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

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EDITORIAL

Is the Cart before the Horse?

Dental schools are becoming increasingly dependent upon clinic income for their survival. Not many years ago, only private schools were faced with this problem, but these days, parent universities and/or state legislatures continually pressure dental schools to pay for themselves. Budget gurus look at all areas of dental education to see how increased revenue can be obtained, and thus have turned their attention to clinic income. Fees for dental service charged by schools have been rapidly increasing to the point where some services actually cost more than in some sections of surrounding communities. There is a yearly report that identifies income per student for every dental school. Frustration and finger pointing often occur for those in the middle or bottom portion of the list. The immediate response from these school administrators is, "Why are we not doing better?" The reason given at one school was that students were lazy and needed to be forced into the clinic. It worked. Students reported faithfully to their assigned clinic units. However, since there were no patients for them to see, they studied, read journals, and patiently put in their time. Another obvious area being targeted for increasing clinic income is increasing the number of weeks of clinic treatment. While this idea is sound on paper, without control of patients and appointments, the end result will backfire, because the percentage of unfilled appointments will go up and the extra cost for support by staff and faculty may be more than the generated income.

Of the other parameters needed to generate clinic income, the two I observe as missing or poorly controlled in many dental schools are patient management and use of assigned clinic time. It used to be that treatment in dental schools was inexpensive, which compensated for the extra time involved for patients. This is no longer true in many areas. Dental insurance has also enabled patients to afford treatment more easily by private practitioners. Consequently, fewer patients are entering our system. In addition to this, dental schools are finding that student use of assigned clinic time is less than optimum (unit utilization of 45% to 75% is common). Clinic income suffers when clinic space is not utilized. Some schools are giving patient scheduling to a receptionist, whose main job it is to make sure students have patients during their scheduled clinic time. These patients come from sources such as recalls, emergencies, etc. But these additional-hire receptionists have to come out of someone's budget. Unfortunately, they are often hired in lieu of additional dental assistants, even though these assistants would help expedite student treatment. Will the gains offset the additional costs? Only time will tell.

While all this seems to be wrapped up in a neat package, an important question needs to be addressed: "What about the student's regularly assigned patients?" A receptionist is not qualified to review records and make decisions on when and where to assign patients. In far too many dental schools, the handling of patients assigned to students is left to the discretion of the student. What results is that students graduate after 2 or more years of clinic experience with many in their patient pool left untreated. I used to participate in a program where my students had to bring in their patient records to discuss them. In over 90% of the cases I found that students had patients assigned to them, many for more than a year, about whose needs they had no idea. In many instances they had never seen the patient. Without controlling this parameter, having receptionists assign extra patients will further decrease the likelihood that regular, assigned patients will be seen. In the past I have had senior students tell me that, after 1½ years in the clinic, they were only treating 4 or 5 patients out of their assigned patient pool of 20 to 25. There was no time in their schedules to treat the rest. When asked why they didn't turn the untreated ones in so other students could pick up the treatment, I was told that they wanted to keep them in their group *just in case* something happened to their other patients!

Schools have instituted comprehensive care clinics, group practices, and other creative plans to increase clinic productivity and control patient management. Some of these have worked well, especially in the pilot project stage, where students receive concentrated help. However, what dental schools MUST realize is that one should not put the cart before the horse by increasing clinic sessions and assigning fill-in patients to students until a solid plan is in place that will ensure that patients already in the system are receiving their dental treatment in a timely manner.

RICHARD B McCOY
Editor

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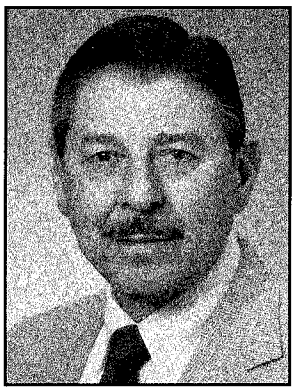
BUONOCORE MEMORIAL LECTURE

Michael Buonocore

The Amalgam-Tooth Interface

DAVID B MAHLER



INTRODUCTION

The discovery by Dr Michael Buonocore that acid etching enamel can produce a substrate that allows the bonding of resin systems ranks as one of the most significant innovations leading to improvements in restorative and preventive dental care.

An example of an ideal application of this innovation is shown in Figures 1 and 2. Before restoration the upper central incisors shown in Figure 1 had suffered a traumatic childhood injury. Some years later, these teeth were restored using Dr Buonocore's acid-etch technique together with composite resins that were commercially available at that time. The upper right incisor was restored with a coarse-particle composite, while the upper left incisor was restored with a microfill composite. Seventeen years after placement, these restorations are shown in their current condition in Figure 2. The restorations are still firmly bonded to the teeth. The extensive wear exhibited by the coarse-filled composite on the upper right incisor compared to virtually no wear exhibited by the microfill composite on the left incisor is a characteristic that has been confirmed in many clinical studies.

Although this represents an ideal application of a composite resin restoration, there are other applications where composite resins, in their present form, produce a less favorable result. A prime example would be a moderate-to-large restoration in a molar tooth, particularly if the restoration is subject to the action of an opposing cusp, and most particularly in a class 2 application where bonding to the gingival floor is tenuous at best. In this application, dental amalgam remains unsurpassed when considering clinical longevity, lack of technique sensitivity, and cost of placement.

Before starting on the topic of the amalgam-tooth interface, which is the primary subject of this paper, a few remarks about the longevity of amalgam might be in order. This is not about the longevity of amalgam restorations in clinical service, but about the longevity of amalgam usage in restorative dentistry. Dental amalgam has been the subject of intense criticism because of concerns about the effect of Hg from amalgam restorations on human health and the impact of amalgam use on the environment. Originally, it was the so-called anti-amalgamists who led the charge. However, due to dramatizations by the news media and the result of some foreign political actions, a small segment of the public and their dental health care providers presently believe that dental amalgam is no longer a safe or viable restorative material. Of more concern, in my view,

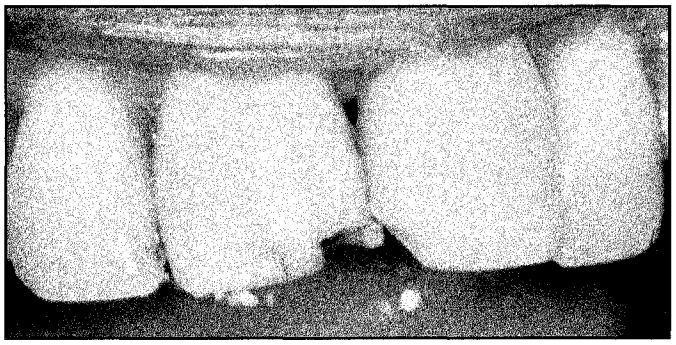


Figure 1. *Example of fractured upper incisors*

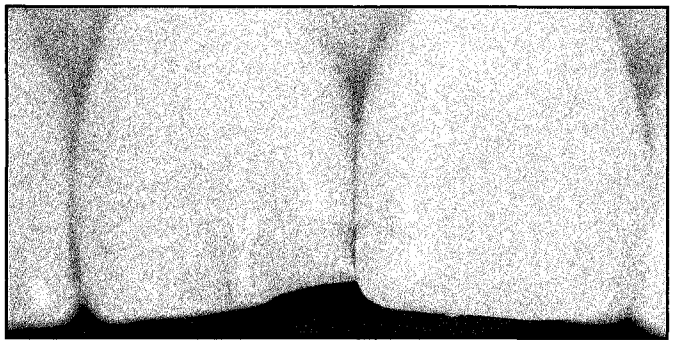


Figure 2. *Restored incisors in Figure 1 after 17 years of clinical service. Coarse-particle composite in upper right incisor and microfill composite in upper left incisor*

is the recent anti-amalgam stance taken by a few members of our research community whose justifications are undocumented assertions that dentists are responding to the demand by patients for tooth-colored restorations and that amalgam is rapidly being replaced by composite resins. These assertions are not supported by facts. Amalgam sales have not changed over the past 10 years, and a recent survey of over 8000 dentists showed that amalgam is favored over composites by a 4:1 ratio for class 2 restorations in both permanent and primary teeth (Clinical Research Associates, 1995).

Because there is no scientifically proven evidence to support a relationship between the presence of amalgam restorations and health problems, and until we have a long-lived, technique-insensitive, low-cost direct filling material for moderate-to-large restorations in posterior teeth, amalgam is still the best material for this restorative application.

IN VITRO MICROLEAKAGE TESTS OF AMALGAM ALLOYS

When amalgams are placed, there is a resulting gap between the amalgam and the prepared cavity walls. My interest in this gap was initiated some years ago when a high-copper all-spherical-particle alloy had been introduced and subsequently had become popular with the profession. Soon thereafter, departments of dental materials in dental schools began receiving calls from dentists about an increase in postoperative sensitivity associated with the use of this new alloy.

The hydrodynamic theory of Brännström and Åström (1972) offered an explanation for this phenomenon. This theory describes the filling of the interfacial gap with pulpal fluid shortly after the restoration is placed, and the movement and pressure changes of that fluid that cause excitation of nerve endings in the pulp. A thermal stimulus can exacerbate this response by changing the pressure and volume of the pulpal fluid in the gap. When the size of the gap is relatively large, postoperative sensitivity has been found to increase (Mahler & Nelson, 1994).

Initially, the setting dimensional change of this newly introduced spherical-particle amalgam was tested to determine if it might exhibit a relatively large setting contraction that would produce a large gap size, thus explaining the increased incidence of sensitivity. However, the dimensional change of this alloy was measured to be a negative 8 micrometers per centimeter, which was well within the ADA specification limit of ± 20 micrometers per centimeter; and similar to many alloys with which increased postoperative sensitivity had not been associated.

Based on these results, we speculated that dimensional change, as measured by the procedure of ADA Specification No 1, might not accurately reflect gap size in a clinical cavity preparation. We then developed a test procedure to measure the gap size directly. We borrowed the technique of Granath and Svensson (1970) for measuring microleakage using an air pressure device, microleakage being considered a direct measure of gap size. Amalgams were condensed into a simulated class 1 cavity prepared in a machinable ceramic mold (MACOR, Corning Glass Works, Corning, NY 14830). The cavity measured 4 millimeters in diameter by 4 millimeters deep (Figure 3). The filled mold was then placed into the

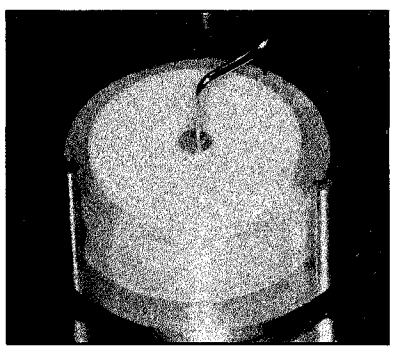


Figure 3. *Amalgam condensed into ceramic mold*

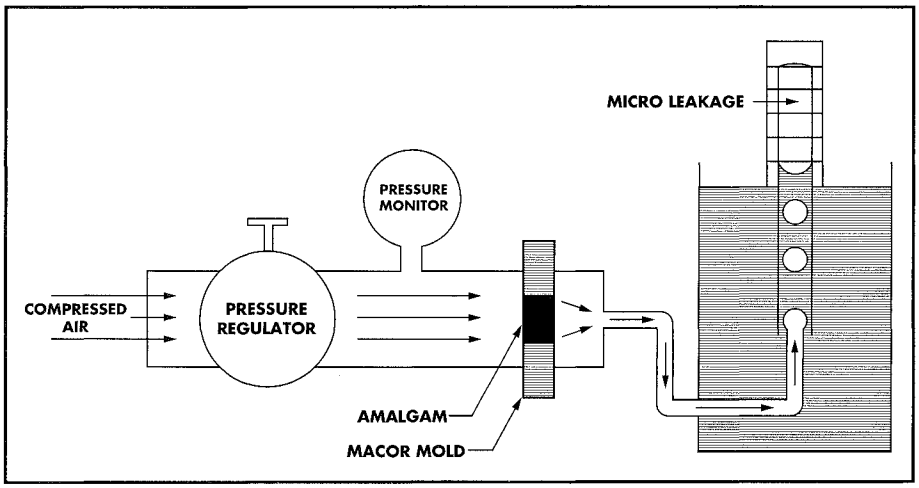


Figure 4. *Air pressure device for measuring microleakage of amalgam in ceramic mold* (Mahler BD, Nelson LW. Factors Affecting the Marginal Leakage of Amalgam. *JADA* 1984;108:52 Reprinted by permission of ADA Publishing Co Inc)

measuring device (Figure 4). Air at a pressure of 600 millimeter Hg was applied to the mold and any air passing through the amalgam-mold interface bubbled through the water chamber and was quantitatively measured in milliliters per minute.

When this test was applied to the newly introduced spherical-particle alloy and an admixed-particle alloy (a mixture of spherical and cut particles) with about the same contraction but exhibiting no evidence of increased postoperative sensitivity, the spherical alloy demonstrated 3-4 times the microleakage (gap size) compared to the admixed alloy (Figure 5). Based on these findings, the effect of various factors on microleakage was evaluated. These factors were mix plasticity, condensation force and technique, and burnishing (Mahler & Nelson, 1984). For both the spherical alloy and the admixed alloy, increased mix plasticity, increased condensation force, forces directed next to and toward cavity walls, and burnishing all decreased microleakage. Because manipulative procedures vary among practitioners, these results might explain why some practitioners had experienced an increased incidence of postoperative sensitivity when using this spherical particle-alloy while others did not.

Following this study, an evaluation was made of a large number of commercial alloys (Mahler & Nelson, 1994). These results are shown in Figure 6. The difference in microleakage among these 26 alloys was found to be remarkable. Spherical particle alloys as a group showed an increased propensity for microleakage even though the setting dimensional changes of these alloys were the same as alloys containing cut particles. In another study it was shown that the microscopic texture of the amalgam surface at the amalgam-tooth interface is much coarser for the spherical alloys than the admix alloys (Mahler & Nikutowski, 1989). This coarse texture may reflect microchannels on the surface of the amalgam at its interface with tooth structure through which microleakage can more readily occur.

These results should not be used to condemn all spherical alloys, particularly those exhibiting relatively low microleakage values. However, for those spherical alloys exhibiting high microleakage values, mix plasticity, and condensation technique are critical. From a practical standpoint, if addressing these measures fails to reduce postoperative sensitivity, then a change to another alloy system would be indicated.

In Figure 6 the three shaded bars (B,C, and G) represent conditions for which there was clinical evidence of postoperative sensitivity. For alloy B, a practitioner had made an error in proportioning a spherical alloy that produced a very dry mix and a microleakage value of 21.6 ml/min. Almost all teeth restored using this reduced plasticity mix (dry mix) exhibited postoperative sensitivity. When more Hg was added to produce a mix of proper plasticity, postoperative sensitivity was eliminated. Alloy C was a commercial alloy being investigated in our clinical research facility for marginal fracture characteristics. Despite the use of two coats of cavity varnish, 10 of the first 15 restorations placed resulted in postoperative sensitivity. Needless to say, we stopped placing this alloy. The microleakage for this alloy was 14.4 ml/min. Alloy G is the spherical alloy mentioned previously in which increased sensitivity has been reported, but not by all practitioners. The microleakage value for this alloy was 3.5 ml/min. This value might serve as a limiting value above which increased sensitivity due to microleakage would be probable.

Most cases of postoperative sensitivity are resolved within a few weeks, presumably due to the reduction

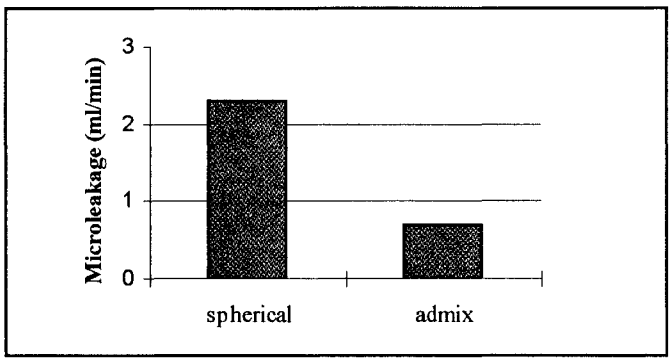


Figure 5. *Microleakage of a spherical-particle alloy and an admix-particle alloy*

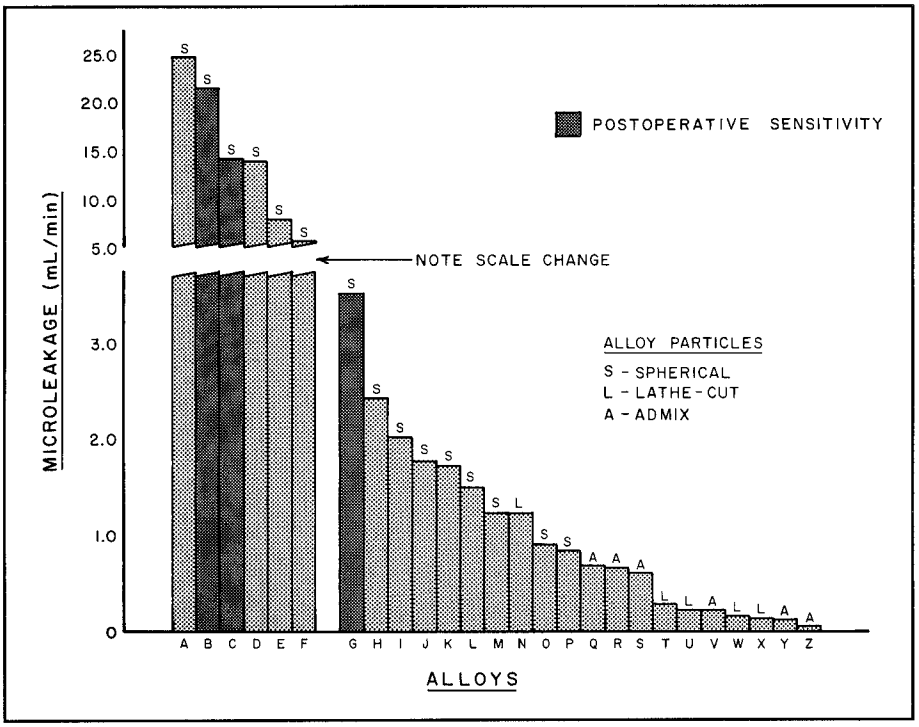


Figure 6. *Microleakage of 26 amalgam alloys. Note the increased microleakage associated with spherical particle alloys and the three shaded bars for alloys for which there was evidence of postoperative sensitivity.* (Mahler DB, Nelson LW. Sensitivity Answers Sought in Amalgam Alloy Microleakage Study. *JADA* 1994;125:285. Reprinted by permission of ADA Publishing Co Inc)

of leakage caused by the formation of corrosion products that form within the interfacial gap. However, this process can be variable, depending on the nobility of the alloy used and the initial gap size. The short-term resolution of postoperative sensitivity, which is often observed, might be better explained by the effect of plasma and salivary constituents on reducing dentin permeability, which can reduce fluid flow (Pashley, Nelson & Kepler, 1982). However, there may be a limit to gap size for this latter mechanism so that resolution of postoperative sensitivity for alloys exhibiting large initial gap sizes may have to wait for the formation of corrosion products.

IN VITRO EVALUATION OF AMALGAM BONDING AGENTS

The presence of a gap at the amalgam-tooth interface has significance other than initial postoperative sensitivity. Bacteria and their toxins can penetrate the gap and give rise to secondary caries as well as pulp pathology. The gap implies no bonding between amalgam and tooth structure. Therefore, the strength of the prepared tooth is not enhanced by the presence of amalgam. These problems together with the advent of adhesive dentistry have recently generated a proposed solution in the form of adhesive agents that can bond amalgam to the tooth. Laboratory studies have shown reductions in microleakage and some measure of increased strength and stiffness of teeth restored with bonded amalgam (Varga, Matsumura & Masuhara, 1986; Eakle, Staninec & Lacy, 1992; Ario & others, 1995).

When bonding two fixed substrates with an adhesive agent that contracts on setting, failure can occur at the interface between the adhesive and either of the two substrates, within the substrates, or within the adhesive itself. In the case of amalgam and tooth structure, if failure occurred at the amalgam-adhesive interface but the adhesive remained bonded to the tooth, dentin tubules would be sealed and postoperative sensitivity due to the hydrodynamic effect would be negated. In time, corrosion products would then fill the interface between amalgam and adhesive. Although the prepared tooth would not be strengthened under these circumstances, postoperative sensitivity would be reduced or eliminated and the tooth would be protected from the decalcifying action of caries-producing bacteria.

If the adhesive remained bonded to the amalgam and if bond failure were to occur at the adhesive-tooth interface, then a number of problems could arise. Dentin tubules would not be sealed and postoperative sensitivity could occur. The prepared tooth would not be strengthened, and bacteria could infiltrate between the adhesive surface and unprotected dentin. Essentially, the amalgam restoration would be isolated from the tooth by a polymeric layer. Metallic ions from the amalgam would not be present in the gap between the adhesive and tooth structure and sealing with corrosion products would probably not occur. Studies have shown an increased incidence of secondary caries with direct composite resins compared to amalgam (Mjör & Jokstad, 1993). This suggests that when polymeric materials do not seal the cavity, there is significant bacterial activity at the unsealed interface, and decalcification is likely to occur.

SEM examination of bond failures between bonded amalgam and tooth structure have revealed that the weak link is at the amalgam-adhesive interface (Santos & Meiers, 1994). If debonding from the amalgam did occur, the tooth would be protected—provided of course, that the adhesive remained

completely bonded to all areas of the cavity preparation.

For the placement of most amalgam bonding agents, it is recommended that the amalgam be condensed into the partially set adhesive immediately after the adhesive is applied to the cavity preparation. Presumably, this ensures close adaptation and wetting of the amalgam by the adhesive. However, the action of condensing the amalgam could displace the adhesive and remove it from some tooth surfaces, thereby leaving the tooth unprotected. Whether this does or does not occur would depend on the characteristics of the bonding agent, the kinetics of the polymerization reaction, and the integrity of the adhesive-tooth bond at the time of amalgam condensation.

Our own studies on amalgam bonding agents (Mahler, Engle & Adey, 1992) utilized the same mold that was used for our leakage studies, which has been previously described. The bonding agent was applied to the mold surface, and amalgam was immediately condensed into the mold cavity. After 24 hours, force was applied to unseat the amalgam from the slightly tapered mold. This force was taken to be a measure of the bond strength of the bonded amalgam.

Because studies of bond failure show the amalgam-adhesive interface to be the weak link in bonding amalgam, the ceramic mold was etched with a dilute hydrofluoric acid solution to ensure that failure would occur at the amalgam-adhesive interface. The advantage of using the ceramic mold was that after amalgam placement, microleakage could be measured first, followed by applying and recording the force to remove the bonded amalgam. This method was employed to evaluate the following bonding agents and cavity liners: 1) no liner; 2) Copalite (H J Bosworth, Skokie, IL 60076); 3) Barrier (Teledyne Getz, Elk Grove Village, IL 60007); 4) Amalgambond (Parkell, Farmington, NY 11735); 5) All-Bond Bonding Resin (Bisco, Itasca, IL 60143); 6) All-Bond Liner F (Bisco); and 7) Panavia (Kuraray/J Morita, Tustin, CA 92680).

The results for both microleakage and removal force are shown in Figure 7. For each material, the height of the bar indicates the force required to remove the amalgam from the mold. The numbers on top of each bar indicate the number of specimens out of a sample of five that demonstrated significant microleakage.

As might be expected, the no-liner condition exhibited no resistance to removal, and five out of five specimens leaked significantly. Copalite also showed no resistance to removal force, while two out of five specimens leaked. Amalgambond and Barrier exhibited very low resistance to removal force, and both showed significant microleakage in nine out of 10 specimens. All-Bond bonding resin exhibited good resistance to removal, but all five specimens leaked. Apparently, this bonding agent bonded strongly to some areas but separated at other areas of the amalgam-adhesive interface, resulting in significant microleakage. All-Bond Liner F showed a similar behavior. Panavia showed the strongest bond and also showed no microleakage in these tests.

CLINICAL EVALUATION OF AN AMALGAM BONDING AGENT

At this point, the question was raised whether these in vitro test results would prevail in the clinical environment. A clinical research project was initiated to address this question (Mahler & others, 1996). There are several applications of bonding amalgam in restorative dentistry. These include core build-ups, repair of fractured restorations and teeth, and large multisurface restorations. However, we chose to limit our study to the application of bonding in traditional class 1 and 2 restorations, which constitutes the major use of amalgam as a restorative material. Because clinical studies are difficult to conduct, particularly in regard to patient availability, the initial study was limited to one bonding agent-alloy combination. However, the bonding

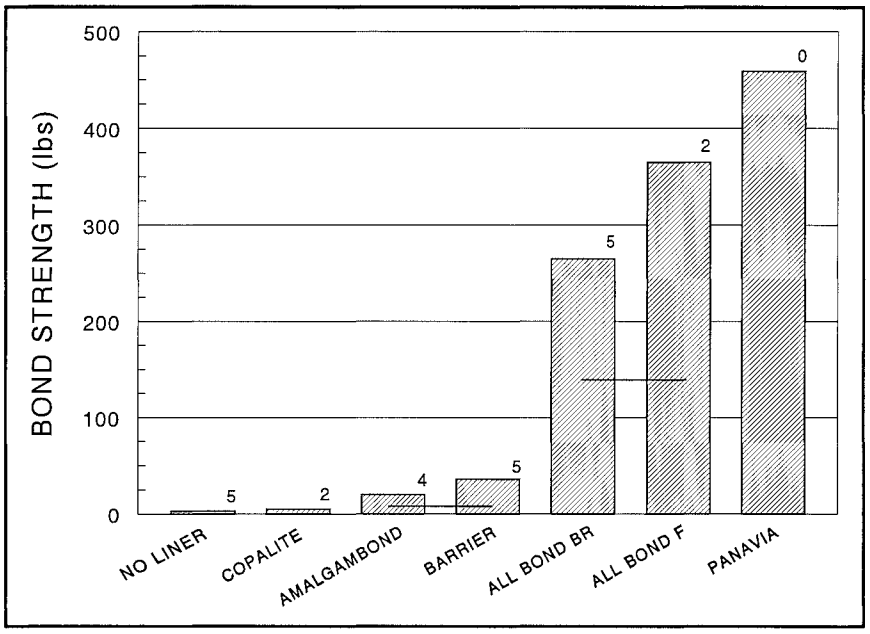


Figure 7. *Bond strength and microleakage of amalgam in ceramic molds lined with various liners and bonding agents*

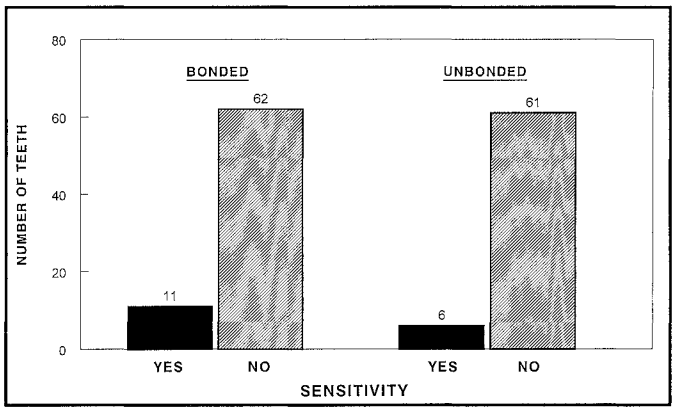


Figure 8. *The chi-square test showed no significant difference in postoperative sensitivity between bonded and unbonded restorations.* (Mahler DB, Engle JH, Simms LE, Terkla LG. One-Year Clinical Evaluation of Bonded Amalgam Restorations. *JADA* 1996;127:347. Reprinted by permission of ADA Publishing Co Inc)

agent selected (Panavia 21) showed the best properties for bond strength and microleakage in the in vitro tests. Therefore, the potential for amalgam bonding success in the clinical environment could be fairly tested.

The two characteristics evaluated in this study were postoperative sensitivity and marginal fracture. Postoperative sensitivity was recorded at the polish recall approximately 1 week after placement of the restoration and was assumed to be a reflection of the ability to seal dentin tubules. Marginal fracture was selected to evaluate the structural effectiveness of the bond under clinical conditions. If the amalgam was bonded to tooth structure, structural reinforcement would be provided, and one would expect less marginal fracture than would be the case for unbonded restorations.

The initial results of this clinical study are shown in the next two figures. In Figure 8, the numbers of teeth exhibiting postoperative sensitivity for both bonded and unbonded restorations are shown. Although the bonded condition appears to show more sensitivity than the unbonded condition, a chi-square test failed to detect a statistical difference.

Despite these results, there are reports from some practitioners that bonding has reduced sensitivity in their patients. An explanation for these anomalous findings could be related to either a difference in bonding agents or to the lack of scientific controls in clinical practice. However, if the results in these reports are indeed valid, then the profession would benefit from controlled clinical studies conducted on selected bonding agents to confirm these findings.

In the case of marginal fracture, the results at 1 year of clinical service are shown in Figure 9. Bonded and unbonded restorations were placed in 26 patients. Marginal fracture was quantitatively determined by comparing occlusal photographs of the test restorations to a scale of photographs depicting increasing amounts of marginal fracture (Mahler & Marantz, 1979). For each patient, the difference in marginal fracture between bonded and unbonded restorations was determined and plotted on this bar graph.

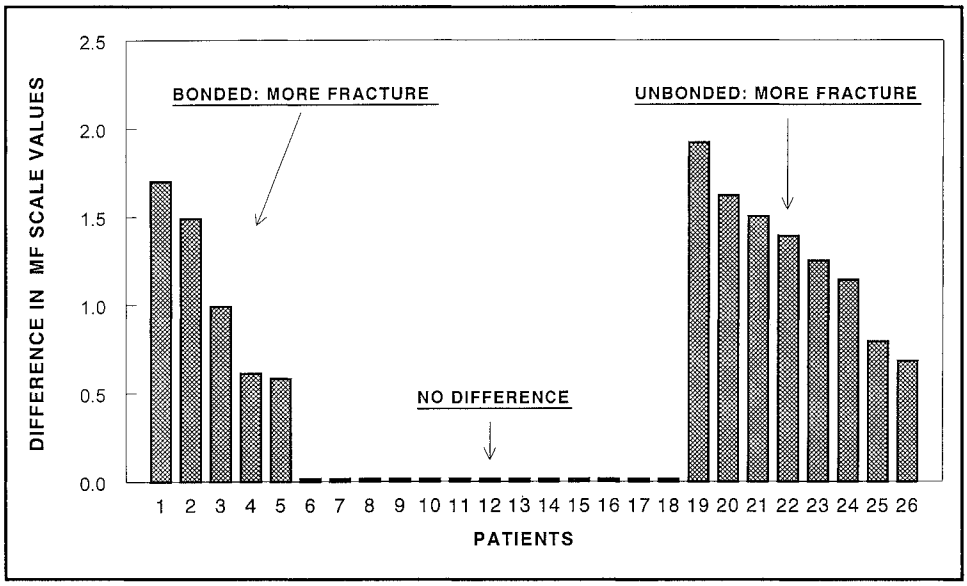


Figure 9. *The paired t-test showed no significant difference in marginal fracture between bonded and unbonded restorations.* (Mahler DB, Engle JH, Simms LE, Terkla LG. One-Year Clinical Evaluation of Bonded Amalgam Restorations. *JADA* 1996;127:347. Reprinted by permission of ADA Publishing Co Inc)

For ease of presentation, numbers were assigned to patients in accordance with the difference in marginal fracture between bonded and unbonded restorations. In patients numbered 1-5, the bonded restorations showed more fracture; in patients numbered 6-18, there was no difference in marginal fracture between bonded and unbonded restorations; and in patients numbered 19-26, the unbonded restorations showed more marginal fracture. Despite what appears to be an advantage to bonding, statistical testing using a paired *t*-test failed to show a difference between the marginal fracture behavior of bonded versus unbonded restorations. Because these are 1-year results, it would be prudent to wait for the 2- and 3-year results as well as the results of testing other bonding agents before generalizing that bonding is not effective in the

clinical environment for class 1 and class 2 restorations in posterior teeth. However, the lack of positive results from this clinical study suggests caution in making a decision on bonding traditional amalgam restorations at this time.

Other factors to be considered when using bonding agents are problems associated with handling these materials. To start with, what might be described as an annoying factor is the adhesive adhering to the condensing instrument during placement. Furthermore, most of these materials are in the unset stage when amalgam is condensed into the cavity preparation and can be displaced onto tooth surfaces and incorporated within the amalgam itself. Adhesive present on occlusal as well as interproximal tooth surfaces is difficult to remove, and its presence can enhance plaque retention. Because the bond strength of these bonding agents to amalgam is considerably less than the cohesive strength of amalgam, adhesive resin within the amalgam restoration in areas of high stress (isthmus of class 2 restorations, marginal areas, and marginal ridges) can weaken the structure. Added to these problems are the cost of the bonding agent itself and the overall increase in operator time associated with its use.

CONCLUSIONS

The interface between amalgam and tooth structure was examined and the results of several related studies were presented. The findings can be summarized as follows.

1. When the size of the gap at the interface between amalgam and tooth structure is relatively large, postoperative sensitivity can be pronounced.
2. The size of the interface gap as measured by microleakage tests varies among alloys, with spherical alloys as a group exhibiting more microleakage than alloys containing cut particles.
3. The size of the gap can be reduced by using mixes of adequate plasticity and good condensation technique.
4. Amalgam bonding agents show potential for benefits based on laboratory test results. However, evidence of benefits for their use in traditional class 1 and class 2 clinical restorations has yet to be demonstrated in scientifically controlled studies.

(Delivered 22 February 1996)

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ORIGINAL ARTICLES

State of the Art of Tooth-colored Restoratives

F LUTZ

Clinical Relevance
Critical assessment of tooth-colored restoratives and adhesive dentistry is mandatory if dentists are to make the transition into the postamalgam age without loss of quality treatment for their patients.

INTRODUCTION

Currently dentistry is characterized by the fact that the amalgam age is fading (BIAM, 1994). Certainly this is progressing at different rates in different parts of the world; nonetheless, the countdown on the amalgam age is running. Operative dentistry is on the threshold of the postamalgam age, which is based on tooth-colored restorative materials and adhesive dentistry (Krejci & Lutz, 1995). Health insurance companies, national dental societies, dentists, and patients all favor a smooth transition from the amalgam age into the postamalgam age without disadvantages to oral health care for the population. This transition is critical and necessitates careful consideration. This paper will assess critically the state of the art of tooth-colored restoratives and adhesive dentistry in operative dentistry as they exist today.

AMALGAM SUBSTITUTES

Basically there are two different classes of tooth-colored restorative materials: amalgam substitutes and amalgam alternatives (Lutz & Krejci, 1993). Amalgam substitutes are metal-free restorative materials that are supposed to replace amalgam on a 1:1 basis (Table 1). Consequently, their definition is skill level- and expenditure-oriented. On purpose, neither marginal quality nor wear resistance are mentioned, besides the fact that compomer restorations should last as long as amalgam restorations. In addition, to keep the risk of secondary caries as low as possible and to allow more conservative restorations, caries-protective properties and strong bonding valences are mandatory requirements. The envisaged indications for amalgam substitutes are the same as those for amalgam. In premolars and molars box-shaped cavities of the class 1, 2, and 5 types should be compatible with and appropriate for the use of amalgam substitutes. In addition, the placement of adhesive class 5 fillings must also be possible with amalgam substitutes (Krejci & Lutz, 1995) (Figure 1). It is claimed that light-curing compomers have this potential.

Compomers are glass-ionomer cement or polyacid-modified amphiphilic resin composites (Rusz & others, 1992; McLean, Nicholson & Wilson, 1994; Sidhu & Watson, 1995). The cement fraction improves the polymerization kinetics of the resin composite: polymerization shrinkage is quantitatively slightly diminished, timewise somewhat retarded, and the stress build-up is significantly reduced (Crim, 1993; Unterbrink & Muessner, 1995). The acid/base reaction is initially nonexistent (McLean & others, 1994). It sets in simultaneously with the gradual water sorption, but is confined to a thin top surface layer. Apart from the release of fluoride, the influence of the glass-ionomer fraction on the material properties is not fully understood (Imai & Suzuki, 1994). Bonding is preferably provided by a one-component self-conditioning adhesive that has in a first application the characteristic of a self-conditioning primer; when subsequently cured, it also functions as an adhesive. In a second application it has the property of an amphiphilic adhesive (Lutz,

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Table 1. Amalgam Substitutes: Requirements

Ease of manipulation
Low costs
Amalgam-like longevity
Caries-preventive properties
Strong bonding valences

Krejci & Schupbach, 1993; Triana & others, 1994; Krejci & Lutz, 1995; Powers & You, 1995; Swift, Perdigao & Heymann, 1995). Two compomers—Compoglass (Vivadent, Schaan, Liechtenstein) and Dyract (DeTrey/Dentsply, Konstanz, Germany)—are commercially available, but other products, possibly with significantly different chemical compositions, based more on a resin composite-like formula will undoubtedly follow.

Evaluating the clinical potential of compomers is rather complex, because there is no quantitatively assessable quality standard. Currently, the only measurable requirement is that the longevity of compomers should match that of amalgam, which itself differs widely, as shown in a recent literature review (Barbakow & others, 1994). Nonetheless, the clinical potential of compomers can probably be determined from their occlusal wear in stress-bearing fillings and their marginal adaptation. The former is claimed to be similar to amalgam (Lutz & Krejci, 1994). In contrast to amalgam alternatives, compromises in marginal quality are possible if no restrictions are set regarding indications and restoration longevity due to an increased risk for secondary caries. In the in vitro wear test (Krejci, 1992), where the maximum loss of substance was

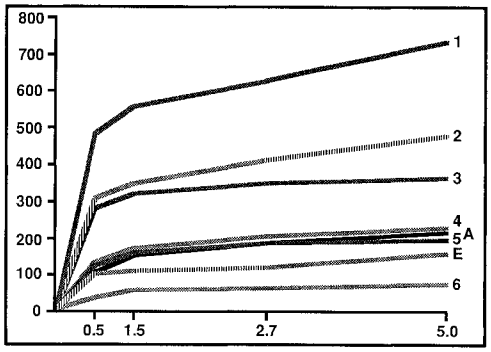

Figure 2. *Graph showing total wear expressed as the sum of the maximum vertical loss of substance (μm) in the occlusal contact area of both the MOD filling + the antagonistic enamel cusp at in vivo equivalents of 0.5, 1.5, 2.7, and 5.0 years of function: 1 = Photac Fil; 2 = Ketac Silver; 3 = Vitremer; 4 = Dyract; A = amalgam (Dispersalloy); 5 = Compoglass; E = enamel; 6 = Brilliant EL.*

assessed in both the occlusal contact point area of the occlusally loaded restoration and the antagonistic enamel cusp, the wear of Compoglass and Dyract against enamel was similar to that of Dispersalloy against enamel (Figure 2), but higher than the total wear of enamel against enamel. However, the wear pattern in the occlusal contact area, characterized by concentric circular fracture lines, was anything but promising and indicated a limited longevity of stress-bearing compomer restorations in permanent teeth, at least at that point in time (Sagesser & Krejci, 1992). Marginal adaptation assessed by the percentage of continuous margin, which ideally should be as close as possible to 100%, was 90% or more and thus almost perfect after restoration placement, both in vivo and in vitro. This high quality of marginal adaptation seems to be stress-

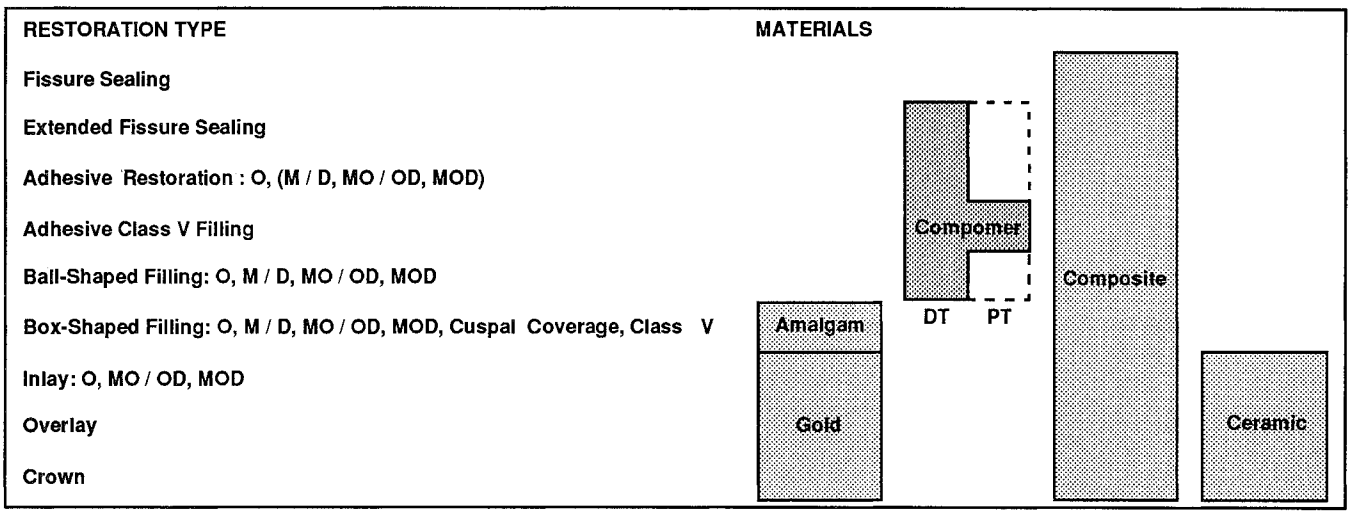

Figure 1. *Diagrammatic indications of amalgam, gold, compomers, composites, and composite and ceramic inlays/overlays/crowns; DT = deciduous teeth; PT = permanent teeth.*

Table 2. Amalgam Alternatives: Requirements

Patient-related	Dentist-related
• Esthetics	• Ease of manipulation
• Stress-proof marginal adaptation	• Radiopacity ≥ enamel
• Wear resistance and form stability	• Finishability and repairability
• Amalgam-like longevity	• Nondestructive replaceability
• Adequate self-care	• Maintenance care

resistant in stress-bearing fillings in primary teeth and in class 5 fillings, even with margins in dentin (Krejci & others, 1994c; Reich & Volkl, 1994; Elderton & others, 1995; Flessa & others, 1995; Jedynakiewicz, Martin & Fletcher, 1995; Roeters, 1995). In these studies the percentage of continuous margin remained above 80% after in vitro and in vivo stressing. In stress-bearing fillings in permanent teeth, however, the percentage of marginal openings was as high as 80% after stressing in vitro (Sagesser & Krejci, 1992). These findings have been confirmed by clinical studies. At this stage of development, compomers are not indicated as stress-bearing fillings in permanent teeth. The currently available clinical results are favorable for both class 1 and 2 fillings in primary teeth and class 5 fillings in permanent teeth, if the material was used correctly (Krejci & others, 1994c; Reich & Volkl, 1994; Elderton & others, 1995; Flessa & others, 1995; Jedynakiewicz & others, 1995; Roeters, 1995). Therefore, based on the current lab and clinical findings, compomers can be considered as true substitutes for light-curing glass ionomers, amalgam substitutes in primary teeth, excellent long-term temporary restoratives in permanent teeth, and new, promising luting materials (Figure 1) (Croll, Killian & Helpin, 1993; Krejci & others, 1994c; Croll & Helpin, 1995; Jung, 1995; Krejci & Lutz, 1995).

AMALGAM ALTERNATIVES

Tooth-colored amalgam alternatives include composite fillings, all types of intracoronal workpieces, and crowns made of composites or ceramics. Resin composite fillings comprise preventive resin restorations, better termed extended fissure sealants, all types of box-shaped class 1 and 2 fillings, and traditional or adhesive class 5 fillings (Figure 1). The definition of an amalgam alternative is quality oriented (Table 2). Besides the material properties, amalgam alternatives also demand an active contribution from both the recipient and the clinician. This includes an adequate home-based self-care program with daily flossing or interproximal brushing and long-term professional restoration maintenance. High esthetics and longevity have their price; ease of manipulation is wishful thinking, at least at the current state of development.

Any thought about amalgam alternatives is futile without first precisely defining the envisaged quality of tooth-colored restorations. While patients expect tooth-colored restorations to be invisible, the polymerization shrinkage (Watts, 1992; Uno & Shimokobe, 1994) and the lack of any caries-protective potential of composites (Imazato & others, 1994) are cause for concern by the profession. Therefore, it is important to ensure a high quality and an excellent durability of marginal adaptation. This means that the amount of continuous margin at any time at any restoration site with margins in enamel and dentin should be ≥ 90% and ≥ 80% respectively. Furthermore, a rating less than alpha in the clinical evaluation (Ryge & Cvar, 1971) is not acceptable. And finally, regarding restoration longevity, the wear resistance must be similar to that of enamel (Krejci, 1992).

The required excellent marginal adaptation can routinely be achieved, as shown by several clinical studies in which replicas of restorations were taken and then quantitated by SEM (Krejci, Besek & Lutz, 1994a; Gschall, 1995; Krejci, Oddera & Lutz, 1995). These findings have not only been documented in university studies, but also in private practices and in clinical courses for students. The latter is proof that dentists unburdened by the traditional mechanistic amalgam thinking can place tooth-colored restoratives perfectly well if properly motivated and directed. The types of restorations in Figure 1 are fully covered by tooth-colored metal-free restoratives. The studies listed above also indicate that there is no difference in quality between restorations placed in the upper or lower jaw. Furthermore, the size of the restoration does not affect the quality, nor is it important whether the margins are in enamel or dentin (Krejci & others, 1994a; Gschall, 1995; Krejci & others, 1996).

Marginal adaptation with tooth-colored amalgam alternatives is critical yet difficult to achieve. A specific clinical protocol must be followed to ensure a 90% or higher score for a stress-resistant continuous margin. This means that a well-defined and clinically tested concept must be available. A principal research goal of the Department for Preventive Dentistry, Periodontology, and Cariology at the University of Zurich School of Dentistry, Switzerland, during the last 20 years was to plan and finalize such a clinical protocol for all types of tooth-colored metal-free restoratives. The restorative concept was definitively formulated and integrated into the Dental School's curriculum in 1991, following major breakthroughs in composite wear (Krejci, 1992; Suzuki & Leinfelder, 1993) and adhesion to dentin (Lutz &

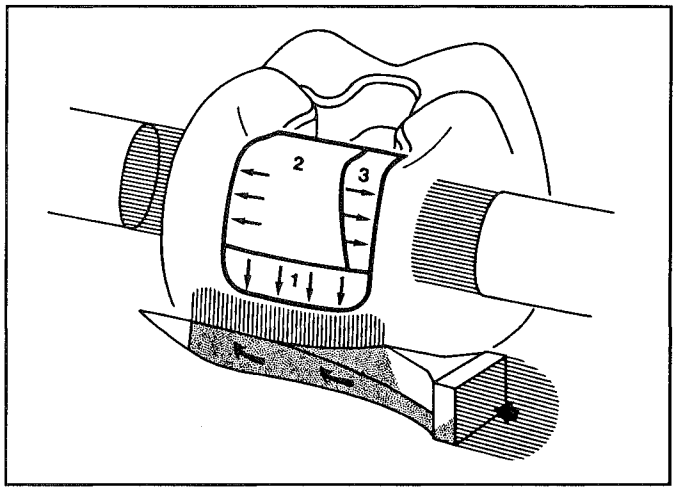

Figure 3A. *Schematic representation of the three-sited light-curing technique. The first increment is cured indirectly through the laterally reflecting light wedge, the larger second increment, and the smaller third increment from the buccal and lingual directions respectively. This ensures that the shrinkage vectors run toward the cavity margins. The occlusal cavity is filled by placing two to three increments, vertically layered.*

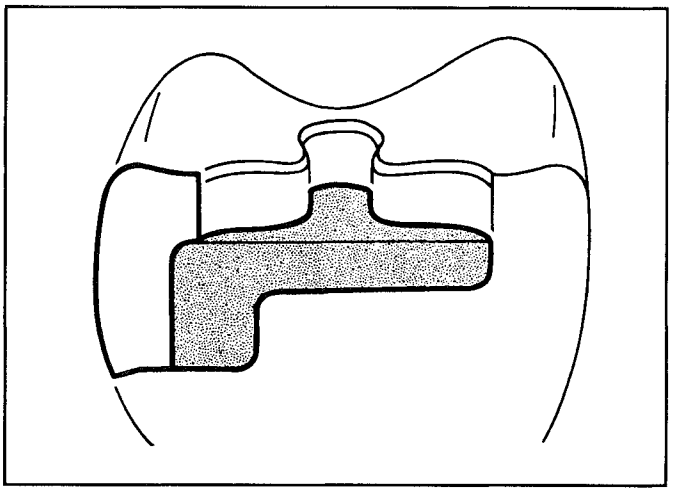

Figure 3B. *Schematic diagram of a built-up unetched glass-ionomer base. The cavity preparation with blunted occlusal margins is diminished, thus reducing the total amount of polymerization shrinkage of the resin composite. The surface-to-volume ratio is increased, which better compensates for the polymerization shrinkage volume.*

others, 1993; Van Meerbeek & others, 1994) after 2 years of clinical testing. The same concept has been integrated into a series of continuing education courses for private practitioners (Krejci & Lutz, 1995).

Direct Fillings

In class 1 and 2 box-shaped cavities excellent marginal adaptation is achieved by using the three-site light-cure technique in the approximals and a vertical layering technique in the occlusals (Figures 3A&B) (Lutz, Krejci & Oldenburg, 1986). The key elements of the placement technique for direct fillings are based on the following operative measures:

(1) cavity preparation as conservative as possible using 100 µm diamond preparation burs and minimizing any cut back of enamel, caries removal with round burs; (2) spot-lining where a therapeutic liner is necessary (Krejci, Lutz & Krejci, 1988); (3) placement of a build-up base using a light-curing glass-ionomer cement to reduce the cavity size and to enlarge the free surface-to-volume ratio (Lutz & others, 1986; Krejci & others, 1988); (4) preparation of sharp-edged fracture-free cavosurface margins with 25 µm finishing diamond burs (Reller, Geiger & Lutz, 1989); (5) blunting of the cavosurface margins in the occlusals by using flexible disks; (6) selective bonding by confining the adhesion to the margins in enamel and dentin; wet finishing of the base using a 25 µm finishing diamond bur and copious water spray; no etching of the base, thereby avoiding a bond between the base material and the composite filling; thus, the inner surface of the filling remains free, ensuring a better flow and less stress build-up during polymerization (Krejci & others, 1988); (7) use of self-retaining transparent matrices and laterally reflecting transparent wedges (Lutz, Krejci & Barbakow, 1992a,b; Unterbrink & Muessner, 1995); (8) guided polymerization of each increment with indirect light-curing procedures to ensure synergism between shrinkage and adhesive vectors (Lutz & others, 1986); (9) nondestructive finishing and polishing using fine diamond burs, flexible disks, and bristle brushes impregnated with abrasives (Lutz, Setcos & Phillips, 1983; Krejci, Lutz & Boretti, 1996); (10) topical application of fluoride after the finishing procedure. An additional key to clinical success is the use of close product chains that include a fine hybrid resin composite for direct use, an inlay material for indirect use in conjunction with a luting composite, and a clinically highly efficient adhesive system. The latter is not compellingly always associated with a high bond strength in vitro. However, it ensures a 90% or more continuous margin with restoration margins in enamel and 80% or more with restoration margins in dentin. These high scores are achieved immediately after placement and also after stress exposure, in both lab and clinical trials. In vitro and in vivo studies carried out at the Zurich Dental School indicate that only six product chains allow the placement of excellently adapted, and in regard to the marginal quality and occlusal wear, stress-resistant restorations (Airoldi, Krejci & Lutz, 1992; Krejci, Kuster & Lutz, 1993; Lutz & others, 1993; Krejci & Lutz, 1995). The six include

the Brilliant line (Coltène, Altstätten, Switzerland), the Charisma line (Kulzer, Wehrheim, Germany), the Clearfil line (Kuraray, Osaka, Japan), the Prodigy line (Kerr, Glendora, CA 91740), the Tetric line (Vivadent), and the TPH line (DeTrey/Dentsply). Both the Clearfil and the Prodigy lines use a filled adhesive and are consequently incompatible with the inlay technique.

Two important points are required to ensure clinical success when margins are in dentin. The adhesive needs time to penetrate the primed dentin, which may be totally or partially demineralized. Therefore, the clinician must allow a precuring penetration time of 20 seconds (Burrow & others, 1993; Yanagawa & Finger, 1994). Furthermore, no dentinal adhesive is currently available that does the trick without separate intensive curing before the composite is inserted (McCabe & Rusby, 1994; Yanagawa & Finger, 1994). Finally, according to basic physical and chemical laws, the minimum curing time is 40 seconds (Lutz, Krejci & Frischknecht, 1992d; Yanagawa & Finger, 1994).

The clinical procedure is different for class 5 lesions. It has been frequently shown that an excellent marginal adaptation in class 5 fillings is incompatible when using a base material (Krejci & others, 1988; Krejci, Lutz & Perisic, 1992b). Consequently, the principle to adopt is that of total bonding; bevelling the enamel margins is undisputed. Furthermore, if necessary, the preparation can be kept minimal because mechanical retentions are ineffectual. Studies on adhesion to dentin have also shown that the hybrid layer is generally thicker and easier to generate on dentin where the tubules are perpendicular to the free surface. In contrast, tubules that are parallel to the free surface form an absolute barrier and prevent penetration of conditioners or self-conditioning primers. Interdiffusion by the adhesive is also hampered because there is no direct access through open tubules into the partially or totally demineralized dentin (Harnirattisai & others, 1993; Schuepbach, Krejci & Lutz, 1994). Consequently, if a box-shaped cavity already exists, both enamel and dentin margins must be bevelled. In erosion or V-shaped lesions, cavity preparations can be limited to finishing only the margins, while a saucer-shaped preparation suffices in carious lesions. Again, the adhesive must be precured before inserting the resin composite. An incremental technique is not a prerequisite for excellent marginal adaptation, but may enhance color match by using different shades apically and incisally (Krejci & others, 1992b; Mangum & others, 1994). The results of clinical studies prove that the principle of total bonding works almost perfectly in class 5 cavities with margins in dentin (Hansen, 1992; Duke, Robbins & Treviño, 1994; Ferrari & others, 1994; Flessa & others, 1994; Krejci & others, 1996).

Inlays, Overlays, and Crowns

The question is now how far the indications for resin composite fillings extend. Lab and clinical studies have repeatedly shown that neither size, localization in molars, nor margins in dentin restrict the indication for direct composite fillings (Krejci & others, 1994a; Gschall, 1995). The main limiting factor is the complexity of the filling to be placed. Thus, besides special conditions such as bruxism, a major contraindication is the clinician's skill and knowledge, and this varies from individual to individual. Consequently, laboratory-processed resin or ceramic inlays or onlays are indicated whenever a complex restoration must be placed, when the access is limited, or when maximum esthetics is demanded (Krejci & Lutz, 1995). Composites are promising inlay-onlay materials because of the ease of the laboratory techniques, the low laboratory investments, the high esthetic quality, and the low costs (Oram & Pearson, 1994). It is therefore logical to assume that crown systems based on resin composites will soon be marketed in Europe.

Inlays always have two interfaces, one between the luting resin composite and the workpiece and the other between the luting composite and the tooth structure. The initial marginal adaptation of ceramic inlays is very good in all restoration sites. However, under load, the marginal quality deteriorates, particularly gingivoproximally in enamel, where very fine fracture lines form (Krejci, Lutz & Reimer, 1993b). Teeth are bent and barreled when mechanically loaded, and these deformations cannot be followed by ceramics because of their physical properties. Consequently, ceramic inlays cannot absorb impact stresses, resulting in a stress build-up along the gingivoproximal margins (Krejci & others, 1993b). Although these microscopic findings are nonetheless compatible with clinical success, ceramic proponents should address this problem with the objective of developing a more resilient glass or glass ceramic. A restorative material should ideally have the physical properties of dentin and the wear resistance of enamel. This has been proved by the excellent clinical performance of resin composite inlays concerning their marginal adaptation (Krejci, 1992). In vitro tests using an experimental material have shown that a resilient glass will adequately absorb impact stresses or occlusal loads, resulting in an excellent marginal adaptation (Marti, Krejci & Lutz, 1996).

Inlays made of fine hybrid resin composites initially show an excellent marginal adaptation. However, the marginal adaptation may also be influenced by the luting resin composite and the adhesive system used. In contrast to ceramic inlays, the marginal quality of fine hybrid composite fillings and inlays is stress resistant, as could be expected from their inherent

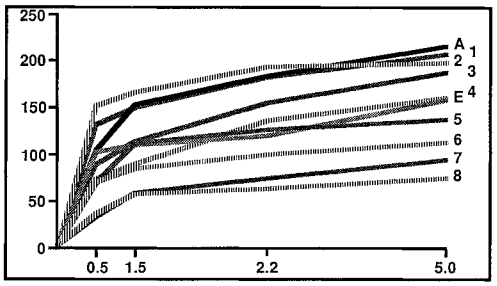

Figure 4. *Graph showing the total wear expressed as the sum of the maximum vertical loss of substance (µm) in the occlusal contact area of both, the MOD filling + the antagonistic enamel cusp at in vivo equivalents of 0.5, 1.5, 2.7, and 5.0 years of function: A = amalgam (Dispersalloy); 1 = Z100; 2 = TPH, 3 = Pertac; 4 = Tetric; E = enamel; 5 = Charisma; 6 = AP.H; 7 = Herculite; 8 = Brilliant EL.*

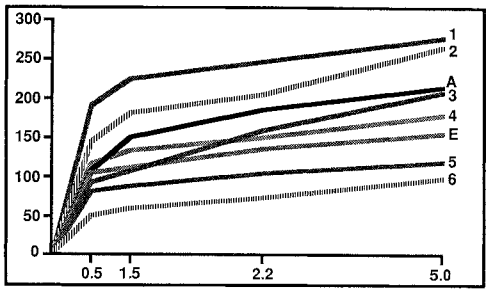

Figure 5. *Graph showing the total wear expressed as the sum of the maximum vertical loss of substance (µm) in the occlusal contact area of both the MOD filling + the antagonistic enamel cusp at in vivo equivalents of 0.5, 1.5, 2.7, and 5.0 years of function: 1 = Dicor MGC; 2 = Vitac Cerec MKI; A = amalgam (Dispersalloy); 3 = Biodent; 4 = Dicor; E = enamel; 5 = Vita Cerec Mk II; 6 = IPS-Empress.*

dentin-like physical properties. Microfilled composites, on the other hand, undergo plastic deformation under repeated occlusal loading, which produces marginal openings at all restoration sites and along both interfaces (Krejci, 1992; Mormann & Krejci, 1992; Krejci, Krejci & Lutz, 1992a; Krejci, Fullemann & Lutz, 1994b; Krejci, Guntert & Lutz, 1994d; Krejci & others, 1994c; Krejci, Lutz & Gautschi, 1994e; Lang, Schwan & Nolden, 1994).

The key operative elements for indirect inlays made of resin composites or ceramics are basically the same as for direct resin composite fillings, but include the following modifications and supplements: (1) a light-curing glass-ionomer cement is used to block out any undercuts and to protect dentin before finishing with 25 µm diamond burs (Reller & others, 1989); (2) the bonding at the luting composite/workpiece interface is a crucial point in inlays. Although no problems with immediate resin composite inlays have occurred, debonding has been a weak link with laboratory-fabricated inlays. Such inlays must be considered as aged and therefore have no free radicals (Burtscher, 1993). Consequently, the luting surfaces of lab-processed inlays must be roughened with finishing diamond burs, flexible disks, or air-abrasive systems before cementation. They must also be chemically activated using either an inlay primer or a silane (Stokes, Tay & Pereira, 1993; Tate, DeSchepper & Powers, 1993; Yoshida, Greener & Lautenschlager, 1993). Ceramic inlays are similarly cleaned and roughened using acids and chemically activated with a silane (Özden, Akaltan & Can, 1994; Thurmond, Barkmeier & Wilwerding, 1994; Aida, Hayakawa & Mizukawa, 1995); (3) selective bonding (Krejci & others, 1988); (4) use of short transparent strips allowing direct access to the inlay/tooth interface approximally and laterally reflecting light wedges; (5) insertion of the luting resin composite and setting of the workpiece up to 80% into the cavity, removal of the bulk excess luting resin composite with a small double-ended spatula (Krejci & Lutz, 1995); (6) complete seating of the workpiece into the preparation leaving any excess luting resin composite; with continuous pressure on the occlusal surface, light curing of the luting resin composite for 60 seconds from the cervical, buccal, oral, and occlusal surfaces, starting through the light-transmitting wedge (Krejci & Lutz, 1995; Sorensen & Munksgaard, 1995); (7) nondestructive finishing using the same instruments as for resin composite restorations (Lutz & others, 1983; Krejci & Lutz, 1995) and topical fluoride application after the finishing procedure.

Clinical results indicate that the bonds are stress resistant between direct resin composite inlays, chemically activated lab-processed resin composite inlays, as well as ceramic inlays and the matching luting resin composite. This holds for bonds between luting resin composites and enamel and between luting composite and dentin (Krejci, 1992; Mormann & Krejci, 1992; Krejci & others, 1992a, 1994b,d,e).

Interestingly, resin crowns, overlays, and inlays are increasingly being preferred as a restorative material for implants because of their superior ability to absorb impact stresses (Skalak, 1983; Watts, 1994). The question is now whether resin composites are adequately wear resistant. If correctly light cured, a crucial point that cannot be overemphasized, total wear of fine hybrid composites is similar to the wear of enamel against enamel (Figure 4) (Krejci, 1992; Krejci & others, 1994e; Krejci & Lutz, 1995). Total wear relates to the sum of the maximum vertical loss of substance in the occlusal contact area and on the opposing enamel cusp. Secondary heat curing does not significantly improve attrition wear of correctly and maximally light-cured resin composites, but it optimizes the physical properties, particularly of undercured workpieces. Heat curing also improves the abrasion and erosion wear, at least with the

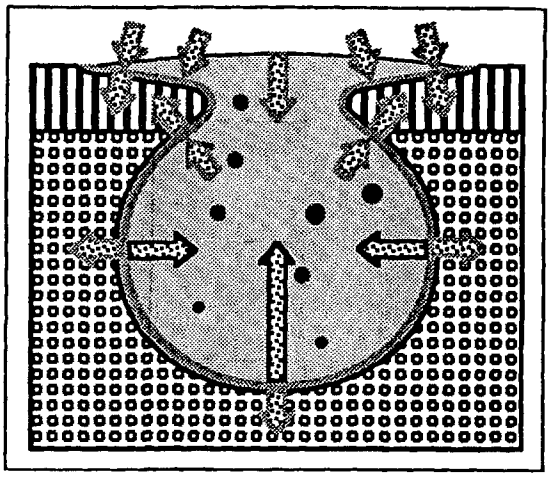

Figure 6. *Schematic diagram of an adhesive preparation showing contraction versus adhesion vectors. In the restorative center, the contraction stresses (black arrows) far exceed the adhesion forces (gray arrows), resulting in marginal openings. Contraction (gray/black arrows) and adhesion vectors on the adhesive bevel and the enamel shoulder are synergistic, resulting in an excellent, perfectly sealed margin.*

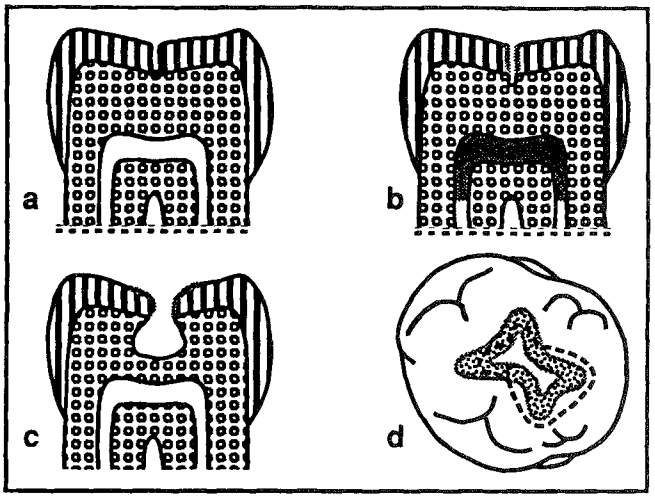

Figure 7. *Schematic diagram of a natural fissure (a), an extended fissure sealing with an explorative drilling in enamel and excavated carious dentin (b), a cross section of an adhesive class 1 preparation (c), and an occlusal view of an adhesive class 1 preparation (d); gray = convex, adhesive bevel.*

polymer chemistry currently in use (Wendt, 1987; Krejci, 1992; Mante, Saleh & Mante, 1993; Shinkai & others, 1994). Fine porcelains and more homogeneous glass ceramics also have an enamel-like wear resistance (Figure 5). However, coarse porcelains and inhomogeneous coarse glass ceramics are too abrasive during functional contact with opposing enamel cusps. Total wear is therefore in the magnitude of amalgam against enamel, or even worse (Figure 5) (Krejci, 1992; Krejci & others, 1993b; Krejci & Lutz, 1995). Consequently, resilient fine porcelains and more homogeneous smooth glass ceramics are the ceramic materials requiring further study and improvement.

LIGHT CURING

The weakest link in operative adhesive dentistry today is light curing. As a rule of thumb, every second composite filling is undercured and resembles a chocolate iced marshmallow rather than a filler-reinforced polymer (Berry & others, 1992; Fowler, Swartz & Moore, 1994). It is hard to believe that many authors do not know that objective and reliable measurements for a comparative assessment of the power output of light-curing units must be made by light source-related principles using an integrating sphere (Ulbricht's Sphere). The values required include radiant power and radiance (Lutz, Krejci & Frischknecht, 1992c). In such a measuring device, the solid angle is equal to 4 (pi). Furthermore, the bands of wavelengths within which the readings are taken must also be defined (Lee & others, 1993). At least three readings must be taken using three different windows with wavelengths varying between 400 nm and 520 nm, between 407 and 421, and between 461 and 475. The latter two windows are given by the maximum absorption for phenantrenequinone (about 414 nm) and camphoroquinone (about 468 nm) (Lutz, Krejci & Frischknecht, 1992c). It is also frustrating that the difference between radiance and irradiance is consistently ignored by manufacturers and clinicians. The minimum irradiation for direct curing and indirect curing through enamel, dentin, or a workpiece is still unknown. Nor can a particular preset be selected from a number of curing programs, optimally tailored for different types of restorations, which have an optimized radiance and illumination time to ensure full and simultaneously adaptation-friendly polymerization. To complicate matters even more, on the average, the radiance/radiant emittance (radiant power/radiant flux per unit area of exit window) of

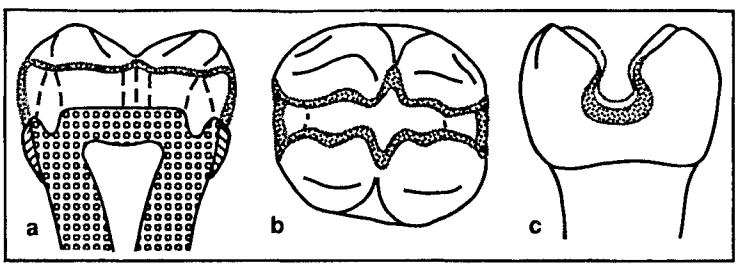

Figure 8. *Schematic diagram of an adhesive class 2 preparation showing the cross section (a), the occlusal view (b), and the approximal view (c); gray = convex, adhesive bevel.*

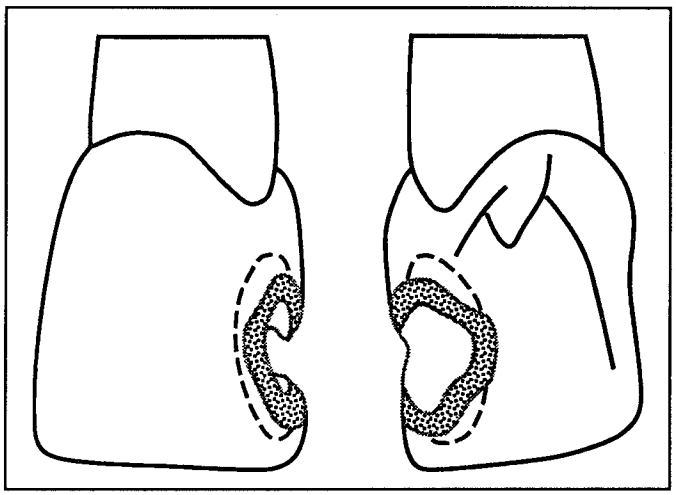

Figure 9. *Schematic diagram of an adhesive class 3 preparation showing the labial and palatal view; gray = convex, adhesive bevel.*

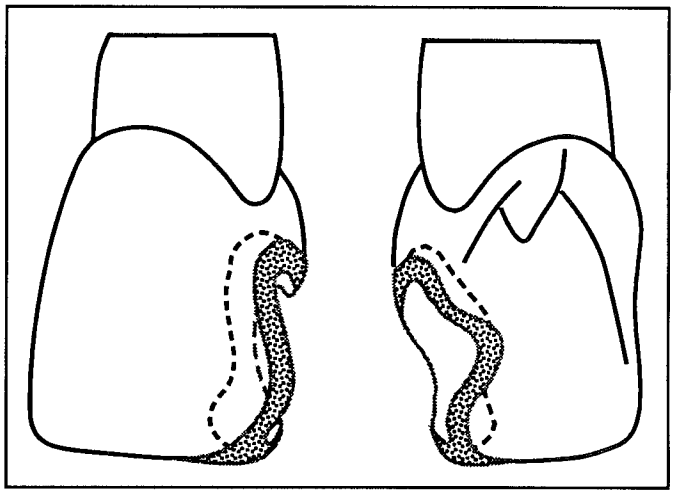

Figure 10. *Schematic diagram of an adhesive class 4 preparation showing the labial and palatal view; gray = convex, adhesive bevel.*

the currently available curing units is too low, and their maintenance is generally very poor, if any at all occurs (Berry & others, 1992; Lutz & others, 1992c,d; Lee & others, 1993; Rueggeberg, 1993; Wojtek, Wernisch & Wiederschwinger, 1993; Fowler & others, 1994; Rueggeberg, Caughman & Curtis, 1994a; Rueggeberg & others, 1994b). Radiometers are totally inappropriate to assess the energy output of newly designed light sources and to compare different light sources (Pires & others, 1993). However, radiometers can help to detect an energy drop in curing units that are regularly monitored in this manner (Rueggeberg, 1993).

ADHESIVE DENTISTRY

The adhesive cavity preparation is a key element in adhesive dentistry. The basic design of an adhesive preparation is dictated by the extent of the carious lesion, which is usually channel-like in fluoride-rich enamel and spherical in dentin. A minimum amount of enamel must still be removed for adequate access. An adhesive bevel, that is a convex bevel without a distinct cavosurface margin, is prepared to better mask the restoration. This cavity design was first

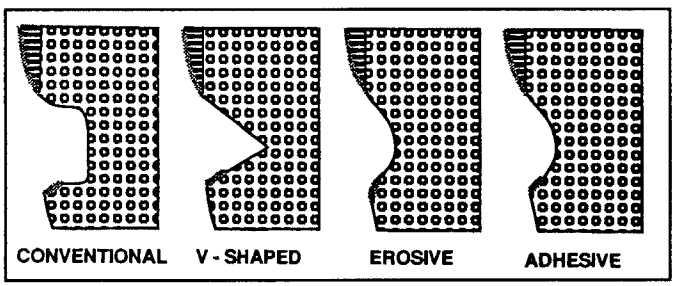

Figure 11. *Schematic diagram of adhesive class 5 preparations in cross sections; gray = convex, adhesive bevels in enamel and sharp-edged or natural bevels in dentin.*

conceived in 1974 and described in 1975 (Figure 6) (Lutz & Burkart, 1974; Lutz, 1975; Lutz & others, 1976b). Marginal adaptation in adhesive preparations is enhanced by rheological effects that result from an interaction between the enamel and dentin shoulder and the shrinkage vectors occurring in both chemically and light-cured resin composites. Adhesive and shrinkage vectors around the marginal shoulder are synergistic, resulting in an excellent marginal adaptation. They are not antagonistic, as is the case in the bulk of the restoration (Lutz & others, 1976b; Porte & others, 1984; Lutz & others, 1986). Therefore, it is important to preserve as much enamel as possible, and it is not necessary to cut away demineralized enamel that is still structured. The adhesive preparation can easily be applied in class 1 cavities (Figure 7). In fact, the adhesive class 1 preparation is simply an enlarged extended fissure sealant. However, it is a true cavity preparation with bevels, whereas in a preventive resin restoration, a small explorative tunnel is drilled to get access to the suspected dentinal caries (Krejci & Lutz, 1995).

The adhesive class 2 cavity preparation (Figure 8) functions well, even when a bulk placement technique is applied (Lutz & others, 1976a,b). However, the problem is that the cavity preparation is not feasible, unless there is direct access to the approximal surfaces, as with 6-year molars in the mixed dentition stage. A ball-shaped cavity design is a compromise between the traditional box-shaped class 2 cavity and the adhesive counterpart. In fact, the ball-shaped and the U-shaped cavity design in occlusals and approximals, respectively, would be highly preferable to the standard box preparation. There is evidence that the required high percentage of excellent margin can also be achieved with this decidedly more conservative cavity design (Lohrer,

1992). However, no instruments are currently available to prepare U-shaped cavities in approximals without direct access.

The adhesive class 3 cavity preparation (Figure 9) is characterized by an extremely conservative access from the palatal surface, preserving as much labial enamel as possible, and the preparation of adhesive bevels (Lutz & Burkart, 1974; Lutz, 1975; Lutz & others, 1976b). Margins in dentin are also bevelled. A 1-year clinical study showed that the percentage of continuous margin was high in adhesive class 3 and 4 fillings, even with margins in dentin. Furthermore, total or selective bonding provided equally excellent results in adhesive class 3 or 4 fillings (Baillod, Krejci & Lutz, 1994). This is in contrast to class 5 cavities where total bonding is a must, and in class 2 cavities, where selective bonding is imperative (Krejci & others, 1988). The adhesive preparation in class 4 cavities (Figure 10) has made the use of pins obsolete, and restorations are truly invisible (Lutz, 1975; Lutz & others, 1976b). Again the adhesive preparation is more conservative than the traditional class 4 preparation. True adhesive preparations for class 5 lesions were only possible after the breakthrough in dentinal bonding in the early 1990s. Preexisting box-shaped cavity preparations must first be bevelled, but in erosion or V-shaped lesions almost no preparation is necessary (Figure 11). The preparation of carious lesions is limited to caries removal only and bevelling. In adhesive dentistry, erosive or abrasive class 5 lesions should be treated early. This is because class 5 fillings are preventive where erosion is induced by alimentary acids and when abrasion is caused by the use of toothbrush/toothpaste and because the cavity preparation is so conservative (Harnirattisai & others, 1993; Schuepbach & others, 1994; Krejci & Lutz, 1995; Krejci & others, 1996). This is in contrast to traditional box-shaped class 5 fillings based on mechanistic operative principles characteristic for amalgam. Such restorations are not esthetic, have a limited longevity, and are not conservative.

CONCLUSIONS

Operative dentistry is on the threshold of the "postamalagam age." As the countdown continues, amalgam substitutes and alternatives are being introduced as tooth-colored replacements for amalgam. These restorative materials have their own unique characteristics and limitations. Successful transition into this new age requires critical assessment of these materials and adhesive dentistry if dentists are to continue high-quality dental treatment in the future.

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Enhancement of Resin Bonding to Heat-cured Composite Resin

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D B BOYER • E J SWIFT, Jr

Clinical Relevance
Treatment of heat-processed composite resin with an air-abrasion or ceramic-deposition system is an important step in maximizing the strength of the resin-to-cement bond.

SUMMARY

The purpose of this study was to evaluate the effectiveness of various surface treatments used to enhance the bond strength of resin cements to two different laboratory-processed composite resins. Seventy specimens of a microfilled composite resin (Concept) and 70 specimens of a micro-hybrid composite resin (Herculite XRV) were fabricated in metal wells and subjected to heat (250 °F) and pressure (85 psi) curing. An additional 70 specimens of each material were fabricated in the shape of disks and also subjected to the same heat/pressure curing. All composite resins were subjected to one of seven treatment regimens. The like-treated specimens were then bonded together using dual-curing resin cement and a uniform seating force (106 gm). After 7 days, bonded specimens were thermocycled 1000 times at 5 and 55 °C, and debond shear strengths were determined on a Universal Testing Machine. The use of microabrasion (50 µm aluminum oxide at 60 psi) and ceramic layer deposition (30 µm aluminum oxide with a ceramic additive at 75 psi) consistently improved the shear bond strength of the resin cements to both composite resins. The other treatment combinations provided varying effects. In conclusion, microabrasion or ceramic layer deposition are preferred methods to enhance the bond of resin cements to composite resins.

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INTRODUCTION

Patient demand for esthetic restorations has led to the use of composite resins in both anterior and posterior teeth (Burgess, Summit & Laswell, 1987; Ruyter, 1992). Although reduced filler particle size and heavier loading have enhanced the physical properties of today's materials (Albers, 1991), polymerization shrinkage remains a serious problem. Realignment of resin monomers into a cross-linked polymeric structure is responsible for a volumetric shrinkage of 2.0-5.0% (Ferracane, 1992). This dimensional change is especially critical when composite resin is directly placed and cured within large cavity

preparations or deep class 2 approximal boxes. Incremental filling (Jensen & Chan, 1985), light-reflecting wedges (Lutz & others, 1986), and glass inserts (Bowen, 1987; Donly & others, 1989) are some of the methods advocated to control polymerization shrinkage of direct composite resin restorations.

Indirect techniques for posterior composite inlay/onlay fabrication eliminate the shrinkage of a polymerizing resin mass within a prepared cavity and have increased in popularity (Ruyter, 1992). Combinations of elevated temperature, increased pressure, intense light, or vacuum can be used to cure these materials extraorally. Elevated temperatures have been shown to enhance the degree of conversion of composite resins over conventional visible light curing alone (Dionysopoulos & Watts, 1989). Increased degree of conversion improves the mechanical properties of composite (Wendt, 1987a,b; McCabe & Kagi, 1991).

Indirect composite resin restorations are bonded to tooth structure using resin cements. To facilitate adhesion, composite resin surfaces to be bonded must be treated in some manner. Composite resin repair studies form the basis for surface preparation techniques. The effectiveness of mechanical roughening (Causton, 1975; Boyer, Chan & Torney, 1978), chemical conditioning and priming (Crumpler & others, 1989), hydrofluoric acid etching (Swift & others, 1992), and silanation (Söderholm, 1986) on bond strengths have previously been reported.

Another technique (the Rocatec system, ESPE-Premier, Norristown, PA 19404) was recently introduced as a method to enhance bonding between resin and metal. An initial microabrasion step removes impurities, roughens, and increases surface energy of the metal. A second microabrasion using a special mixture of abrasive particles and additives deposits a ceramic surface layer. This ceramic layer is then silanated. There is little information available regarding the effectiveness of Rocatec treatment on composite resin. However, it has been recommended by ESPE-Premier as a method to enhance adhesion between the composite resin and resin luting agent (Dasch, 1991).

The purpose of this in vitro study was to evaluate the shear bond strengths of two different heat- and pressure-polymerized composite resins that were treated by various mechanical and chemical means and bonded to themselves with a composite resin luting cement.

METHODS AND MATERIALS

Concept (Ivoclar/Vivadent, Amherst NY 14228), a microfilled composite resin (shade Vivadent 30), and Herculite XRV (Kerr Corporation, Glendora, CA 91740), a micro-hybrid composite resin (shade A-3 "enamel"), were used in this study. Rectangular metal plates were machined with 10 circular wells (4.0 mm wide x 1.5 mm deep) to hold resin. The plates were mounted and secured to Plexiglas blocks to facilitate handling and later testing of bonded specimens. Opaque foil was placed between the metal plate and Plexiglas block to confine the visible light used for initial curing of Herculite XRV and, later, polymerization of luting agents to the area immediately adjacent to an individual well. Additional disk specimens of both materials, used for bonding to the composite resin in wells, were fabricated from the open center area of nylon washers placed against a clear Mylar matrix strip. Composite resin disks had a final diameter of 4.0 mm and a thickness of 1.5 mm, the same as the composite resin placed in the wells.

The wells and washers were treated according to the manufacturer's directions for surface treatment of dies prior to composite resin placement. The Concept technique required coating molds with Concept Separator and air drying. A thin layer of freshly activated Concept Fluid was added prior to filling with the resin. The Herculite XRV laboratory technique also involved the application and drying of a separating agent in molds before placing composite. All molds were overfilled with uncured material and leveled by pressing the wide end of an alcohol-dampened instrument (Greensteincolor, Almore International Inc, Portland, OR 97225) flush against the metal plate or nylon washer to create a flat bonding surface. The excess composite resin was removed. Exposed surfaces of unpolymerized Concept were brushed with a thin layer of Concept Fluid. Herculite XRV specimens were light-cured for 10 seconds using a Cotolux II (Coltene/Whaledent, New York, NY 10001) light unit (12 mm tip). The light was checked daily for consistent light intensity ≥ 500 mW/cm^2) with a Curing Radiometer (Model 100, Demetron Research Corp, Danbury, CT 06810). A Concept 250 oven (Ivoclar/Vivadent) was used for the final curing of both composites. (Although the manufacturer recommends laboratory curing of Herculite XRV via boiling water or equivalent dry heat for 10 minutes, we chose to use the Concept oven in order to maintain consistency between the two groups of specimens.) All specimens were subjected to a combination of heat (250 °F) and pressure (85 psi) for 10 minutes. After curing they were cooled for 15 minutes. Composite disks were separated from the washer molds. The nonbonding sides of disks (polymerized against the matrix) were identified and marked. All specimens were ultrasonically cleaned in distilled water for 15 seconds to remove adherent particulate matter and then dried with compressed air.

For reasons of statistical analysis and maintenance of a manageable number of samples, surface

Table 1. Treatment Provided to Composite Resin

GROUPS		TREATMENTS						
		35% H_3PO_4	50μ AIO Air Abrasion	Special Bond II	Silane	All-Bond Primer A+B and Pre Bond Resin	9.6% HF	30μ Rocatec-Pre and 30μ Rocatec-Plus
Concept Groups	1) Control	+						
	2) Microabrasion	+	+					
	3) Special Bond II System	+	+	+				
	4) All-Bond 2 System		+		+	+		
	5) Scotch Prime System	+	+		+			
	6) Microabrasion/Porc Etch Gel		+				+	
	7) Rocatec System				+			+
Herculite Groups	8) Control	+						
	9) Microabrasion	+	+					
	10) All-Bond 2 System		+		+	+		
	11) Porcelain Etch Gel						+	
	12) Microabrasion/Porc Etch Gel		+				+	
	13) Scotch Prime System		+		+		+	
	14) Rocatec System				+			+

+ = treatments applied to each group.

treatment was limited to seven techniques for each material. Surface treatment combinations for each group are summarized in Table 1. Details concerning these surface treatments follow:

35% Phosphoric Acid Etching Gel (3M Dental Products Division, St Paul, MN 55144) was applied for 20 seconds, rinsed with water for 20 seconds, and dried with compressed air. Used alone, this served as the control treatment.

Microabrasion (Micro-Etcher, Danville Engineering, San Ramon, CA 94583) used 50 μm aluminum oxide particles at 60 psi. The instrument tip was held 1.0 cm away from the surface for 2-3 seconds.

Special Bond II (Ivoclar/Vivadent) was used only on Concept. The manufacturer's Material Safety Data Sheet lists the primary components (99+%) of this product to be di- and methyl methacrylates. Surfaces were first microabraded and treated with 35% H_3PO_4. A thin layer of Special Bond II was applied, dried for 20-30 seconds, and light-cured for 40 seconds.

All-Bond 2 (Bisco Dental Products, Itasca, IL 60143) was used according to its manufacturer's instructions for inlay/onlay cementation. Surfaces were microabraded, ultrasonically cleaned, and silanated. Primers A & B were applied in two coats and dried. A thin layer of Pre-Bond resin was added prior to cementation.

Scotchprime Ceramic Primer (3M Dental Products) silane solution was applied three successive times and dried with compressed air to remove any remaining solvent.

Porcelain Etch Gel (9.6% hydrofluoric acid, Pulpdent Corp, Watertown, MA 02272) was applied for 30 seconds, rinsed with water for 2 minutes, and dried with compressed air.

Rocatec (ESPE-Premier) normally uses a 110 μm Rocatec-Pre corundum abrasive followed by a 110 μm Rocatec-Plus corundum and ceramic additive mixture to mechanically deposit a ceramic layer on metal surfaces. However, a pilot study revealed the metal preparation procedure to be too abrasive for composite. Instead, a specially prepared 30 μm Rocatec-Pre abrasive and 30 μm Rocatec-Plus mixture were provided by ESPE-Premier. The 30 μm Rocatec-Pre cleaned and lightly abraded the composite surface until a matte finish was observed. The 30 μm Rocatec-Plus was then applied for 3-5 seconds. Excess material was shaken off. Rocatec-Sil silane coupling agent was applied in a thin layer and allowed to dry for 5 minutes.

Seventy specimens of each type of composite resin were prepared in the well molds and another 70 were prepared in the disk molds (total = 280 specimens). Flat bonding surfaces of both disk and well specimens received identical surface treatment. A 50 μm-thick adhesive tape (3M) strip with a centered 1.96 mm-in-diameter hole was placed over each well following surface treatment to act as a spacer and to maintain a uniform bonding area with respect to the diameter and thickness of the cement layer.

The luting agents used were those recommended by both manufacturers for use with their respective systems, Dual Cement (Ivoclar/Vivadent) with Concept and Porcelite Dual Cure Cement (Kerr Corporation, Glendora, CA 91740) with Herculite XRV. Equal

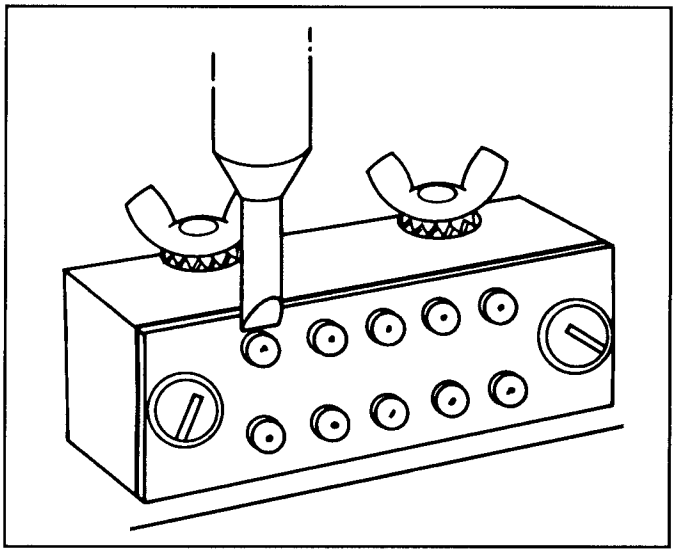

Figure 1. *Specimen block assembly on testing apparatus*

portions of base and catalyst were dispensed, mixed, and applied to the treated surfaces of both disks and wells. Disks were individually aligned over a well, and a uniform weight (106 gm) was placed over the disk/well combination. Excess cement was brushed from the periphery. The Cotolux II light tip was held at a 45° angle close to the surface and activated for 40 seconds to initiate curing the cement. It was rotated 180° at the same angle and activated for an additional 40 seconds. (Surface treatment, cementation, and curing were performed sequentially for each of the 10 specimens per block.) Opaque foil was positioned over previously polymerized specimens to limit light illumination of each to 80 seconds.

Specimens were immersed in distilled water at ambient temperature (23 °C) 10 minutes after bonding was completed. After 7 days all specimens were thermocycled 1000 times in water baths maintained at 5 and 55 °C (±3° C). The dwell time in each bath was 33 seconds. Upon completion of thermocycling, blocks with bonded specimens were dried with compressed air and firmly mounted on a custom jig secured to a 50 kg compression load cell of an Instron Universal Testing Machine (Model TM, Instron Corp, Canton, MA 02021). A Mylar matrix strip was placed between the surface of the metal plate and the knife-edge probe to act as a spacer during probe alignment. The assembled specimen block is shown in Figure 1. All specimens were tested until failure in the shear mode using a crosshead speed of 0.5 cm/min.

Debond strengths in MPa were calculated by dividing the shear bond force by the bonded surface area. For each composite material, one-way analysis of variance (ANOVA) and post hoc Duncan's Multiple Range Tests were performed with SAS statistical software (SAS Institute Inc, Cary, NC 27513). A confidence level of 95% was selected to determine statistical significance. No attempt was made to draw conclusions between the two different composite resins. A subjective evaluation of fractures was made at X40 magnification using light microscopy (Binocular Dissecting Microscope, Model Forty, American Optical Co, Buffalo, NY 14215). Additional sample disks were prepared, surface treated, and mounted for scanning electron microscope (SEM) evaluation. Surface observations were made with a Field Emission Scanning Electron Microscope (Model S-4000, Hitachi, Tokyo, Japan) at 12 kV accelerating voltage and a 10 mm working distance.

Table 2. Shear Strengths, Concept Specimens

Groups*	Mean (+SD)**	Range**	Duncan's Grouping***			
Group 7 Rocatec	41.5 (5.6)	31.5-50.7	A			
Group 6 Micro, HF	41.4 (8.1)	27.0-50.1	A			
Group 5 Micro, H_3PO_4, Silane	39.8 (6.8)	27.3-48.4	A	B		
Group 4 Micro, Silane, AB 2	36.8 (5.1)	26.7-42.9	A	B	C	
Group 2 Micro, H_3PO_4	34.2 (5.9)	21.5-40.6		B	C	
Group 3 Micro, H_3PO_4, SB II	31.6 (5.2)	23.7-38.7			C	
Group 1 Control, H_3PO_4	8.7 (8.9)	0.0-23.7				D

*n = 10 for all groups; **Shear Bond Strength, MPa; ***$P < 0.05$.

Table 3. Shear Strengths, Herculite XRV Specimens

Groups*	Mean (+SD)**	Range**	Duncan's Grouping***				
Group 10 Micro, Silane, AB 2	38.6 (6.0)	25.4-45.5	A				
Group 14 Rocatec	34.5 (8.0)	24.1-47.5	A	B			
Group 9 Micro, H_3PO_4	29.1 (4.5)	24.4-37.1		B	C		
Group 13 Micro, HF, Silane	26.5 (6.5)	13.0-35.8			C		
Group 12 Micro, HF	19.5 (6.2)	4.9-27.3				D	
Group 11 HF	13.5 (6.5)	0.7-24.1					E
Group 8 Control, H_3PO_4	12.9 (5.2)	7.2-23.1					E

*n = 10 for all groups; **Shear Bond Strength, MPa; ***$P < 0.05$.

RESULTS

The data for Concept and Herculite XRV specimens are summarized in Tables 2 and 3 respectively. One-way ANOVA

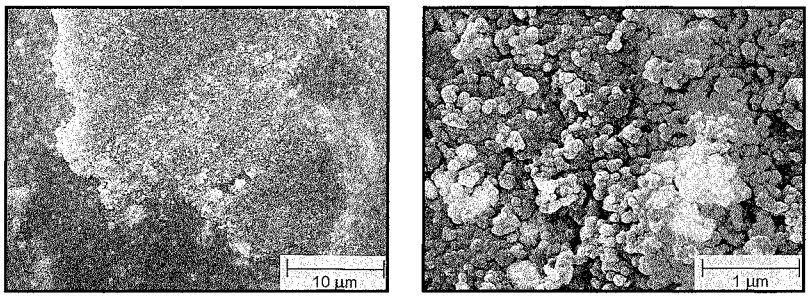

Figure 2. *Concept control (H_3PO_4) specimens at low (A) and high (B) magnifications*

controls, Group 8 (H_3PO_4). Herculite specimens treated only with hydrofluoric acid were similar to the control. Comparison of microabrasion, Group 9 (Micro, H_3PO_4), with controls, Group 8 (H_3PO_4), also demonstrated the increased strength was due to microabrasion rather than other surface treatments. Subjecting specimens to hydrofluoric acid reduced strengths as seen in Group 11 (HF), Group 12 (Micro, HF) and Group 13 (Micro, HF, Silane). Highest shear bond strengths were obtained after treatment with microabrasion and All-Bond 2 (Group 10) or Rocatec (Group 14).

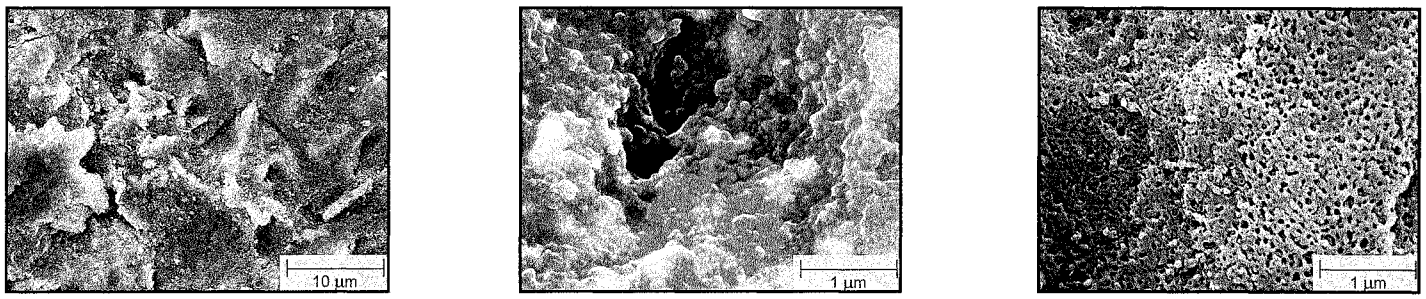

Figure 3. *Concept treated with: (A) microabrasion and H_3PO_4; (B) microabrasion, H_3PO_4, and silane; and (C) microabrasion and hydrofluoric acid*

indicated a significant effect ($P < 0.0001$) of surface treatment on shear bond strength with both materials. Consequently, the mean strengths of the experimental groups were compared with the Duncan test.

Concept specimens (Table 2) that were microabraded (Micro) or treated with the Rocatec system were significantly stronger than the controls that were treated with phosphoric acid gel (H_3PO_4) alone. The Rocatec system produced bond strengths similar to the strongest microabraded groups and was stronger than Group 2 (Micro, H_3PO_4) and Group 3, which utilized Special Bond II (Micro, H_3PO_4, SB II).

Herculite XRV specimens (Table 3) microabraded or treated with the Rocatec system had higher shear bond strengths than the

SEM examination of the Concept control, Group 1 (H_3PO_4), revealed a smooth surface with agglomerates of microfillers visible at higher magnification (Figures 2A, 2B). Microabrasion with 50 µm alumi-

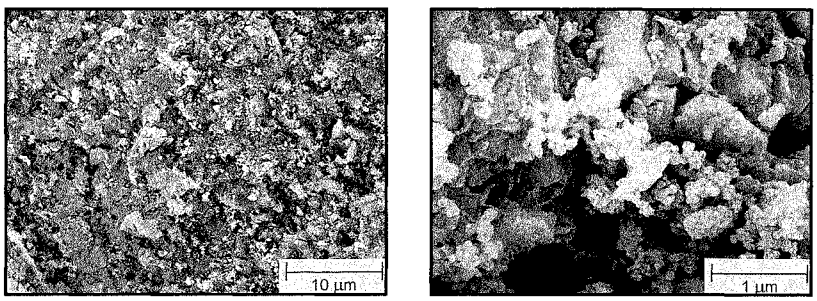

Figure 4. *Concept treated with the Rocatec system at low (A) and high (B) magnifications*

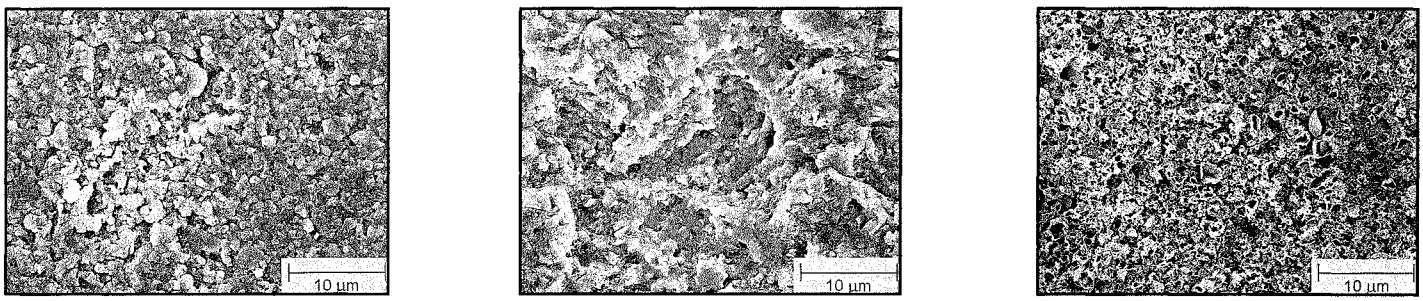

Figure 5. *Herculite XRV (A) control (H_3PO_4) specimen; (B) treated with microabrasion and H_3PO_4; and (C) treated with hydrofluoric acid*

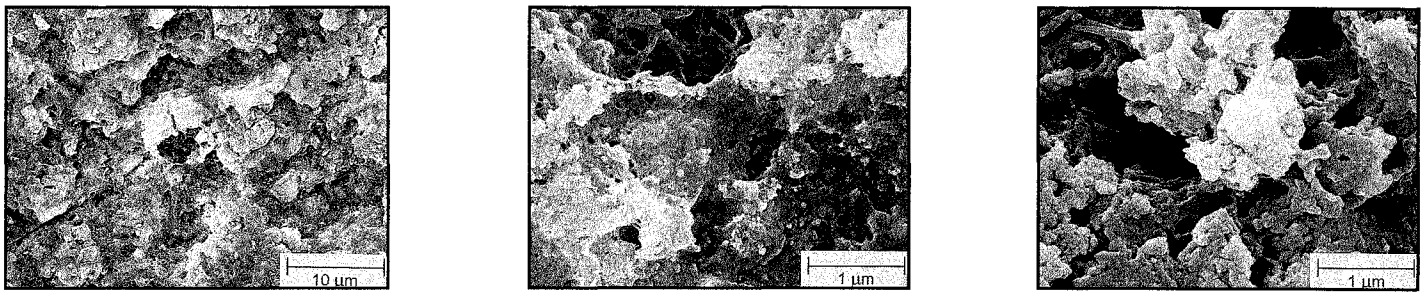

Figure 6. *Herculite XRV treated with microabrasion and hydrofluoric acid at low (**A**) and high (**B**) magnification; and (**C**) Herculite XRV treated with microabrasion, hydrofluoric acid, and silane*

num oxide, Group 2 (Micro, H_3PO_4), resulted in a roughened, irregular surface topography (Figure 3A). Silanated microabraded specimens in Group 5 (Micro, H_3PO_4, Silane) also displayed a roughened irregular surface, which was additionally covered with a uniform thin layer (Figure 3B). Group 6 (Micro, HF) had the characteristic rough surface following microabrasion perforated by numerous pores of less than 0.12 µm produced by hydrofluoric acid (Figure 3C). Ceramic layer deposition (Group 7, Rocatec) left a rough surface covered with abundant particulate matter (Figure 4A). Higher magnification revealed agglomerates of submicron particles, as well as others particles resembling larger glass fillers of approximately 0.5 µm (Figure 4B).

SEM evaluation of Herculite XRV control specimens, Group 8 (H_3PO_4), revealed the combination of submicron and large filler particles on a relatively even surface (Figure 5A). Microabrasion of this material (Group 9, Micro, H_3PO_4), produced a rough surface topography (Figure 5B). Hydrofluoric acid conditioning, Group 11 (HF), created a "cratered" surface texture. The larger glass fillers were noticeably absent, leaving behind a resin lattice framework (Figure 5C). Specimens that were microabraded and hydrofluoric acid conditioned, Group 12 (Micro, HF), presented a similar appearance with greater irregularity and roughness (Figures 6A, 6B). Silane application to Group 13 (Micro, HF, Silane) also deposited a submicron layer (Figure 6C). However, this layer was not uniformly distributed over the surface. There was little difference in the appearance of Herculite XRV after Rocatec treatment (Group 14) when compared to Concept specimens undergoing the same procedure (Figure 4B).

Analysis of fractures using light microscopy showed a wide variety of patterns. In general, the fractures were adhesive (between the luting agent and the processed composite resin disks and wells) at low bond strengths (i e, controls). This changed to partial adhesive/cohesive fractures at intermediate strengths to almost exclusively cohesive fractures within the processed composite of specimens with the highest bond strengths.

DISCUSSION

All Concept treatment groups demonstrated significantly greater mean shear bond strengths, from 31.6 to 41.5 MPa, than the control mean of 8.7 MPa ($P < 0.0001$). A pressure-driven abrasive was employed in all cases, with the exception of the control. This resulted in a roughened, micromechanically retentive surface, as seen on SEM micrographs of this material (Figure 3A).

The submicron layer observed on surfaces following silane treatment (Figures 3B and 6C) corresponds to that of a silane polymer (Suh, 1991). An explanation for improved bond strength of a silanated, microabraded surface over a microabraded surface alone is the presence of the silane polymer. One end of the bifunctional silane molecule bonds with silica of exposed glass fillers, while the other possesses a resin-reactive vinyl group, thus "coupling" the glass to the resin (Paffenbarger, Sweeney & Bowen, 1967). The organic solvent of silane solutions may also play a role. In addition to acting as a carrier for the silane, it removes any bond-weakening resin debris or "smear" layers and can further expose glass particles for silanation. Intact, cross-linked resin is immune to this action of the solvent (Söderholm, 1986). Ivoclar/Vivadent claims the fumed silicon dioxide filler particle in Concept to be 0.04 µm. Although clusters of agglomerated fillers were noted in SEM of this material (Figure 2), their small size may limit the effectiveness of silane application (Suh, 1991). In this study, silane application to Concept following microabrasion did not statistically improve the bond strengths.

The low-viscosity primers and unfilled resins of All-Bond 2 (Bisco) and the adhesion enhancer Special Bond II (Ivoclar/Vivadent) improved surface wetting to aid penetration of resin tags into the irregularities produced by microabrasion. Although Ivoclar/Vivadent recommends using Special Bond II to cement their indirect composite restorations, this particular regimen recorded the lowest of all shear bond strengths to Concept, excluding the control.

Microabrasion augmented by a bonding system or

ceramic layer deposition produced the greatest mean shear bond strengths with the microhybrid Herculite XRV. However, Rocatec treatment and simple microabrasion combined with phosphoric acid treatment were statistically similar (Duncan's B, $P < 0.05$). SEM micrographs of Herculite XRV revealed roughened and mechanically retentive surface features, which contributed to bond strength improvement (Figure 5B).

Any treatment involving the use of 9.6% hydrofluoric acid with Herculite XRV reduced bond strengths compared to those obtained in the highest groups. The mean particle size for Herculite XR is 1.0 μm, while the particle occurring with greatest frequency is 0.8 μm (Willems & others, 1992). The combination of large and small fillers in hybrids allows for increased loading of the inorganic phase and results in less surrounding resin matrix (Albers, 1991). As seen in SEM, dissolution of the large particle glass phase by hydrofluoric acid left what appeared to be ideal retentive areas for resin (Figure 5C). However, the remaining resin remnants that formerly surrounded the fillers may have provided a poor substrate for the luting agent and resulted in weaker bonds (Figure 6B). Significant differences existed between the various treatments involving the use of 9.6% hydrofluoric acid etching with Herculite XRV. Hydrofluoric acid application alone produced a mean bond strength of only 13.5 MPa, which was statistically equivalent to the control value of 12.9 MPa. Microabrasion followed by hydrofluoric acid application improved bond strength to 19.5 MPa. Micromechanical retention may have accounted for this significant improvement. The addition of silane to the microhybrid improved mean bond strength to 26.5 MPa. This particular regimen (microabrasion, hydrofluoric acid conditioning, and silanation) is recommended by Kerr for preparing surfaces of indirect Herculite XRV restorations prior to cementation. SEM evaluation showed evidence of what appeared also to be a surface silane polymer layer similar to that found on Concept (Figure 3B). However, this layer was not uniform on the microhybrid. The polymer layer on Herculite XRV (Figure 6C) was of a more porous and irregular nature than that seen on Concept.

The control values of both Concept (8.7 MPa) and Herculite XRV (12.9 MPa) are in agreement with those found earlier by Heymann and others (1986). They reported that shear bond strengths of a laboratory-fabricated conventional resin veneer material bonded to itself without the benefit of surface preparation and using a low-viscosity bonding resin varied from 4.7-8.5 MPa. Mechanical roughening of heat-treated resin (i e, microabrasion) was a necessary prerequisite to improve bond strength. These results are in agreement with earlier investigations in composite repair as well as recent studies by Crumpler and others (1989) and Swift and others (1992). Conditioning with 9.6% hydrofluoric acid significantly decreased bond strengths on the microhybrid agreeing with the conclusions of Swift and others (1992). The microfilled Concept was not affected in the same manner by hydrofluoric acid application, which coincides with the findings of Tate, DeSchepper, and Powers (1992).

CONCLUSIONS

1. Microabrasion and the Rocatec system were very effective in increasing the shear bond strengths of both Concept and Herculite XRV indirect resins. The effectiveness of the other surface treatments varied between the two composite resin materials.
2. Following microabrasion, treatment of Concept with hydrofluoric acid slightly increased bond strength, whereas treatment of Herculite XRV with hydrofluoric acid significantly decreased bond strength when used alone or in conjunction with microabrasion.
3. Treatment of Herculite with All-Bond 2 increased bond strength when applied following microabrasion. All-Bond 2 did not increase bond strength with Concept.
4. Application of Special Bond II or silane with Concept did not enhance bond strengths following microabrasion.

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Antibacterial Activity of Dentin Bonding Systems, Resin-modified Glass Ionomers, and Polyacid-modified Composite Resins

J C MEIERS • G A MILLER

Clinical Relevance
The antibacterial activity of the various primers was unexpected and indicates a dual antibacterial action of these systems.

SUMMARY

The antibacterial effects of the dentin bonding systems Syntac, ProBOND, Gluma 3-Step, the resin-modified glass ionomers Photac-Fil, Fuji Lining LC, Fuji II LC, and the polyacid-modified composite resins VariGlass, Geristore, and Infinity were evaluated using the cariogenic bacteria *S mutans*, *L salivarius*, *S sobrinus*, and *A viscosus* in vitro with a modified cylinder drop plate agar diffusion assay. All glass ionomers, the polyacid-modified composites, and the primers and adhesives of the dentin bonding systems exhibited various degrees of antibacterial activity against most of the test bacteria. The antibacterial activity of the adhesives of dentin bonding systems was anticipated because of the glutaraldehyde used in their formulations. However, the antibacterial activity of the various primers was unexpected and indicates a dual antibacterial action of these systems.

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INTRODUCTION

Bacteria have been implicated in pulpal inflammation after restoration placement (Brännström, 1984; Bergenholtz & others, 1982; Cox, 1992). The source of bacteria may be from their incomplete removal during cavity preparation or from their reappearance due to microleakage at the margins of the restoration (Going, 1972; Mejare, Mejare & Edwardsson, 1979; Bergenholtz & others, 1982; Brännström, 1984; Ben Amar, 1989; Cox, 1992).

Currently, there are no universally accepted objective tests to determine the bacterial status of a preparation during caries removal. Traditionally, the effectiveness of caries removal has been a subjective judgment based on the color and texture of dentin in the cavity preparation—which may or may not accurately reflect the actual bacterial status (Fisher, 1981; Baum, Phillips & Lund, 1985; Kidd, Joyston-Bechal & Beighton, 1993b). Caries-disclosing solutions of either 0.5% basic fuchsin or 1.0% acid red have been proposed as an objective method for determining the bacterial status of dentin (Sato & Fusayama, 1976; Fusayama, Takatsu & Itoh, 1979; Franco & Kelsey, 1981; Anderson & Charbeneau, 1985; Anderson, Loesche & Charbeneau, 1985; Kidd & others, 1989). However, there is growing skepticism about the accuracy of these dyes in reflecting the true bacterial condition of dentin (Kidd, Joyston-Bechal & Beighton, 1993a; Boston & Graver, 1994; Yip, Stevenson & Beeley, 1994).

Secondary caries, whether the result of bacterial invasion through microleakage or from residual bacteria left in the cavity preparation, has consistently been found to be the most common reason for replacement of amalgam (Mjör, 1981; Boyd & Richardson, 1985; Klausner & Charbeneau, 1985; Klausner, Green & Charbeneau, 1987; Qvist, Qvist & Mjör, 1990a; York & Arthur, 1993) and composite restorations (Qvist, Qvist & Mjör, 1990b; York & Arthur, 1993).

A possible solution to this problem would be the use of dental materials that are antibacterial. Glass ionomers, various dentin bonding systems, and calcium hydroxide have been shown in vitro to be antibacterial toward various types of oral bacteria (Forsten & Soderling, 1974; Barkhordar & Kempler, 1989; Barkhordar & others, 1989; DeSchepper, White & von der Lehr, 1989; Scherer, Lippman & Kaim, 1989; Scherer, Cooper & Antonelli, 1990; Prati & others, 1993; Loyola-Rodríguez, García-Godoy & Lindquist, 1994). Additionally, calcium hydroxide preparations and a glutaraldehyde-containing dentin bonding agent have been shown to reduce or eliminate bacteria within a preparation in vivo (Leung, Loesche & Charbeneau, 1980; Fairbourn, Charbeneau & Loesche, 1980; Felton, Bergenholtz & Cox, 1989).

The continuing emergence of newly formulated restorative materials, which often replace previous materials whose antibacterial properties may be known, requires their evaluation for antibacterial properties to update those clinicians who may want to employ them as a method for controlling bacterial levels within the tooth during and after restorative procedures. The purpose of this study is to examine the antibacterial activity of three current dentin bonding systems containing glutaraldehyde, three resin-modified glass-ionomer cements, and three polyacid-modified composite resins against the cariogenic bacteria *Streptococcus mutans*, *Streptococcus sobrinus*, *Lactobacillus salivarius*, and *Actinomcyes viscosus* using a modified cylinder drop plate agar diffusion assay.

METHODS AND MATERIALS

The dental materials evaluated in this study are shown in Table 1. The antibacterial activity of each material was evaluated against the following bacteria: *Lactobacillus salivarius* subsp *salivarius* (ATCC# 11741); *Streptococcus sobrinus* (ATCC# 33478); *Actinomyces viscosus* (ATCC# 15987), and *Streptococcus mutans* (ATCC# 25175), using a modified cylinder drop plate agar diffusion assay system.

A 10 µl inoculating loop of each bacteria was obtained from trypticase soy agar slants (Difco, Labonia, MI 48152) of the original ATCC cultures that had been incubated at 37 °C in an atmosphere of 5% CO_2 and 95% air for 48 hours. The bacteria were placed in duplicate 10 ml tryptic soy broth (Difco) cultures at 37 °C in an atmosphere of 5% CO_2 and 95% air for 48 hours. Broth cultures for each bacteria were added aseptically to separate 1 liter flasks of sterile tryptic soy broth. Each flask was incubated in a 37 °C shaker water bath for 72 hours. Each bulk culture was then placed into 500 ml centrifuge bottles (DuPont Sorvall Centrifuge Products, Wilmington, DE 19898), spun at 10,000 rpm (16,300 rcf) for 10 minutes using a GSA rotor in a Sorvall Superspeed Centrifuge. Pellets for each bacteria were pooled and resuspended in 50 ml of tryptic soy broth.

Table 1. Dental Materials Used in Study

Materials	Components Tested	Manufacturer
Dentin Bonding Systems		
Syntac	primer, adhesive, adhesive without glutaraldehyde, Heliobond resin	Vivadent USA, Amherst, NY 14228
Gluma 3-Step	conditioner, primer, sealer	Miles Inc, South Bend, IN 46614
ProBOND	primer, adhesive, adhesive without glutaraldehyde	L D Caulk/Dentsply, Milford, DE 19963
Resin-modified Glass-Ionomer Cements		
Fuji Lining LC	complete cement (powder + liquid) & liquid only	GC America, Chicago, IL 60658
Fuji II LC	complete cement (powder + liquid)	GC America
Photac-Bond	complete cement (powder + liquid)	ESPE/Premier, Norristown, PA 19401
Conventional Glass-Ionomer Cement		
Ketac-Bond	complete cement (powder + liquid)	ESPE/Premier
Polyacid-modified Composite Resins		
VariGlass	complete mix (powder + liquid)	L D Caulk/Dentsply
Geristore	complete mix (paste + paste)	Den-Mat Corp, Santa Maria, CA 93456
Infinity	complete mix (paste + paste)	Den-Mat Corp

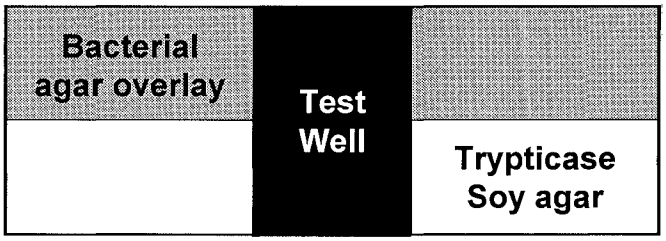

Figure 1. *Cross section of modified cylinder drop plate agar design*

Each bacterial suspension was mixed with 2 liters of sterile trypticase soy agar that had been cooled to 50 °C. Ten milliliters of the resultant suspension was overlaid onto trypticase soy agar plates (NIH Media Bank, Bethesda, MD 20892) that contained 15 ml of agar per plate (Figure 1). Once the overlay solidified, wells of 4.5 mm in diameter were created in the agar with the large bore end of a sterile Pasteur pipet (Ladd Research Industries, Burlington, VT 05402) (Figure 2). There were no more than six wells per plate.

The wells were then filled to the rim with either 1.0% glutaraldehyde (from 70% EM GRADE, Polysciences, Inc, Warrington, PA 18976), which acted as a control and was present in each plate, or in the material to be evaluated. Syntac and ProBOND additionally had adhesives tested that were identical in chemistry to those normally contained in their commercially available dentin bond systems but without glutaraldehyde. The components of each dentin bonding system that required visible light activation and all the resin-modified glass ionomers and the polyacid-modified composite resins were irradiated for 40 seconds with a visible light curing

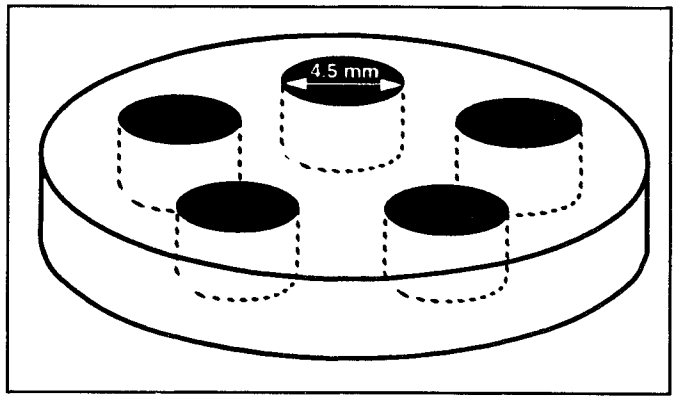

Figure 2. *Layout of typical petri dish for agar diffusion test*

unit (L D Caulk/Dentsply, Milford, DE 19963) immediately after placement into the agar wells. This light unit was tested for adequate light output before each session using a curing radiometer (Demetron Research Corp, Danbury, CT 06810). All materials were handled under aseptic conditions and mixed according to the manufacturer's instructions. Each dental material evaluation was repeated five times.

All plates were incubated at 37 °C in an atmosphere of 5% CO_2, 95% air for 24 hours. Zones of bacterial growth inhibition were measured to the nearest hundredth of a millimeter using a dial caliper (Fowler, Munich, Germany). All measurements of zone diameter included the diameter of the well and were measured at the widest part of the zone (Figures 3 and 4).

pH determinations of the primers, adhesives, and resins of the three dentin bonding systems were

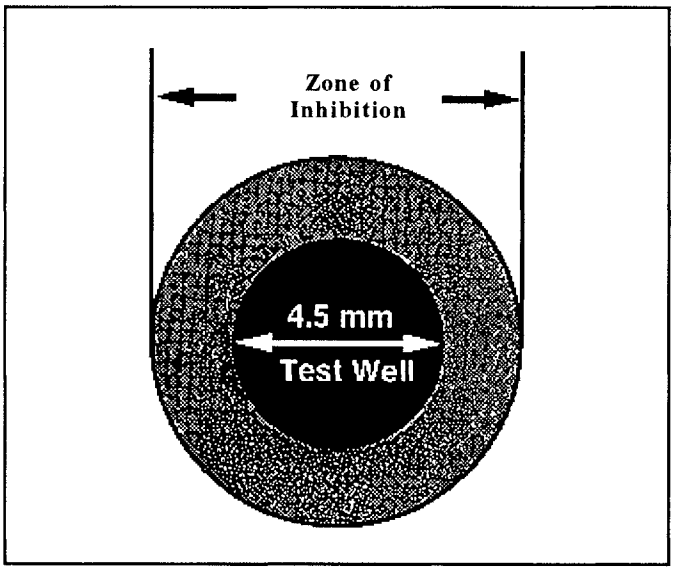

Figure 3. *How the measurements on the zones of inhibition were taken*

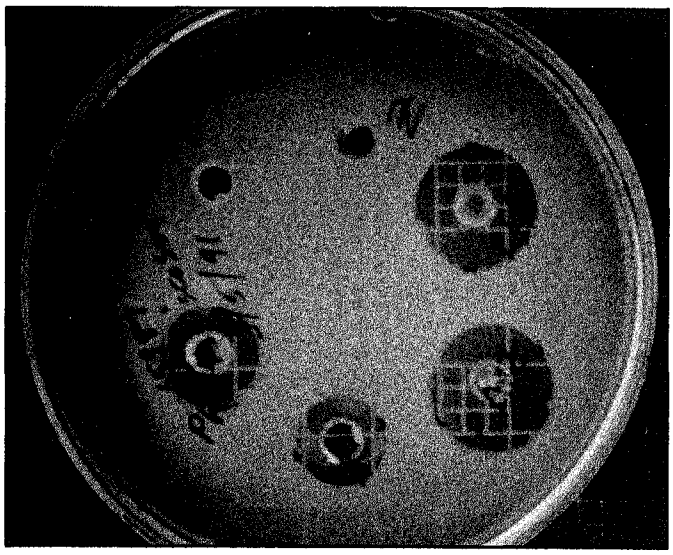

Figure 4. *Actual agar diffusion test showing both lytic zones of inhibition (halo) and nonlytic, no-response zones*

Table 2. Antimicrobial Activity--Syntac

Organism	Component				
	Control (1% glutaraldehyde)	Primer	Adhesive without glutaraldehyde	Adhesive	Heliobond Resin
S mutans	11.86 ± 0.3	20.02 ± 2.5	0	13.72 ± 0.8	0
S sobrinus	13.31 ± 0.3	18.38 ± 0.3	0	17.33 ± 0.8	0
A viscosus	9.44 ± 0.6	28.03 ± 2.1	0	13.12 ± 1.9	0
L salivarius	9.35 ± 0.4	16.51 ± 1.3	0	11.89 ± 1.2	0

Zones of inhibition (mm); n = 5; Mean ± SD.

performed using an Orion EA 940 expandable ionanalyzer (Orion Research, Boston, MA 02129) after the pH electrode (Orion Research) was calibrated with standard buffer solutions at pH 4.01 and 7.00.

Zones of inhibition data for the test bacteria were analyzed using ANOVA and Student-Newman-Keuls multiple comparison test within each dental material at a significance level of $P < 0.05$. The lack of information on the agar diffusion coefficients of the various dental materials and the strong suspicion that these various dental materials would possess different agar diffusion coefficients would make statistical comparisons between materials imprecise and therefore were not performed.

Table 3. Antimicrobial Activity--Gluma 3-Step Bonding System

Organism	Component			
	Control (1% glutaraldehyde)	Conditioner	Primer	Sealer
S mutans	11.25 ± 0.3	14.20 ± 1.7	15.24 ± 0.8	0
S sobrinus	13.54 ± 0.3	18.08 ± 0.8	21.45 ± 0.6	0
A viscosus	10.05 ± 0.2	14.66 ± 1.5	15.24 ± 0.3	0
L salivarius	10.03 ± 0.2	14.10 ± 1.2	15.01 ± 0.7	0

Zones of inhibition (mm); n = 5; Mean ± SD.

RESULTS

The antibacterial effects of the various dental materials are shown in Tables 2-6. Tables 2-4 show the zones of inhibition produced against the test bacteria by the various components of the three dentin bonding systems. There was no consistent ranking regarding the susceptibility of the test bacteria to the conditioner, primers, or adhesives of the dentin bonding systems for the three systems.

Syntac primer produced its greatest inhibitory effect against *A viscosus*, while its adhesive component was most effective against *S sobrinus* (Table 2). The adhesive without the glutaraldehyde and Heliobond resin displayed no inhibitory effect.

Gluma 3-Step Bonding System conditioner and primer both showed significantly greater inhibition against *S sobrinus* than the other three test bacteria (Table 3). The sealer component showed no inhibitory action.

ProBOND primer had it greatest inhibitory effect on *A viscosus*, while the adhesive had its greatest effect on both *A viscosus* and *S sobrinus* (Table 4). The adhesive without the glutaraldehyde showed no inhibitory effect.

The resin-modified glass ionomers all produced varying degrees of inhibitory effects on the test bacteria (Table 5). *Streptococcus mutans* displayed a significantly greater inhibition by Fuji II LC, Fuji Lining LC, and the conventional glass ionomer Ketac-Fil than did *S sobrinus*, *A viscosus*, or *L salivarius*. The liquid component of Fuji Lining LC, when compared to the complete cement, had a significantly greater inhibitory effect on each of the test bacteria.

The inhibitory effect of the polyacid-modified composite resins are shown in Table 6. Infinity and Geristore inhibited *L salivarius* and *S mutans* but did not inhibit *S sobrinus* or *A viscosus*. VariGlass

Table 4. Antimicrobial Activity--ProBOND

Organism	Component			
	Control (1% glutaraldehyde)	Primer	Adhesive without glutaraldehyde	Adhesive
S mutans	11.10 ± 0.2	9.68 ± 0.3	0	9.86 ± 0.7
S sobrinus	13.80 ± 0.3	14.77 ± 0.6	0	13.34 ± 0.9
A viscosus	9.40 ± 0.3	17.62 ± 2.3	0	14.45 ± 1.3
L salivarius	9.86 ± 0.1	11.18 ± 1.6	0	6.51 ± 0.2

Zones of inhibition (mm); n = 5; Mean ± SD.

Table 5. Antimicrobial Activity--Resin-modified Glass Ionomers/Conventional Glass Ionomers

Organism	Product				
	Control (1% glutaraldehyde)	Fuji II LC	Fuji Lining LC	Photac-Bond	Ketac-Bond
S mutans	11.36 ± 0.4	18.43 ± 1.7	20.00 ± 2.0 (L--37.13 ± 0.5)	11.21 ± 0.1	15.44 ± 1.1
S sobrinus	13.65 ± 0.2	12.03 ± 0.3	16.17 ± 0.3 (L--39.23 ± 2.0)	10.34 ± 2.1	13.46 ± 0.2
A viscosus	9.06 ± 0.4	6.80 ± 0.2	15.40 ± 1.2 (L--32.47 ± 1.7)	11.25 ± 0.4	13.16 ± 1.4
L salivarius	9.99 ± 0.2	9.39 ± 0.4	9.29 ± 0.4 (L--22.91 ± 1.0)	8.50 ± 0.2	6.38 ± 0.2

Zones of inhibition (mm); n = 5; Mean ± SD; L = liquid only, no powder added.

was inhibitory to all test bacteria, with *S sobrinus* and *A viscosus* showing significantly greater sensitivity than *S mutans* or *S sobrinus*.

Table 7 is a summary of the antibacterial activity of the various dental materials that allow inter-material comparison. It is arranged to display whether there was or was not an inhibitory action present.

The pH values and general composition of the various components of Syntac, Gluma 3-Step, and ProBOND, and the liquid of Fuji Lining LC are shown in Table 8. The primers for Syntac and ProBOND and the conditioner for Gluma 3-Step all had pH's below 4. Heliobond resin, the adhesives for ProBOND and Syntac, and the sealer for Gluma 3-Step had pH's of 4.6 or higher.

DISCUSSION

The results of this study indicate that the dentin bonding systems and the resin-modified glass ionomers were inhibitory against all the test bacteria, while two of the three polyacid-modified composite resins were not. This confirms and extends the knowledge base gathered from previous investigations on the bacterial effects of other types of glass ionomers and dentin bonding systems (DeSchepper & others, 1989; Loyola-Rodríguez & others, 1994; Barkhordar & others, 1989; Scherer & others, 1989; Emilson & Bergenholtz, 1993; Prati & others, 1990; Scherer & others, 1990). The polyacid-modified composite resin materials Infinity and Geristore had no previous published data regarding their bacterial inhibitory effects, and VariGlass had not been tested against all the bacteria in this study.

The inhibitory effects produced by Syntac adhesive, ProBOND adhesive, and Gluma 3-Step primer were anticipated because they contained glutaraldehyde in their composition. ProBOND and Gluma 3-Step are newer and slightly modified versions of similar products that have been previously shown to have bacterial inhibitory effects (Scherer & others, 1990; Felton & others, 1989). These were chosen for use in our study as standards against which the most recent glutaraldehyde-containing dentin bonding system, Syntac, could be measured. However, what was unanticipated was the presence of antimicrobial activity in the primers of Syntac and ProBOND, as well as the cleanser of Gluma 3-Step. Emilson and Bergenholtz (1993) found similar results with some of the dentin bonding systems they were investigating. However, they found that this effect was material specific and not consistent across all dentin bonding systems tested.

The antibacterial effects shown by the primers/cleansers in this study may be related to either their pH or chemical composition. The pH's of all the primers/cleansers were less than 4, and this pH or less is reported to be bacteriocidal (Davis & others, 1967). The pH within the agar surrounding the wells was not measured, but if these solutions did drop the pH in the agar below 4, this could explain their effect. Irrespective of the exact nature of this result, it is evident that these dentin bond systems possess antimicrobial effects during several aspects of their application.

Table 6. Antimicrobial Activity--Polyacid-modified Composite Resins

Organism	Product			
	Control (1% glutaraldehyde)	Infinity	Geristore	VariGlass
S mutans	11.17 ± 0.2	6.48 ± 0.5	7.28 ± 0.2	14.52 ± 0.6
S sobrinus	13.59 ± 0.2	0	0	25.02 ± 2.7
V viscosus	10.07 ± 0.2	0	0	21.50 ± 1.3
L salivarius	10.04 ± 0.5	7.90 ± 0.2	8.82 ± 0.4	12.66 ± 0.6

Zones of inhibition (mm); n = 5; Mean ± SD.

Table 7. Inter-Material Antibacterial Activity Summary

MATERIAL	TEST BACTERIA *S mutans*	*S sobrinus*	*A viscosus*	*L salivarius*
Syntac				
Primer	+	+	+	+
Adhesive	+	+	+	+
Resin	-	-	-	-
Gluma 3-Step				
Conditioner	+	+	+	+
Primer	+	+	+	+
Sealer	-	-	-	-
ProBOND				
Primer	+	+	+	+
Adhesive	+	+	+	+
Fuji II LC	+	+	+	+
Fuji Lining LC	+	+	+	+
Photac-Bond	+	+	+	+
Ketac-Bond	+	+	+	+
Infinity	+	-	-	+
Geristore	+	-	-	+
VariGlass	+	+	+	+

+ = positive inhibitory reaction.
- = no inhibitory reaction.

The bacterial inhibition displayed by our group of resin-modified glass ionomers reconfirms a property for this category of dental materials that previous investigators had discovered when testing other resin-modified glass-ionomer cements (Scherer & others, 1990; Loyola-Rodríguez & others, 1994). Ketac-Bond was included in the analysis with the resin-modified glass ionomers as a standard of comparison, since it had been shown by other investigators to be inhibitory to the same or similar types of bacteria used in our study (Scherer & others, 1989; Barkhordar & others, 1989; Loyola-Rodríguez & others, 1994).

The antibacterial properties of glass-ionomer cements have been related to either their low initial pH, fluoride release, or other chemical constituents found within the powder (Scherer & others, 1989; DeSchepper & others, 1989; Loyola-Rodríguez & others, 1994). We tested the liquid component of Fuji Lining LC to see if it possessed any bacterial inhibitory properties on its own. Surprisingly, it showed significantly greater effect on all four bacteria than the mixed cement. This effect cannot be attributed to fluoride but could be related to its low pH, chemical composition, or that it had a greater agar diffusion potential. This is the first reported antibacterial effect of a resin-modified glass-ionomer liquid, and it would be interesting to see if other resin-modified glass ionomers have the same inhibitory effect. DeSchepper and others (1989) reported similar antibacterial effects from some conventional glass-ionomer liquids, but all were less than that of the corresponding mixed cement.

The polyacid-modified composite resins Infinity and Geristore did not possess the same inhibitory properties against all four bacteria as seen with the dentin bonding systems or resin-modified glass ionomers. They were ineffective on *S sobrinus* and *A viscosus* but were inhibitory against *S mutans* and *L salivarius*. Why there was this difference in sensitivity between the various bacteria is not known. These are the first published data regarding these materials' antibacterial properties, and it would appear that this category of dental material may not be as effective against bacteria as conventional glass-ionomer or resin-modified glass-ionomer cements. This may be related to the group's chemical composition, which is more composite than glass ionomer in nature. Also, if fluoride release is a factor in a material's antibacterial effect, this category of material has a significantly lower fluoride release when compared to glass ionomers (Loyola-Rodríguez & others, 1994). The polyacid-modified composite resin VariGlass inhibited all four bacteria tested, while Infinity and Geristore inhibited *S mutans* and *L salivarius* but not *S sobrinus* and *A viscosus*. VariGlass is closer in composition to that of resin-modified glass-ionomer cements, which inhibited all four bacteria in the study, than Infinity and Geristore.

Whether the antibacterial results from the materials tested in this investigation would be similar in vivo cannot be determined from this type of study. Also, the duration of this effect is not known, nor can it be hypothesized from this assay system. Is it just at the time of application, or is there a long-term effect that would be useful in case of future microleakage and bacterial infiltration? There are only a few studies that have actually verified the in vitro results with clinical testing (Leung & others, 1980; Fairbourn & others, 1980; Felton & others, 1989).

The agar diffusion test is an accepted method to initially differentiate antibacterial activity between materials; however, it has its limitations (Tobias, 1988). Without further tests, it cannot be determined whether the data gathered from a specific material reflect bacteriocidal or just bacteriostatic effects. Also, it is extremely difficult, if not impossible, to

accurately compare bacterial inhibition data, even for the same material, between different investigators with this technique because of the host of variables that are involved (Tobias, 1988). Therefore, unless all variables are similar in the study design, each study should be looked at as an entity within itself regarding the data gathered on the materials that were tested. What is needed is the development of an experimental system that more closely approximates the environmental conditions within a preparation and uses dentin as the substrate for the testing. This would provide more clinically relevant data to both investigators and clinicians until the results of clinical testing are released.

CONCLUSIONS

Within the parameters of this modified cylinder drop plate diffusion assay investigating the antibacterial effects of various dental materials against *S mutans*, *S sobrinus*, *A viscosus*, and *L salivarius*:

1. The primers and adhesives of ProBOND and Syntac and the conditioner and primer of Gluma 3-Step displayed bacterial inhibition against all four bacteria;
2. The resin-modified glass-ionomer cements Fuji Lining LC, Fuji II LC, and Photac-Bond showed bacterial inhibition against all four bacteria; and
3. The polyacid-modified composite resins Infinity and Geristore inhibited only *S mutans* and *L salivarius*, while VariGlass inhibited all four bacteria.

(Received 8 August 1995)

Table 8. pH Determinations of Primers, Adhesives, and Resins of the Dentin Bond Systems and the Liquid of Fuji Lining LC

Dentin Bond Systems	pH	Composition
Syntac		
Primer	1.2	25% TEG-DMA + 4% maleic acid in acetone and water
Adhesive	3.0	5% PEG-DMA, 5% glutaraldehyde in water
Adhesive without the glutaraldehyde	3.0	
Heliobond resin	4.6	60% BIS-GMA, 40% TEG-DMA
ProBOND		
Primer	2.5	30% HEMA + 6% PENTA in acetone and ethyl alcohol
Adhesive	5.0	5% PENTA, 55% UDMA, TEG-DMA, HEMA, <1% photoinitiators, 0.7% glutaraldehyde
Adhesive without the glutaraldehyde	5.0	
Gluma 3-Step Bonding System		
Conditoner	1.0	1.6% oxalic acid, 2.6% aluminum nitrate, 2.7% glycine water
Primer	3.4	35% HEMA, 5% glutaraldehyde in water
Sealer	5.6	BIS-GMA, photoinitiators
Fuji Lining LC		
Liquid	3.0	HEMA, polyacrylic acid, photoinitiators in water

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West Virginia University, Division of Operative Dentistry, Department of Restorative Dentistry has two full-time, 12-month, tenure- and/or clinical-track faculty positions available as of 1 July 1997, at the rank of assistant or associate professor. Candidates must be eligible for a West Virginia dental license, which requires a DDS or DMD degree from an accredited American or Canadian dental school. Responsibilities include didactic, preclinical, and clinical teaching at the predoctoral level and patient care for a clinical-track position; research is an additional requirement for a tenure-track position. Candidates should be able to demonstrate effective writing and communication skills. Advanced training in operative dentistry or general dentistry is preferred, but not required. Send curriculum vitae plus names, addresses, and phone numbers of three (3) references to: Dr Ronald House, Director, Division of Operative Dentistry, WVU School of Dentistry, P O Box 9460, Morgantown, WV 26506-9460. Applications will be accepted until position is filled. WVU is an Equal Opportunity/Affirmative Action employer.

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ANNOUNCEMENT

26th ANNUAL MEETING of the ACADEMY OF OPERATIVE DENTISTRY

20-21 February 1997
WESTIN HOTEL
CHICAGO, ILLINOIS

The 26th annual meeting of the Academy of Operative Dentistry will focus on the clinical practice of dentistry. Thursday will feature Dr Ed Swift ("Update of Adhesives in Dentistry"), Dr Gerald Denehy ("Excellence in Direct Resin Restorative Dentistry"), Dr Gordon Christensen (Buonocore Lecture), Dr Stanley Malamed ("Management of Office Emergencies"), and Dr Lance Hazelton ("Provisional Restorations—Not Just Temporaries"). Friday's essayists include Dr Fred Eichmiller ("The New American Dental Association Health Foundation: Serving Members and the Public"), Dr Bill Robbins ("The Gingival-Restorative Continuum"), and Dr Mark Latta ("Key Points for Maximizing Success with All-Ceramic Crowns"). Besides these exciting and outstanding speakers, an excellent Table Clinic session will be held on Friday afternoon. In addition, there are always fun spouse events, including a Jeweler's Center tour and wardrobe and makeup designing, a wonderful Gala Reception on Thursday evening, and bountiful shopping on the "magnificent mile."

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

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AMERICAN ACADEMY OF GOLD FOIL OPERATORS
ACADEMY OF OPERATIVE DENTISTRY

OPERATIVE DENTISTRY

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

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