OPERATIVE DENTISTRY

july-august 1994 • volume 19 • number 4 • 121-160

(ISSN 0361-7734)

OPERATIVE DENTISTRY

JULY-AUGUST 1994 • VOLUME 19 • NUMBER 4 • 121-160

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 and letters also are published.

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Operative Dentistry (ISSN 0361-7734) is published bimonthly for $55.00 per year in the US and Canada (other countries $65.00 per year) by Operative Dentistry, Inc, University of Washington, School of Dentistry,SM-57, Seattle, WA 98195. *Operative Dentistry* is the official journal of the American Academy of Gold Foil Operators, P O Box 57, Industry, TX 78944 and the Academy of Operative Dentistry, P O Box 177, Menomonie, WI 54751.

POSTMASTER: Send address changes to: Operative Dentistry, Inc, The University of Washington, School of Dentistry, SM-57, Seattle, WA 98195.

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Yearly subscription in USA and Canada, $55.00; other countries, $65.00 (sent air mail); 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

BETTER, FASTER, LESS EXPENSIVE

These are the new buzz words in the world of business. Ten years ago the statement was, "Better, faster, less expensive; pick any two" but that is no longer good enough. Because we are competing in an international and world market, businesses in the United States have been retooling to become "better, faster, and less expensive." This trend has not been lost on our state and federal legislators. While they may not make those changes in the body politic, they are making the demands on our social, defense, and educational institutions, among others, through budget cuts and paring of programs.

The message is being clearly levied on universities. University presidents must decide how to distribute a 5%, 7%, or greater budget cut. The cuts can be made vertically, wherein campus programs and whole schools are cut. This is a good strategy where nonproductive and outdated technologies are being sustained on a campus. Regardless of what the cut program is, it is bound to gore someone's sacred ox. One of the clear duties of dental school deans is to ensure that the president knows that dentistry is a valuable part of health care. This is particularly important in dentistry, because we are a natural candidate for a vertical cut, since the cost of dental education is among the highest on campus on a dollar-per-student basis. An astute president will ask for some prioritization based on costs and an assessment based on the worth of a school to the university and to the populace the university serves.

The cuts can also be horizontal in nature, where everyone on campus shares the bad news. This second strategy seems the most popular at this time. It is also one of the real headaches for our dental school administrators. There is a rapid explosion in knowledge in dentistry, and the rapid development of new and exciting technologies. Dental schools are being asked to incorporate this new knowledge into a dental curriculum that is constrained to a four-year educational experience. Schools are in essence being asked to provide education in a better, faster, and less expensive manner. Even that would not be an insurmountable problem if deans and other administrators were given the tools to develop a "better, faster, less expensive" system. However, most states have governance and employment rules that preclude the development of effective and efficient teaching institutions.

Industry has responded to the "better, faster, less expensive" challenge by reshaping their work force. Instead of checking your brains at the door, employees in many organizations are being given the opportunity to participate in improvements for the company's products and processes. This phenomenon is an outgrowth of the Deming Total Quality Management system. However, industry has a real and very clear advantage over our hard-pressed dental deans. When a team has a poor performer, the person is given the tools and the opportunity to improve. When that opportunity to improve does not work out, a person can be terminated. This is not an unreasonable mandate for any business. A nonperformer will damage the team and ultimately will damage the company's ability to fulfill its business purpose.

The dental deans of most public institutions are constrained by archaic state labor laws and by outdated governance and tenure documents. In an age where everyone needs to be able to change structure and retrain personnel rapidly, deans and their department chairs have no freedom to act.

The current university employment systems are unresponsive to a rapidly changing world. It is time for our legislators, boards of trustees, university regents, or whoever is the governing body of a particular institution, to rethink these problems and implement a modern and rational personnel policies system. Then when they ask a university president to manage the university like a business and the schools' deans are given that same mandate, they will have the tools to deliver a better, faster, and less expensive product.

M H ANDERSON
Editor

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ORIGINAL ARTICLES

Bond Strength of Glass Ionomers to Coronal and Radicular Dentin

E A BERRY, III • J M POWERS

Clinical Relevance
Glass-ionomer bond strength to dentin is improved by pretreatment with either 25% or 40% polyacrylic acid.

SUMMARY

A study was conducted to compare the shear bond strength of a glass-ionomer cement and glass-ionomer base to coronal and radicular dentin. Two different glass ionomers were bonded to paired coronal and radicular human dentin surfaces that had received no surface treatment or had been treated passively for 20 seconds with either 40% or 25% polyacrylic acid. When only the effect of the type of dentin surface was considered, glass-ionomer bonds were greater to radicular dentin than to coronal dentin. With one exception, bond strengths to both dentin surfaces were greater with the base ionomer (Ketac-Bond) than with the luting cement (Ketac-Cem). Bond strengths of both glass ionomers were greater after dentin surface treatment with either 25% or 40% polyacrylic acid than with no treatment.

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INTRODUCTION

The development of glass-ionomer cement provided restorative dentistry with an adhesive, fluoride-releasing material that was quickly embraced and widely used by clinicians. In a recent survey of US dentists, 79% used glass ionomers as bases or liners and 75% used them for crown cementation (Reinhardt, Swift & Bolden, 1993). The glass ionomers have been particularly useful in the treatment of geriatric patients where both coronal and radicular dentin are involved. The hydrophilic nature of glass-ionomer cement (Wilson, 1974) ensures a reliable bond to dentin in cervical regions under less than perfect conditions of moisture control.

Adhesion to untreated enamel and coronal dentin has been demonstrated and is considered by many to be the most important property of this cement (Prodger & Symonds, 1977; Vougiouklakis, Smith & Lipton, 1982; Beech, Solomon & Bernier, 1985; Aboush & Jenkins, 1986; Joynt & others, 1990). The tensile bond strength to enamel is greater than to dentin, but glass ionomer will bond to both surfaces even in the presence of a smear layer (Hotz & others, 1977).

Eick and others (1970) described the smear layer as the thin layer of organic debris deposited on tooth surfaces following abrasive instrumentation. Although glass ionomer will bond to dentin in the presence of a smear layer, the bond is weakened by the smear layer. Surface conditioning of dentin with various agents that remove the smear layer has led to improved bond strengths (Powis & others, 1982; Barakat, Powers & Yamaguchi, 1988; Joynt & others, 1990).

Powis and others (1982) obtained higher bond strengths of glass ionomer to both enamel and dentin after passive surface conditioning with 25% polyacrylic acid. Long, Duke, and Norling (1986) found the optimum concentration of polyacrylic acid to be between 30% and 35% and demonstrated a bond strength of 3.9 MPa with 35% as opposed to 3.0 MPa with 25% polyacrylic acid. Barakat and others (1988) showed higher bond strengths after active surface conditioning accomplished by scrubbing with 10% polyacrylic acid. Joynt and others (1990) showed that one glass-ionomer cement exhibited a higher bond strength after passive conditioning with the 25% polyacrylic acid, but two other products exhibited higher bond strengths after passive conditioning with 40% polyacrylic acid. All three glass-ionomer products showed the highest bond strengths after active conditioning with 10% polyacrylic acid. Watson (1990) demonstrated improved adaptation to dentin when the dentin was conditioned with maleic acid.

Coronal dentin has been used in numerous studies (Pashley & Livingston, 1978; Pashley, Livingston & Greenhill, 1978; Pashley, Michelich & Kehl, 1981; Tao & Pashley, 1988), but little research has been done on the nature of radicular dentin. In light of the importance of bonding to radicular dentin, this in vitro investigation was designed to compare the shear bond strength of glass-ionomer cements to radicular and coronal dentin under different surface preparation conditions.

Table 1. Dentin Surface Conditioning Materials

Product	Batch Number	Manufacturer
Durelon Liquid	T214 MD080290	ESPE-Premier, Norristown, PA 19404 (all)
Ketac Conditioner	T274 MD100190	
Ketac-Bond Aplicap	T302 MD102990	
Ketac-Cem Maxicap	T171 MD062090	

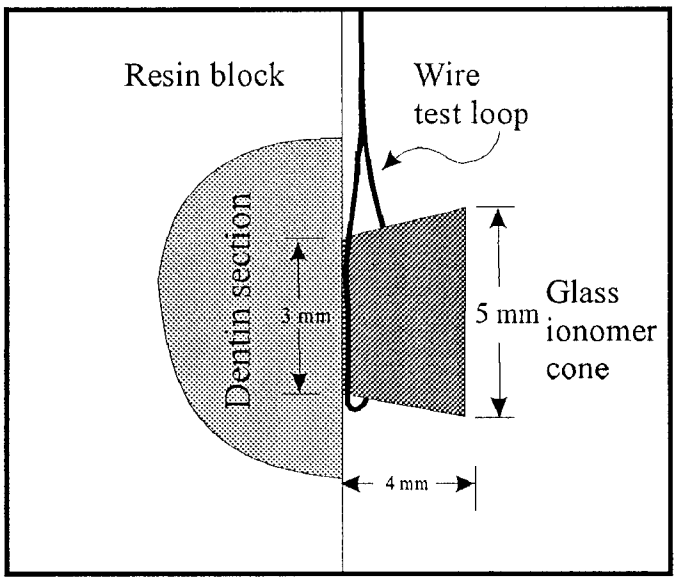
METHODS AND MATERIALS

Caries-free, extracted, human third molars with sound approximal surfaces and roots large enough to yield 3-mm-in-diameter areas of dentin were stored in 10% buffered formalin. Each tooth was sectioned buccolingually through the root and crown, yielding a mesial and a distal segment. Each segment was sectioned at the CEJ, yielding two crown segments and two root segments from each tooth. If either the crown or root segment was unsatisfactory, both sections were discarded. Paired root and crown sections were stored together in deionized water. Sixty crowns with their corresponding roots were obtained, resulting in 120 paired coronal and radicular samples.

Each section was oriented with the mesial or distal enamel surface facing outward, embedded in resin (Sampl-Kwick, Buehler, Ltd, Lake Bluff, IL 60044) and ground with 240-grit silicon carbide paper with copious water irrigation in a metallographic polisher (Polimet I, Buehler, Ltd) until a 3-mm-in-diameter dentin surface was exposed (figure). The dentin was finished for an additional 20 seconds with 320-grit SiC paper and stored in deionized water.

The embedded specimens were randomly divided into six groups of 10 samples each, keeping crowns and roots paired. One-third of the samples received no dentin surface treatment, one-third were treated with a 20-second passive application of 40% polyacrylic acid (Durelon liquid, ESPE/Premier, Norristown, PA 19404) and one-third with a 20-second passive application of 25% polyacrylic acid (Ketac-Conditioner, ESPE/Premier), washed for 20 seconds. Visible moisture was blotted from the dentin surfaces with a dry cotton pellet, taking care not to desiccate the surface. Batch numbers and manufacturers of the dentin surface conditioning materials tested are listed in Table 1.

Two glass-ionomer products, Ketac-Bond Aplicap (ESPE/Premier), a base, and Ketac-Cem Maxicap (ESPE/Premier), a luting cement, were bonded to the crown and root samples. A truncated cone of glass ionomer, 3 mm in diameter at the base, was bonded to each sample with the apparatus described by Barakat and Powers (1986). The entire apparatus



Cross-sectional view of embedded dentin specimen with an attached glass-ionomer cone and wire test loop

was immediately placed into a humidor at 100% relative humidity and 37 °C and left for 30 minutes before removing the sample from the bonding apparatus. Under X3 magnification, flash beyond the diameter of the base of the cone was removed with a #15 Bard-Parker blade and the bonded sample replaced immediately in the humidor. All samples were stored at 100% relative humidity and 37 °C for 24 hours prior to bond testing.

After 24 hours the shear bond strengths were determined using a wire loop on a testing machine (Model 8501, Instron Corp, Canton, MA 02021). A wet cotton pellet was placed on the top of the glass-ionomer cone to prevent desiccation of the glass ionomer during testing. All samples were loaded to failure, and the bond strengths were recorded in MPa. The dentin surfaces were examined with X12 loupes, and bond failures were classified as Type I, II, or III. Clean dentin surfaces with no remnants of glass ionomer were classified as Type I failures. Dentin surfaces with a thin layer of glass ionomer on the surface were classified as Type II failures. Bulk fractures within the body of the glass-ionomer cone were classified as Type III failures.

Means and standard deviations were computed. Bond strength data were analyzed with a three-way analysis of variance utilizing a statistical program (SPSSPC+, Ver. 3.0, SPSS, Inc, Chicago, IL 60611). Tukey's Multiple Comparison Test for equal sample sizes was employed to locate statistical differences in bond strengths at the 0.05 significance level (Guenther, 1964). Coronal and radicular shear bond strengths were compared with a paired *t*-test (SPSSPC+).

RESULTS

Means and standard deviations of shear bond strengths are shown in Table 2. All bond failures were Type II failures at the glass ionomer-dentin interface with a thin granular layer of glass-ionomer cement remaining on the dentin surface.

Statistical comparison of shear bond strengths to coronal and radicular dentin under all experimental conditions using a paired *t*-test showed significantly higher bond strengths to radicular dentin at the 0.05 significance level, $P = 0.047$.

The effect of three variables on shear bond strengths was also analyzed statistically. The Tukey interval between the two glass-ionomer materials and between coronal and radicular surfaces was 0.5 MPa. The Tukey interval among the three dentin surface treatments was 0.7 MPa.

When the luting ionomer (Ketac-Cem) was employed, shear bond strengths to radicular dentin were significantly greater, at the 0.05 significance ($P = 0.05$), than to coronal dentin under all surface preparation conditions. When the base ionomer (Ketac-Bond) was employed, the shear bond strengths to radicular dentin were significantly higher with no dentin surface treatment, significantly higher to coronal dentin when treated with 40% polyacrylic acid, and not significantly different when treated with 25% polyacrylic acid.

When dentin surfaces were treated with 25% polyacrylic acid, shear bond strengths were significantly greater than with no treatment in all cases and greater than when treated with 40% polyacrylic acid except in the Ketac-Cem to root dentin group, in which there was no significant difference. When dentin surfaces were treated with 40% polyacrylic acid, shear bond strengths were significantly greater, when compared to no treatment, in all groups except the Ketac-Bond to radicular dentin group, in which there was no significant difference.

Shear bond strengths of Ketac-Bond to dentin were significantly greater than Ketac-Cem to dentin in all cases except when radicular dentin was treated with 25% polyacrylic acid, in which case there was no significant difference, and when radicular dentin was treated with 40% polyacrylic acid, in which case the bond of Ketac-Cem was greater.

Table 2. Shear Bond Strengths (MPa)

Coronal Dentin	No Treatment	Durelon Liquid	Ketac Conditioner
Ketac-Cem	1.9 (0.2)*	2.7 (0.6)	3.4 (0.7)
Ketac-Bond	2.5 (0.7)	4.1 (1.3)	5.0 (1.0)
Radicular Dentin			
Ketac-Cem	2.6 (0.2)	4.5 (0.4)	4.9 (1.5)
Ketac-Bond	3.2 (0.8)	3.3 (1.1)	5.3 (1.2)

*Mean of 10 replications with standard deviations in parentheses. Tukey intervals for comparisons between glass ionomers, between types of dentin and among treatments were 0.5, 0.5, and 0.7 MPa. Differences between means equal to or larger than the Tukey interval were considered statistically significant.

DISCUSSION

Daily clinical practice requires reliable bonding to both coronal and radicular dentin, often under less than ideal conditions. Shear bond strengths to coronal and radicular dentin of two glass ionomers with three surface treatments were compared to determine if the character of the dentin surface would influence the strength of the glass-ionomer bond. Coronal dentin has been shown to have a higher density of dentinal

tubules (Pashley & others, 1981). Duke and Lindemuth (1990) have shown that sclerotic dentin is less receptive to current resin bonding sytems. They suggest that dentinal tubule density may be a factor in the lower bond strengths of resins to this type of dentin. However, the effect of dentinal tubule density on the glass-ionomer bond is not yet clear. Dentin surface treatment techniques attempt to remove the surface smear without opening dentinal tubules and stimulating an outward flow of dentinal tubule fluid (Berry, von der Lehr & Herrin, 1987). It may be that the intertubular dentin plays an important role in the bond of glass ionomer to dentin. The lower density of dentinal tubules in root dentin would yield an increase in intertubular dentin area and a higher glass-ionomer bond strength.

The bond failure classification employed in this study has no precedent in the literature. A Type I failure is recognized as an adhesive failure in which the strength of the material does not contribute to the bond. A Type III failure is a cohesive failure where the strength of the material bonded to tooth structure is the limiting factor. Bond strength values should be statistically the same over a wide range of experimental variables if bond failures are Type III and thus limited by the strength of the glass ionomer.

A bond failure is designated as Type II when a uniform but thin layer of glass ionomer is left on the surface of the dentin. Because some glass-ionomer material is left bonded to the dentin surface, it is clear that the strength of the material has some influence on the bond strength. However, the wide range of bond strength values and their consistent shear bond strength grouping indicates that the cohesive strength of the material cannot be the only factor involved in this type of failure. The type of dentin surface, dentin surface treatment, and the ionomer-dentin interface would seem to influence a Type II bond failure.

Two statistical comparisons were utilized to compare bond strengths in this study. Crowns and root segments were carefully paired throughout the study so that the robust paired *t*-test could be employed to analyze only the effect of the type of dentin, coronal or radicular, on shear bond strengths under all experimental conditions. A paired *t*-test analysis at the 95% confidence level showed significantly higher shear bond strengths to radicular dentin, $P = 0.047$.

ANOVA and the Tukey Multiple Comparison test were employed to measure the effect of each variable: crown or root dentin, dentin surface treatment, and type of glass ionomer. When differences between means were compared with the Tukey interval, the base cement (Ketac-Bond) yielded significantly higher shear bond strengths under the same conditions than did the luting cement (Ketac-Cem). Since Cattani-Lorente, Godin, and Meyer (1993) have shown that both the flexural and diametral tensile strength of Ketac-Bond was greater than that of Ketac-Cem, Ketac-Bond might be expected to have higher bond strengths.

It has been established that the presence of a smear layer decreases the bond strength of glass-ionomer cements to tooth structure. Studies evaluating the effect of various dentin surface treatments on the bond strength of glass ionomer to dentin are numerous and, though reported bond strength values vary, there is general agreement that bond strengths increase when the dentin surface is treated with an agent that chemically removes the dentin smear layer (Powis & others, 1982; Barakat & others, 1988; Joynt & others, 1990; Prodger & Symonds, 1977; Beech & others, 1985). This study compared a 40% polyacrylic acid conditioner to a 25% polyacrylic acid conditioner. Although clinically these two conditioners are applied for different time periods, they were both passively applied for 20 seconds to standardize the comparison. A surface treatment of 20 seconds with a 40% polyacrylic acid is probably too long clinically. Previous studies have demonstrated a removal of the smear layer without opening dentinal tubules with only a 5-second application. This longer exposure time may be responsible for the one group that did not follow the general pattern of higher bond strengths to radicular dentin. Ketac-Bond showed a lower bond strength to radicular dentin than to coronal dentin when 40% polyacrylic acid was applied for 20 seconds. It may be that, in this case, the longer treatment chemically altered the dentin surface. Otherwise, this study confirmed previous studies that demonstrated enhanced glass-ionomer bonding to dentin treated with smear-layer-removing agents.

CONCLUSIONS

Under the conditions of this in vitro study of the shear bond strength of glass ionomer to human dentin, the following conclusions were made:

1. When crowns and roots were paired and only the influence of the type of dentin surface was considered, shear bond strengths were greater to radicular dentin than to coronal dentin;
2. With one exception, bond strengths to radicular and coronal dentin were greater with the base ionomer (Ketac-Bond) than with the luting cement (Ketac-Cem); and
3. Bond strengths of glass ionomer were greater after dentin surface treatment with either 25% or 40% polyacrylic acid when compared to no conditioning treatment.

Acknowledgments

The authors wish to express their gratitude to ESPE/Premier for furnishing the materials used in this study and to David Ladd for his invaluable assistance in the laboratory.

(Received 10 May 1993)

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Decisions of Practitioners Regarding Placement of Amalgam and Composite Restorations in General Practice Settings

F E PINK • N J MINDEN • S SIMMONDS

SUMMARY

This study was undertaken to analyze the current reasons practitioners in general practice settings choose to place amalgam and composite restorations. Data were gathered on individual restorations in the clinical setting to provide information on reasons practitioners state that restorations are placed, the type of material most often placed in different restoration classifications, and the age of restorations at the time of replacement.

The results of this study indicate that approximately one-half of all restorations, both amalgam and composite, were placed to treat primary caries. One-half of the remaining restorations placed, i e, not including those with primary caries, were placed to treat recurrent caries. With respect to restorative materials, amalgam was most often placed in class 1 and class 2 situations (88.9% of the amalgam restorations reported), while composite was most often placed in class 3, 4, or 5 situations (77.4% of the composite restorations reported). From the total data set returned for replaced restorations, only 20% of the data forms reported on verified longevity of the restoration being replaced. Analysis of these data gave a calculated median longevity for amalgam and composite restorations of 10 years and 5 years respectively.

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INTRODUCTION

According to Mjör (1989), replacement restorations account for approximately 60% of all operative dentistry done. In the last few years the lack of reproducible criteria for the replacement of restorations has received much discussion. Unfortunately, this abundance of discussion has done little to improve the scientific basis for the reliable replacement of restorations, especially in the area of recurrent or secondary caries. A survey of private practitioners by Klausner, Green, and Charbeneau (1987), which addressed many of the important issues, such as surfaces replaced, reason for replacement, age of restoration, and patient age, concluded that 46% of amalgam restorations placed were due to primary caries, and of the remaining 54%

reported, slightly over one-half (53%) of those restorations placed were due to recurrent caries. Their data also revealed that 50% of amalgam restorations over 10 years of age had failed and only 5% of the restorations replaced were 25 to 50 years old.

Clinical studies of amalgam failure were reported in the literature very early by Healy and Phillips (1949). That study and other more contemporary studies by Boyd and Richardson (1973), Lavelle (1976), and Dahl and Eriksen (1978) reveal that amalgam restoration replacement due to caries is the reason given in approximately 55% of all cases of replacement. This is an important finding, because it has been pointed out by Maryniuk (1984) that criteria for "reliable" recurrent caries detection and restoration longevity estimates are impossible to infer for general practice. Later, Maryniuk and Kaplan (1986), in a study of 571 dentists and their attitudes, found that clinical measurements of restoration longevity were influenced by the judgment criteria that were used by the clinicians. In that study dentists believed that on the average, small amalgam, large amalgam, and cast restorations lasted 11, 6, and 13 years respectively. However, the same dentists replaced these restorations on a full-fee basis at 3, 2, and 4.5 years respectively.

Long-term assessment of composite restorative materials and their use in restorations is complicated by the materials themselves being relatively new; material composition and chemistry have changed dramatically in the last 20 years. In a recent study, Mjör and Toffenetti (1992) found that composite restorations were placed 52% of the time to treat primary caries and 48% of the time as a replacement restoration due to some failure. Secondary caries constituted the most prevalent reason for replacement, followed by discoloration and material fracture. They found that less than 20% of the restorations were 7 years old and 8% were at least 10 years old. Moffa (1989) studied amalgam and composite restorations for 12 years using the USPHS criteria as developed by Cvar and Ryge in 1971. He found that 67% of the composite resin restorations remained functional over that time period. There was a linear decrease in percentage of functional restorations over the time frame, and, in general, amalgam restorations were serviceable for a greater period of time than were composite restorations.

The objectives for this study were 1) to analyze the current reasons practitioners in general practice settings choose to place amalgam and composite restorations, 2) to determine the use of dental restorative material in common cavity classifications, and 3) to collect data on the age of restorations that the practitioner has chosen to replace and relate that information to the reason given for replacement of the restoration.

Table 1. Study Demographics—Research Design

- 215 survey introductions were mailed (20% random sample without replacement).
- 51 agreed to participate (following telephone contact of all 215). A study packet was mailed containing: 50 each, amalgam/composite data forms, self-addressed, stamped envelopes, instruction sheets.
- 3483 usable data sheets were returned: 1877 amalgam forms and 1606 composite forms.

METHODS AND MATERIALS

In this study, patterned after that of Mjör (1981), data on restoration placement were collected from general practice facilities, where the majority of dental treatment is rendered in this country. The study was conducted in the summer of 1991.

A 20% random sample, without replacement, of members in clinical practice was taken from the current membership listing of the Academy of Operative Dentistry. The selected sample was mailed an introduction packet that included a description of the study and data collection necessary, with examples of the data collection forms, which had been designed and pilot-tested to require less than 1 minute for the doctor or assistant to complete. The practitioners were provided with written criteria that gave information to guide their decisions on the appropriate category to note when the restoration was placed/replaced. These criteria were designed to eliminate confusion in marking treatment decisions. In this study practitioners were instructed to list primary caries as a reason for placement of a restoration only if the new restoration would in no way involve previously restored surfaces, i e, true primary caries. Furthermore, practitioners were instructed to list recurrent caries in only those instances when the caries was in direct contact with an existing restoration or the location of the caries would require removal/incorporation of a pre-existing restoration on the tooth.

The data collection sheets were color coded for amalgam and composite restorations, blue or yellow respectively. One data collection form was to be used for each restoration reported. The doctors were instructed to review the information packet and make a decision on their desire to participate. They would be contacted by phone to inquire if they would participate.

The practitioners that agreed to participate were then mailed a study packet consisting of study

Table 2. Age Distribution of Patients Receiving Amalgam or Composite Restorations

Age	Amalgam	Composite
≤20	390	233
21-40	808	563
41-60	396	457
≥61	258	327

Table 3. Reasons for Placement (3472 Total Cases Reported)

Reason	Amalgam	Composite
Primary caries	44.5	49.2
Recurrent caries	25.0	20.4
Material failure	12.7	16.8
Lost restorations	4.9	5.5
Tooth failure	8.8	4.8
Other	4.1	3.3

instructions, 50 blue amalgam data collection forms, 50 yellow composite data collection forms, and a self-addressed, stamped envelope in which to return the forms. The practitioners were instructed to use the forms for the first 50 amalgam restorations and the first 50 composite restorations that were planned for adult patients, 18 years of age or older, after receiving the forms. No type of intraoffice randomization was attempted. Eight weeks following mailing of the initial study packet to practitioners, a follow-up telephone call was made to those study participants that had not returned their completed data forms.

Data were entered, managed, and analyzed on a personal computer using SYSTAT statistical software (Wilkinson, 1986).

RESULTS

Of 215 practitioners mailed survey introduction packets and contacted by phone, 51 (24%) agreed to participate. This, of course, is a poor response rate based on the number of practitioners solicited to participate in the study. Because of economic considerations, it was impossible to pursue classification of those practitioners who chose not to participate to compare nonrespondents with respondents. Reasons given during telephone contact included disinterest in the subject, attitudes opposed to research, the practice was too busy to collect data, and some practitioners saw the data collection as an invasion of privacy. The authors realize that a risk exists that the data will not reflect a true "sample" of practitioners because of the low response rate, leading to selection bias. However, in the second tier of sampling in this study, i e, the individual restoration data forms, return rates of between 64% to 75% were accomplished, as noted below.

Of the 5100 data collection forms (2550 amalgam, 2550 composite) mailed to study participants, 3483 usable data collection forms were returned. The total number of 3483 forms analyzed consisted of 1877 (75% response) amalgam forms and 1606 (64% response) composite forms (Table 1). A data collection form was considered "usable" only if all demographic material was complete and reason for placement was stated. Data forms were not discarded if the class of restoration and/or the anticipated replacement material was not indicated.

Age distribution of the sample ranged from 18 years of age to 81 years of age. Fifty-five percent of the sample were male compared to 45% female. The age group with the highest representation, 40% of the total, was the 21-40-year-old age group (Table 2).

When the practitioner expected to place amalgam, 44.5% of the restorations were placed to treat primary caries. If the primary caries cases are removed, 45.1% of the remaining replaced restorations were placed because of recurrent caries present. Material failure, restoration loss, or tooth failure comprised another 47.8% of the replacement restorations (Table 3).

In situations planned for composite restorations, 47.7% of the restorations were placed because of primary caries. If the primary caries cases are removed, 40.4% of the remaining replaced restorations were placed because of recurrent caries present. Composite material failure, lost restorations, or tooth failure were stated as reasons to replace another 53.7% of the composite restorations (Table 3).

When the practitioner initially intended to place an amalgam restoration, if primary caries was stated as the reason for placement, 98% of the time amalgam was the material used. Amalgam restorations were replaced by amalgam material in 84% of the replacement cases, with gold and porcelain restorations accounting for another 12% of the amalgam restoration replacements (Table 4). In composite restorations the usage of the same material, i e, composite, was similar to the results shown in the amalgam data. Composite material was placed in 89% of the cases that were treatment planned for composite restorations because of primary caries. For replacement of composite restorations, a full 95% of the cases were replaced with composite. Interestingly, almost all of the remaining 5% of the composite restorations were replaced with glass-ionomer material (Table 4).

Cavity classification for amalgam and composite restorations was considered to reflect traditional

uses of these materials, with 88.9% of amalgam restorations done as class 1 and class 2 situations, while 77.4% of the composite restorations were class 3, 4, or 5 situations (Table 5).

Twenty percent of the data sheets for replaced restorations returned reported verified longevity of those restorations. Practitioners in this study were instructed to only report age of the restoration being replaced if the date of original placement could be verified in the patient record. Longevity of restorations was reported from 1 to 50 years for amalgam restorations and from 1 to 38 years for composite restorations. The median longevity for amalgam restorations was calculated at 10 years with a mean longevity of 11.7 years. Composite restoration median longevity was calculated to be 5 years with a mean of 7.5 years. A normal distribution of these data was seen in the amalgam longevity, while the composite longevity data were skewed to the low end, which reveals a tendency of a shorter-term longevity for these restorations (Table 6).

One-factor ANOVA analysis of these data revealed that for amalgam replacement restorations, there was no significant difference in the mean number of years of restoration longevity based on the reason for replacement or the restoration classification, e g, class 1, 2, etc ($P = 0.13$ and $P = 0.41$ respectively) (Table 7). However, for composite restoration replacement, there was a significant difference in mean years of longevity based on reason for replacement of the restoration with $P < 0.00$. Tukey HSD pairwise comparison revealed the significant difference ($P = 0.01$) in mean years of longevity to occur between restoration discoloration and material fracture, 12.13 years (2.10) versus 6.05 years (0.97) respectively. No significant difference was shown for composite restoration longevity based on cavity classification, $P = 0.41$ (Table 8).

It is worthy of comment that the reasons for replacement of amalgam and composite restorations, when longevity is reported, closely follow the data where no longevity could be verified. This observation would lend support to the longevity data being an accurate reflection of the data as a whole.

Table 4. Materials placed in Primary Caries describe the material actually used when an amalgam or composite was treatment planned. Replacement materials describe the materials used to replace an existing amalgam or composite restoration.

	Amalgam		Composite	
Material Used	Primary Caries	Replacement	Primary Caries	Replacement
Amalgam	807	848	33	3
Composite	3	32	718	707
Glass Ionomer	8	4	27	35
Gold	1	78	4	0
Porcelain	1	43	23	3

DISCUSSION

This study has reaffirmed previous studies with the finding that approximately 50% of amalgam and composite restorations are placed due to primary caries and approximately 50% of the restoration replacements are due to what is perceived as recurrent caries. Most clinicians, and all researchers, know the difficulty in defining recurrent caries in the oral cavity, and it is prudent to keep this fact in mind when reviewing studies such as this. The results of this study have shown some interesting relationships concerning reasons practitioners state that a restoration needs to be placed or replaced. However, in this study as in others, no true "examiner" calibration has been undertaken, only a listing of suggested criteria to follow.

The analysis of the data in this study suggests that there is no extensive concern on the part of the patient or practitioner about the use of amalgam

Table 5. Cavity Classification, Percentage of Total (3420 Cases Reported)

Class	Amalgam	Composite
1	24.6	10.3
2	64.3	8.3
3	1.7	33.2
4	1.1	19.8
5	7.8	24.4
6/Veneer	0.5	4.0

Table 6. Restoration Retention—Age, Study Findings (375 Amalgam and 323 Composite Cases Reported

Parameter	Amalgam	Composite
Years:		
Minimum	1	1
Maximum	50	38
Mean Years	11.74	7.45
Std Dev	8.14	6.48
Median Years	10.00	5.00
Distribution	Normal	Skewed—Low

Table 7. Amalgam Restoration Longevity

	Mean Age	S E	N
Recurrent caries	11.59	0.66	150
Poor margins	14.47	1.13	51
Isthmus fracture	10.94	1.40	33
Lost restoration	12.19	1.58	26
Tooth fracture	12.38	1.12	52
Pain/sensitivity	8.60	3.60	5
Other	6.33	2.69	9
Class 1	12.02	1.15	50
Class 2	12.16	0.53	239
Class 3	14.71	3.08	7
Class 4	11.50	3.32	6
Class 5	8.55	1.82	20
Class 6	7.50	5.75	2

Table 8. Composite Restoration Longevity

	Mean Age	S E	N
Recurrent caries	6.72	0.60	98
Discolored margins	8.69	1.00	35
Discolored body	12.13	2.10	8
Material fracture	6.05	0.97	37
Material wear	9.13	1.05	32
Lost restoration	4.21	0.86	47
Tooth fracture	8.81	1.48	16
Pain/sensitivity	2.67	3.42	3
Other	6.20	2.65	5
Class 1	5.93	1.56	15
Class 2	6.74	1.39	19
Class 3	8.75	0.69	76
Class 4	5.98	0.63	91
Class 5	5.29	0.82	55
Class 6	8.09	1.83	11

materials for restorations. As stated previously, 84% of the amalgam restorations that were replaced were replaced with amalgam restorative material, with only 4% being replaced by nonmetallic restorative materials. The authors expected a higher percentage of amalgam restorations replaced by nonmetallic materials, i e, composite, glass ionomer or porcelain, because of the recent publicity about the perceived health hazards of amalgam. It is imperative to point out that this study design was not appropriate to show differences in amalgam usage at present and historically; only cross-sectional data were collected. However, it seems reasonable to deduce that the patients, as a whole, were not demanding replacement of amalgam restorations with other dental materials in these dental facilities, based on the data collected in this study. Another interesting finding in the data, which may be a sign of movement toward more contemporary restorative thinking, was that in the appropriate situation 5% of the composite restorations were replaced with glass-ionomer materials.

Many of the amalgam data forms were returned with the "unknown" age column marked with 20-30+ years recorded. The authors surmise that this must be longevity data from the patient's memory, and although these numbers cannot be analyzed as "scientific" information, it does raise important questions as to the research design of most currently published studies. It is the authors' opinion that no definitive study has been done to date on amalgam and composite longevity because of the research design employed. It does not seem to be appropriate to study restorations that need replacement when looking for longevity data, and replacement data may present substantial selection bias when the question being asked is restoration longevity. In other words, for appropriate answers researchers need to look at all amalgams placed, not just those requiring replacements in order to derive accurate longevity data. Well-designed, multicenter, longitudinal studies need to be undertaken to provide a "true" and accurate measure of restoration longevity.

CONCLUSIONS

Data collected in this study revealed restorations placed to restore primary caries at rates of 44.5% and 47.7% for amalgam and composite respectively. Replacement restorations were undertaken in previously restored teeth because of recurrent caries in 45.1% and 40.4% for amalgam and composite restorations respectively. These findings relate well to data presented in previous studies.

The data show that restorations are replaced by the same material at the rate of 84% and 95% for amalgam and composite restorations respectively. Amalgam and composite restorative materials were placed in the cavity classifications that are "traditional" for these materials, i e, classes 1 and 2 for amalgam and classes 3, 4, and 5 for composite materials. No trend to place composite in class 2 situations was shown in data from this study in any large number: In the authors' opinion there appears to be no amalgam "scare" in the dental facilities that collected data for this study.

Based on data collected in this study, median longevity for amalgam restorations is calculated at 10 years, while median longevity for composite restorations is calculated at 5 years. Empirically, the amalgam longevity seems attenuated, while the composite longevity seems reasonable. The authors feel that authoritative longevity data would best be collected from a longitudinal study using life table analysis, with treatment decisions based upon decision tree calculations for replacement decisions. Further research efforts in this area should be designed to utilize such an approach.

Acknowledgment

The authors wish to thank the Academy of Operative Dentistry for the support that made this study possible through the academy's Student-Faculty Fellowship program.

(Received 29 September 1992)

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Microleakage in Facial and Lingual Class 5 Composite Restorations: A Comparison

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Clinical Relevance
There is no difference in adhesion between facial and lingual enamel and cementum.

SUMMARY

The purpose of this in vitro study was to determine if there is a difference in microleakage between facial and lingual enamel and cementum using two different evaluation techniques. Class 5 preparations were made in 50 teeth on the facial and lingual tooth surfaces and restored using dentin bonding and composite resin. The teeth were thermocycled, silver nitrate stained, and longitudinally sectioned into mesial and distal halves through each restoration. The mesial half was scored using a rank order system. A Kruskal-Wallis one-way ANOVA was performed. The distal half was scored by measurement, and a two-sample *t*-test was performed. There were no statistically significant differences ($P \geq 0.05$) in microleakage between facial and lingual tooth enamel or cementum surfaces using either measurement technique.

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INTRODUCTION

As composite resins are improved and accepted by the profession for more general restorative use, continued evaluation of the material's physical and clinical properties is important. Although many advances have occurred in the properties and the clinical placement techniques of composite resins since their introduction by Bowen (1962), many limitations still exist. The marginal adaptation of composite resin is influenced by polymerization shrinkage and the high coefficient of thermal expansion of the resin. Asmussen and Jorgensen (1972) reported that the phenomenon of gap formation is due to the difference in the coefficient of thermal expansion between tooth structure and composite resin with the coefficient for composite resin being three to five times greater than for tooth structure. As a result of gap formation during temperature change, marginal percolation occurs at the tooth-restoration interface. This occurrence is known as microleakage. In assessing the seal of composite resin restorations, Going (1972), Trowbridge (1987), and Ben Amar (1989) revealed that a number of qualitative methods are used for measuring microleakage, including radioactive tracers, dye penetration, bacterial penetration, electrochemical analysis, silver nitrate staining, direct

observation with electron microscopy, and fluorometric assay. The silver nitrate staining technique is currently being used most frequently by investigators. A large number of microleakage studies (McConnell & others, 1991; Nonaka & Baez, 1991; Rigsby & others, 1991) employ both the facial and lingual surfaces of teeth in their methodology. The assumption made by the research community is that facial and lingual enamel, dentin, and cementum respond in a similar manner with respect to microleakage. The clinical assumption is that the facial and lingual (palatal) surfaces can be prepared and restored in the same manner. To date no study directly compares microleakage of facial and lingual tooth structure.

The purpose of this in vitro study was to compare microleakage staining patterns exhibited on class 5 facial and lingual composite resin restorations. In addition, two microleakage evaluation techniques were compared to determine their ability to discriminate variations in leakage between evaluation sites.

METHODS AND MATERIALS

Freshly extracted teeth were collected and stored in isotonic saline at 4 °C until use. Class 5 composite resin restorations (APH Prisma, L D Caulk, Milford DE 19963) were placed in 25 posterior and 25 anterior teeth on the facial and lingual surfaces. Conventional class 5 preparations were cut using a #330 tungsten carbide fissure bur in an ultra-high-speed handpiece with water-spray coolant. One preparation was completed on the facial surface and the other restoration on the lingual surface of the experimental tooth. The depth of the preparation was standardized to the length of the cutting edge of the #330 bur. Each cavity preparation was prepared in the cervical one-third of the tooth with the gingival margin at or below the cementoenamel junction, the mesial and distal width being confined within the line angles of the tooth surface. The cavosurface margin was designed as a butt end to standardize restoration finishing. After preparation, the tooth was cleaned with flour of pumice in a rubber cup, rinsed with water, and air dried. The axial wall of the preparation was lined with Timeline (L D Caulk), a light-cured calcium hydroxide liner. The enamel margin was etched with a 40% phosphoric acid gel for 60 seconds, rinsed thoroughly with water for 20 seconds, and lightly air dried. Universal Bond 3 primer and adhesive (L D Caulk) were applied over all areas of the preparation following the manufacturer's instructions. The composite resin

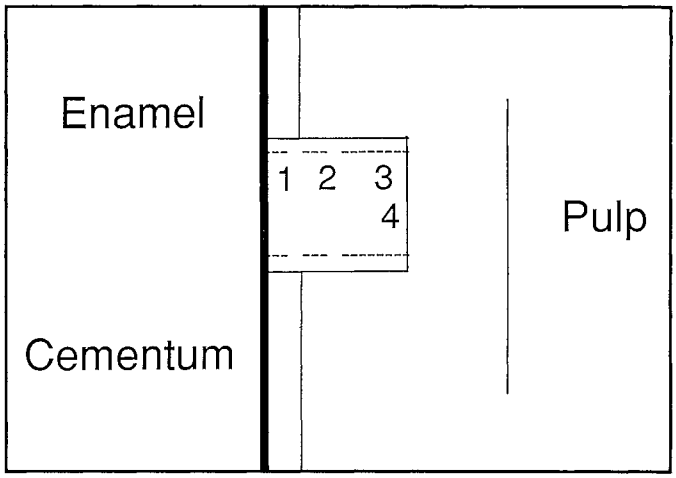

Figure 1. *Rating system for scoring microleakage*

was applied in 1 mm increments and light cured (Prismetics Lite, L D Caulk) for 40 seconds per increment to ensure complete polymerization. The restoration was then finished with a 12-fluted gold shank finishing bur (Midwest Dental Products Corp, Des Plains, IL 60018) followed by polishing disks (Sof-Lex, 3M Dental Products, St Paul, MN 55144). A high-luster finish was achieved by applying a 1.0 μm finishing paste followed by a 0.3 μm polishing paste in a foam cup.

After restoration, the teeth were stored at 37 °C until being thermocycled from 10 to 50 °C for 540 cycles using a 1-minute dwell time at each station. All teeth were subjected to the silver nitrate staining technique described by Wu and others (1983) and later modified by Hovland and Dumsha (1985), then divided in half faciolingually through the restoration using a slow-speed diamond sectioning saw. The mesial tooth half was scored for the degree of microleakage by two calibrated investigators under a X25 stereomicroscope using the rank order scoring system depicted in Figure 1. Dye penetration was

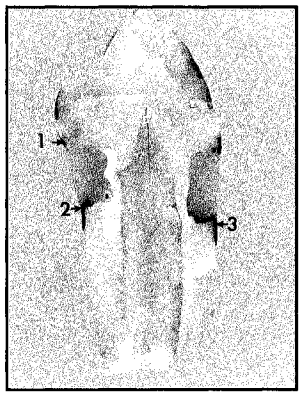

Figure 2. *Arrows indicating microleakage values on a sectioned tooth*

Table 1. Mean Leakage Scores

	Mesial Tooth Half (rank order data)*	Distal Tooth Half (measured data)
Buccal enamel	0.98	0.16
Buccal cementum	2.22	0.50
Lingual enamel	1.00	0.21
Lingual cementum	2.24	0.51

*Descriptive data were used to calculate the mean leakage score of the raw data.

scored using the following 0-4 rating system: 0 = no leakage; 1 = leakage equal to or less than the enamel thickness or the equivalent depth in cementum; 2 = leakage past enamel and up to 50% of the depth of the axial wall; 3 = leakage greater than 50% of the axial wall; and 4 = leakage involving the axial wall. Figure 2 depicts the stained, sectioned tooth using the scoring system depicted in Figure 1.

Prior to scoring the experimental teeth, the investigators were calibrated in the use of the scoring indexes using random samples of restorations subjected to the silver nitrate staining. An 85% level of agreement was reached between raters prior to scoring the experimental teeth. Any disagreement between raters was resolved by consensus to 100% agreement. A Kruskal-Wallis one-way ANOVA was performed on the rank order data at a confidence level of 95%, leading to a significant result in microleakage when $P < 0.05$.

The distal tooth half dye penetration was measured by a single evaluator. The depth of dye penetration and the depth of the cavity preparation were measured using a traveling microscope at X40 magnification. The depth of the dye penetration was divided by the depth of the cavity preparation, and the resulting score recorded as a percentage. A two-sample *t*-test was performed on the measured data at a confidence level of 95%, leading to a significant result when $P < 0.05$.

RESULTS

The mean leakage scores for the rank order and measurement data are presented in Table 1. Descriptive data were used to present the average rank leakage score of the raw data (Table 1).

A comparison of the microleakage using a Kruskal-Wallis one-way ANOVA test demonstrated that there was no significant difference ($P \geq 0.05$) in leakage between the facial and lingual enamel values for the mesial tooth specimens.

Table 2. Results of the Kruskal-Wallis One-Way ANOVA Performed on the Mesial Tooth Half Data

	Facial Enamel (N = 50)	Facial Cementum (N = 50)
Lingual enamel (N = 49)	Not significant $P = 0.0343$	Significant* $P = 0.000$
Lingual cementum (N = 49)	Significant* $P = 0.000$	Not significant* $P = 0.9133$

Similarly there was no significant difference ($P \geq 0.05$) between the facial and lingual cementum mesial tooth specimens. These data are represented in Table 2.

Using the distal tooth specimens, the samples were evaluated for microleakage by measuring the dye penetration. Applying the two-sample *t*-test, there was no significant difference ($P \geq 0.05$) in microleakage between the facial and lingual enamel. Likewise, there was no significant difference ($P \geq 0.05$) in leakage between the facial and lingual cementum samples. The data are represented in Table 3. There were significant differences in ($P < 0.05$) dye penetration when comparing enamel to cementum margins using both evaluation techniques.

DISCUSSION

The results of this in vitro study indicate that there were no statistically significant differences in microleakage between facial and lingual enamel and cementum tooth surfaces in class 5 restorations using both the rank order system and the measured data system for evaluation of microleakage. There

Table 3. Two-Sample t-Test for Experimental Groups (Distal Tooth Half)

	Buccal Enamel (N = 50)	Buccal Cementum (N = 50)
Lingual enamel (N = 49)	Not significant $P = 0.3729$	Significant* $P = 0.000$
Lingual cementum (N = 49)	Significant* $P = 0.000$	Not significant $P = 0.8277$

*($P \leq 0.05$) = Significant.

was a statistically significant difference ($P < 0.05$) when comparing the enamel margin leakage to the cementum margin leakage in all areas of the tooth surfaces examined. Leakage occurred in both halves to a greater depth at the cementum margin than at the enamel margin. This finding is well documented in other studies (Gross, Retief & Bradley, 1985; Retief, 1987; Retief & others, 1988). Asmussen (1985) stated that the dentin and cementum bond is the weak link, since etching the less-calcified dentin does not provide the degree of mechanical bond that can be obtained in enamel. However, recent studies (Øilo & Olsson, 1990; Wang & Nakabayashi, 1991), using third-generation dentin bonding agents, have reported predictable bond strengths to dentin.

Our findings indicate that the experimental technique of using the facial and lingual surfaces appears to introduce no positional variables in an in vitro research design. The findings also support the clinical assumption that the facial and lingual surfaces can be prepared and restored in the same manner. These findings are supported in a recent study by McConnell (personal communication, 1991). This study stimulates speculation on the possible clinical significance of using both facial and lingual tooth surfaces for in vivo studies. By using both surfaces as identical sample possibilities, an investigator could reduce the number of subjects needed for a study, therefore reducing the cost of the project. In addition, by treating these as identical surfaces, interesting research possibilities will arise, such as comparing different bonding agents on the same tooth. However, positional differences may be more significant in vivo than in the lab, due to occlusion, saliva, contact with the tongue, and oral hygiene accessibility; more research is necessary.

The microleakage evaluation techniques used in this study resulted in the same outcomes. Both techniques worked well and can be considered viable options for evaluating microleakage. Further comparison studies between the two techniques are necessary in order to verify reproducibility and repeatability.

CONCLUSION

The results of this in vitro study demonstrated that there was no statistically significant difference ($P \geq 0.05$) in microleakage between the facial and lingual enamel and cementum tooth surfaces. Additionally, there was a statistically significant difference ($P < 0.05$) when comparing the enamel margin leakage to cementum margin leakage in all areas examined. Both evaluation techniques used to score the leakage data worked well, and similar results were obtained.

Acknowledgment

This investigation was supported in part by University of Maryland DRIF Funds and the L D Caulk Company, Milford, DE 19963. We would like to thank Dr Steven Jeffries for his guidance and assistance during the course of this study.

(Received 17 November 1992)

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Trends in Elastomeric Impression Materials

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SUMMARY

In the past three years more addition silicones have been supplied as hydrophilic materials and heavier viscosities have been provided in automatic mixing cartridges. Also, a polyether is now supplied in an automatic mixing system. There has been an increase in the number of products available as monophase or single viscosity systems. Both addition silicones and polyethers are available as bite registration materials.

INTRODUCTION

Reviews of the four general types of elastomeric impression materials and commercial products were reported by Craig (1986), and Craig, Urquiola, and Liu (1990). More recently Farah and Powers (1989, 1992) reviewed and qualitatively ranked crown and bridge impression materials and bite registration materials; the present review mainly was based on data presented in the 1992 paper. Also recently, Kim, Craig, and Koran (1992) reported on the viscosity of five monophase addition silicones as a function of shear rate.

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Since the earlier reviews by Craig (1986) and Craig and others (1990), the following trends in elastomeric impression materials have occurred: (1) more addition silicone products are now supplied as hydrophilic materials, (2) automatic mixing has been extended from low and medium to high and even putty consistencies, (3) more monophase, or single consistency, addition silicone impression materials are available, (4) putty impression materials are being supplied as soft as well as regular products, (5) automatic mixing has been extended to polyether materials, and (6) addition silicones and polyethers have found increased application as bite registration materials and are available as hand and automatic mixing types.

It is the purpose of this paper to present quantitatively the properties of the newer products not reviewed earlier by Craig (1986) and Craig and others (1990) but reported qualitatively by Farah and Powers (1992).

METHODS AND MATERIALS

The products included in this review are listed in Table 1 along with the manufacturer, consistency type, type of mixing, batch number, and type of impression material. The bite registration materials evaluated are listed in Table 2, which also lists their manufacturer, type of material, type of mixing, and their batch number.

Table 1 lists a number of manufacturers that produce hydrophilic addition silicones since the introduction of the first hydrophilic material, Express by 3M. There initially was some concern that adding a surfactant to the silicone would decrease its shelf

life; however, this effect has not been observed. It is also apparent that more monophase hydrophilic addition silicones with shear-thinning properties have been introduced, so that a single material can be used as a syringe and a tray material in a syringe-tray impression technique.

Table 1 also shows that more products and heavier consistencies of addition silicones are available in automixing systems. Not only are addition silicones available as low and medium consistencies (Type 1 and 2) in automixing cartridges, but several heavy-consistency (Type 3) products are now available, as well as one putty-consistency (Type 4) material. Although the automatic mixing system was originally available only for addition silicones, Table 1 shows that a polyether material (Permadyne Garant) is supplied in automixing cartridges.

The putty-wash technique with silicone impression materials was reasonably popular, but there were some concerns about the high stiffness of the putty. Thus, more putty, or very high viscosity, materials are now marketed as a regular and a soft putty.

Although addition silicones continue to be more popular than condensation silicones, one condensation silicone product (Rapid) has been introduced that has smaller shrinkage on setting than other condensation silicones. This effect has been accomplished by having only two alkoxy reactive groups on the cross-linking agent, with the remaining two organic groups increasing its reactivity and decreasing the amount of the alcohol condensate.

Finally, the high stiffness elastomeric impression materials designed for taking bite registrations are listed in Table 2. Of these, all are addition silicones, with the exception of one polyether material. The polyether and one addition silicone are mixed by hand, while the remaining six addition silicones are available as automixing systems.

The methods used to determine the working time, permanent deformation, strain in compression, flow, tear strength, and dimensional change are the same as those described by Craig and others (1990). The consistency type is identified as light (1), medium

Table 1. Product Name, Manufacturer, Consistency, Mixing Type, Batch Number, and Elastomeric Impression Type

PRODUCT	MANUFACTURER	CONSISTENCY TYPE	BATCH #	TYPE OF MIXING
		Hydrophilic Addition Silicones		
Abformmaterial	Coltene-Whaledent	1	—	Auto
		2	—	Auto
Accumix	Coe	Mono	092691	Auto
Cinch-Platinum	Parkell	Mono	216	Auto
		Mono	217	Hand
Examix	G-C	Mono	032192A	Auto
Exaphase	G-C	Mono	083090	Auto
Hydrosil XT	Caulk	Mono	091191	Auto
Imprint 1:4	3M	2	P911017	Auto
Imprint 2:5		2	P910718	Auto
Reprosil	Caulk	3	112191	Auto
		Hydrophobic Addition Silicones		
Baysilex CD	Miles	3	0358F-Exp0492	Auto
Correct VPS	Jeneric-Pentron	1	041692	Hand
		2	042092	Hand
		3	042092	Hand
		4	41592	Hand
Correct VPS	Jeneric-Pentron	1	049050	Auto
		2	055056	Auto
Exaflex	G-C	3	042492G	Hand
Extrude-Fast	Kerr/Sybron	4	052692	Hand
Formasil A	Kulzer	1	6991	Auto
		4	4991	Hand
Permagum	ESPE-Premier	1	V214 MD 080291	Hand
		2	V176 MD 062591	Hand
		3	V154 MD 060391	Hand
		4Soft	S220 MD 080889	Hand
		4Reg	V214 MD 080291	Hand
Permagum Garant	ESPE-Premier	1	V241 MD 082991	Auto
Reprosil Quixx Putty		4	920401	Auto
		Condensation Silicones		
Accoe	Coe	3	111191G	Hand
Correct SIM	Jeneric-Pentron	1	010892	Hand
Cutter Sil	Cutter-Miles	1ExLt	21 Mar 91	Hand
		1	B-3330 102 Oct 91 C-3223 J05 Sep 91	Hand
		2	B-3065118 July 91 C-3223 J05 Sep 91	Hand
Elasticon	Kerr/Sybron	1	010292 3346	Hand
		3	102491 1276	Hand
		Denture	102391 1275	Hand
Rapid	Coltene	1	B-060291-22 C220191-18	Hand
		4Soft	B-301190-29 C-100191-45	Hand
		4Reg	B-050291-14 C-100191-45	Hand
		Polyether		
Permadyne Garant	ESPE-Premier	1	V241 MD 082991	Auto

(2), heavy (3), very heavy (4) or mono; the letter A or H following the identification of the type indicates whether it is an automixing or hand mixing material. The Tukey intervals for the various properties of the different consistencies are listed in the footnotes in Table 3. The properties of two products are statistically different if the difference between the values is greater than the Tukey interval.

Table 2. Product Name, Manufacturer, Material Class, Mixing Method, and Batch Number of Bite Registration Elastomers

PRODUCT	MANUFACTURER	CLASS	BATCH #	MIXING TYPE
Blue Mousse	Parkell	Addition Silicone	080188	Auto
Correct-Bite	Jeneric-Pentron	Addition Silicone	042092	Hand
Correct-Bite	Jeneric-Pentron	Addition Silicone	43092	Auto
Green Mousse	Parkell	Addition Silicone	5009-5010	Auto
Memosil CD	Cutter-Miles	Addition Silicone	3446J-3430J	Auto
Ramitec	ESPE-Premier	Polyether	V170 MD 061991	Hand
Regisil 2x	Caulk	Addition Silicone	0661991	Auto
Stat BR	Kerr-Sybron	Addition Silicone	111291	Auto

Hydrogen evolution for addition silicones was evaluated by making a cylindrical specimen used to determine permanent deformation and strain in compression. After removing the specimen from the 32 °C water bath, it was placed in an inverted test tube filled with distilled water. The samples were observed for gas bubbles for a half hour.

Wettability of addition silicones, classified as hydrophobic or hydrophilic, was determined by observing the advancing contact angle of distilled water on specimens made in the mold for dimensional change. Hydrophilic addition silicones listed in Table 3 had advancing contact angles of about 45°, while hydrophobic addition silicones had values of about 90°. Contact angles for water on silicones used for taking bite registrations were measured (Table 4) to determine if they were hydrophilic or not.

RESULTS AND DISCUSSION

Working Time and Time in the Mouth

Although one might expect the automixing hydrophilic addition silicones to be designed to have shorter working times than the hand mixing materials, as suggested from testing of earlier products by Craig and others (1990), no such trend was observed in Table 3. Working times for the automixing hydrophilic addition silicones ranged from 1.46 to 4.26 minutes and from 1.86 to 3.39 minutes for hand mixing materials. The hand mixing hydrophobic silicones had working times from 3.42-4.00 minutes, which was somewhat longer than the average value of 3 minutes for products reported by Craig and others (1990).

The working time for the condensation silicone products (Table 3) mixed by hand varied from 1.47 to 4.83 minutes, with the majority being between 2 and 3 minutes; the average reported earlier by Craig and others (1990) was 2.67 minutes. The automixed condensation silicone was in this common range at 2.12 minutes.

The automixing polyether, Permadyne Garant, had a slightly shorter working time of 2.22 minutes than the hand mix counterpart, Permadyne (Craig & others, 1990) of 2.5 minutes; this is reasonable, since no mixing time is required for Permadyne Garant.

The values for time in the mouth were taken from manufacturers' directions. These values are important, since they are the times the samples must be kept in a water bath at 32 °C during their preparation, and thus they have an effect on the reported properties. The temperature of 32 °C is intended to simulate mouth temperature during impression taking, and impressions should be left in the mouth for this time if the properties reported in the tables are to be obtained.

Recommended times in the mouth for addition silicones varied from just less than a minute for Abformmaterial to a little more than 5 minutes for Correct VPS type 2-H; however, most of the products had recommended times of 3-4 minutes. Times in the mouth for condensation silicones varied widely from about 1-8 minutes, while the automixing polyether had a value similar to addition silicones of 3.78 minutes.

Permanent Deformation

The permanent deformation values of addition silicones were generally between 0.1 and 0.4%, with an average value of 0.28%, which is comparable to earlier published data. This average represents an excellent recovery from 12% compression for 30 seconds of 99.72%. However, Cinch Platinum Mono A, Exaflex 3-H, Imprint 2-A, and Permagum Soft 4-H had values of 2.18, 2.31, 0.96, and 1.11% respectively. It should be noted that this test is conducted at a time based on the manufacturer's recommended time for removal from the mouth and would be lower if left in the 32 °C bath for a longer time before testing. Also, these values would be lower if the bath temperature specified by ADA Specification 19 was increased from 32 to 37 °C (body temperature).

The permanent deformations for condensation silicones were generally higher than for the addition

*Table 3a. Physical and Mechanical Properties of Recently Introduced Silicone and Polyether Impression Materials**

PRODUCT	TYPE	WORKING TIME	TIME IN MOUTH	PERMANENT DEFORMATION	STRAIN IN COMPRESS	FLOW	TEAR STRENGTH	DIMENSIONAL CHANGE %		HYDROGEN RELEASE
		min	min	%	%	%	g/cm	1 day	7 days	
HYDROPHILIC ADDITION SILICONES										
Abform – Material	1-A	3.25[0.02]	0.98	0.18[0.06]	4.50[0.08]	0.03[0.03]	2950[420]	-0.01[0.01]	-0.09[0.04]	YES
	2-A	3.64[0.17]	0.86	0.24[0.03]	3.76[0.76]	0.02[0.01]	2480[100]	-0.03[0.01]	-0.06[0.02]	YES
Accumix	Mono-A	2.70[0.21]	3.30	0.06[0.05]	2.63[0.05]	0.02[0.01]	3420[60]	-0.01[0.03]	-0.11[0.01]	NO
Cinch Platinum	Mono-A	2.04[0.14]	3.22	2.18[0.15]	2.70[0.16]	0.01[0.00]	2140[100]	-0.09[0.06]	-0.11[0.04]	YES
	Mono-H	2.78[0.28]	3.36	0.28[0.24]	3.02[0.33]	0.03[0.01]	3550[380]	-0.01[0.01]	-0.03[0.04]	YES
Examix	Mono-A	2.77[0.05]	2.73	0.14[0.14]	2.81[0.26]	0.00[0.00]	3360[150]	-0.04[0.02]	-0.08[0.05]	NO
Exaphase	Mono-A	2.70[0.21]	2.80	0.34[0.06]	2.63[0.05]	0.02[0.01]	3420[60]	-0.01[0.01]	-0.11[0.01]	NO
Hydrosil XT	Mono-A	4.43[0.09]	3.07	0.36[0.04]	2.04[0.03]	0.02[0.01]	2670[160]	-0.03[0.03]	-0.21[0.05]	NO
Imprint 1:4	2-A	2.47[0.09]	3.03	0.96[0.14]	2.14[0.39]	0.01[0.00]	4150[750]	-0.11[0.02]	-0.35[0.39]	NO
Imprint 2:5	2-A	4.26[0.14]	4.24	0.31[0.14]	1.99[0.09]	0.00[0.00]	3140[240]	-0.08[0.17]	-0.15[0.07]	NO
Reprosil	3-A	2.26[0.01]	3.74	0.35[0.03]	1.28[0.02]	0.00[0.00]	3600[350]	-0.04[0.05]	-0.19[0.04]	NO
HYDROPHOBIC ADDITION SILICONES										
Baysilex CD	3-A	1.46[0.04]	3.54	0.40[0.01]	2.67[0.09]	0.01[0.00]	3590[270]	-0.08[0.04]	-0.15[0.05]	YES
Correct VPS	1-H	2.50[0.17]	4.50	0.38[0.19]	5.60[0.13]	0.00[0.00]	1640[60]	-0.13[0.08]	-0.15[0.09]	YES
	2-H	1.86[0.13]	5.14	0.20[0.06]	3.95[0.17]	0.00[0.00]	2270[360]	-0.16[0.02]	-0.17[0.06]	YES
	3-H	2.75[0.08]	4.25	0.52[0.47]	2.43[0.09]	0.00[0.00]	2790[210]	-0.01[0.03]	-0.10[0.03]	YES
	4-H	2.61[0.17]	3.39	0.42[0.05]	2.73[0.50]	0.02[0.02]	–	-0.10[0.05]	-0.22[0.07]	YES
Correct VPS	1-A	2.72[0.05]	4.28	0.31[0.15]	3.39[0.06]	0.01[0.00]	1740[140]	-0.01[0.05]	-0.06[0.04]	YES
	2-A	2.17[0.17]	4.83	0.23[0.13]	4.10[0.12]	0.01[0.01]	2240[220]	-0.01[0.05]	-0.09[0.01]	YES
Exaflex	3-H	2.29[0.19]	2.16	0.53[0.26]	2.18[0.03]	0.00[0.01]	1680[120]	-0.09[0.07]	-0.17[0.03]	NO
Extrude Fast	4-H	1.33[0.01]	2.67	0.35[0.07]	4.31[0.48]	0.01[0.01]	–	-0.23[0.15]	-0.28[0.14]	YES
Formasil-A	1-A	2.08[0.08]	2.42	0.58[0.20]	5.56[0.11]	0.01[0.01]	4140[450]	-0.10[0.04]	-0.10[0.03]	NO
	4-H	3.39[0.19]	3.61	0.36[0.04]	2.14[0.44]	0.02[0.01]	–	-0.01[0.02]	-0.02[0.03]	NO
Permagum	1-H	3.42[0.08]	1.58	0.13[0.05]	2.94[0.03]	0.00[0.00]	1850[240]	-0.01[0.01]	-0.04[0.01]	YES
	2-H	4.00[0.08]	3.00	0.11[0.03]	2.06[0.27]	0.00[0.00]	5070[140]	-0.13[0.07]	-0.24[0.16]	YES
	3-H	3.49[0.09]	3.50	0.12[0.02]	2.44[0.25]	0.02[0.01]	5260[890]	-0.07[0.04]	-0.20[0.02]	YES
Permagum Garant	1-A	1.91[0.14]	3.09	0.45[0.14]	2.50[0.64]	0.01[0.01]	3090[320]	-0.05[0.04]	-0.11[0.02]	YES
Permagum Regular	4-H	3.66[0.26]	4.50	0.29[0.11]	1.81[0.03]	0.00[0.00]	–	-0.12[0.03]	-0.26[0.04]	YES
Permagum Soft	4-H	3.86[0.17]	3.14	1.11[0.60]	2.78[0.42]	0.03[0.01]	–	-0.15[0.10]	-0.02[0.04]	YES
Reprosil Quixx Putty	4-H	1.75[0.22]	4.25	0.13[0.00]	1.77[0.05]	0.00[0.00]	–	0.08[0.12]	-0.22[0.11]	NO

*Table 3b. Physical and Mechanical Properties of Recently Introduced Silicone and Polyether Impression Materials**

PRODUCT	TYPE	WORKING TIME	TIME IN MOUTH	PERMANENT DEFORMATION	STRAIN IN COMPRESS	FLOW	TEAR STRENGTH	DIMENSIONAL CHANGE %		HYDROGEN RELEASE
		min	min	%	%	%	g/cm	1 day	7 days	
					CONDENSATION SILICONES					
Accoe	3-H	2.72[0.25]	6.28	0.36[0.08]	3.50[0.24]	0.07[0.04]	3450[150]	-0.80[0.30]	-1.05[0.57]	NO
Correct Sim	1-H	1.47[0.25]	6.00	1.78[1.10]	4.87[2.26]	0.04[0.02]	2280[90]	-0.65[0.22]	-0.67[0.34]	NO
Cutter Sil Extr	1-H	4.83[0.60]	2.17	0.48[0.09]	3.67[0.56]	0.00[0.00]	4210[890]	-0.59[0.12]	-0.63[0.09]	NO
Cutter Sil	1-H	3.28[0.42]	3.72	1.20[0.47]	3.66[0.25]	0.02[0.02]	2700[500]	-0.46[0.05]	-0.59[0.05]	NO
	2-H	3.39[0.43]	4.11	1.39[0.32]	6.29[0.34]	0.04[0.02]	2330[40]	-0.19[0.42]	-0.52[0.11]	NO
Elasticon	1-H	2.08[0.08]	7.92	0.84[0.14]	6.37[0.26]	0.03[0.02]	2760[40]	-0.63[0.06]	-1.05[0.09]	NO
	3-H	1.94[0.10]	8.06	0.47[0.28]	7.77[1.32]	0.00[0.00]	4370[410]	-0.61[0.01]	-0.70[0.08]	NO
Rapid	1-H	2.95[0.25]	1.05	1.73[0.13]	4.98[0.50]	0.01[0.00]	3260[420]	-0.28[0.06]	-0.39[0.05]	NO
Rapid Regular	4-H	2.68[0.30]	2.32	1.09[0.20]	1.66[0.58]	0.01[0.01]	–	-0.13[0.07]	-0.40[0.27]	NO
Rapid Soft	4-H	3.08[0.17]	0.92	1.63[0.14]	4.76[0.20]	0.04[0.04]	–	-0.39[0.02]	-0.42[0.01]	NO
					POLYETHER					
Permadyne Garant	1-A	2.22[0.13]	3.78	1.30[0.10]	2.86[0.10]	0.01[0.01]	1700[180]	-0.33[0.06]	-0.36[0.17]	NO

*Tukey intervals at P = 0.05 for the addition silicone properties within the same viscosity type are

Permanent deformation, % - low 0.40, medium 0.67, heavy 0.60, putty 0.67, mono 0.37

Strain in compression, % - low 1.08, medium 0.59, heavy 0.34, putty 1.01, mono 0.50

Flow, % - low 0.04, medium 0.01, heavy 0.01, putty, 0.03, mono 0.02

Tear Strength, g/cm - low 2100, medium 1000, heavy 1200, mono 500

Dimensional change @ 1 day, % - low - 0.11, medium - 0.12, heavy - 0.13, putty - 0.21, mono - 0.08

Dimensional change @ 7 days, % - low - 0.12, medium - 0.46, heavy - 0.10, putty - 0.22, mono - 0.09

silicones with an average value of 1.1%; six of the 10 materials had values greater than 1%. These results are consistent with earlier values having a mean of 1.7%. The one automixing polyether, Permadyne Garant 1-A, had a permanent deformation of 1.30%, which was slightly lower than earlier values for the comparable hand-mixed material of 1.52%. Thus, addition silicones offer the lowest permanent deformation on removal from undercut areas, followed by the polyethers and then the condensation silicones.

Strain in Compression

It can be seen from Table 3 that strain in compression, or flexibility, of addition silicones does not have an indirect relationship to consistency as the consistency is decreased from putty to heavy to medium to light. However, products with values of above 5% have light consistencies. The values for putty materials varied from 1.77% for the automix material, Reprosil Quixx, to 2.78% for Permagum Soft. Again, like permanent deformation, the strain in compression is affected by time in the bath and the 32 °C temperature of the bath.

Condensation silicones had higher strains in compression than addition silicones with values from 3.50 to 7.77% for consistencies other than putty. The soft putty, Rapid, was much more flexible at 4.76% than the regular putty at 1.66%. Rapid 1-H had a flexibility similar to the soft putty of 4.98%, which would make it a useful combination for a putty-wash impression where severe undercuts exist.

The light-consistency automixed polyether, Permadyne Garant, had a stiffness comparable to a number of the lower viscosity addition silicones

Table 4. Physical and Mechanical Properties of Bite Registration Elastomers

PRODUCT	CLASS	MIXING TYPE	WORKING TIME	TIME IN MOUTH	CONSISTENCY	PERMANENT DEFORMATION	STRAIN IN COMPRESS	FLOW	DIMENSIONAL CHANGE %	
			min	min	mm	%	%	%	1 day	7 days
Blue Mousse	Addition Silicone	Auto	2.00[0.00]	2.00	30.7[0.58]	6.84[1.09]	1.02[0.35]	0.00[0.01]	-0.04[0.01]	-0.11[0.02]
Correct-Bite	Addition Silicone	Hand	1.42[0.05]	2.50	25.3[0.58]	0.65[0.05]	0.92[0.13]	0.00[0.00]	-0.06[0.02]	-0.08[0.03]
Correct-Bite	Addition Silicone	Auto	1.64[0.05]	2.50	29.3[1.53]	0.73[0.12]	1.32[0.30]	0.00[0.00]	-0.03[0.03]	-0.12[0.03]
Green Mousse	Addition Silicone	Auto	2.43[0.21]	2.00	34.3[1.04]	5.64[1.07]	1.79[0.07]	0.00[0.01]	-0.01[0.01]	-0.04[0.03]
Memosil CD	Addition Silicone	Auto	2.03[0.05]	3.00	26.8[0.76]	3.11[0.68]	2.89[0.42]	0.00[0.00]	-0.14[0.05]	-0.20[0.06]
Ramitec*	Polyether	Hand	2.14[0.05]	3.00	34.5[0.56]	2.62[0.20]	1.97[0.53]	0.00[0.00]	-0.29[0.05]	-0.32[0.06]
Regisil 2X	Addition Silicone	Auto	0.88[0.04]	1.50	28.0[1.00]	1.29[0.15]	1.32[0.06]	0.00[0.00]	-0.15[0.06]	-0.19[0.06]
Stat BR	Addition Silicone	Auto	1.33[0.16]	2.50	26.3[0.76]	4.36[1.44]	1.00[0.09]	0.01[0.01]	-0.12[0.06]	-0.16[0.07]

*Hydrophilic

and to the earlier hand-mixed Permadyne product.

The values for flexibility of these elastomeric impression materials can be summarized by noting that addition silicones have a rather wide range from product to product, that condensation silicones generally are more flexible than addition silicones, and that the polyethers have flexibilities comparable to the lowest addition silicones.

Flow

All of the products have excellent low values for flow, and selection of a material on the basis of the small differences between products is not appropriate. The slightly higher values for some of the condensation silicones is of no concern clinically.

Tear Strength

Rather wide ranges of tear strengths were observed as well as rather high standard deviations, shown in parentheses (Table 3). It does appear that light-consistency silicones have higher tear strengths than comparable heavier-consistency products. It is also apparent that the polyether light-consistency material had lower tear strengths than comparable consistencies of addition or condensation silicones.

Dimensional Change

The excellent low dimensional change of addition silicones of generally <0.1% in 1 day, compared to condensation silicones and the polyether, are apparent. However, it should be noted that for any given addition silicone, more dimensional change occurred after 7 days. Although a number of manufacturers state that addition silicone impressions are stable up to 7 days and pouring dies can be delayed, for best accuracy, pouring dies the same day is recommended. The large dimensional change observed for light-consistency condensation silicones compared to putty consistencies illustrates that adequate accuracy can be obtained only by using a putty-wash technique, and that dies and models should be poured promptly. The lower values for Rapid 1-H are noteworthy and are accomplished by reducing the number of reactive groups on the crosslinker. However, dies from a putty-wash impression made from Rapid still should be poured promptly.

The dimensional change of 0.33% in 1 day for Permadyne Garant 1-A is typical of polyethers and even when used as a dual-mix impression (light-heavy), dies should be poured promptly for greatest accuracy.

Hydrogen Evolution

Of the recently introduced products, 11 did not release hydrogen, while 18 products did. However, the 18 products that released hydrogen were supplied by six manufacturers, while the 11 that did not release hydrogen were produced by four manufacturers. The trend appears to be to provide addition silicones that do not release hydrogen, since

formerly only one major supplier provided a product that did not release hydrogen.

Clinicians should be advised that waiting a half hour to an hour (depending on the product) before pouring high-strength stone dies in addition silicones will avoid bubble problems from the release of hydrogen. However, if slow-setting epoxy die materials are used, a waiting time of 4 hours or more may be needed to prevent bubbles in these dies. Recently introduced fast-setting epoxy die material can be poured at earlier times comparable to those recommended for high-strength stone die materials without experiencing problems with bubbles from hydrogen release. Heating the addition silicone impression to 100 °C for 15 minutes speeds up the release of hydrogen so that improved stone dies can be poured as soon as the impression returns to room temperature (Craig & Johnson, 1993). No significant problems with dimensional accuracy have been noted as a result of this heating and cooling.

Wettability

Eleven of the addition silicones listed in Table 3 had surfactants added to increase their wettability by gypsum mixes, and they are listed as hydrophilic, while 18 products were found to be hydrophobic. The former had water contact angles of about 45°, while the latter had values of 90° or more. Although Johnson and Drennon (1987) found no significant difference in the number of surface voids when taking clinical impressions with hydrophilic or hydrophobic addition silicones, Pratten and Craig (1989) found significant improvement in the ease of pouring void-free improved stone dies into hydrophilic addition silicone impressions. Although the use of hydrophilic silicones reduces the number of surface voids in improved stone dies, the use of automixing rather than hand spatulation has a much more dramatic effect on the reduction in the number of voids and bubbles as reported by Craig (1985, 1988).

Bite Registration Elastomers

The physical and mechanical properties of these materials are listed in Table 4. Of the materials evaluated, seven were addition silicones and one was a polyether. All but one of the addition silicones were supplied as automixing systems, while the polyether was a hand mixing type.

Working Time and Times in the Mouth

The times varied from under 1 minute to less than 2.5 minutes. Three of the eight products had working times of less than 1.5 minutes, while three others had working times of just over 2 minutes. These short working times should be adequate for taking bite registrations, since all but one of the products are supplied as automixing systems, and the one hand mixing product had an adequate working time of 2.14 minutes. The times listed by the manufacturer for the time the materials should remain in the mouth are generally 2 to 3 minutes, which are appropriately shorter than for addition silicones designed for inlay and crown and bridge impression materials.

Consistency

As can be seen in Table 4, there is a general trend for products with shorter working times to have lower consistency disk diameters and thus are further along in the setting process at the time of testing. Products except Ramitec and Green Mousse had consistency values in the range of 25 to 31 mm, while these two products had consisting values of 34-35 mm.

These higher consistency values indicate greater shear thinning for Ramitec and Green Mousse. The effect of shear stress on the viscosity of the bite registration materials was not determined in this study; however, Kim and others (1992) found a 2.5 times decrease in viscosity of Green Mousse with increasing shear stress.

Permanent Deformation

The permanent deformations of the bite registration materials were substantially higher than for any of the elastometic impression materials listed in Table 3. Correct-Bite and Regisil 2X had the lowest values of 0.65-0.73 and 1.29%, while the remainder had values from 2.62-6.84%. To put these high values into proper perspective, the stiffness or strain in compression should be considered as well as the method of testing for permanent deformation. The strain in compression values shows that the bite registration materials are very stiff, and thus it is difficult to compress them the 12% required by the ADA test for permanent deformation. Enough force to compress the bite registration materials 12% is unlikely in a clinical situation, and it is improbable they would be placed in areas of severe undercuts. Thus, the recovery from deformation during removal should provide the accuracy needed for this application.

Strain in Compression

Bite registration materials are very stiff compared to addition silicone or polyether impression materials, with values for most products of 1-2% strain. The products have been formulated with higher concentrations of filler, since a stiff registration material is desired. Since the bite registration

products are intended to record a double-arch impression of the occlusal surfaces, their stiffness reinforces the tray. Their stiffness is an advantage when mounting study models and for coping or bonnet transfers.

Flow

The values listed in Table 4 indicate that flow is negligible and in most instances was so low it could not be measured by the instrumentation used.

Dimensional Change

The values listed in Table 4 demonstrate the excellent stability of the dimensions of the bite registration materials. They also show that the addition silicones have lower dimensional change than the polyether material. Although the dimensional shrinkage was always greater after 7 days compared with 1 day, even the greatest increase in shrinkage between 1 and 7 days of 0.09% would not be clinically significant. Certainly any of these materials has greater stability with time than a bite registration taken in wax.

CONCLUSIONS

Trends in addition silicone impression materials include (1) introduction of more products containing surfactants to make them more wettable by mixes of stone or more hydrophilic, (2) development of automatic mixing systems for heavy and putty consistencies, (3) introduction of more products that do not release hydrogen after setting so pouring of models can proceed directly, (4) development of more products that have sufficient shear thinning (monophase) so that a single material can be used as both a syringe and tray material, and (5) introduction of softer putty materials with increased flexibility to aid in the removal of putty-wash impressions.

A condensation silicone has been introduced that has less dimensional shrinkage or setting, although the values are large enough that the material should still be used only with the putty-wash impression technique.

A light-consistency polyether material with acceptable clinical properties has been introduced as an automixing system.

A number of addition silicone bite registration materials have joined a polyether material, with most being supplied in automixing cartridges.

The addition silicone-type bite registration materials had less dimensional change than the polyether material.

The bite registration materials were noted for short working times, short times in the mouth, high stiffness, and exceptionally low flow compared to addition silicone impression materials.

Several bite registration materials had a desirable combination of high stiffness and low permanent deformation at the time of removal.

(Received 25 May 1993)

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The Effects of Varied Etching Time and Etching Solution Viscosity on Bond Strength and Enamel Morphology

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Clinical Relevance
Etching times and etchant consistency are not critical to enamel bond strengths.

SUMMARY

The effects of varied etching time and etching solution viscosity on bond strength were evaluated by measuring the tensile bond strength of a composite resin to bovine enamel. Also, six enamel surfaces were examined to evaluate the effect of acid treatment on the morphology of etched enamel using scanning electron microscopy.

There was no significant difference in tensile bond strength between three etchants of differing viscosity or between etch times. Light microscopy revealed that most bond failures were cohesive in nature. When the three etchants of differing viscosity were compared under the scanning electron microscope, the liquid and the thin gel produced a more even etch pattern than the thick gel. In addition, the thin gel appeared to produce the most well-defined pattern of the three conditioners.

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INTRODUCTION

The technique of bonding resin to etched enamel surfaces to improve micromechanical retention was first described by Buonocore (1955). Since that time this procedure has become a standard technique in the placement of composite restorative materials, fissure sealants, resin and porcelain veneers, orthodontic attachments, and etched fixed partial dentures. Etching of the enamel is used to remove contaminants, raise the surface energy of enamel, and create micropores, into which resin may flow. The result is an increase in the bond strength of resin to enamel and a reduction of marginal leakage (Phillips, 1982). Standard treatment time for enamel conditioning has routinely been 60 seconds (Swanson & Beck, 1960). However, it has been suggested that a reduction in etching time may be equally effective and be much less destructive to the enamel (Beech & Jalaly, 1980). Currently, recommended etching times vary between the research literature and textbooks. However, a 15- to 20-second etch is considered appropriate (Phillips, 1982).Until recently, most conditioning solutions were liquid in nature. However, with the advent of high viscosity etching gels for better control during placement, the question has arisen as to their ability to penetrate enamel as effectively as a liquid (Brown & others, 1988), as well as their ability to etch enamel like a liquid in terms of the resulting morphologic characteristics and bond strength (Brännström, Malmgren & Nordenvall, 1982).

The purpose of this study was to determine the optimal time for enamel etching in relation to tensile bond

strength of composite resin to enamel, and further to assess and compare different types of etching solutions with respect to their efficacy, i e, ability to produce an etched surface capable of providing a resin bond that fails cohesively. The percent of cohesive failure after debonding was studied, and the effect of acid treatment on the morphology of the enamel was evaluated using scanning electron microscopy.

METHODS AND MATERIALS

Specimen Preparation

A total of 180 extracted bovine incisor teeth, free of gross irregularities, were obtained and stored in distilled water until testing began. The specimens were prepared by removing the roots and grinding the buccal surfaces to create a flat surface, using 240-grit and 400-grit carbide paper mounted on a wheel on slow speed, under continuous flow of water. Each specimen was then mounted horizontally with the flat buccal surface exposed, in an aluminum ring, embedding the tooth in a self-curing polymethyl methacrylate resin before being treated and tested. When the acrylic was cured, the ring was removed, and the specimens were cleaned with a mild detergent, rinsed thoroughly, and returned to distilled water for storage.

Specimen Organization into Groups

Sixty teeth were randomly assigned to each of three groups. These groups were further divided into 12 subgroups of 15 teeth each, based on the type of etchant used and application time (Table 1). The specimens were then numbered for identification and returned to the storage container.

The three etching agents used were Phosphoric Acid Liquid (37%, made in laboratory), thin Ultraetch Gel (40%, Ultradent Products, Inc, Salt Lake City, UT 84124), and thick Kerr Gel (37.5%, Sybron/Kerr, Romulus, MI 48174). These agents were applied at four varied etch times of 10, 20, 40, and 60 seconds respectively.

Table 1. Specimen Organization into Groups

Materials Group	Etch Time	Appl Mode	# Samples	Subgrp
#1: Phosphoric Acid Group	10 seconds	Freshen	15	1
	20 seconds	Freshen	15	2
	40 seconds	Freshen	15	3
	60 seconds	Freshen	15	4
#2: Thin Gel—Ultraetch	10 seconds	Single	15	5
	20 seconds	Single	15	6
	40 seconds	Single	15	7
	60 seconds	Single	15	8
#3: Thick Gel—Kerr Gel	10 seconds	Single	15	9
	20 seconds	Single	15	10
	40 seconds	Single	15	11
	60 seconds	Single	15	12

Application of the Agents

The teeth were thoroughly dried with compressed air, and the etching agents applied with a small brush for four designated intervals. Each specimen was then rinsed for 30 seconds with water, and dried for 20 seconds with compressed air. All specimens were etched and the composite applied in a controlled temperature/humidity (25 °C/60% relative) room; and within each viscosity group, all specimens were prepared on the same day.

The three different etching solutions were applied in the following manner:

Phosphoric Acid Liquid: The liquid was applied initially and freshened with more liquid every 10 seconds until the designated etching time was reached.

Thin Ultraetch Gel: The thin gel was applied and left passively to etch for the appropriate time with only the single initial application.

Thick Kerr Gel: The thick gel was applied and left to etch passively for the appropriate time with only the single initial application.

After etching, rinsing for 30 seconds, and drying for 20 seconds, the bonding agent supplied with the Herculite X-R Resin Kit (Sybron/Kerr), Bondlite, a Universal Bonding Agent composed of two liquids, a resin and an activator, was applied in accordance with the manufacturer's instructions and cured for 20 seconds with a Coe Curing Lite (Imperial Chemical Industries PLC, Macclesfield, England). Composite Resin (Herculite X-R, Sybron/Kerr), a bimodally filled light-cured hybrid resin, was then bonded to the prepared enamel surface by placing a Delrin mold, 6 mm high and 3.85 mm inside diameter, against the tooth surface to form a cavity to receive the restorative materials. The resin was condensed into the mold in three separate increments, with each increment being polymerized by a 60-second exposure to a curing light. After bonding, the specimens were placed in a humidor at 31 °C for 1 hour, then removed and stored in distilled water at 37 °C for 48 hours in preparation for thermocycling.

All groups were thermostressed in an automatic thermocycling apparatus to approximate the temperature differential that would likely occur in the oral cavity. The cycling temperature ranged from a low of 4 °C to a high of 44 °C in water. Each group of specimens was carried in a wire basket alternately between the

two water baths for 2500 cycles, with a dwell time lasting 30 seconds in each bath. After thermocycling the specimens were placed back in the 37 °C water for storage. Three weeks from the date of bonding the specimens were tested.

Table 2. Tensile Bond Strength and Percent Cohesive Failure of Each Group

Group	N	Etch Time in Seconds	Mean Stress kg/cm²	Standard Deviation	Average % Cohesive Failure
A1	15	10	150	46.3	99
A2	15	20	194	51.6	100
A3	15	40	180	50.8	98
A4	15	60	188	50.5	100
B1	15	10	180	55.7	99
B2	15	20	157	44.4	100
B3	15	40	180	47.5	100
B4	15	60	207	52.8	100
C1	15	10	173	65.0	100
C2	15	20	155	47.5	100
C3	15	40	197	50.3	100
C4	15	60	202	55.8	98

Group A = Liquid H_3PO_4
Group B = Thin Gel H_3PO_4
Group C = Thick Gel H_3PO_4

Instron Testing

The specimens from each group were tested in tension in an Instron Testing Machine Model 1123 (Instron Corp, Canton, MA 02021). An apparatus designed to minimize the introduction of stresses other than tensile was used to support the specimen and was fastened to the moving crosshead of the Instron. This apparatus suspended the specimen's bonded restorative material and the Delrin mold downward from a platform freely movable in all directions (except vertically). The lower attachment consisted of a wire with a threaded cap attached but freely movable. The threaded cap was then screwed onto the Delrin mold already situated in the upper support, and was attached by the wire to the lower stationary grip on the Instron testing machine.

A tensile load was applied at a crosshead speed of 0.5 mm per minute until bond failure occurred. The tensile strength of the bond was expressed in kg/cm² obtained by dividing the load at failure by the specimen area (0.1164 cm²).

Microscopic Evaluation

After testing, the specimens were evaluated under light microscopy to determine the percent of adhesive versus cohesive failure. This was done by placing the specimen under the light microscope, viewing the complete failure area, and visually estimating the percent cohesive versus adhesive failure present in each specimen. In addition, the effect of acid treatment on the morphology of both the fractured flat ground surface and intact enamel was studied using scanning electron microsopy. One tooth per subgroup was evaluated. Also, six specimens were etched with the three respective etching solutions, three specimens for 20 seconds, and three specimens for 60 seconds; a seventh specimen was left unetched for comparison.

In preparation for viewing in the scanning electron microscope (Hitachi S-450, Tokyo, Japan), impressions of the selected specimens were taken with low-viscosity President vinyl siloxane impressions material (Coltene, Altstätten, Switzerland), and epoxy replicas fabricated using Stycast 1266 (Emerson and Cuming Inc, Canton, MA 02021. The debonded specimen replicas, along with the replicas of the variably etched specimens, were attached to SEM stubs with an adhesive. The stubs and the sides of the specimens were painted with colloidal silver and stored in a dessicator overnight. The specimens were then sputter-coated by a Hummer V (Techniques Inc, Alexandria, VA 22303) with 50% gold/palladium and viewed in the SEM operated at 20 kV and at magnifications of X20 and X1000.

The specimens were examined for the type of failure present, and the nature of the pattern produced with various etch times by the three different etching agents. Photomicrographs were taken of representative areas of each specimen.

Statistical Evaluation

The bond strength data were analyzed by two-way analysis of variance (time and etchants) at the $P < 0.05$ level of significance, and the Student-Newman-Keul's test was used for multiple comparison of test groups.

RESULTS

Etching Viscosity and Time

Table 2 presents the number of specimens, mean tensile bond strength, percent cohesive failure, and the standard deviation of each group tested. Figure 1 graphically represents a comparison of the mean tensile strengths and standard deviations.

The highest mean tensile bond strength was recorded by the Thin Gel H_3P0_4 group etched for 60 seconds (207.2 ≤ 52.8 kg/cm²). The Liquid H_3P0_4 group etched for 10 seconds had the lowest tensile bond strength

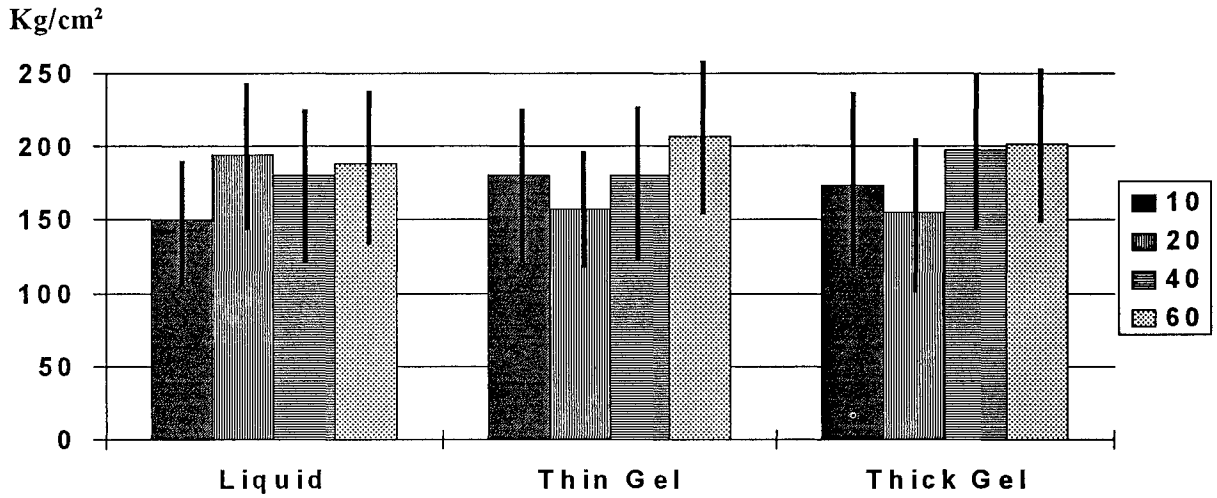

Figure 1. Mean tensile bond strengths and standard deviations of the three acid consistencies at the four test times

Figure 2. *SEM of a debonded specimen showing 100% cohesive failure (marked by arrows) within the resin (orig mag X500)*

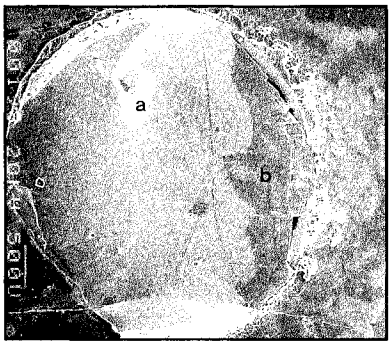

Figure 3a. *SEM of a debonded specimen showing a combination of cohesive (a) and adhesive (b) failure (orig mag X10)*

Figure 3b. *SEM of a debonded specimen showing a close-up of the enamel (a)/resin (b) interface in Figure 3a (orig mag X500)*

Figure 4. *SEM of a debonded specimen showing the interface of a resin (r)/ bonding agent (ba)/enamel (e) adhesive failure (orig mag X500)*

Figure 5. *SEM showing ground unetched enamel specimen (orig mag X500)*

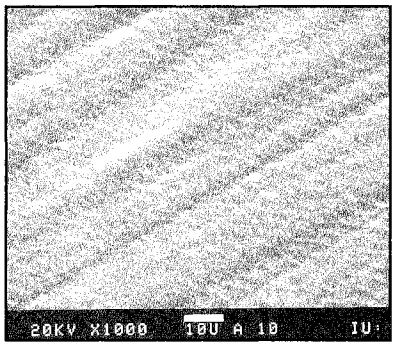

Figure 6a. *SEM of an enamel specimen etched with an H_3PO_4 liquid etchant for 10 seconds (orig mag X500)*

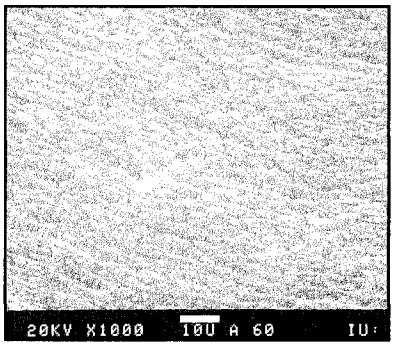

Figure 6b. *SEM of an enamel specimen etched with an H_3PO_4 liquid etchant for 60 seconds (orig mag X500)*

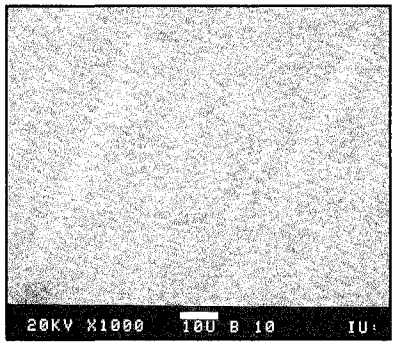

Figure 7a. *SEM of an enamel specimen etched with an H_3PO_4 thin gel etchant for 10 seconds (orig mag X500)*

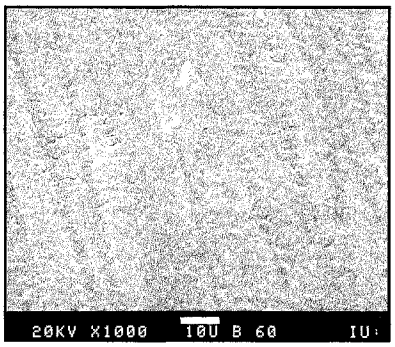

Figure 7b. *SEM of an enamel specimen etched with an H_3PO_4 thin gel etchant for 60 seconds (orig mag X500)*

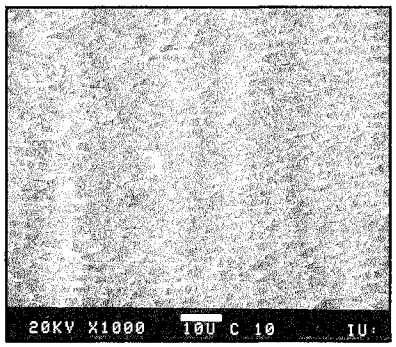

Figure 8a. *SEM of an enamel specimen etched with an H_3PO_4 thick gel etchant for 10 seconds (orig mag X500)*

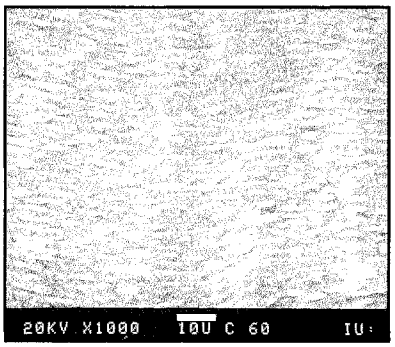

Figure 8b. *SEM of an enamel specimen etched with an H_3PO_4 thick gel etchant for 60 seconds (orig mag X500)*

(150.3 ≤ 46.3 kg/cm^2). A statistical evaluation of the data using two-way analysis of variance showed that there was no statistical difference ($P < 0.05$) in the tensile bond strength between the three etchants. However, there was a significant difference between etching times. The interaction between the etchants and the etching times was not significant (Figure 1). The summary of the analysis of variance results for the mean tensile bond strength is presented in Table 3. In order to investigate the influence of etching time for each specific etchant, one-way analyses of variance were performed on the data for each etchant group. This was followed by Newman-Keul's multiple comparisons among the etch times. The results are shown in Table 4. The results showed essentially no dependence for bond strength on etching times with any of the etchants studied.

Type of Bond Failure

Light microscopy revealed that most bond failures were of a cohesive nature as seen in Table 2.

Representative scanning electron micrographs of debonded specimens of common bond failures are shown in Figures 2-4.

Figure 2 shows an example of 100% cohesive failure at X1000 magnification. Figure 3a shows a combination of a cohesive and an adhesive failure at X20 magnification, while Figure 3b shows a portion of the interface between the resin/enamel failure of Figure 3a at X1000. Figure 4 shows the interface of an enamel/bonding agent/resin adhesive failure.

Table 3. Analysis of Variance Procedure for Tensile Bond Strength

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
Etchant	3	Liquid, Thin, Thick
Time	4	10, 20, 40 60

Number of Observations in Data Set = 180; Alpha = 0.05

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
Etchant	2	476.84	238.42	0.09	nonsignificant
Time	3	31067.70	10355.90	3.85	significant
Etch/Time Interaction	6	27420.44	4570.07	1.70	nonsignificant
Within or Error	168	451470.40	2687.32		

Etching Morphology

Six specimens were etched with the three etching solutions, three specimens for 10 seconds, and three for 60 seconds; a seventh specimen was left unetched for comparison. These seven specimens were examined under the SEM for etching morphology and are seen in Figures 5-8. All SEM's were at X1000 magnification. Figure 5 shows ground unetched enamel. Figures 6a and 6b show SEM's of enamel etched with a H_3P0_4 liquid at 10 seconds and 60 seconds respectively. Figures 7a and 7b represent SEM's of enamel etched with a H_3P0_4 thin gel at 10 and 60 seconds, and Figures 8a and 8b show SEM's of enamel etched with a H_3P0_4 thick gel at 10 and 60 seconds.

DISCUSSION

Varied Etching Time

Standard treatment time for enamel etching has routinely been 60 seconds (Swanson & Beck, 1960; Retief, 1973). However, it has been suggested that a reduced etching time may be equally effective, and be much less destructive to the enamel (Beech & Jalaly, 1980; Labart, Barkmeier & Taylor, 1987; Kanca, 1988). The etching times used in this study were established on the basis of a careful review of the literature. These studies found minimal differences in bond strength for enamel etch times that ranged from 5 to 60 seconds (Nordenvall, Brännström & Malmgren, 1980; Roberts, Garner & Moore, 1983; Barkmeier, Gwinnett & Shaffer, 1985; Barkmeier, Shaffer & Gwinnett, 1986; Cartensen, 1986; Glasspoole & Erickson, 1987; Oliver, 1987; Barkmeier, Gwinnett & Shaffer, 1987; Khairy & Simonsen, 1987).

Results of the tensile bond strengths are depicted in Figure 1 and Table 2. The variations in bond strength of the three groups were generally not significant for each etching time, with the exception of the thin gel etched for 60 seconds, which did differ significantly when compared to the thin gel group etched for 20 seconds (Table 4). The true significance of this exception is questionable, due to the difficulty of testing specimens in adhesion. It is probably happenstance and of no clinical significance. Overall, the interaction between the etchants and the etching times showed no significant differences (Table 3). These results support the findings of

Table 4. Newman-Keuls Test for Multiple Comparison of Etching Times

	Group A Means	Group B Means	Group C Means
10 seconds	150	180	173
20 seconds	194	157	155
40 seconds	180	180	197
60 seconds	188	207	202

Groups connected by vertical lines are not significantly different ($P < 0.05$)
Group A = Liquid H_3PO_4
Group B = Thin Gel H_3PO_4
Group C = Thick Gel H_3PO_4

other investigators.

Microscopy Evaluation

Morphologically, a properly treated enamel surface should allow penetration of adhesive materials into the microscopic pores of enamel to form resin tags to increase the retention of the material to the surface (Gwinnett & Matusi, 1967; Buonocore, Matusi & Gwinnett, 1968). Light microscopy evaluation of the debonded specimens in this study showed that most failures were cohesive in nature (Table 2), indicating that the bond of the resin to the enamel at all four etching times was stronger than the tensile strength of the resin. Since the failures were predominantly cohesive in nature, the bond strength to the etched surface was not really demonstrated, since the material itself failed.

Microscopic examination by the scanning electron microscope of a 10-second versus a 60-second etch time showed that etching the enamel for 10 seconds produced a very superficial etch, as seen in Figures 6a, 7a, 8a. A deeper etch is evidenced in specimens etched for 60 seconds as seen in Figures 6b, 7b, 8b. These differences in etching depth apparently, however, did not have a significant impact on tensile bond strength.

Application of etchants for shorter periods of time appeared to present a slight problem. The 10-second etch was difficult to obtain simply because the time between application of the etchant and the rinse was so short. Clinically, an etching time of between 20 and 30 seconds would probably be ideal both in terms of efficacy and chairside manageability.

Etching Solution Viscosity

Many restorative kits now provide phosphoric acid in the form of a gel (both thick and thin) instead of a liquid. The primary advantage of using a gel is that it gives better control of the acid solution when etching several teeth, lingual surfaces, and other difficult-to-reach places (Brännström, Nordenvall & Malmgren, 1978). The question of differences in etching abilities between acid gels and liquids has been raised by Sheykholeslam and Brandt (1977), who suggested that the etching effect is reduced when the etching viscosity of the acid is high. However, this concern proved unfounded in several other studies (Brännström, & others, 1978; Walker & Vann, 1984; Maijer, 1982). In addition, morphologic studies have shown no significant differences based on the viscosity of the etchant (Brown & others, 1988; Maijer, 1982; García-Godoy & Gwinnett, 1987). This study also showed no significant differences between the three etchants as related to their viscosities as indicated by tensile bond strength data (Figure 1 and Table 2).

CONCLUSIONS

The results indicate that, within the parameters of this study, differences in etching time and viscosity of the conditioners do not affect bond strength to bovine enamel. An adequately conditioned surface for the retention of resin can be produced by any of the agents at any of the etching times.

(Received 25 May 1993)

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The Effect of Dentin Surface Moisture on Bond Strength to Dentin Bonding Agents

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Clinical Relevance
For the products tested, the dentin's surface moisture did not affect bond strengths.

SUMMARY

This in vitro study compares the mean shear bond strengths of two dentin bonding agents to dry and to moist human dentin. The occlusal surfaces of 60 extracted human molars were ground to produce flat dentin surfaces. The teeth were divided into four groups of 15 specimens each. For Scotchbond Multi-Purpose dentin bonding agent, the teeth were etched, rinsed, and then either blotted with gauze, which left the dentin moist, or dried with compressed air. The primer and adhesive were then applied, and composite cylinders were bonded to the teeth. For Optibond, the teeth were again either blotted with gauze or dried with air. The primer and dual-activated adhesive were applied, and composite cylinders were bonded to the teeth. After storage in room-temperature distilled water for 48 hours, the specimens were thermocycled. Shear bond strength testing was performed at 1 week. Analysis using two-sample *t*-tests found no significant difference for either product in bond strengths to moist and to dry dentin ($P > 0.05$). This study indicated that for some current-generation dentin bonding agents, the presence of moisture on dentin surfaces does not compromise short-term bond strength.

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INTRODUCTION

Dentin bonding agents have undergone dramatic changes in chemistry and clinical use over the last decade. Changes have been made in the basic chemistry of these products, as well as in their clinical application. With these modifications has come a significant improvement in the strength and durability of the bond that they mediate between composite resins and dentin.

One of the most recent changes in the way that dentin bonding agents are clinically applied centers around their use in the presence of moisture. It has generally been accepted that moisture on dentin precludes successful bonding (Glasspoole, Erickson & Pashley, 1991; Mitchem, Terkla & Gronas, 1988; Terkla & others, 1987). Recent research, however, indicates that strong bonding to dentin can occur in the presence of moisture (Kanca, 1992a). In fact, certain third-generation dentin bonding agents have been found to form significantly stronger bonds to moist dentin than to dry dentin (Gwinnett, 1992). It has been suggested that these products are able to form strong bonds to moist dentin because they employ acetone-containing, hydrophilic primer solutions.

Because dentin bonding agents differ compositionally from each other, it is important to assess each product's ability to form strong bonds in the presence of moisture. This is especially true if the product's manufacturer claims that it exhibits this characteristic. Recently, two new dentin bonding products were introduced to the market. The manufacturers of Scotchbond Multi-Purpose Adhesive and Optibond claim that their products form strong bonds to humid or moist dentin. The purpose of this study was to measure and compare the in vitro shear bond strengths of these two products to moist and to dry human dentin.

METHODS AND MATERIALS

A total of 60 extracted human molars stored in formalin were used for the bond strength test. The occlusal surfaces of the teeth were ground on a water-cooled model trimming wheel to prepare flat dentin surfaces. The teeth were then mounted with autopolymerizing acrylic resin using cylindrical polytetrafluoroethylene molds so that the prepared dentin surfaces were approximately 2 mm above one end of the resin cylinders. After the resin had completely polymerized, the dentin surface was hand finished using 20 strokes each on wet 400- and 600-grit silicon carbide abrasive papers. After finishing, the teeth were examined at X8 magnification using a stereomicroscope (Zeiss Stemi SR, Carl Zeiss Inc, Thornwood, NY 10594) to ensure that all enamel had been removed. The teeth were then stored in room temperature (23 ± 2 °C) distilled water. The teeth were randomly divided into four groups of 15 specimens each to test two commercially available dentin bonding products. The test groups were treated in the following ways: Group 1, Optibond (Kerr Mfg Co, Romulus, MI 48174) to dry dentin; Group 2, Optibond to moist dentin; Group 3, Scotchbond Multi-Purpose Adhesive (3M Dental Products, St Paul, MN 55144) to dry dentin; and Group 4, Scotchbond Multi-Purpose Adhesive to moist dentin. The specimens were prepared in the following manner.

Group 1: After being dried for 10 seconds with oil-free, compressed air, the dentin was treated with Optibond Prime. The primer was applied to the dentin for 30 seconds with a light scrubbing motion, using a Kerr applicator tip. The primer was then dried for 10 seconds with a gentle stream of air and light activated by exposure for 20 seconds to a visible-light polymerization unit (Optilux 400, Demetron Research Corporation, Danbury, CT 06810). The adequacy of the light unit's intensity was verified before use by testing with a radiometer (Demetron Radiometer, Demetron Research Corporation). One drop of Dual Cure Activator was thoroughly mixed with one metered dose of Dual Cure Paste, and the mixed material was applied with a Kerr applicator tip to the primed dentin in a thin (approximately 0.5 mm) layer. The material was then light activated for 30 seconds. A 3-mm-thick split polytetrafluoroethylene mold with an internal diameter of 5 mm was placed against the dentin surface and stabilized with an alignment tube. Composite resin (Herculite XRV, shade B2, Kerr) was inserted into the mold in 1 mm increments, and each increment was light activated by exposure for 40 seconds to the visible light unit. After polymerization of the final increment, the alignment tube and mold were removed and the specimen placed in room-temperature distilled water.

Group 2: The wet dentin surface was lightly blotted with a gauze square to produce a visibly moist dentin surface. Composite resin was bonded to the dentin surface using the Optibond Prime, Dual Cure Activator, and Dual Cure Paste as described for Group 1. Following preparation, the specimens were stored in room-temperature distilled water.

Group 3: After being dried for 10 seconds with oil-free, compressed air, the dentin was conditioned with Scotchbond Multi-Purpose Etchant by applying the etchant with a brush and allowing it to remain undisturbed for 15 seconds. The etchant was then removed by rinsing for 15 seconds with tap water, and the dentin was dried for 10 seconds with oil-free, compressed air. Multi-Purpose Primer was applied to the dentin surface with a brush and was dried with compressed air for 10 seconds. Multi-Purpose Adhesive was then applied in a thin layer using a brush and was light activated by exposure for 10 seconds to the visible-light unit. The split polytetrafluoroethylene mold was placed against the dentin surface and stabilized with the alignment tube. Composite resin (Z100, shade A2, 3M Dental Products) was inserted into the mold in 1 mm increments and was light activated by exposure for 40 seconds to the visible-light unit. After polymerization of the final increment, the alignment tube and polytetrafluoroethylene mold were removed and the specimen was placed in room-temperature distilled water.

Group 4: The dentin surface was dried for 10 seconds with oil-free, compressed air. The dentin was conditioned for 15 seconds with Multi-Purpose Etchant by applying the etchant with a brush and allowing it to remain undisturbed for 15 seconds. The etchant was removed by rinsing for 15 seconds with tap water. The dentin surface was then lightly blotted with a gauze square to produce a visibly moist dentin surface. Composite resin was bonded to the dentin surface using the Multi-Purpose Primer and Adhesive as described for Group 3. Following preparation, the specimens were stored in room-temperature distilled water.

Following preparation, the specimens were stored for 48 hours and were then thermocycled for 500

cycles between a 5 °C water bath and a 55 °C water bath. A dwell time of 40 seconds was used for each bath. The specimens were tested at 1 week in shear using a perforated steel ring attached by a chain to a testing machine (Tinius Olsen, model 1000, Willow Grove, PA 19090). The specimens were loaded to failure at a crosshead speed of 0.5 mm/min. After shear bond strength testing, the specimens were examined at X8 magnification using a stereomicroscope to determine the mode of failure between the adhesive materials and dentin. Failures were recorded as adhesive (those which occurred between the dentin bonding agent and dentin), cohesive (those which occurred within either the dentin, dentin bonding agent, or composite resin), or mixed (those which were a combination of adhesive and cohesive).

Bond strength data for each bonding agent were analyzed using a two-sample *t*-test at the 0.05 level of significance to determine if a significant difference existed between mean bond strengths to dry and to moist dentin.

Table 1. Mean Shear Bond Strengths (MPa)

	Optibond	Scotchbond Multi-Purpose
Dry dentin	16.4 ± 5.2	15.4 ± 2.5
Moist dentin	13.3 ± 4.1	15.5 ± 2.9

Mean ± standard deviation
N = 15

RESULTS

The mean shear bond strengths for the four groups are presented in Table 1. No significant difference was found between bond strength to dry dentin and bond strength to moist dentin for either Optibond ($P = 0.08$) or Scotchbond Multi-Purpose Adhesive ($P = 0.94$). Modes of failure for the specimens are presented in Table 2. Specimens of Optibond bonded to dry dentin all showed cohesive failures either entirely within dentin or within dentin and composite resin. The majority of specimens of Optibond bonded to moist dentin exhibited cohesive failures entirely within dentin. All Scotchbond Multi-Purpose specimens bonded to dry dentin showed mixed failures with a combination of adhesive as well as cohesive within both the dentin and composite resin. A similar mode of failure was noted for the Scotchbond Multi-Purpose specimens bonded to moist dentin.

Table 2. Modes of Failure

	Optibond			Scotchbond Multi-Purpose		
	C	A	M	C	A	M
Dry dentin	15	0	0	0	0	15
Moist dentin	12	0	3	0	0	15

C = Cohesive failure within the dentin bonding agent, restorative material or dentin.
A = Adhesive failure between the dentin bonding agent and dentin.
M = Combination of cohesive and adhesive failures.

Numbers indicate the number of specimens exhibiting a particular type of failure.

DISCUSSION

It has generally been accepted that the presence of moisture on dentin adversely affects the bond formed by dentin bonding agents. Using an in vitro model to simulate pulpal pressure, Mitchem and Gronas (1991) found that the mean shear bond strength of Scotchbond 2 (3M Dental Products) to moist dentin was only one-half as great as that to dry dentin. Also using a model to simulate pulpal pressure, Glasspoole and others (1991) found that even minute amounts of surface moisture can adversely affect dentin bonding.

Recently, however, studies have indicated that several currently marketed bonding products form strong bonds to moist dentin (Gwinnett, 1992; Kanca, 1992b; Swift & Triolo, 1992). Gwinnett (1992), in fact, found that some bonding agents actually form significantly stronger bonds to moist dentin than to dry dentin.

The results of the present study do not support the finding of higher bond strengths to moist dentin, but do indicate that bond strength is not significantly compromised by the presence of dentin moisture. This finding is in agreement with the results of Swift and Triolo (1992), who measured the shear bond strength of Scotchbond Multi-Purpose Adhesive to moist and to dry dentin and found no significant difference.

It has been suggested that many current dentin bonding products are capable of forming strong bonds to moist dentin because they contain acetone-based, hydrophilic primer solutions (Gwinnett, 1992; Suh, 1991). Gwinnett and Kanca (1992) have hypothesized that acetone facilitates the penetration of monomers into moist dentin. After penetration, the acetone evaporates and the monomers polymerize to produce strong micromechanical retention. For bonding agents such as Scotchbond Multi-Purpose and Optibond, whose primers do not contain acetone, it is believed that the strongly hydrophilic nature of their primers is sufficient to promote adequate monomer penetration into dentin for micromechanical retention. Swift and Triolo (1992) have suggested that polycarboxylic acid in the Scotchbond Multi-Purpose primer contributes to its ability to bond to moist dentin. Both Scotchbond Multi-Purpose and Optibond also contain the hydrophilic monomer 2-hydroxyethyl methacrylate (HEMA), which may further contribute to strong bonding.

The ability to form strong bonds to moist dentin is a positive feature for a dentin bonding system. Being able to leave the dentin surface slightly moist before primer application not only saves treatment time but, more importantly, obviates the need for desiccating the dentin, which may have adverse effects on pulpal tissues. Being able to form strong bonds to moist dentin would appear to be of particular benefit for products such as Scotchbond Multi-Purpose, which use an etchant that completely removes the smear layer and exposes dentin tubule orifices (Figure 1). In a situation such as this, outward dentin fluid flow resulting from normal intrapulpal pressure may produce a moist dentin surface requiring a strongly hydrophilic bonding agent for adequate bond formation. This consideration may not be as great for products such as Optibond that forgo the application of an etchant or conditioner and instead employ a primer to treat the smear layer-covered dentin. When dentin is treated in this fashion, a different type of surface is produced (Figure 2). This surface may remain drier because dentin tubule orifices are covered with resin, which may reduce or prevent outward dentin fluid flow.

The finding that bonding agents can adhere to moist dentin should not be interpreted to mean that these products should be applied to saliva- or blood-contaminated dentin. Research by Ario, Aasen, and Fundingsland (1993) indicated that saliva contamination of dentin during application of bonding agents significantly lowers bond strengths. It is important, therefore, to use a rubber dam or other means of isolation to ensure that the dentin surface to be treated remains free from blood and saliva contamination.

Future research concerning the effect of dentin moisture on the performance of current-generation dentin bonding agents should focus on at least two areas. First, attempts should be made to standardize the amount of moisture present on dentin immediately prior to bonding. The technique used in this study, although inexact, may in actuality simulate the clinical situation quite well. Being able to quantify and standardize the amount of water present on the dentin surface, however, would permit easier replication of studies by future researchers and may lead to a better understanding of the effects of varying degrees of moisture on the performance of bonding agents. Another subject for future research is the effect of dentin moisture on the long-term performance of bonding agents. All of the studies published to date on this subject have measured only short-term (i e, 24-hour or 1-day) bond strength. Future research should evaluate the effects of dentin moisture on 6-month and 1-year bond strengths.

CONCLUSIONS

The presence of moisture on dentin surfaces has, until recently, been considered an impediment to strong bonding with a dentin bonding agent. Some current dentin bonding products appear to be able to form strong bonds to dentin even in the presence of moisture. This study found that Scotchbond Multi-Purpose and Optibond dentin bonding products formed strong bonds to moist and to dry dentin. The bond strengths formed to moist dentin were not statistically significantly different from those formed to dry dentin.

Future research should evaluate the long-term in vitro and in vivo performance of current-generation dentin bonding agents bonded to moist dentin.

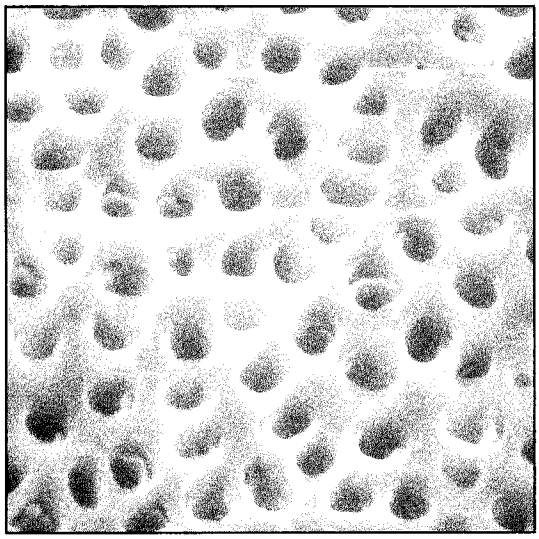

Figure 1. Scanning electron microscope photograph of dentin following treatment with Scotchbond Multi-Purpose Etchant. Smear layer debris has been completely removed and dentin tubule orifices are patent (X1000).

Figure 2. Scanning electron microscope photograph of dentin following treatment with Optibond Prime. The dentin surface and tubule orifices are covered with the primer solution (X1000).

The opinions, interpretations, conclusions, and recommendations expressed herein are those of the authors and are not necessarily endorsed by the United States Air Force.

(Received 2 June 1993)

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DEPARTMENTS

LETTER

MORE ON BASES, LINERS, AND VARNISHES

I would like to commend the group from the University of Texas at San Antonio who took it upon themselves to address the issue of base, liner, and varnish terminology in their letter to the editor (vol 19, number 1, page 35, Jan-Feb 1994). My only suggestion would be to eliminate the term *resin bonding agents*. I propose that we consider *resin adhesives* a subcategory of *liners*, as the resin adhesives satisfy the definition given to liners. We might speak of liners in general but if we intend to be more specific we would refer to *adhesive resin liners* or *glass-ionomer liners*, or *calcium hydroxide liners*, etc. The categories would then read:

1. Cavity Sealers
    a. Varnishes
    b. Liners
2. Bases

As Dr Summitt pointed out, the definitions are not material specific, and hence certain materials may serve as either bases or liners depending upon their thickness. I encourage more members of the audience to offer their opinions on this topic and again, kudos to Dr Summitt and his colleagues for their willingness to tackle a problem that most of us only complain about.

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BOOK REVIEWS

DISEASES OF THE ORAL MUCOSA A COLOR ATLAS

Manfred Strassburg, Gerdt Knolle

Published by Quintessence Publishing Co, Inc, Chicago, 1993. 800 pages, 1000+ illustrations. $210.00.

This is an impressive text, encompassing the scope of disorders of the oral soft tissues with exceptional illustrations and photographic reproductions. It is a contemporary English translation of a classic, previously published German-language atlas. The authors are Drs Manfred Strassburg and Gerdt Knolle, professor and associate professor respectively of the Clinic for Oral and Maxillary Diseases of the University of Dusseldorf. Their stated purpose for the book is to depict and demonstrate several different variations of oral soft-tissue disorders and to include the oral-facial regions as well as intraoral structures. In addition, they strive to present an interdisciplinary approach to oral diseases with correlations to both medicine and dentistry.

Following an introductory chapter on nomenclature and basic principles, the book is organized into chapters consistent with the US ICD-DA coding system. There are 34 chapters, each covering a specific disease entity or process. The arrangement is logical and systematic, presenting material in coherent topical segments familiar to most dental practitioners. Although the obvious strength of the publication is the exceptionally well-produced photographs, most of which are in color, the accompanying text is complete, albeit succinct, and correlates well with the related illustrations. Some disorders have only a brief paragraph, but there is considerably more detail for some of the more critical disorders. For example, the chapter "Carcinomas of the Oral Cavity" contains an excellent description of classification and staging systems important to dentists managing oral cancer patients and a sound explanation of diagnostic procedures in suspected cancer cases. In general, the text is readable and well organized, although understandably concise. The authors intentionally chose not to include references at the end of each chapter, although there is a bibliography of selected readings at the end of the text. An ample index of topics and key words is included at the end.

This is a remarkable text, not only for the extent and quality of its photographs, but also for the comprehensive nature of its coverage of the subject. It is clearly superior in the illustrative realm to most other atlases of oral mucosal disorders currently available. It is, however, considerably more expensive than most and thus would likely be considered more as a reference book rather than a working text in a personal library. For practitioners with an interest in oral medicine or clinical oral pathology, it would be of great value and relevance.

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ITI DENTAL IMPLANTS: PLANNING PLACEMENT, RESTORATION, AND MAINTENANCE

TG Wilson, Jr

Published by Quintessence Publishing Co, Inc, Chicago, 1993. 99 pages, 213 illustrations. $58.00, hard cover.

According to the preface, this book is designed for the clinician who wants a concise, useful introduction to the ITI system. The book is thoughtfully organized into eight chapters and contains a very brief list of references and a chapter on patient treatment presentations.

Chapter 1 begins by discussing the advantages of the ITI system, the different types of restorative components, and a brief discussion of the implant to bone interface materials. The next two chapters evaluate the critical areas of diagnosis and treatment planning. Excellent color illustrations are supported by indications, contraindications, and medical and dental histories.

Template fabrication and radiographic analysis are well covered, including indications of different radiographic techniques. Periodontal, endodontic, and orthodontic therapies as part of the treatment planning are also outlined.

Chapter 4 discusses principles of wound healing, anatomic regions and considerations that are critical to placement of the implants. This is followed by presurgical procedures, armamentarium, flap design, and surgical procedures, augmented by excellent photographs and illustrations.

Chapter 5 is dedicated to the use of guided tissue regeneration around implants. Good surgical and photographic techniques are presented when used at recent tooth extraction sites and mature sites.

Chapter 6 covers the prosthetic procedures. It is perhaps the weakest chapter in the book. While all aspects are covered, they are very brief and leave the reader with unanswered questions.

The impression technique could benefit from expansion and illustration. It is difficult for an inexperienced dentist to understand the laboratory procedures through this chapter.

The last two chapters, "Implant Maintenance" and "Treatment of Failing Implants," could have been more descriptive and illustrated.

Overall, this book provides good introductory information to the clinician who wants to get started in the ITI System. Some of the chapters are well written and illustrated, while other chapters require the clinician to make assumptions regarding clinical and laboratory procedures.

For the price, this book can be a valuable supplemental text for general dentists and those who are looking to enter the field of implant dentistry.

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ABSTRACT

The editor wishes to thank the second-year Advanced General Dentistry residents at US Army Dental Activity, Fort Knox, Kentucky, for their assistance in the preparation of this abstract.

Interferometric measurements of cusp deformation of teeth restored with composites. *Suliman AA, Boyer DB & Lakes RS (1993) *Journal of Dental Research* 72(11) 1532-1536.

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Cusp movement due to composite polymerization shrinkage was measured. The effects of cavity size, type of composite, and tooth hydration were examined. A Michelson interferometry apparatus permitted real-time measurements of buccal cusp displacement in extracted premolars with MOD composite restorations. In previous studies, the amount of contraction ranged from 18 to 45 μm. Two studies found the cusp movement to be sporadic, indicating possible microfracturing. A third study found the movement to be smooth. In this study the deformation was smooth and ranged from 10.8-45.7 μm. Most deformation took place within the first 5 minutes. Small cavities had less cusp movement than large cavities. Teeth restored with P-50 generally showed greater cusp movement than those restored with Heliomolar, although the results were not significant. The hydrated teeth had less cusp movement than dry teeth.

Polymerization shrinkage is one of the most important limitations of dental composites. Although this study did not evaluate the effects of incremental composite placement, other studies have shown this to be an effective method of distributing contraction strain in large cavities. The researchers speculated that hydration of a tooth may interfere with bonding and offset cusp movement by gap formation between the composite and tooth. Water absorption by the composite may also offset some polymerization shrinkage.

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