide and copper sulfate-based solution (McHenry Labs Inc, Edna, TX 77957) was applied with a brush. The cavity cleanser stayed in contact with the teeth for 20 seconds, and then the teeth were air dried for 15 seconds. After cavity disinfection the dentin bonding agents Syntac (Vivadent USA Inc, Amherst, NY 14228) or Tenure (Den-Mat Corp, Santa Maria, CA 93456) were applied to their appropriate groups following the manufacturer's instructions. In the Syntac groups enamel margins were treated with a viscous 35% phosphoric acid solution (Ultradent Products Inc, South Jordan, UT 84095). Groups 7 and 8 had no enamel etching performed or unfilled resin placed. Only the appropriate disinfectant was applied as described. Tetric composite resin (Vivadent) was condensed into the preparations and cured for 60 seconds using an Optilux 400 visible light curing unit (Demetron Research Corp, Danbury, CT 06810). Curing efficacy was verified using a Model 100 Curing Radiometer (Demetron) to measure light intensity prior to each sample preparation session. The composite restorations were finished to the cavosurface margins using a 12-fluted carbide

*Table 1. Treatment Groups*

| Group | Dentin Bonding Agent | Cavity Wash |
|---|---|---|
| 1 | Syntac | No |
| 2 | Tenure | No |
| 3 | Syntac | Bisco Cavity Cleanser |
| 4 | Tenure | Bisco Cavity Cleanser |
| 5 | Syntac | ORA-5 |
| 6 | Tenure | ORA-5 |
| 7 | No | Bisco Cavity Cleanser |
| 8 | No | ORA-5 |

*Table 2. Occlusal/Enamel Microleakage Scores*

| Treatment Groups (n=10) | Leakage Score | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| Syntac | 35* | 4 | 0 | 1 |
| Tenure | 26 | 14 | 0 | 0 |
| CHX + Syn | 28 | 12 | 0 | 0 |
| CHX + Ten | 24 | 16 | 0 | 0 |
| ORA-5 + Syn | 33 | 7 | 0 | 0 |
| ORA-5 + Ten | 36 | 4 | 0 | 0 |
| CHX | 35 | 4 | 1 | 0 |
| ORA-5 | 15 | 16 | 4 | 5 |

*number of sections

*Table 3. Gingival/Cementum Microleakage Scores*

| Treatment Groups (n=10) | Leakage Score | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| Syntac | 12* | 18 | 6 | 4 |
| Tenure | 17 | 16 | 6 | 1 |
| CHX + Syn | 10 | 24 | 6 | 0 |
| CHX + Ten | 17 | 16 | 6 | 1 |
| ORA-5 + Syn | 2 | 23 | 10 | 5 |
| ORA-5 + Ten | 16 | 17 | 3 | 4 |
| CHX | 0 | 22 | 14 | 4 |
| ORA-5 | 1 | 9 | 21 | 9 |

*number of sections

finishing bur (S S White Burs Inc, Lakewood, NJ 08701) and Sof-Lex Disks (3M Dental Products, St Paul, MN 55144).

All teeth were stored at 37 °C for 24 hours in distilled water. The teeth were thermocycled in water between 5 °C and 55 °C with a dwell time of 30 seconds for a total of 1000 cycles. After thermocycling, the root apices were sealed with modeling compound (L D Caulk/Dentsply, Milford, DE 19963) and the teeth completely sealed to within 2 mm of the restorations with two coats of fingernail polish (Wet and Wild Pavilion, Nyack-on the-Hudson, NY 12407). The specimens were immersed in 0.5% basic fuchsin dye at 37 °C for 24 hours.

After staining, teeth were rinsed to remove residual stain and each tooth was embedded in a chemically cured orthodontic resin (Dentsply). Teeth were sectioned longitudinally on an isomer sectioning machine (Leco Corp, St Joseph, MI 49085) with the buccal and lingual restorations being divided into four sections. Microleakage was assessed for both the occlusal (enamel) and gingival (cementum) margins by an examiner blinded to the test groups using a dissecting microscope (Bausch & Lomb, Rochester, NY 14604) at X30 magnification and scored on the degree of dye penetration according to the following scale: 0 = no leakage; 1 = penetration less than 1/2 the length of the occlusal/gingival wall; 2 = penetration greater than 1/2 the length of the occlusal/gingival wall; 3 = penetration up to and along the axial wall.

Each restoration had a total of eight microleakage scores recorded (enamel and cementum microleakage scores for each of the four sections). The scores were averaged to produce a single leakage score for each enamel and dentin margin. SEM analysis of dentin sections treated with the various disinfectants, primer or conditioner and disinfectant/primer or conditioner combinations was performed to visualize the effects of any interactions from the use of dentin disinfectants. Cementum specimens were sputtered with gold and examined with a JEOL 5300 SEM (JEOL Inc, Peabody, MA 01960) at an acceleration voltage of 25 kV.

Statistical analysis of variances was performed on the microleakage data from the average scores derived from the four sections for each margin using the Kruskal-Wallis test. Pair-wise comparisons between groups were made using the Dunn multiple comparison test for nonparametric data. Occlusal and gingival margins within treatment groups were compared using the Wilcoxon Signed Rank Test. All tests were run at a significance level of $P < 0.05$.

## RESULTS

The occlusal/enamel and the gingival/cementum microleakage scores are shown in Tables 2 and 3. When compared to the groups treated with Syntac and Tenure only, the use of the chlorhexidine cavity cleanser did not increase microleakage scores with either Syntac or Tenure. However, use of the iodine/potassium iodide cavity cleanser provided mixed results when compared to the controls. When ORA-5 was used prior to the application of Tenure or Syntac, there was no significant increase in microleakage at either margin with Tenure, but there was a significant increase in microleakage at the gingival margin with Syntac. Chlorhexidine, when used without a dentin bonding system, provided the same protection against microleakage as either Syntac or Tenure when total microleakage scores (both occlusal and gingival combined) were evaluated. However, it demonstrated significantly more microleakage than the Tenure- and Syntac-treated groups along the gingival/dentin margin. The iodine/potassium iodide solution, when used alone, exhibited significantly higher microleakage than all of the test groups. When the dentin bonding systems were compared to each other, without the use of a disinfectant, no significant differences in microleakage scores were observed.

## SEM ANALYSIS

SEM analysis of the various cementum surfaces produced in this study is shown in Figures 1-9. The iodine/potassium iodide and chlorhexidine washes did not remove the smear layer, but did modify its appearance by removing loose smear debris (Figures 1-3). When Tenure conditioner was applied to these same surfaces, the chlorhexidine-treated smear layer was more resistant to removal by the action of the 2.5% nitric acid than the iodine/potassium iodide-treated smear layer (Figures 4-6). Syntac primer applied to the surfaces in Figures 1-3 produced less modification of the chlorhexidine-treated smear layer than the iodine/potassium iodide smear layer (Figures 6-9).

## DISCUSSION

Chlorhexidine and an iodine/potassium iodide, copper sulfate solution have been found to be effective in reducing levels of *S mutans* found in occlusal fissures and on exposed root surfaces (Meiers & Schachtele, 1984; Fure & Emilson, 1990; Schaeken & others, 1991). The use of these products as a cavity wash after tooth preparation and before the application of dentin bonding agents could help reduce the potential for residual caries and postoperative sensitivity. However, any positive benefits would be negated if the solutions significantly increased the amount of microleakage by interfering with the bonding agent's interaction with dentin.

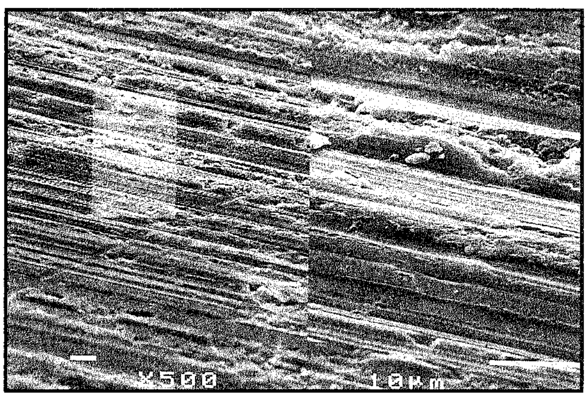

Figure 1. *Dentin smear layer produced by high-speed bur; tilt at 55°; original magnification X250*

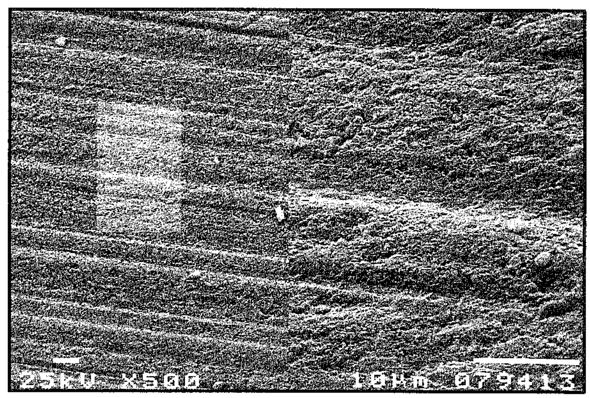

Figure 2. *Dentin smear layer treated with 2% chlorhexidine cavity wash; tilt at 55°; original magnification X250. Notice alteration in smear appearance from Figure 1.*

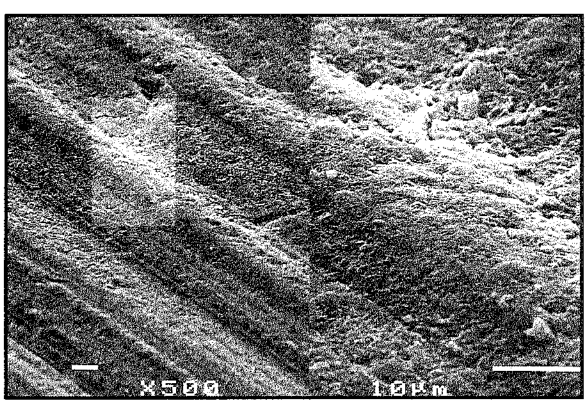

Figure 3. *Dentin smear layer treated with 0.11% iodine/potassium iodide solution; tilt at 55°; original magnification X250. Notice alteration in smear appearance from Figure 1.*

The results of this study indicate that using a cavity wash of 2% chlorhexidine prior to the application of Syntac or Tenure does not affect the sealing ability of these dentin bonding systems. This is consistent with previous research showing that chlorhexidine did not have an effect on the shear bond strength of composite to treated dentin using All-Bond 2 (Perdigao & others, 1994). However, these investigators' sequence of disinfectant application was different than ours. We applied the disinfectants immediately after cavity preparation, prior to the removal of the smear layer. In Perdigao's study, the disinfectant was applied after the smear layer was removed using the all-etch technique. We chose our sequence in preference to that followed by Perdigao,

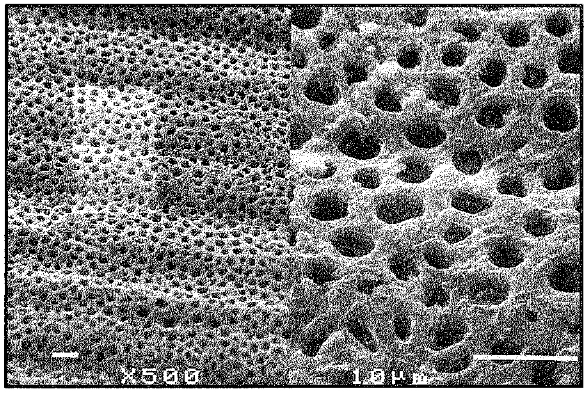


Figure 4. *Dentin smear layer after treatment with Tenure conditioner; tilt at 55°; original magnification X250*

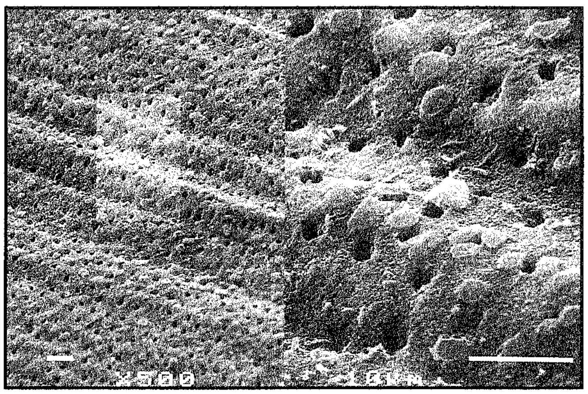


Figure 6. *Dentin smear layer after 0.11% iodine/potassium iodide solution followed by Tenure conditioner treatment; tilt at 55°; original magnfication X250. Notice less resistance to smear removal than in Figure 5.*

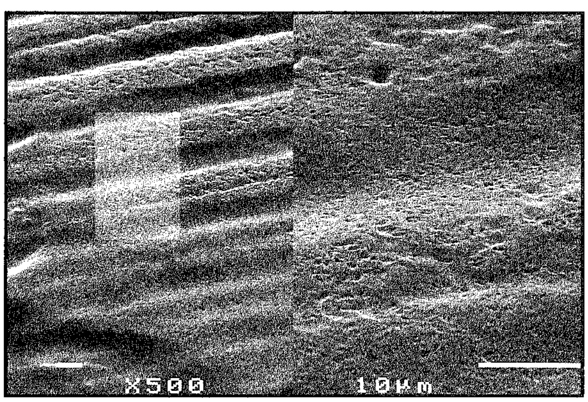


Figure 8. *Dentin smear layer after 2% chlorhexidine cavity wash followed by Syntac primer treatment; tilt at 55°; original magnification X250. Notice different appearance than in Figure 7: Smear layer is more resistant to modification.*

because in our method of teaching cavity disinfection, the disinfectant is applied after the preparation stage, prior to the start of the restorative sequence. This would then be done before the start of any

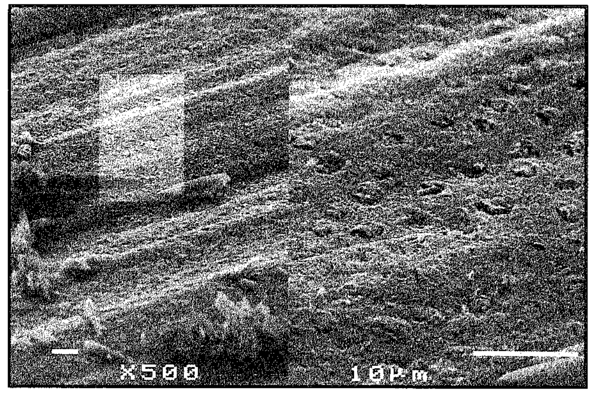


Figure 5. *Dentin smear layer after 2% chlorhexidine cavity wash followed by Tenure conditioner treatment; tilt at 55°; original magnification X250. Notice resistance to removal compared to Figure 4.*

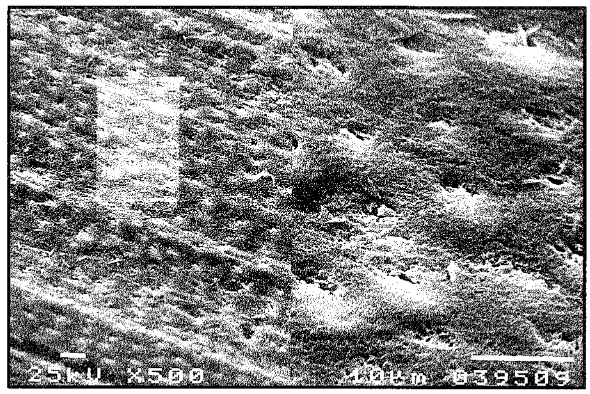


Figure 7. *Dentin smear layer after treatment with Syntac primer; tilt at 55°; original magnification X250*

dentin bonding procedures.

The iodine/potassium iodide, copper sulfate solution did not adversely affect the sealing ability of Tenure; however, the combination of ORA-5 with Syntac did significantly increase gingival microleakage levels. This may be indicative that there may have been some negative interaction between the iodine/potassium iodide, copper sulfate solution and the primer or adhesive of Syntac. SEM observation of the cementum samples did not show a great difference in the appearance between the ORA-5/Syntac-treated smear layer versus the Syntac control. This would lead to the speculation that the chemical residue left from the ORA-5 may have contributed to a decrease in wettability of the adhesive and a resultant decrease in its ability to impregnate the dentin surface.

The two dentin bonding systems used in this study were chosen to examine how the disinfectant cavity washes would affect two different smear layer management techniques. Tenure operates by completely removing the smear layer using nitric acid as its conditioning step, followed by a water rinse (Figure 4). Syntac does not entirely remove the smear

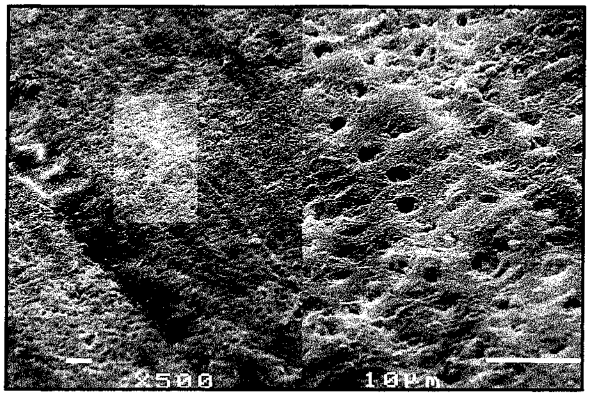


Figure 9. *Dentin smear layer after 0.11% iodine/potassium iodide solution followed by Syntac primer treatment; tilt at 55°; original magnification X250. Notice less resistance to modification than in Figure 8.*

layer but alters it using a milder acidic monomeric primer with no rinse step (Figure 7). Scanning electron microscope examination of cavity-disinfected smear layers showed differences in their response to the dentin primer of Syntac and the conditioner of Tenure. The chlorhexidine-treated smear layers were less affected by the dentin primer of Syntac and the conditioner of Tenure, indicating this treated smear layer was made acid resistant (Figures 5 and 8). However, the iodine/potassium iodide, copper sulfate-treated smear layers did not show the same resistance to removal or modification as did the chlorhexidine (Figures 6 and 9).

An unexpected result from this study was the relative effectiveness of the chlorhexidine used by itself in reducing microleakage. This group was expected to have one of the highest leakage scores because of the lack of etching of the enamel margin and lack of a dentin bonding agent. Statistically, there was no difference in the total microleakage scores (enamel and cementum) when compared to the dentin bond-treated groups. However, it did have significantly more leakage at the gingival margin, indicating that at this critical junction, it broke down. The somewhat surprising result with the chlorhexidine might be explained by a possible stabilizing effect exerted on the smear layer, turning it from a semipermeable, loosely bound layer to a more impermeable, firmly bound layer. This would help make the dentin resistant to fluid flows, in both directions, and may be the reason for the reported reduction in postoperative sensitivity after its use (Goho & Aaron, 1992). Our SEM analysis would seem to support this possible hypothesis, because the chlorhexidine-treated smear was resistant to both the effects of nitric acid conditioning of Tenure and acid hydrophilic monomer priming of Syntac, indicating that a stabilized and acid-resistant layer was formed that in effect either aided or participated in reducing the microleakage along the occlusal margin of these samples.

## CONCLUSION

The results of this in vitro study indicate that a 2% chlorhexidine cavity cleanser can be used as a cavity wash prior to the use of Syntac and Tenure without affecting these dentin bonding agents' ability to prevent microleakage. A 0.11% iodine/potassium iodide, copper sulfate solution had no adverse effect on Tenure but produced significantly higher gingival microleakage when used with Syntac.

*(Received 23 May 1995)*

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# A Survey of Failure Modes in Composite Resin Restorations

W D BROWNING • J B DENNISON

**Clinical Relevance**
Class 4 and 5 restorations fail twice as fast as class 3 composite restorations; therefore caution is called for when making a decision to treat noncarious class 5 lesions.


## SUMMARY

This study was undertaken as a first step in identifying opportunities to decrease the need for replacement of class 3, 4, and 5 composite resin restorations. Data regarding the reasons for original placement or replacement of a restoration, the age of restorations at the time of replacement, and patient/doctor factors that may be associated with a decision to place or replace a restoration were recorded by use of a cross-sectional survey. During a 2-week period 108 dentists recorded reasons for placing or replacing 1360 restorations.

Of the 1360 restorations, 42.8% were classified as primary placement and 57.2% as replacement restorations. Of the primary placements 80% were categorized as being due to caries; 9.1% fracture of tooth; 8.4% other (erosion lesions were specified 94% of the time). By class, caries was the dominant cause for class 3 (96.2%); caries and other (erosion) for class 5 (77.3% and 16.4%); fracture of tooth and caries (48.9% and 40.2%) for class 4 restorations.



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The percentages, by category, for replacement restorations were: Recurrent Decay, 28.6; Marginal Failure, 14.1; Marginal Discoloration, 21.7; Shade, 4.5; Contour, 1.9; Fracture of Composite, 16.2; Fracture of Tooth, 8.7; and Other, 4.3%. Lost restorations and erosion accounted for 76% of the Other category. By class, recurrent decay, marginal failure, and marginal discoloration accounted for 78% of class 3 and 5 replacements but only 36.1% for class 4. Fracture of composite was the dominant reason for replacement of class 4 restorations, at 47.0%. For primary placement restorations the breakdown by class was: class 3, 45.5%; class 4, 15.8%; and class 5, 38.7%. For replacement restorations it was: class 3, 42.9%; class 4, 31.1%; and class 5, 26.0%. The proportions by class were found to differ significantly between the primary placement and replacement groups (chi square, $P < 0.0005$).

The median age of class 3 restorations at the time of replacement was 10 years, while for class 4 and 5 restorations it was 5 years. Of the existing class 4 and class 5 restorations, 35.5% and 33.3% respectively were three years old or less at the time of replacement, while only 12.8% of class 3 restorations failed over 3 years.

The doctor's income, practice location, and type of practice (group or solo) were found to have no association with the replacement of a restoration for esthetic or functional reasons. The patient's plaque score was negatively associated with the replacement of a restoration for esthetic reasons; i e, those with less plaque were more

**prone to have restorations replaced.**

**There is an opportunity to increase the longevity of class 4 and 5 restorations by improving the techniques and/or materials used by general practitioners.**

## INTRODUCTION

Dentists spend a significant portion of their time each year replacing failed restorations (Klausner, Green & Charbeneau, 1987; Qvist, Qvist & Mjör, 1990). As Elderton (1976) noted, without thoughtful reflection on the reasons the previous restoration failed, a practitioner cannot assure that the same fault will not exist in the replacement restoration. Similarly, practitioners will have little impetus to alter their choices of materials and/or techniques without evidence that there is a better way. Several investigators have studied the reasons for failure of amalgam (Elderton, 1977; Klausner & Charbeneau, 1985; Letzel & others, 1989), and Mount (1986) has studied glass-ionomer restoration failures. Following identification of the reasons for failure, Mount (1986) found considerable improvement in the longevity of glass-ionomer restorations. However, little has been done to investigate the reasons for failure of anterior composite resin restorations.

The present study was the first step in a research plan designed to improve the longevity of anterior restorations. Its purpose was to investigate the modes by which class 3, class 4, and class 5 composite resin restorations fail, the criteria used by Michigan dentists in assessing the need to place or replace these restorations, and the age of restorations at the time of replacement. Improvements in the criteria used to decide when and how a restoration should be replaced will result in better dental health for the public by reducing the number of patient visits and treatment cost. Coming at a time when the nation is re-evaluating how health care is provided, a reduction in the need for replacement

*Table 1. Sample Data Collection Form*

| | | For Existing Restoration | | | For Restoration about to be Placed | | Patient Data | | |
|---|---|---|---|---|---|---|---|---|---|
| Case # | Reason for Re/placement | Class | Surface | Age | Class | Surfaces | Sex | Age | Plaque Score |
| 1 | P | X | X | 0 | 3 | ML | M | 20 | 1 |
| 2 | R | 3 | DL | U | 3 | DL | F | 39 | 2 |
| 23 | F2 | 3 | MFL | 7 | 4 | MFLI | M | 18 | 0 |
| 24 | MF, MD1 | 5 | F | 13 | 5 | F | M | 62 | 1 |

**Reasons for Placement or Replacement**

P= Primary or new caries
R= Recurrent decay (soft to explorer)
MF= Marginal Failure (explorer penetrates margin)
MD1= Marginal Discoloration (match to photo MD1)
MD2= Marginal Discoloration (match to photo MD2)
S= Shade
C= Contour
F1= Fracture of Restoration
F2= Fracture of Tooth
O= Other--explain

**Plaque Score**

0= No plaque present
1= Presence of plaque apparent with probing
2= Plaque evident visually

**Age rounded to nearest whole year**

U = unknown

**Surfaces**

M= mesial
D= distal
F= facial
L= lingual
I= incisal

restorations represents an important advancement opportunity in dental care.

## SURVEY METHOD

Questionnaires were sent to 378 users of the Command Dental Computer System, the same computer system used by the School of Dentistry at the University of Michigan.

These dentists were asked to make nine observations about every composite resin restoration they placed during a two-week period in the summer of 1993. First, the participants were asked to note the reason(s) for placement of any original restorations (primary placement restorations) and the reason(s) for failure of any existing restorations where the restoration was to be a replacement (replacement restorations). The dentists were provided eight predefined reasons for failure and were allowed to use the category of Other to specify any reasons they felt were not included in the eight (Table 1). Second, they were to note the class; the surfaces involved; and the age, where known, for any previous restorations. The classification and the surfaces involved for the restoration to be placed were also to be indicated on the questionnaire. The patient's sex, age, and a plaque score for the area to be restored were also requested. Finally, every dentist contacted was asked to return anonymously a card containing demographic information about his/her practice.

Our original intent was to investigate the degree of marginal discoloration that prompted participants to recommend restoration replacement. In order to assess this, a color photograph depicting examples of two levels of discoloration was included. However, in the returned data one-third of the observations involving marginal discoloration were simply denoted as MD, rather than MD1 or MD2, so these data were recombined into only one category, Marginal Discoloration (MD).

One hundred and eight questionnaires (28.6%) were returned with observations on 1431 composite resin restorations. About 5% of the data was unusable because of recording errors. Failure to record the class and surfaces of the restoration made another 9% of the data unusable for two of the intended analyses.

## RESULTS

### Primary Placement Restorations

Of the 1360 restorations for which we have data, 582 (42.8%) were primary placement restorations and 778 (57.3%) were replacement restorations. Table 2 displays the reasons for placement for these restorations by class as well as for all classes combined. For class 3 restorations Caries is the predominate category listed. While caries is clearly the major reason behind placement of a class 5 restoration, Other is cited for a significant number of restorations. Ninety-four percent of the dentists using this category specified the problem as erosion. By contrast, fracture of tooth and caries are cited almost equally as reasons for placement of class 4 restorations.

### Replacement Restorations

The participants were encouraged to list multiple reasons for failure where they felt it was warranted. For the 778 replacement restorations there were 860 reasons for failure listed. Fourteen restorations had three reasons for failure listed, 54 restorations listed two, and the remaining 710 one. Table 3 displays the reasons for replacement restorations for all classes combined as well as by class. The categories Recurrent Decay, Marginal Failure, and Marginal Discoloration account for three-quarters of the failures observed for class 3 and class 5 restorations. Class 4 restorations, by contrast, had Fracture of Composite cited for almost half of all failures with the three categories, noted above, as representing breakdown at the margin, accounting for an additional one-third.

*Table 2. Primary Placement Restorations (Percent)*

| Reason for Placement | All Restorations | Class 3 Restorations | Class 4 Restorations | Class 5 Restorations |
|---|---|---|---|---|
| Caries | 80 | 96.2 | 40.2 | 77.3 |
| Fracture of Tooth | 9.1 | 2.3 | 48.9 | 0.9 |
| Other | 8.4 | 1.1 | 9.8 | 16.4 |
| Contour | 1.7 | 0.4 | 1.1 | 3.6 |
| Shade | 0.8 | 0 | 0 | 1.8 |

### Proportion of Primary and Replacement Restorations by Class

Table 4 presents the proportion of restorations that were class 3, 4, or 5 for both the primary placement and replacement groups. A comparison of the two groups reveals that there is a significant difference in the proportions of class 4 and class 5 restorations for the two groups (Pearson Chi-Square $P < 0.009$; adjusted for multiple comparisons).

*Table 3. Replacement Restorations (Percent)*

| Reason for Replacement | All Restorations | Class 3@ Restorations | Class 4@ Restorations | Class 5@ Restorations |
|---|---|---|---|---|
| Recurrent Decay | 28.6 | 34.2 | 18.6 | 36.3 |
| Marginal Failure | 14.1 | 19.6 | 6.8 | 11.7 |
| Marginal Discoloration | 21.7 | 25 | 10.7 | 30.1 |
| Shade | 4.5 | 5.6 | 4.5 | 3.6 |
| Contour | 1.9 | 1.8 | 0 | 4.6 |
| Fracture of Composite | 16.2 | 7.4 | 47 | 6.1 |
| Fracture of Tooth | 8.7 | 3.1 | 9.6 | 1 |
| Other | 4.3 | 3.3 | 2.8 | 6.6 |

@Ninety-one restorations were excluded from this analysis because the class of the restorations was not recorded.

## Age at the Time of Replacement

Participating dentists were instructed to record the age of the restoration only where it could be confirmed in the patient record or to record it as unknown. Time of replacement age was noted for 429 of the 778 replacement restorations (55.1%). It ranged from 1 to 62 years. Since composite resin materials have only been commercially available since the mid 1960s, it was obvious that some of the observations were unreliable. Therefore, a decision was made to restrict the age observations to a range of 1 to 25 years. This meant the exclusion of 16 observations from the analysis.

*Table 4. Restorations by Class*

| | Primary Placement | | Replacement | |
|---|---|---|---|---|
| Class | Number | Percent | Number | Percent |
| 3 | 265 | 45.5 | 318 | 42.9 |
| 4* | 92 | 15.8 | 230 | 31.1 |
| 5* | 225 | 38.7 | 193 | 26 |
| Totals | 582 | 100 | 741 | 100 |

*There is a significant difference in the proportion of restorations for the primary and replacement groups for classes 4 and 5; Pearson Chi-Square, $P < 0.009$.

(There were 37 observations that could not be used for this analysis because the dentists failed to record information about the class of the restorations that was to be placed.)

The mean ages at the time of replacement, the standard deviations, the range and the percent of restorations failing within 3 years for all restorations and for each of the three classes of restorations is contained in Table 5. For all classes of restorations, half had failed within 6 years. By class, half of all class 3 restorations had failed within 10 years; half of class 4 and class 5 restorations by 5 years.

## Failure of Restorations over Time

It is interesting to observe the differences in the reasons for failure between the three classes for the restorations failing within 3 years (Table 6). Class 3 and 5 restorations failed predominately due to breakdown at the margins (first three categories). Class 4s, by comparison, failed predominately due to fracture.

Similarly, it is of interest to observe the differences between reasons for initial failures (Table 6) compared to the reasons for failure overall (Table 3). For all three classes marginal discoloration (MD) becomes a more prominent reason for replacement. This is especially so for class 3s and class 5s.

## Relationship of Patient Factors and Doctor Factors to the Need for a Replacement Restoration

Using the eight predefined reasons for placing or replacing a restoration, the data were recombined to create two new groups of restorations: functional and esthetic. The functional group was comprised of all restorations that were replaced because of recurrent decay, marginal failure, fracture of the composite, and fracture of the tooth. The esthetic group was defined as restorations that were replaced because of problems with marginal discoloration, shade, and contour. The data about the primary placement restorations were used with both groups to create a baseline. For subsequent analyses, the data for the functional group became binomial; i e, restorations contained in the group were either replaced for functional reasons or for nonfunctional reasons. Similarly, data became either esthetic or nonesthetic. This recombination of the data allowed identification of whether any of the doctor factors or patient factors were predictive of a need for a replacement restoration for either functional or esthetic reasons. The patient factors for this observational analysis were: 1) sex, 2) age, and 3) plaque score. The

*Table 5. Age of Replacement Restorations*

| | All Restorations | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|
| Mean age at replacement | 8.15 | 10.04 | 6.09 | 6.25 |
| Standard Deviation | 5.71 | 5.89 | 5.07 | 4.57 |
| Range | 1 to 25 | 1 to 25 | 1 to 25 | 1 to 20 |
| Median age | 6 | 10 | 5 | 5 |
| Percent failing within 3 years | 23.3 | 12.8 | 35.5 | 33.3 |

doctor factors were: 1) the number of restorations produced during the 2-week period; 2) the practice locale; 3) whether the practice was solo, group, etc; and 4) the doctor's personal gross income.

Spearman's Rank Correlation was used to investigate whether any statistically significant associations existed. For both the functional and esthetic groups a significant association ($P < 0.0001$) was found with patient age. Plaque score and esthetic restorations were found to be negatively associated; i e, those patients with less plaque were more prone to have replacements for esthetic reasons ($P < 0.0001$). The patient's sex and the four doctor factors were not found to be significantly associated with the need for either type of restoration.

## DISCUSSION

### Survey Methodology

Survey research of this type presents an opportunity to gather information that is more descriptive of the kind of care the American public receives, and thus more suggestive of ways to improve care, than university-centered studies. It also presents unique challenges.

Since the patients involved were equally distributed by sex, their mean ages were comparable to that of the population as a whole, and the dentists who participated were well distributed in all the zip code areas covered by this survey, there is no reason to believe the results obtained are biased. Furthermore, there was no evidence of a relationship between a decision to participate in this study and the criteria and thought processes that the dentist would use in a decision to place or replace a composite resin restoration.

To deal with any potential problem of missing data and erroneous data, the questionnaire was designed to provide for simple responses and redundancies, which allowed for confirmation of the accuracy of the data.

### Opportunities for Reducing the Number of Restorations Needed

Approximately 80% of all primary placement restorations were placed due to caries. At present, a wide variation in opinions exists between practitioners as to when it is appropriate to treat a given situation and when it is appropriate to observe it (Maryniuk, 1990). The profession's efforts to prevent caries and to establish criteria that reduce unnecessary treatment need to continue. It would seem particularly prudent to limit the restoration of erosion lesions wherever feasible.

Reductions in the need for replacement restorations would have an even greater impact on the public's dental health than a reduction in original placement restorations. It is apparent from the data on replacement restorations that secondary caries and problems with marginal integrity are the major modes of failure for class 3 and class 5 restorations, while loss of restorative material is the major mode of failure in class 4 restorations. In light of the problems with retention of restorative materials, improvements in restorative techniques need to be evaluated.

### Pattern of Primary and Replacement Restorations

If the incidence of class 3, class 4, and class 5 lesions was steady and the longevity of these three

*Table 6. Restorations Failing within 3 Years (Percent)*

| | Class 3 | Class 4 | Class 5 |
|---|---|---|---|
| Recurrent Decay | 37.5 | 11.4 | 46.2 |
| Marginal Failure | 15.6 | 8.6 | 7.7 |
| Marginal Discoloration | 6.3 | 0 | 17.9 |
| Shade | 3 | 0 | 5 |
| Contour | 0 | 0 | 2.6 |
| Fracture of Composite | 18.8 | 68.6 | 10.3 |
| Fracture of Tooth | 9.4 | 11.4 | 2.6 |
| Other | 9.4@ | 0 | 7.7* |

@One restoration was replaced because of a white margin, another "fell out," and the third was replaced due to postoperative sensitivity.

*One was a lost restoration and the other two were reported as "bond failure."

classes of restorations were equal, one would expect to replace restorations in roughly the same proportions that they were placed. Our data clearly indicate this is not the case. There is a significant difference between the proportion of class 4 and class 5 restorations in the primary and replacement restoration groups. A higher incidence of class 5 restorations needed and a greater need for replacements of existing class 4 restorations are supported by the data. Coupling these observations with the data on the median age of restorations at the time of replacement, it appears the greatest benefits will be gained by improvements in longevity of class 4 and 5 restorations.

### Class 5 Restorations

There is a need for development of clear criteria that demonstrate at what point discolored margins indicate a need for replacement of a restoration, since marginal discoloration was cited in almost one-third of replacements. Greater use of glass-ionomer materials in class 5 situations may help decrease the number of required replacement restorations.

### Class 4 Restorations

For class 4 restorations it is evident that problems with loss of composite resin material due to fracture present the profession with a great challenge. Further investigation to discover whether the data presented indicate fractures due to cohesive failures or bond failure is needed. Ways need to be found to reduce the need for replacement of class 4 restorations using the materials and techniques we already have. It is generally accepted that composite resin restorations require very careful attention to detail, and it has been shown that failure to obtain adequate isolation can lead to a loss of bond strength (Hormati, Fuller & Denehy, 1980). It is reasonable to believe that improvements in the retention of class 4 restorations can be achieved now with improvement in isolation techniques. Further investigation into the causes of this rapid loss (50% in 5 years) of class 4 restorations is needed.

### Life Expectancy of Composite Resin Restorations

The life expectancy of the composite resin restoration, as well as that of other materials, is difficult to determine (Smales, Webster & Leppard,1991). Because there are restorations that continue to be serviceable despite being placed at approximately the same time as the failed restorations observed in our study, cross-sectional data of this type will tend to underestimate the mean life of a restoration. The median age for all restorations was 6 years. Smales and others (1991) found a median age of 7.9 years for anterior composites. The amount by which these values underestimate the true life expectancy is unclear.

Class 3 and 5 amalgam restorations had a mean age at replacement of 12 and 10 years compared to 10 and 6.25 respectively for composite resin restorations (Klausner & others, 1987). The data showing that patients receiving a class 4 or 5 composite resin restoration have a one-in-three chance it will last 3 years at the most and a one-in-two chance it will last 5 or less are disturbing. Perhaps a more important question than What is the average life expectancy of a composite resin restoration? is, Why do class 4 and 5 composite resin restorations seem to compare so poorly to class 3 restorations?

### Patient and Doctor Factors

The association between patient age and the need for restorations for esthetic and functional reasons seems to indicate that older patients are more likely to need replacement restorations. The association probably reflects the fact that most people are cavity prone early in life, and as a result, most of the original placements would be for younger people, and replacements would be required later in life.

The negative association between plaque score and the need for a replacement restoration for esthetic reasons would seem to be driven by the fact that patients who are concerned enough to practice good home care are also concerned about the appearance of their teeth and vice versa. Since the study design was capable of finding the association between plaque score and esthetic restorations, then it would have found a similar association for functional restorations if one existed. It would seem that improved dental techniques as well as plaque control are needed to improve the longevity of restorations.

## CONCLUSIONS

Caries remains the dominant reason for the original placement and the replacement of class 3 and class 5 restorations. Fracture of the tooth and of existing restorations are the main reasons for class 4 restorations, both original placement and replacement.

A significant difference was found between the proportions of original placement to replacement of class 4 and 5 restorations.

By class, half of all class 3 restorations had failed within 10 years; half of class 4 and class 5 restorations by 5 years.

The patient's age was found to be associated with the need for a replacement restoration both for esthetic and functional reasons. Those patients with less plaque were more prone to have replacements for esthetic reasons ($P < 0.0001$). By contrast, no association was found between plaque score and the need for replacement restorations categorized as functional.

No association between any of the doctor factors (personal gross income, practice locale, group or solo practice) and the need for either a functional or esthetic replacement restoration was found.

In light of the percentage of class 5 restorations failing within 3 years, the decision to restore noncarious cervical lesions should be made cautiously.

Investigation is needed to determine whether the class 4 failures observed as fracture of composite are failures within the composite resin material or failure to achieve an adequate bond to enamel and dentin.

Studies comparing the longevity of the newer resin and polyacid-modified ionomer materials to composite resin are also needed.

*(Received 23 May 1995)*

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# Influence of Dentin Primer Application Methods on Dentin Bond Strength

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H ONOSE • B K MOORE

**Clinical Relevance**
Primer application methods can influence dentin bond strength.

## SUMMARY

**This study was carried out to determine the influence of dentin primer application methods on bond strength to human dentin. Two dentin bonding restorative systems, Imperva Bond/Lite-Fil II A (Shofu) and Scotchbond Multi-Purpose/Z-100 (3M) were employed. Human molars were mounted in self-cured resin and the buccal surfaces were prepared with #600-grit SiC paper. These surfaces were then conditioned according to each manufacturer's instructions. Two experiments were designed: (1) effect of the primer application procedures (inactive and active application), and (2) effect of the air drying time (0, 1, 5, 10, 20, and 30 seconds). The adhesives were applied and resin composites were bonded to the teeth. Ten samples per test group were stored in 37 °C deionized water for 24 hours, and shear tested with a circular knife edge at a crosshead speed of 1.0 mm/minute. A one-way ANOVA followed by the Newman-Keuls multiple comparison at $P < 0.05$ was done. For both restorative systems, the bond strengths for active application were higher than those for inactive application, but there was no significant difference between the two mean values. According to the air drying time, there appeared to be an optimal range of drying times, longer for Imperva Bond (10-30 seconds) than for Scotchbond MP (1-5 seconds). The data suggest that the bond strengths of employed dentin bonding systems were greatly influenced by the methods of the dentin primer application.**

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## INTRODUCTION

The reliability of third-generation dentin bonding systems has been remarkably improved and dentin bond strengths greater than 15 MPa have been reported (Burrow & others, 1994; Triolo, Swift & Barkmeier, 1995). These systems require dentin conditioning or priming steps prior to bonding agent application to ensure maximum adhesive strength. Munksgaard and Asmussen (1984) introduced dentin primer and reported that the pretreatment of dentin surfaces with an aqueous mixture of HEMA and glutaraldehyde improves the bonding efficacy of restorative resins. Use of a dentin primer is said to improve monomer penetration into the hydrophilic dentin substrate and improve wettability of the dentin surface by the bonding agent (Inagaki & others, 1989; Erickson, 1992). Although these dentin primers improve the efficacy of the third-generation dentin bonding systems, extra steps are required to achieve good bond strength to dentin. This may lead to an increasing possibility for technical error, and the resultant dentin bond strength may be greatly influenced by the application procedure in the clinical situation.

The application methods of various dentin primers to the dentin surface are different because of the different concepts of dentin bonding mechanisms, and the effect of different primer pretreatments may create variable structural changes in the dentin (Van Meerbeek & others, 1992). The duration of dentin primer application is varied from a few seconds to 30 seconds, and some manufacturers recommend continued scrubbing of the primer on the dentin surface in order to get maximum performance of the bonding systems. After application of primer, the primed dentin surface should be air dried because it contains solvents like water, ethanol, and acetone that may have an adverse effect on polymerization of the bonding agent applied after the dentin priming step. The duration of air drying suggested is different for each manufacturer.

Though the application of a dentin primer plays an important role in getting good bond strength, the influence of the dentin primer application method is not well understood. The purpose of this study was to investigate the influence of dentin primer application procedures and drying time of the primed dentin surface on bond strength to human dentin.

## METHODS AND MATERIALS

Dentin bonding systems employed in this study were Imperva Bond/Lite-Fil II A (Shofu Inc, Kyoto, Japan) and Scotchbond Multi-Purpose/Z-100 (3M Dental Products, St Paul, MN 55144). The input voltage for the curing light (Coe-Lite Model 4000, Imperial Chemical Industries, Macclesfield, Cheshire, England) was fixed by using a variable transformer to fix the light intensity. The light intensity was adjusted to 400 $mW/cm^2$ as measured with a radiometer (Model 100, Demetron Research Corp, Danbury, CT 06810).

Extracted human molars that were stored in 10% formalin for several months were used. The teeth were debrided and washed several times in running water to remove the formalin, and then roots were sectioned using a carbide bur with high-speed turbine. The buccal surfaces were ground on wet 240-grit silicon-carbide paper to a flat surface. Each tooth was then mounted in Plexiglas with cold-curing acrylic resin to expose the flattened area and placed into tap water to reduce the temperature rise from the exthothermic polymerization reaction of the embedding resin. Final finish was accomplished by grinding on wet 600-grit SiC paper until a 4 mm-in-diameter area of dentin was exposed. After ultrasonic cleaning with distilled water for 3 minutes to remove the debris, these surfaces were washed and dried with oil-free compressed air. Dentin surfaces were etched 10 seconds with phosphoric acid for Imperva Bond and 15 seconds with 10% maleic acid for Scotchbond Multi-Purpose. These surfaces were washed and dried with compressed air.

Two experiments were designed for study of the influence of the primer application method on bond strength to dentin:

(1) **Effect of the primer application procedures:** The dentin primer was just applied (inactive application) or was applied and agitated by brush (active application), 30 seconds for Imperva Bond and 10 seconds for Scotchbond Multi-Purpose; and

(2) **Effect of the air drying time:** The primer was applied on the dentin surface according to the manufacturers' instructions (Table 1). The primed dentin surfaces were dried with oil-free compressed air (40 psi) using a three-way syringe for 0, 5, 10, 20, and 30 seconds from 10 cm above the dentin surface.

Pieces of double-sided adhesive tape (Nichiban Co, Tokyo, Japan) that had a 4 mm-in-diameter hole were firmly attached to the dentin surface to restrict the adhesive area. A Teflon mold, 2.0 mm high with a 4.0 mm internal diameter, was used to form and hold the composite resin materials to the dentin surface. Bonding agent was applied and then irradiated (30 seconds for Imperva Bond, 10 seconds for Scotchbond Multi-Purpose) with the light-curing unit. Composite resin was condensed into the mold and cured for 40

*Table 1. Bonding Systems Used in This Study*

| Bonding System | Component (Batch #) | Manufacturer's Instruction |
|---|---|---|
| Imperva Bond | Etchant (109396) | 10 seconds' etch, 20 seconds' rinse |
| | Primer (109334) | 30 seconds' agitation, 20 seconds' air dry |
| | Bonding Agent (019427) | 30 seconds' irradiation |
| Scotchbond Multi-Purpose | Etchant (3DD) | 15 seconds' etch, 15 seconds' rinse |
| | Primer (3CR) | apply, gently air dry |
| | Adhesive (3BX) | 10 seconds' irradiation |

*Table 2. Shear Bond Strengths (MPa) of the Bonding Systems with Inactive and Active Primer Application Procedures*

| Bonding System | Procedure | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Imperva Bond | Inactive | 11.45 | 3.08 | 6.64 | 16.12 |
| | Active | 12.51 | 2.44 | 9.55 | 17.79 |
| Scotchbond | Inactive | 17.06 | 3.49 | 10.42 | 21.9 |
| | Active | 18.24 | 5.42 | 11.16 | 27.78 |

Values connected by vertical lines are not significantly different ($P < 0.05$).

seconds. The finished specimens were transferred to deionized water and stored at 37 °C for 24 hours. Ten specimens per group were tested in a shear mode using a tension knife-edge testing apparatus in an Instron testing machine (Type 1123, Instron Corp, Canton, MA 02021) at a crosshead speed of 1.0 mm/minute. Shear bond strength values (MPa) were calculated from the peak load at failure divided by the specimen surface area.

The mean and standard deviation for each group were calculated and were tested for homogeneity of variance using Bartlett's test. Because of the homogeneity of variances, the data for each group were subjected to a one-way ANOVA followed by the Newman-Keuls multiple comparison among the groups ($P < 0.05$).

After the testing, the specimens were examined by use of an optical microscope at a magnification of X40 to define the location of the bond failure according to the method of Fowler and others (1992).

*Table 3. Shear Bond Strengths (MPa) of the Bonding Systems with Various Drying Times*

| Bonding System | Time (Seconds) | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Imperva Bond | 20 | 12.41 | 2.20 | 9.55 | 16.79 |
| | 10 | 12.28 | 2.44 | 9.84 | 16.59 |
| | 30 | 10.34 | 2.40 | 7.63 | 15.57 |
| | 5 | 9.44 | 2.48 | 6.15 | 13.24 |
| | 1 | 7.02 | 2.08 | 3.60 | 9.62 |
| | 0 | 6.91 | 2.17 | 3.83 | 10.19 |
| Scotchbond Multi-Purpose | 5 | 18.43 | 5.19 | 11.16 | 27.78 |
| | 1 | 15.77 | 4.09 | 9.66 | 23.95 |
| | 10 | 12.56 | 3.76 | 7.89 | 18.08 |
| | 20 | 9.92 | 3.57 | 5.13 | 17.44 |
| | 0 | 8.41 | 3.86 | 4.70 | 16.28 |
| | 30 | 8.32 | 1.55 | 5.63 | 10.89 |

Values connected by vertical lines are not significantly different ($P < 0.05$).

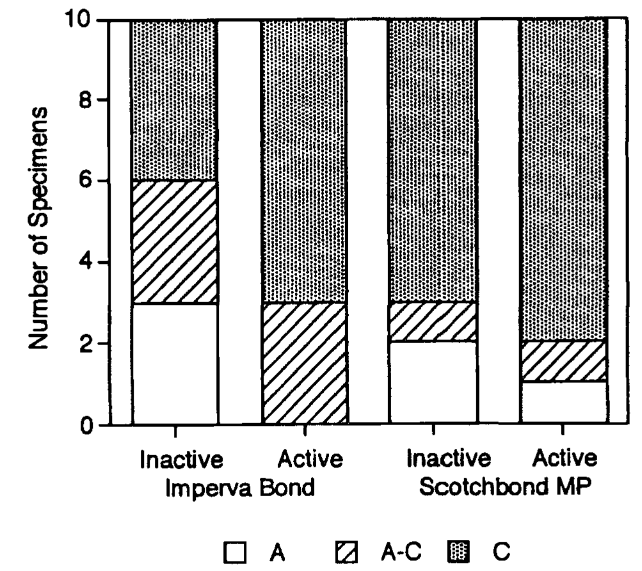


Figure 1. *Fracture modes of specimens tested with inactive and active applications*

The test area on the tooth was divided into eight segments, and the percentage that was free of material was estimated. The type of failure was determined based on the percentage of substrate free material: adhesive (A), adhesive-cohesive (A-C), and cohesive (C).

## RESULTS

The results of the shear bond strength and fracture mode with inactive and active application are shown in Table 2 and Figure 1. The bond strengths with active application were higher than with inactive, but there were no significant differences between the means for the two application procedures. A trend toward differences in failure mode between inactive and active application tended to exist. The fracture of active application specimens showed more tendency to fail in the cohesive or mixed mode than did the inactive.

The results of the shear bond strength and fracture mode with various air drying times of primed dentin surface are shown in Table 3 and Figures 2 and 3. The maximum shear bond strength was obtained with 20 seconds of air drying time for Imperva Bond and with 5 seconds of air drying time for Scotchbond Multi-Purpose. The bond strengths of each bonding system were lower when the primed dentin surface was not air dried. For both restorative systems, there appeared to be an optimal range of drying time, longer for Imperva Bond (10-30 seconds) than for Scotchbond Multi-Purpose (1-5 seconds). The fracture mode of bond strength specimens

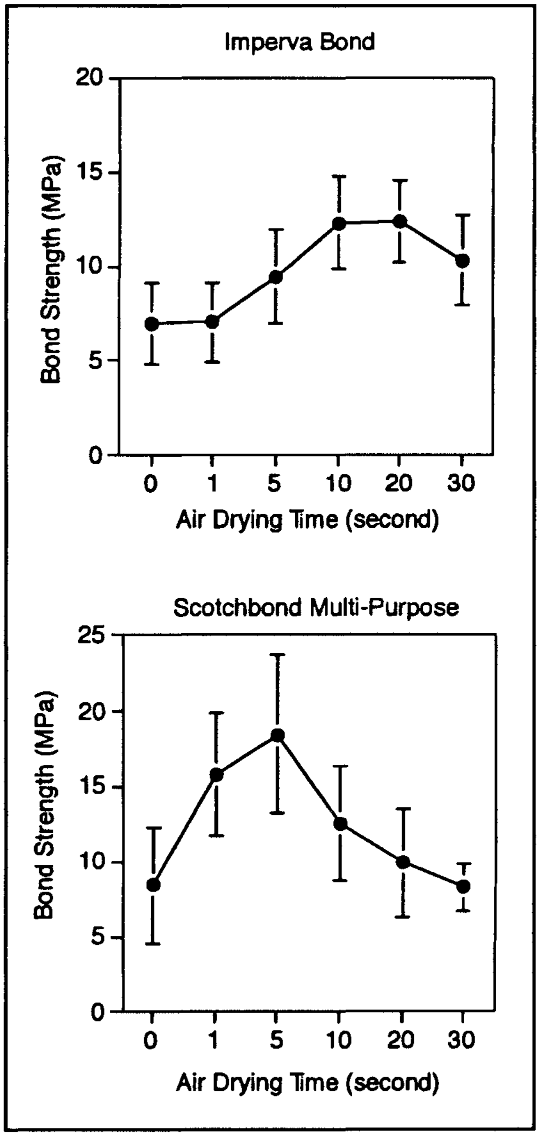


Figure 2. *Shear bond strength to dentin with various drying times*

was also affected by the air drying time. As the air drying time increased, the fracture mode tended to change from adhesive to cohesive failure, and longer air drying tended to increase adhesive failure again.

## DISCUSSION

A hybrid zone is created by resin diffusion into the demineralized and/or collagen-rich dentin surface after smear layer removal (Nakabayashi, Kojima & Masuhara, 1982). The diffusion rate of the resin monomer is a function of the penetrability of dentin substrate and the diffusibility of the resin monomer. To increase the penetrability of the dentin surface, the smear layer must be removed. However, smear

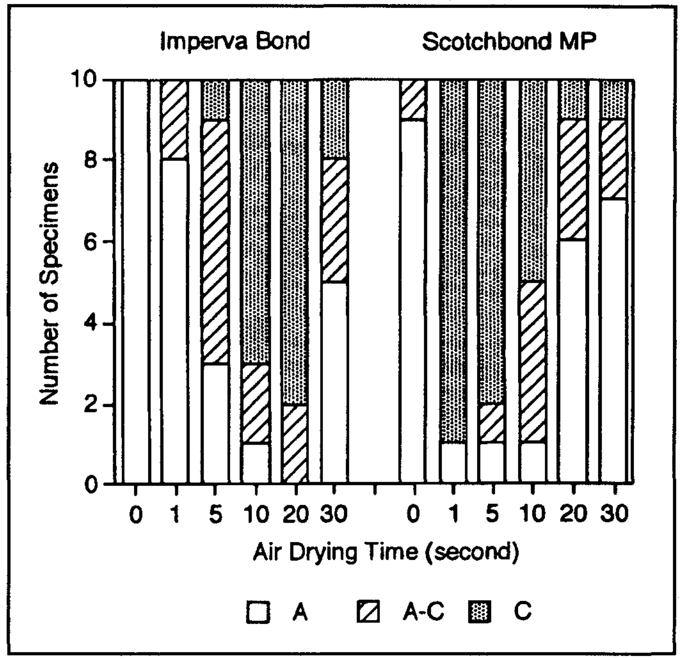


Figure 3. *Fracture modes of specimens tested with various drying times*

layer removal with acid makes the collagen shrink so that the porosity and penetrability decrease (Nakabayashi, Watanabe & Gendusa, 1992). To maintain the structural integrity of the collagen into which the bonding resin impregnates, dentin primer containing hydrophilic monomers must be applied following acid etching (Van Meerbeek & others, 1992).

Some manufacturers recommend agitating the primer on the dentin surface before the bonding agent application. The active application may ensure the diffusion of dentin primer into the collagen-rich zone and into the partially demineralized zone. Miyazaki and others (1991) suggested that the role of agitating the primer may be seen by observing the smear layer remaining on the dentin surface. From the SEM observations of dentin surfaces primed with active application, the smear layer was removed while the smear plugs remained intact. The function of active application is to remove the smear layer in order to achieve micromechanical as well as chemical interaction with the underlying dentin (Miyazaki & others, 1991). However, no significant differences were observed for the bond strengths between the two types of primer application procedures.

The effect of active application could be seen by the observations of the fracture mode after the bond strength test. The fracture mode varied with primer application procedures, and there was an increasing tendency to fail in the mixed and cohesive failure with active application specimens. It has been suggested that resin fails to completely infiltrate the deeper portions of the demineralized dentin, which might weaken the bond between dentin and bonding agents (Nakabayashi, Ashizawa & Nakamura, 1992; Van Meerbeek & others, 1993). Active application of dentin primer may help to ensure the penetration of the dentin primer into subsurface demineralized dentin.

The air drying time of the primed dentin surface had a significant effect on bond strength. With shorter air drying time, lower bond strengths were obtained for both systems. A possible explanation for the reduction in bond strengths seen with the short drying times is that the solvents used as carriers for the primers may act as inhibitors for the polymerization of the bonding agent. To test this hypothesis an additional experiment was done. Amounts of primer varying from 0 to 20% were admixed with the bonding agent and the polymerization of the mixture studied by monitoring the temperature rise during exposure to the curing light. Care was taken to avoid any evaporation of the water-based primer mixtures by placing glass coverslips on top of the molds immediately after insertion. This variable would have been more difficult to control had different solvents been used with the primer agents.

The temperature change during the polymerization reaction of bonding agent was monitored according to the method of Masutani and others (1988) and followed ISO specification #4049. A white Teflon cylindrical mold (inside diameter 4.0 mm, 3.0 mm high) was filled with the bonding agent mixed with primer in the volumetric ratios of 10:1, 5:1, and 1:0 for the control. To monitor the temperature change during 60 seconds' exposure to the light, a DP thermister (the dimension of the probe was 0.8 mm in diameter and 0.5 mm high; PBSS-41E, Shibaura Denshi, Tokyo, Japan) connected to a digital thermometer (TF-300, Shibaura Denshi) was inserted into the center of the specimen, and temperature versus time was plotted by X-Y recorder. For both Imperva Bond and Scotchbond Multi-Purpose, the addition of primer delayed the curing exotherm and reduced its height. This effect was more pronounced for Imperva Bond than Scotchbond Multi-Purpose. These results could explain the initial increase in bond strength with drying time.

A reduction in bond strength was also seen with excessive air-drying times. Excessive air thinning of the primer might partially negate its effectiveness. It is also possible that remaining primer becomes saturated with air that could in turn inhibit polymerization of the bonding agent. Barkmeier and Erickson (1994) reported that the bond strength of Scotchbond Multi-Purpose declined slightly when the primed dentin surface was completely air dried. Excessive air drying might lead to imperfect wettability of the surface and decrease the potential for chemical interaction with the bonding agent with a subsequent decrease in bond strength. This has been shown in the case of excessive air drying of the dentin surface, which leads to a significant loss in bond strength (Gwinnett, 1992). According to the principal of moist bonding, it is important not to desiccate the dentin surface (Gwinnett, 1994). When the dentin surface was air dried for longer times, the superficial layer of exposed collagen fibers collapsed and formed a dense amorphous layer. The longer air drying of the primed dentin surfaces might cause such an amorphous layer to form, which may impede the infiltration of bonding agent.

Current dentin bonding systems have the promise of higher and more reliable bond strengths while claiming to reduce technical sensitivities that arise from complicated restorative procedures that require extra steps. When using the present-generation dentin bonding systems, clinicians must be aware of factors that contribute to achieving higher or lower bond strengths.

## CONCLUSION

Shear bond strengths with active primer application were higher than for inactive, but there were no significant differences between the two. From the observations of fractured specimens, the active application ensured the penetration of dentin primer into etched dentin. There appeared to be an optimal range of drying times to get good bond strength. The polymerization reaction of the bonding agents might be inhibited by the presence of primers if inadequate drying occurs. Desiccation of the primed dentin surface may alter the nature of the hybrid layer. Both of these would tend to reduce the bond strength.

*(Received 30 May 1995)*

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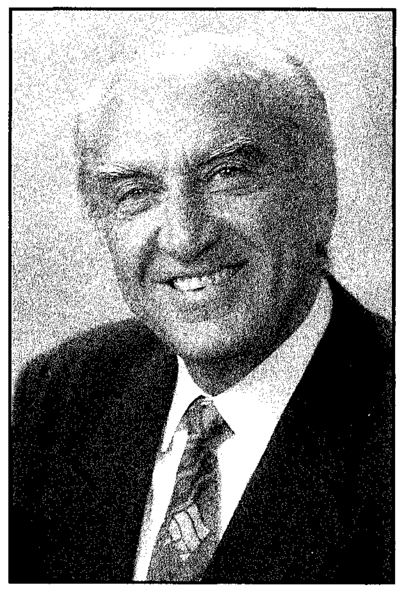
# Award of Excellence

It is an honor for me to introduce to you Dr Harry Rosen, this year's recipient of the Academy of Operative Dentistry's Award of Excellence. This award is given annually to leaders in dental education and in dental practice who are recognized as having made outstanding contributions to the art and science of operative dentistry and to the dental profession at large.

Harry Rosen's clinical expertise, his research, and his clinical teaching cover a broad range of dental disciplines, which have been demonstrated well by his numerous lectures presented before many dental organizations worldwide and his publications in a variety of dental journals. Those of you who have followed Harry's career will note that he has published continuously since 1958; contemporary topics include restorative dentistry for the geriatric patient, problem-solving for root caries, and the challenges of the transitional interim fixed or removable partial denture for implants, for which he has coined the phrase "conversion prostheses" as an adjunct to problem-solving implant cases. In his long career, Dr Rosen has made a number of presentations before our own Academy of Operative Dentistry, as well as before the Academy of Gold Foil Operators, and has published several papers in our own journal, *Operative Dentistry*.

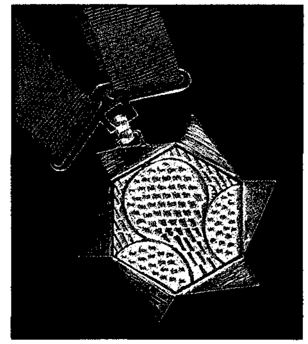
Harry's contributions to our profession have resulted in many awards, which recently have included honorary membership in the Canadian Academy of Restorative Dentistry and the Distinguished Service Award from the Canadian Dental Association. Recently at McGill University, Harry was honored with the Willian Winston Wood Memorial Teaching Award for Excellence in Dental Education at the Health Sciences Convocation in 1994, an award given annually by the Association of Canadian Dental Faculties.



*Harry Rosen*

Harry has contributed 41 years of uninterrupted teaching at McGill, where he is our only part-time full professor. At the national level in Canada, he was the founding president of the Canadian Academy of Restorative Dentistry, and is a member of the Royal College of Dentists in Canada. He stimulates all who are fortunate enough to be able to interact with him, whether at the clinical level or through the many meetings he attends and the Academies of which he is a member. In Montreal Harry was instrumental in saving the Faculty of Dentistry at McGill, which was threatened with closure four years ago; by his efforts and that of others, sufficient funds were raised not only to save the Faculty, but to fund a major clinical renovation and re-equipment project, which we have recently completed.

There are many anecdotes that come to mind regarding Harry Rosen's long and distinguished career as a teacher at the Faculty of Dentistry at McGill University. I would like to relate one particular incident that underscores Harry's commitment to his students and his personal fortitude. The circumstances of this incident involved a riding accident that Harry had one eventful weekend when his horse slipped on a wet autumn day, falling and rolling on Harry, who was pinned momentarily beneath the large, heavy animal. The very next teaching session, a day or so later, Harry Rosen turned up at the clinic on crutches looking bruised, bandaged, and much the worse for wear. When I asked about his well-being, he responded, "Well, I'm fine. But more importantly, the horse was okay."



It is a privilege to introduce Harry Rosen to you. I will leave you with a motto of his: "A man is young if he has fully lived all his days, but old if they have passed him by without event." By this yardstick, Harry is still in his youth, and has got a lot of living to do. It is because of his combination of interests and talents and all the great contributions that he has made to dentistry and the community beyond, that this Academy presents its Award of Excellence for 1996 to Harry Rosen.

J V BLOMFIELD

# DEPARTMENTS

## BOOK REVIEWS

### ENDODONTIC THERAPY
*Fifth Edition*

Franklin S Weine

Published by Mosby-Year Book, Inc, St Louis, 1996. 880 Pages, 1027 illustrations. $77.95.

Dr Frank Weine is a longtime teacher and author who has been recognized for many years for his clinical skills, knowledge, teaching, and clinical practicality. With the fifth edition of *Endodontic Therapy*, he has updated an already useful textbook. The author states that this edition, like its predecessors, is aimed at the clinical aspects of endodontics. This is clearly evident throughout the text. This edition has included even more clinical radiographic illustrations than before, demonstrating realistic and practical methods of case management. In many cases, Dr Weine includes longtime follow-up radiographs that reinforce his clinical authority. The text is updated well and includes the use of the surgical microscope and ultrasonic root-end instrumentation. The chapters are sequenced in a logical manner. The first two chapters, "Basis for Successful Endodontics" and "Diagnosis and Treatment Planning," are done extremely well and are designed to organize the reader's thoughts and direction. Considerations to success given in the first chapter are exceptionally well done and are clinically applicable. The review of AIDS and other medical complications is well done in the second chapter.

Dr Weine stresses in his book that the techniques and materials that we use today may be proven to be unacceptable in the future. He points this out when discussing the newer materials used for reverse fillings in endodontic surgery. Also, because of recent reports, the author does not endorse bleaching of teeth; however, he states that he may well do so in the future if further studies support this procedure. The above views of the author stimulate the reader to always consider that treatment that is delivered today is an evolution of what we have learned before, and we need to be willing to be watchful of what is currently accepted.

Dr Weine groups his references into subject areas at the end of each chapter and does not note them by number in his text. While this method is not distracting to the reviewer, it's unique among endodontic textbooks. Someone seeking additional references may have to use another book. The author also writes in the first person, which is always refreshing and confers his sincerity to the reader.

This book would be an excellent addition to the library of any clinician providing endodontic care. It would be especially valuable as a well-indexed clinical reference study guide for endodontic review.

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### 1996 MOSBY'S DENTAL DRUG REFERENCE

Tommy W Gage and Frieda Atherton Pickett

Published by Mosby, St Louis, 1996. 550 pages. $31.95, softbound.

This 550-page drug reference text published by Mosby is well organized and convenient to use. At the list cost of $31.95, it is well worth the investment. In addition, the authors are well qualified to write such a text.

The book was intended to focus upon basic drug information relevant to dental patient evaluation and treatment planning, and it does this very well. Further, it is intended to serve as a quick, convenient reference rather than a comprehensive drug compendium. Again, this objective is met. This book would be well suited for the dental professional who wants such a reference in each treatment area. The index with the list of brand names of drugs makes finding generic or brand-name drugs very convenient.

Listing the side effects as common or life threatening, with the more serious life threatening in bold italics, is helpful to the reader.

Although not the stated objective of this text, the reference would be far more valuable if it included more information on indications for and appropriate dosage and routes for prescribing the drugs. This is undoubtedly the major problem with this text. Including this material would make this book invaluable to the dental professional.

The heading of "Teach Patient/Family" is of little value and, in fact, for the most part is a waste of space. This heading should be altered to include facts that are really specific to effects of the drug in question and not as a general comment on dental hygiene.

Overall, this is a text that all dental professionals would find useful, and with some modifications and additional information, it could be excellent.

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## *RADIOGRAPHIC CEPHALOMETRY: FROM BASICS TO VIDEOIMAGING*

Alexander Jacobson

Published by Quintessence Publishing Co, Inc, Chicago, 1995. 336 pages, 378 illustrations. $88.00.

This book is a thorough revision of a previous textbook entitled *Introduction to Radiographic Cephalometry*; not only have many of the original chapters been revised, but no less than 13 new chapters have been added. The book's purpose is to give a comprehensive description of existing methods for cephalometry. Thus it would be particularly suited for the orthodontic student, orthodontists, and for others in the dental profession who in their practice rely on cephalometric radiographs and data.

The book has 23 chapters: "The Significance of Radiographic Cephalometry," "Twenty Centuries of Cephalometry," "Radiographic Cephalometric Techniques," "Tracing Technique and Identification of Landmarks," "Down's Analysis," "Steiner Analysis," "Ricketts Analysis," "Wits Appraisal," "McNamara Analysis," "The Geometry of Cephalometry," "The Complexity of Facial Growth Analysis," "Superimposition of Cephalometric Radiographs," "Natural Head Position: The Key to Cephalometry," "The Continuous and Dynamic Measurement of Natural Head Posture and Position," "Proportional Analysis of the Human Face in a Mesh Coordinate System," "Template Analysis," "The Proportional Template," "Soft-tissue Evaluation," "Advances in Cephalometric Analysis," "Videocephalometry," "Facial Analysis in Two and Three Dimensions," "How Reliable is Cephalometric Prediction?" and "Records and Transfer Case Guidelines."

The titles of the different chapters give a good idea of the scope of the book and its completeness. Including the editor there are 18 contributors who take the reader on a journey along the path of evolution of modern radiographic cephalometry. "Competing" systems are presented in an objective way and, in most chapters, a discussion of the pros and cons is included. A special chapter is dedicated to the reliability of cephalometric prediction, which also includes reliability of landmark identification. It is a small chapter of only a few pages but perhaps the most important in the book, especially for readers who are not well acquainted with the limitations of cephalometry.

"Advances in Cephalometry," "Videocephalometry," and "Facial Analysis in Two and Three Dimensions" are chapters that introduce newer technology, including the Digigraph. It is not apparent that these new modalities introduce more reliable measurements, but they may offer other advantages. Two chapters have been devoted to natural head position, for some a "key to cephalometry," for others a necessity. The book offers a number of opportunities to compare various methods for cephalometric evaluation of the facial skeleton. Many orthodontists and academic orthodontic departments use their own modifications or combinations of the various classical methods for analysis.

The book is very pleasing to the eye with clear figures, easily read print, and spacious layout. It is indeed a beautiful book. It certainly has great value not only to the practicing orthodontist and the orthodontic student but to oral and maxillofacial surgeons who specialize in orthognathic surgery, to oral and maxillofacial radiologists, and to the general practitioner with a keen interest in orthodontics. The question is, however, whether the general practitioner at large will consider buying the book, even in the era of esthetic dentistry.

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## *ORAL IMPLANT POSITIONING & SOFT TISSUE MANAGEMENT FOR THE BRÅNEMARK SYSTEM*

Patrick Palacci

Published by Quintessence Publishing Co, Inc, Chicago, 1995. 83 pages, 202 color illustrations. $68.00.

The diverse combination of qualifications of the author and coauthors together with the excellent work of the dental technician and the illustrators made it possible to produce this fine textbook. The author, Dr Patrick Palacci, is the codirector of the Graduate Implant Program at Marseille University and has been a visiting professor at Boston University since 1982. Dr Ingvar Ericsson has written many papers on various restorative and periodontal-related dental implant topics and holds two university positions, one in the Department of Periodontology at Göteborg University, Sweden, and the other in the Department of Prosthetic Dentistry at Lund University, Malmö, Sweden. Dr Per Engstrand and Dr Bo Rangert both hold positions at Nobelpharma AB, Sweden. Dr Rangert's background in mechanical engineering uniquely qualifies him to collaborate in this text on the topic of Biomechanical Principles.

The author's purpose of this book is twofold. The first is to present the reader with new concepts for optimizing implant positioning. He claims that these techniques will help create better esthetic and functional results and increase patient satisfaction. The second purpose is to present his papilla-regeneration technique for peri-implant soft tissue management. To my knowledge this book is the first effort to concentrate an in-depth discussion on this topic. In my opinion it is a very important topic and critical for the success of any practitioner involved in the restoration of dental implants.

The forward to this book is unique, as it is written by Professor Per-Ingvar Brånemark. In it he credits this book with identification of many problems that can be avoided when treating patients with an implant-supported prosthesis.

A brief history of the Brånemark implant system is given in the introduction. An explanation is also given of how the constant demands for improved esthetic results have helped in the evolution of optimal implant placement and how optimal esthetics is not only related to tooth position, inclination, size, and contours but also to the health and architecture of the peri-implant mucosa. It is stressed that restoring the partially edentulous patient is in fact more difficult than the completely edentulous, and that they are more susceptible to overload failure due to the linear load configuration. For those practitioners who may still underestimate these facts, the book nicely covers this topic.

The targeted audience, according to the author, is all practitioners involved with dental implant treatment. The book is certainly useful for the general practitioner. The information is well written and simple to understand yet detailed enough to hold the interest of a practitioner with specialty training. In Chapters 2 and 3 there is plenty of useful information for the dental technician. I would recommend this text to any practitioner who is involved with any aspect of implant therapy, but more so for those who routinely use the Brånemark system. The reason for this is that Chapter 4 covers the topic of optimal implant positioning using newly developed Brånemark surgical components designed by Dr Palacci and Nobelpharma. The written information in most chapters is concise yet well complemented with references, and, as is common with Quintessence publications, with many excellent illustrations.

The book is well organized with easy-to-read print. Its six chapters appropriately embrace and cover the subtopics necessary for the author to meet his stated purposes. The number and high quality of the illustrations are by themselves worth the cost of the book. The only critique that is worth mentioning is that the tooth-soft tissue and implant-soft tissue illustrations in Chapter 1 would have been easier to follow if they had the same tooth/implant-to-soft-tissue orientation.

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## *ORAL BIOLOGY*
### *First (English) Edition*

G Jansen van Rensburg

Published by Quintessence Publishing Co, Inc, Carol Stream, IL, 1995. 500 pages, 56 chapters and 176 figures, softbound.

B G Jansen van Rensburg is Professor of Oral Biology, Faculty of Dentistry, University of Stellenbosch in South Africa. This work was originally published in 1981 as the first textbook in dentistry in the

Afrikaans language. A second revised edition followed in 1990 and formed the basis for this present English edition.

It is clear that as dentistry advances toward the 21st century, ever-new concepts are emerging in the basic sciences and with increasing rapidity. This is an exciting development, but also a very challenging one. How can one relate this voluminous amount of new basic science information arriving on the scene to a clinical setting? The author attempts to bridge this gap with this book. He cites two specific objectives for writing the book. First of all, he wishes to present a core curriculum in oral biology in which selected aspects of the basic sciences are elaborated and targeted at the oral environment to enable the dental clinician to diagnose problems in this field.

Secondly, he wishes to put basic oral biological sciences into a single textbook to avoid the problem of having to consult several specialized works in order to get this type of information. To accomplish his objectives, Professor van Rensburg has divided the content of his book into two parts. Part I is intended as an introduction to oral biology and deals with general aspects of embryology, gross anatomy, histology, and physiology of the oral cavity, its contents, and related systems. In addition, attention is also given to genetics, blood groups, hemostasis, evolution, as well as relevant aspects of anthropology and comparative anatomy. Clearly, this is an enormous amount of information to cover in only 217 pages. As a result, there is so little detail presented in Part I that the reader is provided with only the most superficial coverage of the topics. For example, the entire discussion of endocrinology is alloted only four pages; epithelial tissue is given four and a half written pages, and muscle tissue is discussed in two and a half written pages.

Part II is presented in somewhat more detail and deals with the teeth and surrounding structures, tooth eruption, the temporomandibular joint, salivary glands and saliva, fluorides, mastication, taste, and deglutition. However, the reader who is interested in any discussion of dental caries, periodontal disease, dental calculus, or dental pellicle will be disappointed, for there is none. The author may be forgiven for the superficial coverage of many topics, because to do otherwise would require a book of enormous size. The author states that this book is "primarily intended for use by undergraduate dental students." In addition, it may serve as a reference work for those dental clinicians interested in basic science correlations with clinical practice without having to read material in great depth. Since it is not laden with great detail, this book is rather easy to read. It is well organized and the index seems to be complete, which enables the reader to access wanted information quickly.

For readers looking for a modern textbook providing a general overview of the basic oral biological sciences and their relationship to the oral cavity, a significant void currently exists. This well-illustrated, but very general text should satisfy those readers. For individuals looking for a more detailed examination of the oral biological sciences, this text will not meet that need.

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## *THE PERIODONTAL LIGAMENT IN HEALTH AND DISEASE*
### *Second Edition*

B K B Berkovitz, B J Moxham, and H N Newman

Published by Mosby, St Louis, 1995. 448 pages, 391 illustrations. $147.00.

In this second edition the authors have basically written a brand-new monograph and, with the addition of two new chapters, they consider it an entirely new book. The new chapters are: 1) "Cell Biology Associated with Orthodontic Tooth Movement," and (2) "Reattachment and Regeneration of the Periodontal Ligament," making a total of 21 chapters. Dr Berkovitz is affiliated with the Biomedical Sciences Division of the Anatomy and Human Biology Group at Kings' College, London; Dr Moxham is with the Anatomy Unit of the School of Molecular and Medical Biosciences at the University of Wales at College of Cardiff; and Dr Newman is associated with the Eastman Dental Institute of Oral Healthcare Sciences, University of London. This triad of experts in biomedical sciences is uniquely qualified to edit this text and have blended their skill and knowledge into a smooth reading monograph. They have also sought the knowledge of 29 colleagues in contributing to the writing of these 21 chapters. One obvious omission is the listing of their professional titles and their clinical, research, or academic affiliations. This deletion does not detract from their scholarly, in-depth knowledge as they accepted the challenge of writing their assigned chapters. The senior authors only mention that they are colleagues from various fields of dental science and dental surgery.

Each chapter reflects the diversity of the contributor's background, and the combined knowledge and writing reveals to the reader everything about the periodontal ligament. It could be said that nothing has been omitted, and this reviewer is amazed by the amassed information presented about the periodontal ligament in these 448 pages.

Each chapter includes an introduction, a text with its accompanying illustration, and ends with either a summary or conclusion with frequent suggestions toward needed research. References are listed at the end of each chapter in alphabetical order and are referred back to the text by author and year. The traditional numbering system was not used. However, the reader is soon acclimated to the system and soon adjusts to the author-year format. The chapters' references are current, all inclusive, and voluminous in number. The text of each chapter is augmented by numerous charts, graphs, figures, and tables, with many colored photographs and photomicrographs to illustrate clinical and histological features.

At the conclusion of the text is a 13-page index, referencing the readers to the myriad technical terminology used throughout the book, from abscess to zymogens. Together with the inclusive bibliography in each chapter, these two reference sources enable the reader to readily use this book as a text, research guide, or as a source for defining terminology on all facets of the periodontal ligament.

This text is best suited for the academic-research periodontist or orthodontist, or for a basic scientist involved in connective tissue research. It is not directed toward the clinical dentist, since it does not delve into the clinical areas of restorative or operative dentistry. Its value to those interested individuals is to present an updated and exhaustive insight into the periodontal ligament and to suggest areas for further research.

This book is unique among textbooks, being entirely directed to the periodontal ligament, excluding the other components of the periodontium, namely, the gingiva, cementum, and alveolar bone.

To the reviewer's knowledge, no text has ever been written solely on one portion of the periodontium in such an exhaustive and all-inclusive manner.

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## *ATLAS OF ORAL PATHOLOGY*

John W Eveson and Crispian Scully

Published by Mosby-Wolfe, London, 1995. 137 pages, 350 illustrations. $65.00.

The authors, both oral pathologists recognized as leaders in their field, are eminently qualified to produce this atlas of histopathology. Each of the authors has written hundreds of scientific articles and numerous texts and atlases of pathology and oral pathology for various audiences including undergraduate dental students and dental specialists. This most recent atlas is intended to be a basic guide to the identification of histopathologic features of either common or important oral disease. It is intended for individuals without access to microscopic sections for study. It is designed to prepare dental undergraduate students, graduate dentists, and physicians for examinations that will include histopathology. The authors achieve their goals in the production of this beautifully illustrated book.

The slim manual contains 16 chapters with topics including normal anatomy and development and defects of teeth, including dental caries and pulpitis. Most of the book is dedicated to the histopathology of more than 120 oral lesions. The chapters are divided into logical divisions, some based on clinical features such as stomatitis and white patches, and others based on anatomic divisions such as salivary gland diseases. The text reviews pertinent clinical and radiographic features as appropriate. Many topics include comments about treatment and prognosis. The chapters on cysts, odontogenic and squamous epithelial tumors, and granulomatous lesions are especially strong. The entry on epithelial dysplasia clearly describes and illustrates the correlations between histomorphology and the diagnosis of preneoplastic epithelial alterations. The importance of clinicopathologic diagnoses requiring clinical and radiographic information in the diagnosis of fibro-osseous lesions is reinforced. There is a page of recommendations for further reading, although references are not given for each entity.

The strengths of this book are the brilliant illustrations that accurately depict the histopathologic features of oral disease. The text is clearly written and concise. The authors reflect the current understanding of the cellular and molecular manifestations of specific pathologic processes. Important diagnostic immunohistochemical reactions are included as appropriate.

Readers in the United States will have little difficulty in recognizing that the gingival soft tissue swellings described as the fibrous and giant cell epulides refer to the peripheral ossifying fibroma and the peripheral giant cell granuloma respectively. These small differences in nomenclature do not detract from the value of the text for readers in the U S, but serves to remind us that dental practice and disease are global in scope.

Even in the face of constantly changing new technology, including diagnosis by immunohistochemistry, flow cytometry, and polymerase chain reaction, the mainstay of oral disease tissue diagnosis is by routine histopathology. This book would be a valuable addition to the library of any operative dentist interested in the relationship of the cellular basis of pathology to common and important pathology of the oral and perioral structures. The book can serve two important purposes for the restorative dentist: 1) It is very readable and can serve as a quick review, update, or self-study of common and important oral pathology in several hours; and 2) It will serve as a valuable reference to aid in the diagnosis and understanding of oral disease as specific lesions are encountered in the course of patient care.

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# 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.

**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 a separate sheet. **Graphs** are to be submitted with any lettering proportional to their size as indicated for illustrations, and with their horizontal and vertical axes values, <u>as well as all values used to create the graphs</u>. **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.

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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 <u>all</u> 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.

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JULY-AUGUST 1996 • VOLUME 21 • NUMBER 4 • 133-180





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Periodicals