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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 and letters also are published.

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EDITORIAL

Dental Benefits: Essential and Important

As Congress continues its deliberations on health care reform, it is important that dentistry be vocal on a number of issues. We must let our legislators know that we have developed an efficient health care delivery system for the people we serve and that organized dentistry recommends a basic level of care for children. That basic package is focused on prevention and includes, but is not necessarily limited to, examination, diagnosis, and treatment planning; fluoridation of community water supplies; oral prophylaxis and application of topical fluorides and sealants; dietary fluoride supplements; restoration of carious teeth; maintenance of space resulting from the early loss of primary teeth; and patient education.

As the American Dental Association has testified on a number of occasions, dentistry is doing an excellent job in cost containment and the delivery of quality care. When you examine the cost of dental care in a family's budget, you can see that cost containment in dentistry is at work. In major metropolitan areas families spend approximately 31% of their budget on housing, 18% on transportation, and 4.6% on health care. Dentistry consumes about 5% of the 4.6% of a family's budget or 0.23% of a family's budget. For example, if we assume a family's budget is $50,000.00 per year, the housing cost is $15,500.00, transportation costs $9000.00 per year, health care consumes $2300.00, and dentistry's portion of that is $115.00. These are clearly averages and include a number of families and individuals that do not seek dental care. However, it does put our contribution to health care market costs in perspective.

Unfortunately, a number of members of Congress equate efficient delivery and its low cost with low worth. If dentistry is such a small part of the overall picture, how can dentistry be an essential benefit? Currently, only the Clinton health plan includes dentistry for the underserved. All other bills view dental care as outside the Uniform Benefits Package and as a nonessential benefit. This is truly unfortunate, because all health care packages but the Clinton package are proposing taxation of nonessential benefits as a funding mechanism for the greater health care package. That taxation may take several forms. One of the proposals taxes patients on any amount that is spent by their employers on their dental or other nonessential benefits. That is, patients will have the amount spent on their nonessential health care added to their W-2 and be responsible for the taxes at their taxable rate. A second taxation mechanism looks to the employer for revenue. Taxes would be levied directly against the employer on the amount spent on any nonessential benefits for employees. Most employers have stated that this would make funding nonessential benefits too costly, and therefore they would drop those benefits. These nonessential benefits include vision, dental, and a number of ancillary medical and mental health services. Organized labor is clearly against this taxation of benefits, since this would be a substantial reduction in their overall pay packages. Most of the business community also sees this as a serious threat to their employees' health.

It is important for dentistry to be vocal on this issue. Taxation of nonessential benefits will seriously impair our delivery system for important health care components such as dentistry. I encourage each of you to write or call your senator or representative about this issue. First, dentistry is essential to the health and well-being of our patients. The ADA recommendations for a basic package should be essential. Second, if taxation of nonessential benefits occurs, it will probably tax a supplemental package of benefits that includes restorative dentistry. If that happens, the national spending on dental care is predicted to decrease from $44 billion to around $31 billion. That amount of money represents a serious degradation of our nation's oral health status. The impact of that reduction will be felt immediately by our dental community, and as oral health continues to be neglected, the compounding of disease will make the backlog of unmet need grow. The clear loser in this sequence is the patient. It is our responsibility to help our patients in this aspect of their oral health as well as in the direct delivery of dental care. Speak to your legislators on behalf of your patients now.

M H ANDERSON
Editor

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BUONOCORE MEMORIAL LECTURE

Michael Buonocore

GLASS-IONOMER CEMENTS: PAST, PRESENT AND FUTURE

GRAHAM J MOUNT

SUMMARY

It was Michael Buonocore who focused the attention of the profession on adhesion in the oral cavity. He expanded the concept of adhesion of resins to enamel and investigated adhesion to dentin. The problem has been solved through the glass-ionomer cements rather than with resins, but sadly, he did not live to see them achieve maturity.

The glass-ionomer cements were introduced to the profession in 1976, and they provide adhesion to both enamel and dentin through an ion exchange with the additional benefit of a continuing fluoride release throughout the life of the restoration. Solubility is low, abrasion resistance is high, and biocompatability is excellent. As a water-based material, they have an excellent chance of survival in the hostile environment of the oral cavity.

Acceptance of the early versions was slow because of perceived problems with water exchange, a poor color range, and a lack of translucency. Considerable research has been carried out over the last 20 years by members of the profession and the manufacturers; at this point, the glass-ionomer cements make a very valuable contribution to everyday practice.

They are now available as both an autocure and a dual-cure cement, and the color range and translucency are excellent. Problems of clinical placement have been overcome, and it is now a simple matter to take advantage of the adhesion and the fluoride release and place a restoration that is esthetic, resistant to microleakage, long lasting, and a deterent to recurrent caries.

Their only limitation lies in the fact that they

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lack the fracture strength to rebuild marginal ridges and incisal corners. In spite of this limitation, they have opened the way for the introduction of a new range of microcavity designs that allow for conservation of remaining tooth structure to an extent never before available.

In the near future physical properties will be improved still further, and the use of these cements will expand considerably.

THE PAST

It has always been recognized that adhesion between a restorative material and tooth structure is a highly desirable attribute in dentistry. However, the oral cavity represents a hostile environment for any chemical exchange, and water is regarded as the enemy of adhesion. Dr Oscar Hagger (1951), a Swiss chemist working for Amalgamated Dental Company in the late 1940s, is thought to have been the first to demonstrate adhesion to tooth structure using a glycerophosphoric acid dimethacrylate, which could be catalytically polymerized by the action of sulphinic acid in a period of 5-30 minutes. This work led to the development of Sevriton and Sevriton Seal, the first resin restorative with a sealant available to the profession (Amalgamated Dental, Broadwich, London W1). Others continued to work along these lines, and Kramer and McLean (1952) were probably the first to show alterations to the dentin surface using this chemistry. The bond to dentin was not particularly effective, but they went on to show adhesion to enamel using a similar technique (McLean & Kramer, 1952).

It was not until Buonocore's classic paper in 1955, however, that the system of micromechanical adhesion to enamel was really recognized. He pursued the idea with considerable vigor and, over time, defined the principles of the acid-etch technique to the extent that he is clearly regarded as the father of the concept. It is interesting to note that there was a time lapse of approximately 20 years between his early papers and the general acceptance of acid etching for composite resins by the profession. Manufacturers began to provide an etchant with their products in the 1960s, but it was not until the middle of the 1970s that the technique was being widely taught in dental schools and the profession in general accepted the technique as a normal routine requirement for the placement of resin composites.

Dentin bonding has always been more problematic because of the difficulties of developing adhesion in the presence of water in the oral environment, particularly the positive dentin fluid flow. A chemical bond seemed more logical than a mechanical one, and progress was slow. Following Hagger's pioneering work, there was little development for some years. The breakthrough came when Smith (1968) presented the polycarboxylate cements to the profession, showing that it was possible to develop an ionic exchange with dentin and enamel using a polyalkenoic acid as the liquid. The powder that Smith used was essentially zinc oxide, so the cement lacked physical properties, and it was a further few years before Wilson and Kent (1972) perfected the combination of glass powders with a polyalkenoic acid to produce the glass-ionomer cements with sufficient physical properties to be used for restoration. McLean was involved in the clinical aspects of refining these cements, and he eventually presented them to the profession in 1976 at Congress in Adelaide, South Australia. Subsequently he published a series of papers (McLean & Wilson, 1977a,b,c) outlining their development and essential properties.

Since then the glass-ionomer cements have been shown to be a very versatile group with many applications in modern clinical dentistry. They are defined as a water-based cement wherein, following mixing, the glass powder and the polyalkenoic acid undergo an acid/base setting reaction. The acid attacks the surface of the powder particles, releasing calcium and aluminum ions, thus developing a diffusion-based adhesion between the powder and the liquid (Akinmade & Nicholson, 1993).

A similar diffusion-based adhesion occurs on the surface of the tooth, because phosphate ions are displaced by the polyalkenoic acid as it attacks and penetrates both dentin and enamel. Each phosphate ion takes with it a calcium ion to maintain electrolytic balance at the interface, and the result is the development of an ion-enriched layer between the two materials and a union of considerable strength. The union is based initially on hydrogen bonding and, over time, matures and evolves into a stronger chemical bond of a polar/ionic kind.

Fluoride ions are also released during the acid/base reaction, and as these are not an essential part of the matrix formation, they are free to move both out of and back into the cement. There is a chemical similarity between fluoride and hydroxyl ions in as much as they are of a similar size and show an identical charge, so they can readily move between the cement and the environment. The result is that a glass-ionomer cement restoration can behave as a reservoir and maintain a steady flow of fluoride ions into surrounding tooth structure and enhance resistance to caries attack throughout the life of the restoration (Forsten, 1991).

These two properties, diffusion-based adhesion through the acid/base setting reaction and continuing fluoride release, make this group of cements unique in dentistry and of considerable value in a preventive context. The profession must be careful not to be confused by other products that claim to release fluoride. Similarly, manufacturers should not use the term "glass-ionomer cement" for products that do not clearly show an acid/base setting reaction and a continuing fluoride release.

Within the scope of the above definition there are a number of applications for these cements, and the following classification was developed and is generally accepted (Wilson & McLean, 1988a; Mount, 1989a):

Type I: luting crowns, bridges, and orthodontic brackets,

Type II: restorative cements,

Type II.1: esthetic restorative cements,

Type II.2: reinforced restorative cements, and

Type III: powder/liquid ratio 1.5:1—lining cements, powder/liquid ratio 3:1—dentin substitute or base.

The chemistry is essentially the same for all three categories, but there are variations in powder/liquid ratio and powder particle size to accommodate the desired function. For example, for a Type I luting cement, it is necessary that the particle size be no greater than 10μm in order to attain a satisfactory ultimate film thickness. Also the powder proportion should be approximately 1.5:1. The cement will then demonstrate a thixotropic flow, and it is relatively simple to achieve optimum placement with a crown.

On the other hand, the restorative cements require optimum physical properties, so the powder content must be at a maximum. The proportion can be varied for the Type III lining cements, depending on their intended use. As a lining, they should be mixed with a low powder content so they can easily flow into place. They do not require high physical properties, but a lining must be totally covered with another restorative material and not be subjected to high occlusal load. The same cement used with a high powder content can be placed as a dentin substitute in the lamination technique and may remain exposed to the oral environment as an integral part of a final restoration.

Initial development was undertaken by the Laboratory of the Government Chemist in England, but most of the subsequent materials research has been carried out by manufacturers. The cements have been researched at a clinical level in England (Wilson, Wilson & Setcos, 1993), Australia (Mount, 1986; Mount, Knight & Forsten, 1994), and Scandinavia (Forsten, 1993a). A recent survey (Reinhardt, Swift & Bolden, 1993) of the profession in America shows that they are being accepted more extensively in that country, although it must be noted that they are not being used there very frequently as a restorative material. It is understood that they are not very popular with European dentists, although their acceptance is increasing. Anecdotal evidence suggests that they are becoming more popular in Japan and the Pacific Rim countries.

A problem that appears to have inhibited progress is that there has been considerable misunderstanding concerning their strengths and weaknesses among both researchers and clinicians. Many researchers in particular have failed to recognize that most of the early problems have been effectively overcome, and they continue to suggest, quite incorrectly, that color matching is difficult, abrasion resistance is poor, and maintaining water balance is a problem. They pay little attention to powder/liquid ratio and do not understand the dynamic nature of the setting reaction. It is accepted that amalgam takes at least 1 week to achieve reasonable physical properties, and 7-day figures are noted as the normal standard. The glass-ionomer cements also continue to mature for several days, and they do not reach reasonable physical properties for at least 7 days (Crisp, Lewis & Wilson, 1976). In spite of this, researchers continue to test them to destruction at 24 hours. There have been many papers published demonstrating failure in vitro (Sparks & others, 1992; Wieczkowski & others, 1992) that are effectively refuted by in vivo studies showing excellent results (Ngo, Earl & Mount, 1986; Powell, Gordon & Johnson, 1992; Tyas, 1990, 1991). There have also been numerous adverse reports where the materials have been used in an entirely inappropriate manner, and it is apparent the researchers have failed to take into account the relative lack of physical strength in these cements (Kovarik, Breeding & Caughman, 1992; Eakle, 1985).

THE PRESENT

It has been noted that it took at least 20 years to introduce the acid-etch technique to the profession, and it has been 20 years since the glass-ionomer cements were first evolved. Considerable developmental work has been carried out over this time, and it could be assumed that, at this point, the glass-ionomer cements have come of age.

There are several factors that should be discussed further to clarify the present position and eliminate doubts and problems from previous experience.

Chemistry of the Setting Reaction

The setting reaction of the glass-ionomer cements is essentially the same throughout the entire family. In the initial stage divalent calcium ions are released from the glass and rapidly form calcium polyacrylate chains capable of leading to a moderately set material. These chains are relatively weak and soluble in water and must therefore not be exposed to the oral environment. Trivalent aluminum ions are released thereafter, and they form aluminum polyacrylate chains, which are strong and relatively insoluble and form the basis for a long-lasting cement.

In the early history of the cements, the relative fragility and solubility of the calcium polyacrylate chains posed problems, because it was necessary to maintain the cement in isolation for at least 1 hour to allow sufficient maturation to prevent their dissolution. Manufacturers provided a varnish that was intended to ensure a water-tight seal, but none of these was efficient. An alternate technique was developed to overcome the problem. Excess calcium ions were washed off the surface of the powder particles during manufacture, thus reducing the period of time occupied by the calcium ion exchange during the setting reaction. This was satisfactory to the extent that a range of fast-setting cements was evolved using this technique. However, there remained problems with the Type II.1 restorative esthetic cements, because the lack of calcium polyacrylate chains reduced the translucency in the ultimate restoration to an unacceptable level.

The most efficient solution for the Type II.1 cements was evolved by Earl, Mount, and Hume (1989), when they showed that the use of a very low-viscosity, single-component, light-activated enamel resin bond provided the best sealant for the newly placed restoration and would allow the development of entirely satisfactory translucency in the oral cavity. All that is required is that the newly set cement be covered, immediately after removal of the matrix, with the resin seal. Minimal trimming should be undertaken at that time and the resin seal replaced before being light activated. The seal should remain in place and the restoration isolated from water contamination for at least 24 hours. All subsequent contouring and polishing should, however, be carried out under air/water spray (Mount & Makinson, 1982).

Recently a resin dentin bond has been marketed that fulfills these requirements and contains a polyalkenoic acid as well (Pertac Universal Bond, ESPE GmbH, Seefeld/Oberbay, Germany). This makes the sealant more compatible with the glass-ionomer system and provides an excellent seal and a surface glaze and should be placed over both autocure and dual-cure restorations.

Dual-Cure Cements

A recent modification to the chemistry of the setting reaction has resulted in the introduction of the dual-cure cements (Mitra, 1991). The actual formula varies between manufacturers, but in essence there has been an addition of 18-20% of other resins to the liquid so that, in a finally set restoration that was mixed at a powder/liquid ratio of 3:1, there will be an additional 4.5% of resin. The principal component of the extra resins is HEMA, and there are traces of other resins and photoinitiators as well.

The term "dual cure" has been suggested, because these cements still undergo the original acid/base setting reaction, and there is a light-activated resin reaction superimposed over that. As soon as the powder and the liquid are combined, the acid/base reaction begins as usual and will continue in the same way over many weeks. However, a light-activated command set is available over the top of this reaction, which will immediately protect the acid/base reaction from the problems of water balance and stabilize the setting cement.

The presence of the HEMA will modify the autocure mechanism to a limited degree, because some of the available carboxyl bonds will be taken up by the HEMA; the significance of this is not yet fully understood. Also there will be an increase in water uptake because the HEMA is strongly hydrophylic. Therefore the powder/liquid ratio is even more important, because a reduction of powder content will inevitably mean an increase in the proportion of HEMA and a potential for greater water uptake.

The formulas currently available incorporate a further chemical cure mechanism similar to the autocure resin composite materials, which ensures that, over time, there will be a complete cure throughout the entire restoration, and there will be no free HEMA or other resins remaining. This phase has been called a "tri-cure" phase or a "dark cure," but the term "dual cure" is preferred for the entire system, because it identifies the presence of both chemical-cure mechanisms as well as light-cure mechanisms in the same material.

It is important to note from the forgoing that these materials are not a combination of a composite resin and a glass-ionomer cement. In fact, to be correct, the glass-ionomer cements should be recognized as a composite resin in the first place. The polyalkenoic acid is a resin, and the glass is a filler. The most significant difference lies in the diffusion-based adhesion available with the glass-ionomer cements between the polyalkenoic acid and the glass powder, as well as the tooth structure as discussed above. By comparison the adhesion systems available with resin composites are rather tenuous.

In the dual-cure cements there is a small increment of additional resins incorporated to protect the chemical cure mechanism with a light-activated one, and the principal additional resin (HEMA) happens to be one of the resins used in resin composites. This does not convert the glass-ionomer cement into a resin composite, and the two materials should not be confused. Each has its place in restorative dentistry, and they should be used, each in its own place, to complement each other and make up for each other's deficiencies. Resin composites have a high resistance to fracture and adhere strongly to sound enamel, while glass-ionomer cements adhere to enamel and dentin and release fluoride throughout the life of the restoration.

Adhesion

The chemistry of the adhesion of glass ionomers to underlying tooth structure has been carefully investigated over recent years and is now relatively clear. A study by Mount (1991a) covered the stages and detailed the present understanding. Watson, Billington, and Williams (1991) have subsequently traced the ion exchange using a dye technique followed by examination of specimens under a confocal optical microscope.

A recent paper by Akinmade and Nicholson (1993) related the adhesion interactions to a standard diffusion-based adhesion system in as much as the polyalkenoic acid will soften the surface of the tooth structure and the chains will diffuse into the surface of the tooth, displacing calcium and phosphate ions. These authors also make the point that, to achieve such an ion exchange, it is necessary to change the surface of the tooth from high energy to low energy to encourage total adaptation of the cement to the dentin. A 10-second application of a 10% solution of polyacrylic acid will lower the surface energy so that the cement, which has a high surface energy, will adapt and flow readily over the tooth.

The polyacrylic acid has a double action in as much as it will remove the smear layer and surface contaminants at the same time as altering the surface energy, thus exposing the highly mineralized tooth surface to the diffusion of the acid and the exchange of ions. The term "conditioning" was coined originally (McLean & Wilson, 1977c) to cover both these actions and is very appropriate because it distinguishes them from the action of acid etching used in relation to resin composites.

An important conclusion from the above is that studies of adhesion in the glass-ionomer system generally measure the tensile strength of the cement rather than the adhesion (Mount, 1991a). It is necessary always to examine the remaining tooth surface for the presence of the ion exchange layer (Causton & Johnson, 1979) and, in its presence, the failure should be recorded as cohesive in the cement rather than adhesive at the interface. The figures for the tensile strength of the cement will be found to be closely related. Also, in view of the relatively slow rate of maturation, it is desirable to determine the 7-day results rather than the strength at 24 hours.

Fluoride Release

During the manufacture of the glass powder, fluoride is used as a flux so that the final powder particles contain up to 23% fluoride in the form of calcium and sodium fluoride ions (Crisp & Wilson, 1974). Mainly the sodium fluoride ions are released during the acid diffusion phase and, as these are not a matrix-forming species, the cement will not be weakened by their loss (Wilson, Groffman & Kuhn, 1985).

The general pattern of release was established very early (Forsten, 1977), and it has been shown that, following an initial flush, the rate will drop to quite a low level by the end of the first 2 to 3 months. However, Forsten (1993b) has demonstrated that the rate does not decline any further over the first 5 years, so it can be assumed that it will continue for the life of the restoration.

Even more significant is the suggestion (Forsten, 1991) that, depending on the local gradient of fluoride present in the mouth, glass-ionomer cement will take up further fluoride and increase the rate of release again for a brief period. This ability to act as a fluoride reservoir makes these cements very valuable, particularly in the presence of a high caries rate.

The significance of fluoride in the demineralization/remineralization cycle is becoming well understood, and it is apparent that any additional source of fluoride is valuable in the presence of caries. It has been shown by Wesenberg and Hals (1980) that there is a fluoride halo around a glass-ionomer restoration up to 3 mm in diameter, and this will influence both the surrounding tooth structure as well as adjacent teeth.

Biocompatability

When these cements were first developed, McLean and Wilson (1974) suggested that it was unlikely that they would be irritating to the pulp or the soft tissue, and clinical experience bears this out. Subsequently Wilson and McLean (1988b) expanded further, noting that the polyalkenoic acid is a reasonably weak acid initially and becomes even weaker over time. Also, because of the high molecular weight of the liquid and the long entanglement of the chains, it is not able to penetrate dentin very easily. Dentin is an excellent buffer to all acids, and most are precipitated by calcium ions in the dentin tubules. This has been confirmed subsequently by Hume and Mount (1988), and recently Snuggs and others (1993) have been able to demonstrate dentin bridging in monkeys' teeth where mechanical exposures in otherwise healthy pulps were capped with a Type III glass-ionomer cement.

It is therefore suggested that there is no need to place a sublining under a glass-ionomer cement. If the exposed pulp is healthy, there is likely to be a mild inflammatory response over a period of 30 days or less, which will recover in the absence of bacterial activity. As the cement offers such a sound adhesion to tooth structure, there should be no microleakage. If there is no exposure, there will be no inflammatory response, and the presence of another lining material such as calcium hydroxide will reduce the area of dentin available for adhesion with the inherent risk of encouraging microleakage.

It is likely that the continuing fluoride release plays a significant role in maintaining a good soft tissue response in relation to glass-ionomer restorations (Svanberg, Mjör & Örstavik, 1990; Berg & Farrell, 1990; Palenik & others, 1992). The growth of *mutans streptococci* in particular appears to be inhibited, and the result is an excellent response in the gingival tissues in relation to adjacent restorations, in spite of the lack of surface gloss after polishing.

In the past there was concern over the possibility of postinsertion sensitivity following cementation of full crowns with glass-ionomer cement, but it has been shown that the problem is, in fact, similar when zinc phosphate cement is used (Johnson, Powell & DeRouen, 1993; Brackett & Metz, 1992). There are a number of factors likely to cause an irreversible pulpal inflammation following cementation of a crown, including the fact that, in a tooth that needs to be crowned, the pulp has often been irritated by other causes already. It has always been recommended when cementing with zinc phosphate cement that two layers of copal varnish be laid down beforehand to prevent the acid, which is released by filtration through hydraulic pressure, being forced through the dentin tubules to the pulp.

When using glass-ionomer cement, there is a temptation to try to utilize the available adhesion to dentin to enhance retention of the crown. However, this requires removal of the smear layer with subsequent opening of the dentin tubules and an added risk of forcing acid down into an already inflamed pulp. It is suggested that a safer procedure is to seal the dentin first with an application of an oxylate solution (Causton & Johnson, 1982) or alternatively use a dentin bonding agent containing maleic acid.

It is possible to enhance adhesion between a metal crown and the cement by coating the inner surface of the crown with a 5 µm layer of tin oxide (Hotz & others, 1977), but it must be noted that the additional adhesion under any circumstances is only as strong as the tensile strength of the cement, and that is in the order of 2-3 MPa.

Lamination

The adhesion of glass-ionomer cement to dentin has been shown to be long lasting (Mount, 1986), but there are still apparent problems in developing the same longevity with resin dentin bonding agents. McLean and others (1985) suggested that a combination of composite resin over glass-ionomer cement would overcome the shortcomings of both and explained the lamination or sandwich technique. A number of workers have subsequently supported the technique, and Mount (1989c) set down the principles involved in detail.

It is essential that the two materials are placed in bulk. The glass-ionomer cement should be regarded as a dentin substitute and the resin composite as an enamel replacement. Many researchers make the mistake of placing the glass-ionomer cement as a traditional lining using a cement with a low powder/liquid ratio and placing it in very thin sections only. Such a lining lacks strength and has a relatively high solubility and therefore cannot be exposed to the oral environment. The setting shrinkage of a light-cured resin composite will lift off any section of the cement that is thin and weak, and this may lead to microleakage.

The preferred technique is to use the strongest cement available, such as a dual-cure cement, and place it as a full dentin substitute, almost filling the cavity entirely. Excess cement can be cut back at intermediate high speed under air/water spray to free the enamel margins for enamel adhesion and to make room for the composite resin, which will act as an enamel substitute. Some of the cement should be left exposed to the oral environment to retain the advantages of aesthetics and continuing fluoride release. There should be sufficient thickness of composite resin to minimize the tendency of the resin to flex, and approximal contact areas are best restored in resin. Also maximum use must be made of the potential for an acid etch enamel union, because it is the strongest bond to tooth structure available. However, the glass-ionomer cement provides the best adhesion to dentin, and there are the additional advantages of the on-going fluoride release and high tissue tolerance.

THE FUTURE

The glass-ionomer cements have become firmly established as a very useful restorative material, and research continues on improving physical properties and ease of clinical placement. It is essential that both the acid/base reaction, which leads to the chemical adhesion, and the continuing fluoride release and further uptake that leads to it becoming a fluoride reservoir, be maintained intact through any further development.

Even in its present form, it is leading to a new concept in operative dentistry, and it is now possible to reconsider the need to remove otherwise sound tooth structure to make room for a restorative material. There are two aspects at present that deserve serious consideration.

Microcavities

One of the most important changes in operative dentistry arising from the advent of the glass-ionomer cements is the potential for modification of cavity design in treatment of the early carious lesion. Since GV Black first proposed his classification of carious lesions and the cavities required to restore them, it has been necessary to remove considerable amounts of healthy tooth structure to make room for the restorative material. In view of the fact that no restorative material can be regarded as permanent, this has meant that the first lesion has often placed the tooth on an irreversible slide downwards to destruction. The problem for the profession has then been to limit the speed of decline.

The limitation for the glass-ionomer cements in their present form is the lack of fracture strength. As long as they are adequately supported by remaining tooth structure, the adhesion, fluoride release, low solubility, and high abrasion resistance make them a very useful restorative material for a small lesion. If the initial lesion can be dealt with in a very conservative manner and sound tooth structure preserved as far as possible, the next stage of restoration may be delayed for some time, and the ultimate breakdown delayed still further.

In the presence of fluoride, an initial demineralized lesion in both enamel and dentin can be successfully remineralized and a carious lesion healed. However, there comes a point in the carious process where there is cavitation in either enamel or dentin to the extent that it is no longer possible to eliminate plaque retention, and some form of restoration is required. In the presence of fluoride this does not mean the elimination of all demineralized enamel surrounding the cavitation but only restoration of the cavity itself. The demineralized enamel will remineralize and be stronger than the original enamel.

The concept of the microcavity for restoration with glass-ionomer cement was first discussed by Hunt (1984) and Knight (1984) and subsequently refined by Wilson and McLean (1988c). A classification was devised by Mount (1989b), and a number of recent reports show that these cavity designs are being used by dentists in the United States (Hunt, 1990), Australia (Knight, 1989; Mount, 1991b; Mount & others, 1994), Scandinavia (Forsten, 1993a), and England with considerable success.

It is suggested that all new carious lesions should be assessed in the first instance with a microcavity design in mind. Access should be gained very conservatively and the extent of the problem explored. On many occasions it will be found that a considerable area of sound tooth structure can be retained. Unsupported enamel can be retained, because it can be supported by the adhesion available with the glass-ionomer cement (McCullock & Smith, 1986). If the occlusal load appears to be excessive for the cement alone, it can be laminated with composite resin. Subsequent loss of small sections of enamel may also be repaired with a resin composite.

In the class 1/fissure seal, for example, the enamel over the caries should be removed to gain access to the infected dentin, but the remaining fissures should be sealed and not excavated. For the approximal lesion on an anterior or posterior tooth, it is sufficient to gain access to the caries through the lingual or occlusal enamel and leave the approximal enamel, with the marginal ridge, intact. If there is no cavitation in the enamel, it should be left as it is, but if there is a degree of cavitation to the extent that plaque accumulation cannot be eliminated, then it is necessary to reseal that surface. This can often be achieved relatively simply with glass-ionomer cement, because it flows readily and there is no need to remove all demineralized enamel surrounding the lesion.

Obviously not all lesions will be able to be repaired satisfactorily in this manner, and subsequent breakdown of restorative material or supporting tooth structure may require restoration with more conventional designs. However, this is a sound method of extending the functional life of a wounded tooth and at the same time greatly reducing the risk of recurrent caries.

Long-Term Temporary Restorations

The concept of sealing an active carious lesion to stabilize it is not new (Malone, Bell & Massler, 1966; Massler, 1965). It has been shown that removal of infected dentin with retention of softened demineralized affected dentin is a reasonable approach to stabilization. The sealant commonly used in the past was zinc oxide and eugenol, but that material has a limited life span in the oral cavity. Recent investigations of the system have been carried out using a Type II.2 glass-ionomer cement with enhanced physical properties and an early resistance to water uptake. Early results suggest that it is a very useful material under these circumstances and may prove invaluable in those areas of the world where there is still a very high caries rate and restorative dental facilities are not always available.

CONCLUSIONS

The last 20 years have seen considerable progress in the development of adhesion of restorative materials in the oral cavity. The concept of mechanical adhesion to enamel through the enamel-etch technique as advocated by Buonocore has come of age and is universally accepted. Chemical adhesion to both enamel and dentin through glass-ionomer cement has evolved to a stage where its potential and limitations are well understood. There will be further progress in the foreseeable future, but in the meantime, the profession should be prepared to make the most of a system that is simple to apply, safe, effective, conservative, and incorporates a high level of prevention as well.

(Delivered 17 February 1994)

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ORIGINAL ARTICLES

In Vitro Inhibition of Marginal Caries-like Lesions with Fluoride-containing Amalgam

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Clinical Relevance
Fluoride-containing restorative materials inhibit carious lesion formation by *Streptococcus mutans*.

SUMMARY

Carious lesions surrounding restorations represent one of the main causes of restoration failure. The addition of fluoride compounds to dental restorative materials prevents or reduces recurrent caries. The purpose of this study was to compare the capacity of three restorative materials to inhibit the development of recurrent caries in vitro. Thirty unrestored, noncarious premolars that were being extracted for orthodontic reasons were sectioned in half buccolingually and divided into three groups. One of the groups was restored with conventional amalgam. The second group was restored with a fluoride-containing amalgam, and the third group was restored with a glass-ionomer cement. All the samples were submitted to a medium containing *Streptococcus mutans* (Ingbritt strain) for 8 weeks.

At the end of the 8-week incubation period, the samples were cut into 100 µm sections, soaked in Quinoline (IR = 1.62), and observed with light transmission and polarized light microscopy. The development of artificial caries in the cavity walls was measured in microns. The results show that conventional amalgam had an average caries penetration of 160 µm, fluoride-containing amalgam 46 µm, and glass-ionomer cement 11 µm. Glass-ionomer cement gave the best protection against recurrent caries.

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INTRODUCTION

In spite of the great advances in esthetics in restorative dentistry, the most utilized restoration in premolars and molars is still silver amalgam. This is because of amalgam's good physical properties, easy manipulation, and low cost. However, one of the more important causes for replacing amalgams is secondary caries around the restorations. Different studies show that between 38% and 56% of amalgam failures are due to recurrent caries (Dahl & Ericksen, 1978; Mjör, 1981; Qvist, Qvist & Mjör, 1990).

One of the predisposing factors in the development of recurrent caries is microleakage. Microleakage occurs when a margin is open, regardless of the cause. The opening permits penetration of microbiological agents along the interface between the dental tissue and the restoration (Fayyad & Ball, 1987). Restorative materials that leach fluoride into this opening may have specific anticariogenic properties.

The ability of fluoride ions to prevent caries has been well established and widely demonstrated through water fluoridation, topical fluorides, rinses, and dentifrices (World Health Organization, 1984). Fluoride also acts as an antimicrobial by inhibiting the enzymatic activity of some of the cariogenic bacteria (Ferretti, Tanzer & Tinanoff, 1982; Camosci & Tinanoff, 1984).

The first restorative material that showed anticariogenic effect with its fluoride content was silicate cement. This quality has subsequently been demonstrated in glass-ionomer cements (Council on Dental Materials, Instruments, and Equipment, 1988) and composite resins (Swift, 1989). Silver amalgam containing leachable fluoride might provide a benefit in reducing recurrent caries.

A study has been carried out to evaluate the liberation of fluorides by amalgam restorations (Skartveit, Tveit & Ekstrand, 1985), and the absorption of the released fluoride by dental hard tissues (Tveit & Lindh, 1980). The changes in the mechanical and electrophysical properties of fluoride-containing amalgam have been investigated (Le Quang & others, 1979). The changes in the amalgam's manipulation characteristics have also been reported (Valenzuela, Cifuentes & Stanke, 1990). However, no previous studies have reported the effectiveness of fluoride-containing amalgams in inhibiting recurrent caries in the presence of cariogenic microorganisms.

The purpose of this study was to compare fluoride-containing amalgam, regular amalgam, and glass-ionomer cement for their abilities to inhibit the development of recurrent caries. The in vitro model used a known odontopathogenic strain of *Streptococcus mutans* (Kristofferson, Gröndahl & Bratthall, 1985; Thylstrup & Fejerskov, 1988) as the caries-inducing agent.

METHODS AND MATERIALS

Selection and Preparation of Samples

Thirty sound premolar teeth were used for the study. These teeth were obtained from teeth extracted for orthodontic purposes from patients of both sexes between the ages of 10 and 15 years. After extraction the teeth were washed, cleaned, and kept in an isotonic sterile saline solution. During selection, all teeth that presented with caries or enamel failures were discarded.

The chosen teeth were prepared using a high-speed handpiece with air-water coolant. Class 5 cavities were prepared using round diamond burs. The approximate cavity sizes were 5 mm mesiodistally by 3 mm occlusogingivally by 1 mm deep into the dentin. All preparations were finished using a slow-speed handpiece and cylindrical diamond burs, so that the cavosurface margin approximated 90°. Each tooth was sectioned mesiodistally using a carborundum disk and water. The 60 tooth halves were arbitrarily divided into three groups of 20.

The first group was restored with a conventional amalgam (Standalloy, Degussa AG, Frankfurt, Germany), the second group with a fluoride-containing amalgam (Fluoralloy, Dentoria SA, Cachan, France), and the third group with a glass-ionomer cement (Chelon-Fil, ESPE, Seefeld/Oberbay, Germany). All three materials were polished after 24 hours. Each tooth was sealed with sterilized (autoclaved) solid paraffin except for a 1 mm-wide space surrounding each restoration.

Microbiological Stage

The culture medium that was used was sucrose broth 5% with a pH of 6.5. For each 5 ml of this medium, 2 microliters of Bacitracin (500 μg/ml) and 100 microliters of a solution of *Streptococcus mutans*, serotype C (Ingbritt strain), were used. The mixture was dispensed into 60 hemolysis tubes that had been premarked for each study group. Each half-tooth was suspended in the medium with a steel wire.

All procedures were performed inside a laminar flow chamber. All the tubes were incubated in an anaerobic jar at 37 °C for 8 weeks. The medium was replaced with fresh materials every 7 days. The pH of each used culture was measured with a strip of indicator paper, and a slide was prepared by Gram staining to ensure the purity of the cultures and to identify possible contaminators.

Histologic Examination

After 8 weeks, all the tooth halves were removed from the culture medium and washed. Photographs were taken of the changes around the restorative materials. The teeth were then placed in autocured

Table 1. Conventional Amalgam (C Am), Fluoride-containing Amalgam (F Am), and Glass-Ionomer (G-I) Fillings after 8 Weeks in a Streptococcus mutans *Culture*

	Teeth Filled with					
	Group 1		Group2		Group 1	
	(C Am)		(F Am)		(G-I)	
	N	%	N	%	N	%
with decay	19	95	9	45	5	25
without decay	1	5	11	55	15	75

Chi-square (2 df) = 21.010; P < 0.0001 acrylic and sectioned into 100 µm slices using a Gilling-Hamco (Hamco Machines Inc, Rochester, NY 14624-5110) diamond wafering machine. For each tooth half, three slices were prepared by dehydrating them and then soaking them in quinoline (IR = 1.62).

Caries development at the restoration margins was observed using transmitted light microscopy and polarized light microscopy at X40. Using a double-blind system, three observers measured the caries extension along the cavity walls. The mean value in microns was used in the statistical analysis. Photomicrographs were taken for representative samples.

Statistical Analysis

The differences between mean caries development group scores were analyzed using the chi-square and Mann-Whitney U tests.

RESULTS

Figure 1 shows schematically the type of lesions that were produced in the enamel after 8 weeks in the *Streptococcus mutans* culture medium at a pH between 5.0 and 5.5. White-spot-type lesions formed in the superficial enamel around some restorations. When these areas were cut and soaked in quinoline, the typical lesions described by Darling (1956) were observed. A superficial zone, body of the lesion, dark zone, and translucent zone could be clearly seen using both transmitted light and polarized light microscopy. When viewing the cavity wall, a variety of lesion types were seen.

Caries development was dependent on the restorative material used. In conventional amalgam filling (Group 1), 19 of 20 tooth halves developed caries in the cavity wall. In the fluoride-containing amalgam filling (Group 2), 9 of 20 teeth developed cavity-wall decay. In the glass-ionomer cement group (Group 3), 5 of the 20 teeth showed decay at the cavity wall.

When considering only the presence or absence of caries at the cavity walls, the results showed that 95% of the conventional amalgams had caries, while 45% of the fluoride-containing amalgam and 25% of the glass ionomer showed carious lesion development. The differences between the three groups are highly significant (chi-square = 21.01, df = 2, $P < 0.0001$) (Table 1).

Table 2 shows the mean and standard deviation of wall lesion distances in microns. For conventional amalgam restorations, the mean lesion depth was 160.4 µm. Figure 2 shows representative wall lesions from this group. The fluoride-containing amalgam group had a mean depth of 46.15 µm. Figure 3 shows an example of this type of restoration. The glass-ionomer cement lesions had a mean depth of 11.15µm, and an example is seen in Figure 4, where no wall lesion formed. Figure 5 shows a frequent finding for the fluoride-containing amalgam group where the cavity wall is free of caries but the adjacent tooth is affected. The Mann-Whitney U test was used to discriminate differences between groups. The conventional amalgam lesion depths were found to be statistically different from either the fluoride-containing amalgam or the glass ionomer ($P = 0.001$). The differences in lesion depths between the fluoride-containing amalgam and the glass ionomer were not statistically different.

Table 3 compares the depth of caries penetration when comparing only the teeth that developed carious lesions. Teeth that did not become carious were removed from the calculation set in an attempt to compare only teeth that were susceptible to decay. The Mann-Whitney U test demonstrated significantly less caries penetration for the glass-ionomer cement compared to both the conventional amalgam and the

Table 2. Depth (in Microns) of Decay Developed in Cavity Walls in Relation to the Three Restorative Materials

Restorative materials	N	$\overline{X}$	DS
1) Conventional amalgam	20	160.4	103.9
2) Fluoridated amalgam	20	46.15	61.67
3) Glass-ionomer cement	20	11.15	20.56

Mann-Whitney U test: 1 v/s 2 $T = 3.687$ $P < 0.0001$
1 v/s 3 $T = 5.068$ $P < 0.0001$
2 v/s 3 $T = 1.699$ $P < 0.0890$

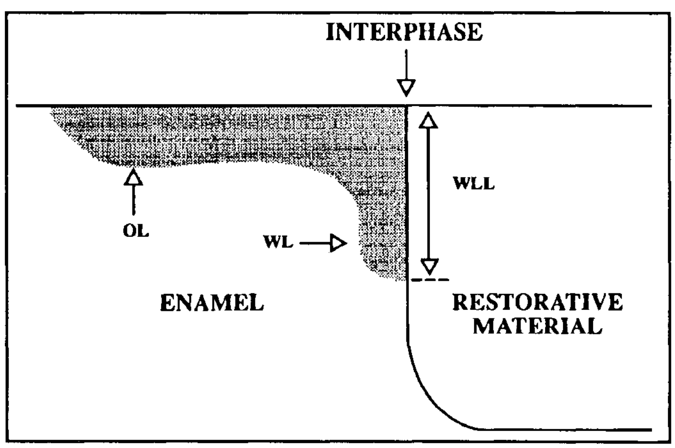

Figure 1. *Schematic drawing of lesions produced in enamel after the experimental period. OL = surface lesion; WL = wall lesion; WLL = depth of lesion from surface to translucent zone.*

fluoride-containing amalgam. The fluoride-containing amalgam's caries penetration was not statistically different than the conventional amalgam's.

Table 3. Depth (in Microns) of Lesions Developed in the Cavity Walls of Decayed Teeth Only

Restorative material	N	X̄	DS
1) Conventional amalgam	19	169.11	102.2
2) Fluoridated amalgam	9	102.67	54.9
3) Glass-ionomer cement	5	44.6	15.8

Mann-Whitney U test: 1 v/s 2 $P = 0.089$

1 v/s 3 $P < 0.005$

2 v/s 3 $P < 0.050$

DISCUSSION

This experimental model produced caries using strains of *Streptococcus mutans* that have previously been shown to cause caries (Clarkson, Wefel & Miller, 1984; Kaufman & others, 1984). It seems to be as efficient as the system of acid gels that produces enamel lesions that are indistinguishable from naturally occurring lesions (Hals, Andreassen & Bie, 1974; Kidd & Silverstone, 1978; Silverstone, Hicks & Featherstone, 1988). The model used in this study includes two very important variants, a truly cariogenic microorganism (*Streptococcus mutans*) and a sucrose metabolic substrate. This is closer to the conditions under which natural carious lesions are produced and investigates not only the effect of fluoride on the tooth structure at the restoration tooth interface, but also the effect of fluoride on *Streptococcus mutans*. This effect on *Streptococcus mutans* is particularly important, since it is considered to be the primary initiator of enamel lesions because of its acidogenesis and its adherence to teeth.

The addition of fluorides to conventional amalgam was first referred to in the works of Innes and Youdelis (1966), Jerman (1970), and Stoner, Senti, and Gileadi (1971). It is postulated that the liberation of fluoride ions occurs by two mechanisms: dilution of salt crystals that are in contact with the cavity wall and by corrosion that liberates fluorides contained in the mass of the amalgam (Fazzi, Vieira & Zucas, 1977; Leitaó, 1982). These ions should be capable of interacting with the calcium from hydroxyapatite-producing calcium fluoride. Ionic interchange should produce fluorohydroxyapatite, which is more resistant to acid attack (Larsen & Fejerkov, 1978; Thylstrup & Fejerskov, 1988).

Our results show that when comparing the capacity to inhibit decay, glass-ionomer cement protects 75% of the sample teeth, compared to 55% for the fluoride-containing amalgam and 5% for a conventional amalgam. Histologic analysis shows that no significant statistical difference exists between the caries inhibition of fluoride-containing amalgam and glass-ionomer cements. The glass-ionomer cement appears to be more efficient, because it demonstrated a greater number of teeth without any type of lesion. In glass-ionomer-filled teeth that did develop lesions, the size of the lesion was smaller.

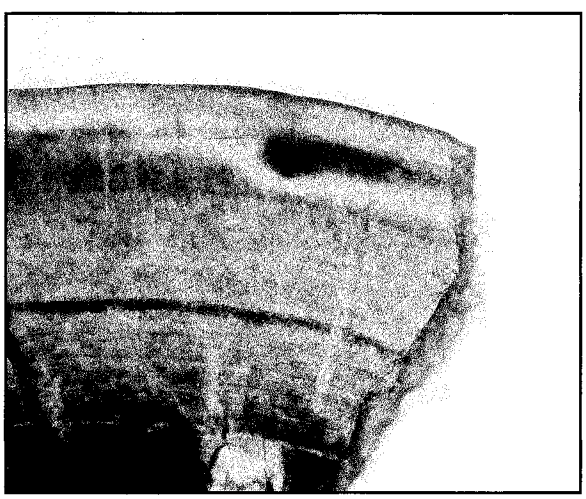

Figure 2. *Photomicrograph of the degree of compromise of a cavity wall in contact with a conventional amalgam. Imbibed in Quinolin (X24)*

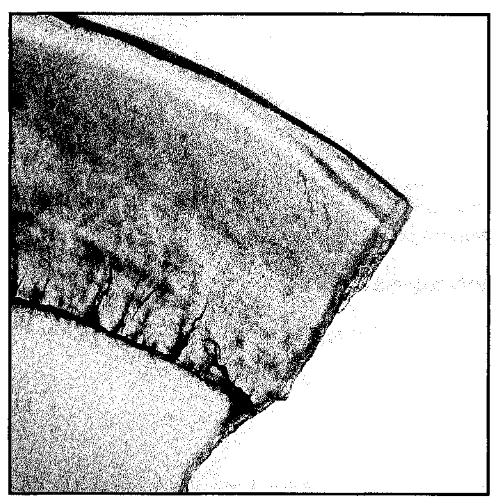

Figure 3. *Photomicrograph of the degree of compromise of a cavity wall in contact with the fluoride-containing amalgam. Depth of lesion is diminished. Imbibed in Quinolin (X20)*

This capacity of the fluoride-containing amalgam to inhibit caries is limited to the interface between the material and the tooth. This material did not affect the development of external lesions. The glass ionomer, on the other hand, protected not only the cavity wall but also the zones adjacent to the restoration (Figure 4). This could be because the cement has a greater quantity of fluoride that is liberated in greater quantities. The interface of the dental tissue and the restorative material appears to be the critical zone for development of new lesions. We consider the inhibition of caries formation in this zone an important finding in this study. Skartveit and others (1985) and Tveit and Gerdet (1981) found that fluoride-containing amalgam liberates small amounts of fluoride ions and that they are absorbed in the enamel that is in contact with the amalgam. Thus we were not surprised to find no extension of protection to areas outside the fluoride-containing amalgam/tooth interface.

Our work corresponds with that reported by Hattab, Mok, and Agnew (1989), who found differences in the capacity to inhibit initiation and progression of experimental caries between different restorative materials. Their efficiency ranking of the materials examined was: glass-ionomer cement > fluoride-containing amalgam > conventional amalgam > composite resins.

The standard deviations in our study were large, in spite of the fact that all premolars were derived from the same population. We hypothesize that the teeth may have had different degrees of mineralization or that fluoride exposures of the patients were not uniform.

To evaluate the impact of the restorative materials on the development of lesions, only the teeth that developed lesions were compared. This comparison decreased the variance, but the glass-ionomer group continued to show significantly less caries penetration. The fluoride-containing amalgam's ability to limit caries penetration was slightly better than the conventional amalgam, although there was no statistical significance. The development of fluoride-containing amalgams may be important because they limit recurrent caries. This precludes replacement of restorations and thereby saves all the costs associated with replacement procedures. It is necessary to develop in vivo studies to observe the clinical behavior of fluoride-containing amalgams.

CONCLUSION

This experimental model has shown that fluoride-containing amalgams do inhibit the development of recurrent caries in the cavity walls in a manner similar to glass-ionomer cements.

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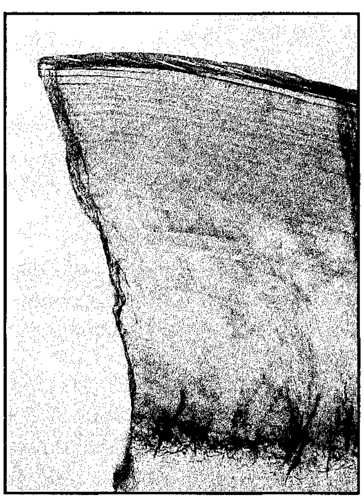

Figure 4. *Photomicrograph of the degree of compromise of a cavity wall in contact with a glass-ionomer cement. Contiguous enamel is free of lesions. Imbibed in Quinolin (X15)*

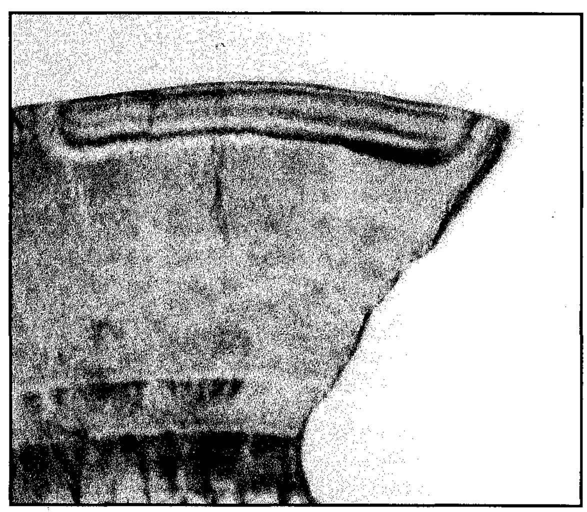

Figure 5. *Photomicrograph of the degree of compromise of a cavity wall in contact with the fluoride-containing amalgam. The enamel wall is free of demineralization, but a surface lesion is nearby. Depth of lesion is diminished. Imbibed in Quinolin (X24)*

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In Vitro Comparison of Filled and Unfilled Universal Bonding Agents of Amalgam to Dentin

A BAGLEY • C W WAKEFIELD • J W ROBBINS

Clinical Relevance
Amalgam can be bonded to dentin under these test conditions

SUMMARY

In this study, four different adhesive amalgam systems were compared(Amalgambond Plus, Amalgambond Plus with HPA, All-Bond 2, and All-Bond 2 with Liner-F) regarding their ability to bond amalgam to freshly prepared dentinal surfaces. The two groups that yielded the highest mean bond strengths, Amalgambond Plus with HPA and All-Bond 2 with Liner-F, were the only two groups in comparison that were not statistically different ($P > 0.05$). The use of the filled resin bonding agents created significantly higher bond strengths between tooth and freshly triturated amalgam than the unfilled resin bonding agents. Further study is required to determine: a) the exact nature and mechanism of the bonds, and b) clinical in vivo presence and longevity of the bonds.

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INTRODUCTION

Dental amalgam has been used by dentists for more than 150 years for both extracoronal and intracoronal restoration of tooth structure. It possesses excellent physical properties, yet it lacks adhesive properties and must rely on undercuts for mechanical retention. Some manufacturers claim that their recently introduced bonding agents will bond amalgam to tooth structure, thus allowing a more conservative approach to amalgam cavity preparation.

Studies have shown that the use of adhesive resins as liners under amalgam will create greater retention than mechanical undercuts (Staninec, 1989). Christensen and others (1991) demonstrated that the cusp fracture resistance of molars with MOD preparations restored with an adhesive amalgam was significantly higher than teeth restored with just amalgam. Another study (Staninec & Holt, 1988) found that the bonded amalgam had a mean tensile bond strength of 1404 psi to etched enamel and of

469 psi to dentin with less microleakage being noted in the resin-bonded amalgam restoration.

Two bonding agents that claim to bond tooth structure to various dental materials are Amalgambond Plus (Parkell Products Inc, Farmingdale, NY 11735) and All-Bond 2 (Bisco Inc, Itasca, IL 60143). Although the two products possess different chemistries, they both claim to bond freshly triturated amalgam to dentin.

Amalgambond Plus is a hydrophilic universal bonding agent based on the 4-methacryloxyethyl trimellitate anhydride (4-META) system. The dentin is treated with an acidic conditioner that leaves collagen fibrils partially demineralized. Hydroxyethyl methacrylate (HEMA) is the vehicle that carries the TBB catalyst and 4-META base into the dentin, where oxygen and water purportedly serve as co-catalysts for polymerization (Nakabayashi, 1992). The contents of the Amalgambond Plus system are listed in Table 1. This system also offers a filled adhesive alternative, called HPA (High-Performance Additive), which is primarily composed of small methyl methacrylate fibers.

All-Bond 2 (Table 2) offers two alternatives. The operator may choose either a 10% phosphoric acid total etch technique that etches enamel and dentin simultaneously, thus removing the smear layer, or an enamel-only etch technique utilizing 32% phosphoric acid.

All-Bond 2 uses ethanol and acetone, which act as solvents and vehicles for the N-tolyglycine-glycidyl methacrylate (NTG-GMA) and biphenyl dimethacrylate (BPDM) primers that constitute a hydrophilic bonding system (Erickson, 1992). The All-Bond 2 system is so hydrophilic that greater efficacy has been reported when the dentin is slightly wet.

An optional step with the All-Bond 2 system, which is reported to provide extra adhesive bonding strength, requires the placement of All-Bond Liner-F (Table 3). This is a filled resin bonding agent that also provides fluoride release.

Both systems bond micromechanically to both enamel and dentin. After dentin etching or conditioning, the bonding agent flows around the exposed collagen fibrils and into microscopic retention points in both peritubular and intertubular dentin. The zone of resin impregnation is termed the hybrid layer, and is the primary source of the high retentive values associated with third-generation bonding agents (Van Meerbank & others, 1992).

The purpose of this study was to evaluate the in vitro shear bond strength of freshly triturated amalgam that was bonded to human dentin, and to compare the values obtained when the additional filled materials supplied by each manufacturer were employed.

METHODS AND MATERIALS

Ninety-one freshly extracted teeth stored in normal sterile saline at room temperature were prepared to receive the amalgam restorations. Either the mesial or distal enamel surface was ground under copious water spray with a model trimmer to expose flat dentinal surfaces. The teeth were then sequentially polished under water with 250-grit, 440-grit, and 600-grit silicon carbide paper (3M Dental Products, St Paul, MN 55144) to provide a smooth smear surface. The teeth were vertically embedded in autopolymerizing acrylic resin (Orthodontic Resin, LD Caulk, Milford, DE 19963) utilizing a surveyor to ensure that the flat, prepared dentin surface was parallel to a straight surveyor rod. The samples were then stored in deionized water until amalgam placement, which was begun immediately following the preparation of all the teeth. A rubber washer, with an inner diameter of approximately 5 mm and a depth of 5 mm, was affixed to each prepared surface, ensuring that only dentin was exposed in the inner periphery of the washer. The washer was luted to the prepared surface by flowing sticky wax around its entire external periphery to allow complete stabilization.

The teeth were divided into four groups. Group 1 consisted of 22 teeth treated with Amalgambond Plus according to the manufacturer's directions. The prepared area was rinsed and dried and the dentin activator applied for 10 seconds. The area was again rinsed for 30 seconds, dried, and a thin layer of the adhesive agent was brushed on the activated surface and left undisturbed for 30 seconds. The base and

Table 1. Chemical Composition of Amalgambond Plus & HPA

1. Activator/Conditioner: 10% citric acid, 3% ferric chloride
2. Adhesive: HEMA (hydroxyethyl methacrylate)
3. Catalyst: TBB (tri-N-butyl-borane-oxide)
4. Base: 4-META (4-methacryloxyethyl trimellitate anhydride)
5. HPA (High-Performance Additive): methyl methacrylate fibers

Table 2. Chemical Composition of All-Bond 2

1. Conditioner: 10% H_3PO_4 (total etch technique)
32% H_3PO_4 (enamel-only technique)

2. Primer: 2% NTG-GMA (N-tolyglycine-glycidyl methacrylate)
16% BPDM (biphenyl dimethacrylate)

3. Bonding Resin: BIS-GMA (bisphenol glycidyl methacrylate)
UDMA (urethane dimethacrylate) HEMA (hydroxyethyl methacrylate)

catalyst were mixed according to the manufacturer's directions for 5 seconds, and a thin layer was brushed onto the dentinal surface. Amalgam (Tytin, Sybron/Kerr, Romulus, MI 48174) was immediately hand-condensed into the center of the washer and allowed to harden for 5 minutes. The samples were then stored in deionized water. Group 2 consisted of 25 teeth, an unintentional slightly larger sample size, treated with Amalgambond Plus using the same method as Group 1, except that HPA powder was utilized in the base/catalyst mixture according to the manufacturer's directions.

Group 3 consisted of 22 teeth treated with All-Bond 2 according to the manufacturer's directions. The dentin surface was treated with 10% orthophosphoric acid (H_3PO_4) for 15 seconds, rinsed thoroughly, and air dried for 1-2 seconds to remove excess water but still leave moist dentin. The primer was mixed as prescribed and applied in three to six coats until a glossy surface was obtained. Equal volumes of the bonding resin and prebond resin were mixed and a thin layer brushed on the dentin surface. After 30 seconds, amalgam (Tytin) was triturated and hand condensed into the inner periphery of the washer, allowed to set for 5 minutes, and the samples stored in deionized water. Group 4 consisted of 22 samples treated with All-Bond 2 in the same fashion as Group 3 except that Liner-F was utilized instead of the bonding resin and prebond resin mixture. Equal volumes of the Liner-F base and catalyst were mixed and a thin layer applied to the dentin surface. The amalgam (Tytin) was immediately hand condensed into the washer periphery and allowed to set for 5 minutes before storing the samples in deionized water.

After 24 hours, the rubber washers were sectioned in two areas using a high-speed handpiece with water spray and a #557 carbide bur (SS White, Lakewood, NJ 08701). The washers were then gently lifted from the teeth, and the teeth were stored for 72 hours in deionized water at room temperature to allow a slight aging period and to allow time for transport to the testing facility.

The specimens were tested in shear on an Instron Testing Machine (Model 1125, Instron Corp, Canton, MA 02021) with a crosshead speed of 5 mm/min. A blunt testing point was loaded directly against the amalgam-tooth interface in a direction parallel to the long axis of the tooth, and the load was applied until the restoration sheared from the tooth surface. The force required to dislodge the specimen was recorded in megaPascals.

RESULTS

Shear bond values of the four groups were analyzed using a one-way analysis of variance (ANOVA) and a Scheffé F-test post hoc analysis. Results indicated a statistically significant difference ($P < 0.05$) between Amalgambond Plus with HPA and All-Bond 2 with Liner-F as compared to Amalgambond and All-Bond 2. However, no statistical difference was noted between Amalgambond Plus with HPA and All-Bond 2 with Liner-F. Table 4 lists the mean shear bond strength and standard deviation values.

DISCUSSION

The latest generation of dentinal bonding agents shows very promising results regarding dentin-amalgam bond strengths. In this study, amalgam was bonded to tooth structure utilizing both filled and unfilled adhesive resin systems. The filled resin restorations resulted in significantly higher shear bond strengths as compared to the samples prepared with the unfilled restorative materials.

It should be noted that the bond strengths obtained in this study only indicate short-term, nonthermally stressed values, which should provide the maximum bond strength values one would expect. Also, the continually increasing load applied to the specimens

Table 3. Chemical Composition of All-Bond 2's Liner-F

1. Resin: BIS-GMA (bisphenol glycidyl methacrylate) HEMA (hydroxyethyl methacrylate) MEMHF (morpholine ethyl methacrylate hydrofluoride)
2. Filler: barium glass, strontium, quartz
3. Tertiary Amine
4. Peroxide
5. Camphoroquinone (photoinitiator)
6. P-TID catalyst (dihydroxyethyl-P-toluidine)
7. Proprietary methacrylate monomer

Table 4. Mean Shear Bond Strength in MPa and Standard Deviation Values

Group	Bond Strength	Std Dev
1 (Amalgambond Plus)	2.268	0.778
2 (Amalgambond Plus & HPA)	9.208	3.557
3 (All-Bond 2)	5.845	2.088
4 (All-Bond 2 & Liner-F)*	11.736	4.34

* indicates significant difference ($P < 0.05$).

in this study may not have clinical applications. Normal masticatory stresses may have an entirely different effect on the resin bond that was not simulated in vitro in this study. Because of the duration of this study, any deterioration of the bond over time that may occur was not observed. Resin fatigue, if found to occur, could adversely affect the longevity of the bonded restoration. Therefore, further studies are necessary in order to test the long-term stability of these bonding mechanisms.

The mechanism of failure was not investigated in this study, thus leaving one to speculate at what phase of the adhesive interface breakdown occurred, such as at the amalgam-primer interface, amalgam-liner interface, or was the fracture completely in the amalgam? Further research in this area would be interesting and would help gain better insight into the interaction between resin and amalgam.

Although the chemistries between the two bonding systems utilized in this study are different, several similarities do exist. Both use HEMA, a bifunctional molecule that is an outstanding adhesion promoter that enhances the diffusion of monomer into the dentin and around the exposed collagen to form the hybrid layer (Nakabayashi & Takarada, 1992). This hybrid layer may be considered an admixture of polymer and dentinal components, creating a resin/dentin composite (Nakabayashi, 1982; Wang & Nakabayashi, 1991). Both systems are extremely hydrophilic, and both modify or remove the smear layer, facilitating contact with intact dentin to create a zone of decalcification. Van Meerbeek and others (1992) have shown that the success of all third-generation bonding agents is dependent upon the formation of a hybrid layer. The thickness of the hybrid layer is not the determinant of bond strength. However, if the resin-impregnated layer is less than the depth of etched decalcification, this may create a weakened base beneath the hybrid layer that will have a negative impact on restoration performance over time (Pashley, Horner & Brewer, 1992). In addition, modern bonding systems are increasingly technique sensitive. If the dentin is overetched, the collagen is completely decalcified and denatured. When this occurs, the collagen is compressed by the resin monomers rather than being surrounded by them, resulting in the absence of a hybrid layer and inadequate bond strength (Nakabayashi, 1985, 1989). Currently, it is evident that the dangers of overetching are being addressed by the recommendation of shorter etching times for dentin (Blosser, 1990). Also, etchant/conditioner properties are being carefully adjusted as to concentration, osmolarity, and pH to form the optimum hybrid layer (Pashley, 1992).

Pashley (1989) and Maroli, Khera, and Krell (1992) have discussed variations in dentin. It becomes wetter and possesses decreasing mineral substrate as the pulp is approached. In addition, bond strength variations appear in dentin that have been altered by aging and pathological processes such as caries (Ogawa & others, 1983; Tagami & others, 1991). This study does not address these variables.

CONCLUSIONS

With the advent of the new generation of adhesive materials, the protocol for the placement of amalgam must be reevaluated. It has been demonstrated in vitro that bonded restorations can provide much greater retention than those retained by conventional grooves alone or dovetails alone (Staninec, 1989). If similar results can be obtained in long-term in vivo studies, then the future may find practitioners able to conserve tooth structure by only having to remove the carious lesion, once adequate access has been obtained.

Clinically, the use of the bonded amalgam restorations can serve many purposes besides increasing bond strength. A microleakage study demonstrated a better seal with less microleakage in the bonded amalgam than that produced with a composite resin (Staninec & Holt, 1988). In another study (Torii & others, 1989), the progression of artificial caries was inhibited along cavity walls in bonded amalgam restorations. Finally, teeth restored in vitro with amalgam bonded to the tooth have been found to fracture at a significantly greater load than did teeth restored with conventional amalgam (Eakle, Staninec & Lacy, 1992).

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

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CLINICAL ARTICLE

Bite Registration Using Impression Plaster

B A PENCE, Sr • L BAUM • T LI

Clinical Relevance
A simple and cost-effective method of bite registration is presented.

INTRODUCTION

Registration of correct centric jaw relations is most important in fabricating a fixed or removable prosthodontic appliance. Several variable factors are involved in this process: the presence or absence of posterior vertical stops and anterior vertical stops, tooth mobility, number and location of remaining teeth or implants, and inflammation of the temporomandibular joint (TMJ). There are conceptual differences among clinicians as to which of these variables are clinically relevant and which are not. Despite these differences and variables, dentists have taken and will continue to take vertical registrations utilizing different methods and materials. The trend away from complete dentures toward complex oral rehabilitation complicates the problem even more.

Impression plaster is probably one of the oldest materials used in dentistry. It was promoted by some clinicians for complete denture impressions well into the 1950s. The purpose of this short paper is not to debate or compare the merits of the various materials commonly used in taking bite registrations. Rather the objective is to describe the art of utilizing impression plaster for this purpose and to suggest certain conditions where its use is indicated.

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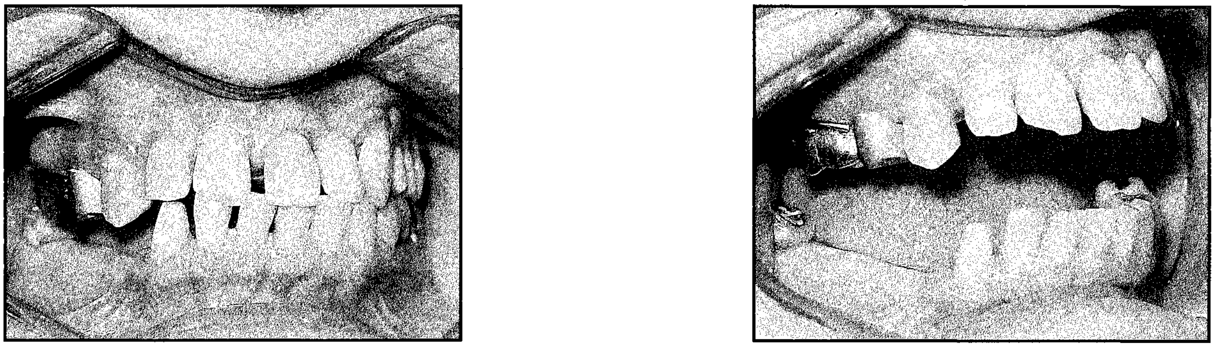
INDICATIONS

Edentulous mouths, devoid of piers and compressible periodontal membranes, are commonly recorded by base plates and wax bite blocks that distribute forces uniformly over edentulous ridges.

On the other hand, where most teeth are present an elastomeric or similar kind of material is used so that the teeth rather than the gingivae provide the support for orientating the casts.

In partially edentulous mouths, however, where some anterior vertical stops remain but where long ridge areas extend distalward, impression plaster is the material of choice. Edentulous areas may be unilateral or bilateral or they may be opposing each other or opposing natural teeth (Figures 1a, 1b). The rationale in these instances is to establish vertical dimension and anterior stops through the natural dentition, then record with plaster the related ridge areas.

Ordinarily these partially edentulous areas would



Figures 1a & b. *Patient with missing teeth on lower right side. No vertical stop was present on the right side except the lateral and central incisors. Objective: To fabricate a provisional metal bridge to stabilize the occlusion on the right side. A permanent treatment plan has not yet been determined.*

Figures 2a & b. *Impression plaster of proper consistency is inserted into the right vestibule of the patient. After closure the maxillary teeth will leave their imprint on the superior side of the index; the mandibular ridge will leave an imprint on the inferior side of the index.*

be recorded with a wax bite block. Impression plaster is a substitute for this base plate/bite block registration process.

MATERIALS NEEDED

Materials needed include impression plaster (No 2, Snow White, Sybron/Kerr, Romulus, MI 48174), approximately a 3-minute set; flexible plaster bowl; paddle-shaped spatula; and water syringe. The mixing is done at the chair.

DENTIST AND PATIENT PREPARATION

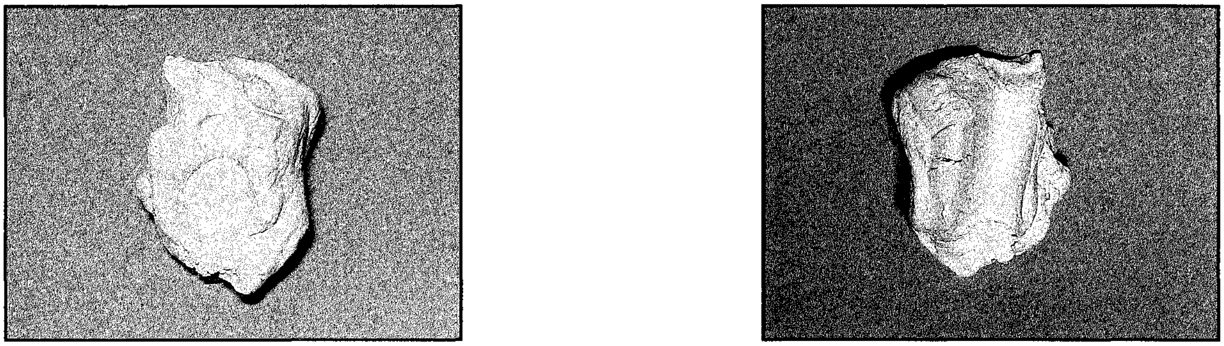
Using impression plaster is a technique-sensitive process. If the material is placed into the mouth too soon, it flows out of control; if it is placed too late, it will not adapt itself to the gingival contours. Recognition of the correct stage during the setting process—a stage that lasts only 10 seconds—is very important.

Proportion of water and plaster is not critical; however, it is best to err by a low rather than a high viscosity mix. A mass of plaster (comparable to a scoop of alginate) is placed into the mixing bowl, and water from the syringe is added. Spatulation is begun immediately and more water added, if needed, to produce a somewhat "sloppy" mix.

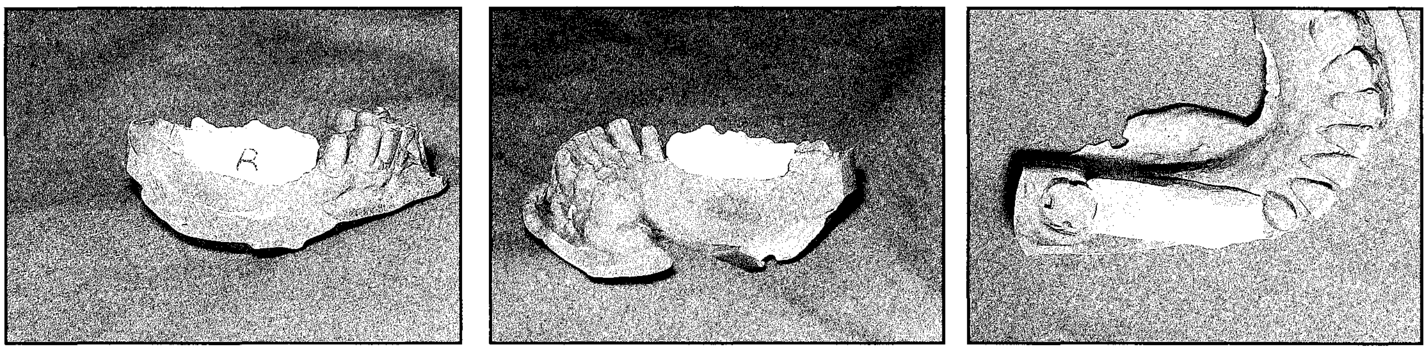
Spatulation is continuous until the material gradually hardens to a kind of "slump" stage. This slump stage is recognized by its viscosity, because the material has now become dense enough so that a mass can be picked up from the spatula with the fingers. As the right cheek of the patient is reflected to the side, a mass about the shape and size of a walnut is deftly deposited with the index finger into the vestibule so that it rests on the surface of the lower ridge or teeth (Figures 2a, 2b). Quickly a similar mass is deposited into the left vestibule, and the patient is instructed to close together and not move. Passive closure is recommended; patients should not "crunch" together with force. With gentle pressure the cheeks may then be pressed inward to better align the plaster over the ridge areas.

A waiting period of at least 2 minutes takes place before testing the stage of set. Probing the plaster with an explorer identifies the degree of set that has taken place and the appropriate time for its removal. Ordinarily this stage occurs about midway between the time of placement and the time of exothermic heat generation.

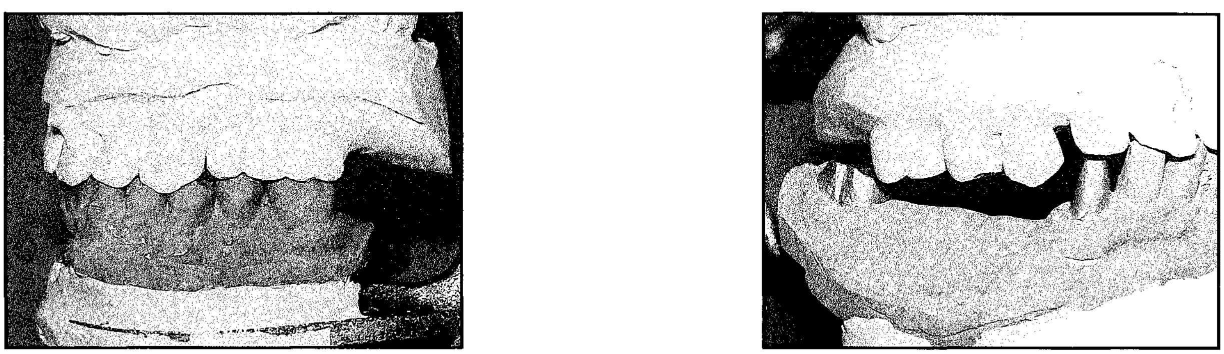
The patient is instructed to open. The two plaster indexes are removed, marked "R" and "L" with an indelible pencil for easy identification, and then set



Figures 3a & b. *Plaster index waiting to be trimmed. (Top and bottom view)*



Figures 4a, b & c. *Plaster index trimmed to fit the lower cast. Its buccolingual width has been reduced to 10-12 mm. Note the accuracy of fit to both upper and lower casts.*



Figures 5a & b. *Working models mounted in the articulator, ready to wax up the provisional metal bridge*

aside (Figures 3a, 3b). The patient's mouth is rinsed to remove plaster fragments.

PRECAUTIONS

1. Don't use too much plaster.
2. Don't worry about the tongue. The natural rest position of the tongue will provide a lingual wall to support the soft plaster.
3. Don't wait too long to remove the plaster indexes. If necessary, fracture the plaster before it achieves a hard set. Then repeat the procedure.
4. Beware of undercuts that exist beneath lower bridges, undercuts where plaster may leak and lock the index to the teeth. Block out material (OraSeal putty, Ultradent Products Inc, Salt Lake City, UT 84124) can be inserted from the lingual into such areas to occlude the opening.
5. Be sure the impression is taken at the same appointment as the bite registration, so the index will fit the models. The topography of the gingiva may vary considerably from day to day, and the less time between the impression and the index, the better the index will fit the cast.

FITTING AND MOUNTING THE MODELS IN THE ARTICULATOR

After pouring and trimming the models, inspect them for irregularities and remove any interferences. Then fit the plaster index to each respective portion of the upper cast. The plaster index should be trimmed so that only the occlusal crest of the ridge or surface of the teeth is left. The width of the contacting areas that remain need only be 10-12 mm wide (Figures 4a, 4b, 4c).

After being assured that the fit of the indexes to the maxillary cast is precise and complete, fit the indexes to the respective areas of the lower arch. Then set them aside, along with the casts, until they have dried and can be fastened to each other with sticky wax. Mount them without the use of a face bow in an articulator of choice (Figures 5a, 5b).

TECHNIQUE MODIFICATION

Frequently the clinician is confronted with an instance where ridge registration is required on one side but tooth-to-tooth registration is required on the other. This poses no problem. Simply mix the plaster, use it for the edentulous ridge, and utilize the occlusal facets of wear as the contralateral index. If the wear facets are nonexistent or some teeth are missing, a polyvinyl siloxane material (Regisil, L D Caulk, Milford, DE 19963) is mixed and injected with a syringe into the occlusal embrasures and spaces of that side while the plaster is hardening on the other. The patient must be warned, of course, to keep the mouth closed and the teeth together while the operator reflects the cheek and injects the elastomeric material. A heavy bead of material is then injected along the buccal surface to provide bulk. This will help in providing stability of this registration while mounting the casts.

Some laboratory technicians are quite capable and can be depended upon to assemble the parts and mount the cast. However, as some clinicians prefer to trim their own dies, some dentists prefer to prepare the parts and test them for fitting before turning them over to the technician to mount them on the articulator.

CONCLUSION

Assurance and satisfaction achieved by this system provides great confidence in the predictability of the finished results. Those who become adept in the use of impression plaster for this purpose are most enthusiastic about the improved accuracy, greater convenience, and saving of chair time. They seldom revert to using base plate and bite blocks again.

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The Antimicrobial Action of Chlorhexidine-containing Zinc-Phosphate Cement

W W BRACKETT • S ROSEN

Clinical Relevance
A cement that inhibits cariogenic organisms in vitro without loss of strength is presented.

SUMMARY

In this study chlorhexidine dihydrochloride and diacetate salts were incorporated at a low level into a zinc-phosphate luting cement. Inhibition of three cariogenic organisms by cement specimens aged up to 8 weeks was significantly greater than the bacterial inhibition of unaltered zinc-phosphate cement. The addition of chlorhexidine caused no significant degradation in strength, film thickness, or solubility of the cement.

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INTRODUCTION

The role of a luting cement in maintaining the marginal integrity of cast restorations is to seal the interface between restoration and tooth structure. As the cement degrades over time, this interface becomes susceptible to colonization by plaque microorganisms and resultant secondary caries (Schwartz & others, 1970).

Fluoride-releasing materials, such as glass-ionomer and silicophosphate cements, assume a less passive role primarily through fluoride uptake and increased caries resistance of adjacent tooth structure (Swartz & others, 1980), although bacterial metabolism can be suppressed by sufficiently high fluoride concentrations (Harris & Christen, 1982).

If chlorhexidine, a safe and highly effective plaque suppressant (Fardal & Turnbull, 1986), could be incorporated into a cement and be released over time in an active form, luting agents could assume an active role in the prevention of secondary caries. In the only previous report on this subject (Schwartzman

& Caputo, 1982), chlorhexidine was shown to enhance the antimicrobial activity of a zinc-polycarboxylate cement, but the effect was evaluated only over 96 hours.

The purpose of this study was to evaluate the bacterial inhibition of a chlorhexidine-containing cement over an extended time period. In order to eliminate any variability from fluoride release, zinc-phosphate cement was selected. In addition, the effects of chlorhexidine addition on the physical properties of the cement were evaluated.

METHODS AND MATERIALS

A representative commercial zinc-phosphate cement (Fleck's Cement, Mizzy, Inc, Cherry Hill, NJ 08002) was altered through addition of chlorhexidine diacetate or chlorhexidine dihydrochloride to the cement powder. These salts are less soluble than the more familiar chlorhexidine digluconate. Although not commercially available in the US, they were obtained from the research department of a chemical company in pure form. The level in the cement powder of added chlorhexidine was 1 or 2% by weight.

The physical properties of film thickness, compressive strength, and solubility and disintegration of the unaltered and the chlorhexidine-containing cements were evaluated according to the methods set forth in American Dental Association Specification Number 8 (Council on Dental Materials and Devices, American Dental Association, 1978). In order to achieve an appropriate film thickness, the powder:liquid ratio of the chlorhexidine-containing cements was reduced by 10%. All subsequent tests were carried out with this powder:liquid ratio for the experimental cement and the specified powder:liquid ratio for the commercial cement. Average values for all cements for each property were compared using an analysis of variance ($P < 0.05$).

To evaluate the antimicrobial effects of each cement, inhibition zones produced on agar plates streaked with cariogenic microorganisms were measured. The organisms used were *Streptococcus mutans*, *Lactobacillus salivarius*, and *Actinomyces viscosus*. These were grown on trypticase soy + 5% sheep blood agar plates. Cement specimens for inhibition testing were 6 mm disks of 2 mm thickness. Specimens were stored in 37 °C distilled water, which was changed twice weekly.

At intervals of 1, 2, 4, and 8 weeks, the cement specimens were placed on plates inoculated with the three organisms. After 24 hours' incubation, the diameter of the inhibition zones was measured to the nearest millimeter using a caliper. The average zone diameters for each cement at each time interval for all microorganisms were compared using an analysis of variance and Tukey's Studentized range test ($P < 0.05$). Sample size was six.

RESULTS

No significant difference in any physical property was found in comparing the chlorhexidine-containing cements to the unaltered cement (Table 1).

At each time interval, and for each microorganism, the chlorhexidine-containing cements demonstrated significantly larger zones of inhibition than the unaltered cement (Table 2, Figures 1-3).

Table 1. Physical Properties of Chlorhexidine-containing and Unaltered Zinc-Phosphate Cement (Ac = chlorhexidine diacetate; Hc = chlorhexidine dihydrochloride)

Property-Mean (sample size)	Zinc Phosphate (unaltered)	Zinc Phosphate (+ Ac 2%)	Zinc Phosphate (+ Ac 1%)	Zinc Phosphate (+ Hc 2%)	Zinc Phosphate (+ Hc 1%)
Compressive Strength MPa [SD] (n = 6)	81.75 [2.6]	75.9 [6.0]*	73.6 [9.3]*	77.0 [1.1]*	76.0 [8.0]*
Film Thickness µm [SD] (n = 5)	31 [4.4]	28 [2.5]*	19.4 [4.2]*	25.4 [6.2]*	17.0 [4.2]*
Solubility and Disintegration % [SD] (n = 3)	0.16 [0.01]	0.22 [0.04]*	0.24 [0.06]*	0.24 [0.03]*	0.17 [0.02]*

*not significantly different from unaltered cement, ANOVA, $P > 0.05$

Table 2. Average Inhibition Zone Diameters of Chlorhexidine-containing and Unaltered Zinc-Phosphate Cement (Ac = chlorhexidine; Hc = chlorhexidine dihydrochloride)

Organism, Interval (n = 6)	Zinc Phosphate (unaltered) mm [SD]	Zinc Phosphate (+ Ac 2%) mm [SD]	Zinc Phosphate (+ Ac 1%) mm [SD]	Zinc Phosphate (+ Hc 2%) mm [SD]	Zinc Phosphate (+ Hc 1%) mm [SD]
S mutans					
1 week	6.0 [0]	12.2 [1.0]*	11.8 [0.4]*	13.2 [0.4]*	11.7 [0.5]*
2 weeks	6.2 [0.4]	10.8 [1.2]*	10.3 [0.5]*	12.8 [1.2]*	11.0 [0.6]*
4 weeks	6.3 [0.5]	12.7 [0.8]*	9.0 [0.6]*	14.0 [0.9]*	9.5 [0.8]*
8 weeks	6.0 [0]	12.7 [0.8]*	10.5 [0.5]*	13.0 [1.1]*	10.7 [0.5]*
A viscosus					
1 week	6.2 [0.4]	13.8 [1.2]*	11.8 [0.4]*	14.5 [1.0]*	12.0 [0.6]*
2 weeks	6.3 [0.5]	15.2 [2.4]*	10.0 [0.6]*	19.0 [0.9]*	10.2 [0.8]*
4 weeks	6.5 [0.8]	15.0 [2.2]*	8.8 [0.4]*	15.8 [3.2]*	9.7 [0.5]*
8 weeks	6.8 [0.8]	11.0 [0.6]*	9.6 [0.5]*	11.7 [0.8]*	10.3 [0.5]*
L salivarius					
1 week	6.0 [0]	12.0 [0.6]*	11.5 [0.5]*	13.5 [0.5]*	11.5 [0.5]*
2 weeks	6.0 [0]	10.0 [0.6]*	11.0 [0]*	12.2 [0.8]*	12.0 [0.6]*
4 weeks	6.8 [0.4]	12.8 [0.8]*	10.7 [0.5]*	13.3 [0.5]*	11.3 [0.5]*
8 weeks	6.2 [0.4]	11.5 [0.8]*	10.7 [0.5]*	13.3 [0.8]*	11.5 [0.5]*

*significantly higher than unaltered cement for same organism at same time interval, ANOVA, Tukey's Studentized range test, $P < 0.05$

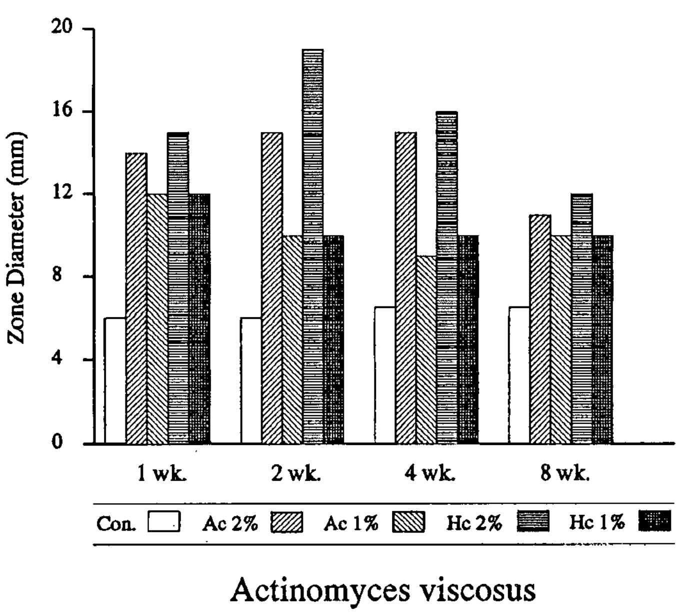

Figure 1. *Bacterial inhibition of each cement at each time interval for* Actinomyces viscosus *(Con = unaltered control group; Ac = chlorhexidine diacetate; Hc = chlorhexidine dihydrochloride)*

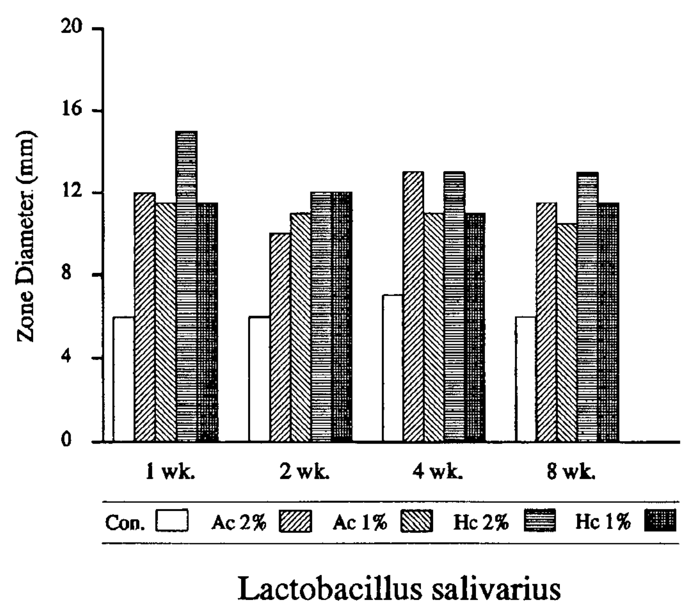

Figure 2. *Bacterial inhibition of each cement at each time interval for* Lactobacillus salivarius *(Con = unaltered control group; Ac = chlorhexidine diacetate; Hc = chlorhexidine dihydrochloride)*

DISCUSSION

Increasing the level of either form of chlorhexidine to 2% seemed to offer little advantage over the 1% level. Although the physical properties of the zinc-phosphate cement used were not significantly diminished by the addition of chlorhexidine, no correlation between these properties and the clinical longevity of cast restorations has been established. Clinical trials are needed to establish the efficacy of any experimental cement in retaining castings.

Because chlorhexidine mouth rinses present little risk of systemic toxicity, it is unlikely that any harmful amount of chlorhexidine would be ingested by patients from a luting cement. Unfortunately, the regulations of the US Food and Drug Administration and comparable agencies in other countries would make approval of such cements very expensive, and severely limit their commercial viability.

The persistence of bacterial inhibition over 8 weeks from a low level of antimicrobial agent, given storage of the samples in water, is impressive. As part of a pilot study for a future investigation, selected specimens from this study were placed on inoculated plates after 6 months' storage in water. These showed perceptible bacterial inhibition, suggesting that some inhibitory effect persists almost indefinitely.

Based on the findings of this study, it seems probable that the chlorhexidine species diffuses through the cement. Addition of chlorhexidine to glass-ionomer cements, to gain the additional benefits of fluoride release, would also seem promising.

Despite favorable laboratory results, any presumed reduction in bacterial colonization or secondary caries at casting margins should be confirmed in a clinical setting.

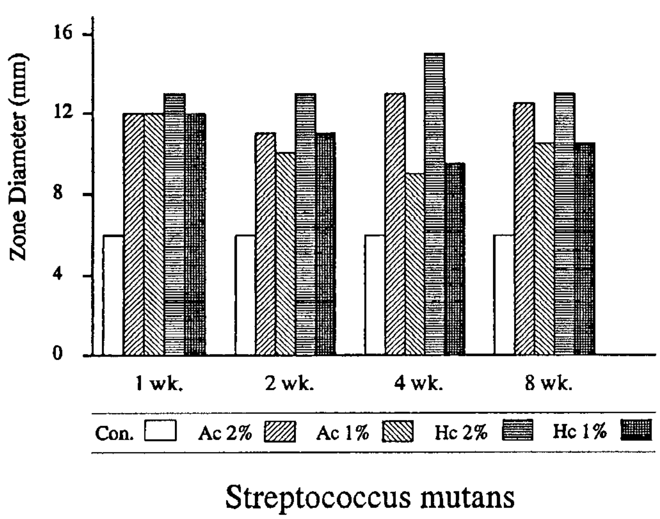

Figure 3. *Bacterial inhibition of each cement at each time interval for* Streptococcus mutans *(Con = unaltered control group; Ac = chlorhexidine diacetate; Hc = chlorhexidine dihydrochloride)*

CONCLUSIONS

The addition of chlorhexidine to a zinc-phosphate luting cement significantly increases its inhibition of cariogenic bacteria in vitro, without significantly reducing its physical properties.

Acknowledgment

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Fracture Toughness of Pin-retained Class 4 Restorations

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Clinical Relevance
A tested pin technique gives a small increase in fracture resistance

SUMMARY

Standardized class 4 cavities were prepared in bovine incisors and restored with a microfilled composite resin. The composite restorations were retained either by acid etching technique (AET) alone or by acid etching technique in combination with a self-threading retentive pin. Pins covered with a bonding/opaquer coating (PCR pin) and uncovered pins (FO pin) were used. After having been aged for 3 days, the fracture resistance of the restorations was determined with a Universal Testing Machine. The restorations were loaded at an angle of 45°. The restorations retained by AET and a PCR pin showed the highest failure load. The restorations accomplished with AET and a FO pin yielded the lowest fracture load. The fracture toughness of the restorations retained by AET and a PCR pin was slightly but statistically significant, higher compared to the restorations exclusively attached by acid etching technique. It was concluded that there was only a small increase of fracture toughness of large class 4 composite restorations if the acid etching technique was combined with the application of bonding/opaquer-covered retentive pins.

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INTRODUCTION

Large class 4 fractures are restored with composite resins and acid etching technique. Controversy exists about the efficiency of retentive pins to enhance the retention of class 4 composite build-ups (Tyas, 1990; Smales, 1991; Dietz & Mesko, 1980; Darveniza, 1987). Pins that provide a macromechanical retention of the filling material and pins with a bonding/opaquer coating are available. The coating provides a chemical bond between the composite resin and the pin (Caeg & others, 1990). Moreover, it does not interfere with the esthetical appearance of the restoration. Interocclusal shear forces can cause fractures of class 4 restorations (Denehy, Doering & Torney, 1980). Previous clinical investigations revealed that even pin-retained class 4 restorations fractured (Smales, 1991). It is known that the use of retentive pins faces numerous risks (perforation of the pulp chamber, inflammatory responses of the pulp, dentin cracks, perforation of the root surface) and a more problematic handling (Schuchard & Reed, 1973; Irvin & others, 1985; Trabert & others, 1973; Felton & others, 1991). Considering these complications, it is questionable whether the use of retentive pins in addition to acid etching technique is reasonable or not. The purpose of the present study was to investigate whether the use of self-threading pins improves the fracture resistance of class 4 restorations to shear forces. Pins with a bonding/opaquer coating and without a coating were tested.

METHODS AND MATERIALS

Individual celluloid crown formers (Adapta Set, Bego, Bremen, Germany) were created for 64 freshly extracted bovine incisors. A standardized class 4 preparation was performed at the mesial edge of each tooth with a water-cooled diamond bur (125 µm grit, Brasseler, Lemgo, Germany). The cavities were extended 2 mm in a mesiodistal and 7 mm in a cervicoincisal direction (Figure 1) respectively. The maximum extension in the buccolingual direction varied due to the different morphologies of the teeth; it amounted to about 5 mm. The cavities were dried with a stream of air, and the dentin was covered with a base (Harvard Cements, Richter & Hoffmann, Berlin, Germany) except for a small area, where the retentive pin was placed later on. The cavities were bevelled 1 mm around the entire cavosurface margin (30 grit, Brasseler) and etched with 37.5% orthophosphoric acid gel for 60 seconds. The etchant was washed off thoroughly for 45 seconds, and the cavity was dried with air. In 48 teeth a pin was placed 1 mm from the dentinoenamel junction in the middle of the labiolingual extension of the cavity. The pin preparation was started with a round bur (0.5 mm in diameter). The pin canal was prepared with a special drill belonging to the respective pin type. The drill was slightly pressed halfway into the dentin, cleaned, and then pressed again until it reached its desired position. Then the pins were placed as recommended. Two kinds of pins were used: PCR pins (Brasseler) with a bonding/opaquer coating (Silicoater, Kulzer/Dentacolor, Kulzer, Wehrheim, Germany) on their retention parts and FO pins (Brasseler) without coating (Figure 2). Data of the pins are listed in Table 1.

The composite restorations of all 64 teeth were performed in the same way. A bonding resin (Heliobond, Kulzer) was applied on the etched enamel and cured for 20 seconds with visible light (Translux, Kulzer). The composite resin was applied in a two-step incremental technique. With the individual crown formers, the original shapes of the teeth were reconstructed. Each composite increment was photocured for 40 seconds. The crown formers were removed and the restorations were finally cured for 40 seconds. Then the fillings were finished and polished with Sof-Lex disks (3M Dental Products, Neuss, Germany). According to the mode of retention, the restorations were distributed among the following groups:

1. **AET:** Retention by acid etching technique (n = 16);
2. **AET + PCR 2** Retention by acid etching technique and a retentive pin (PCR, size 2; n = 16);
3. **AET + PCR 4** Retention by acid etching technique and a retentive pin (PCR, size 4; n = 16); and
4. **AET + FO 4** Retention by acid etching technique and a retentive pin (FO, size 4; n = 16).

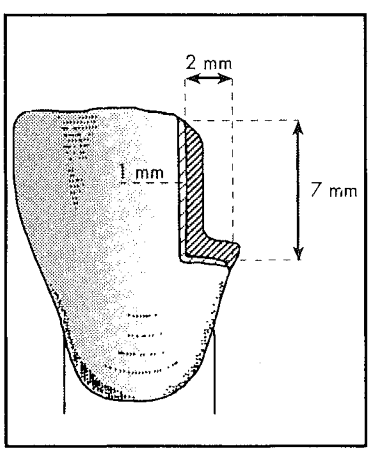

Figure 1. *Buccal aspect of the standardized class 4 cavity*

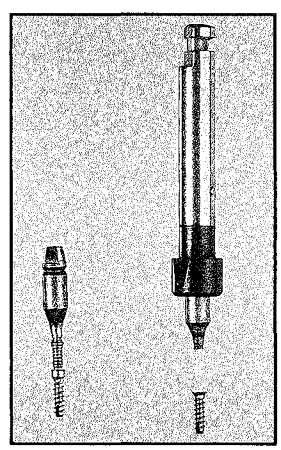

Figure 2. *PCR pin mounted on an adapter for the contra-angle (right), FO pin (left)*

Table 1. Data of Applied Pins

	Type of Pin		
	PCR 2	**PCR 4**	**FO 4**
Diameter of drill	0.43*	0.54	0.54
Diameter of pin	0.52	0.70	0.70
Length of drill	2.80	2.90	2.90
Length of pin thread	2.60	2.60	2.60
Length of pin retention part	2.75	2.90	2.90
Bonding/opaquer coating	yes	yes	no
Alloy		Ti_6Al_4V	

*Values expressed in millimeters

The teeth restored with acid etching technique (AET) only (group 1) served as control. All specimens were stored in synthetic saliva for 72 hours at 37 °C (Klimek, Hellwig & Ahrens, 1982). After 48 hours 10 teeth of each group (1-4) were additionally submitted to mechanical aging (MA). The mechanical aging was performed in order to imitate the natural chewing forces in human dentition. For this purpose these specimens were mounted in a special device (ZWPS 90, Pneumatik Automaton, Gevelsberg, Germany). A ceramic cylinder (Vitadur, Vita, Bad Säckingen, Germany) contacted the incisal edge of the restoration at an angle of 45° and slid over the oral surface of the restoration. The build-ups were submitted to 120,000 (77/min) loads. The loading force amounted to 7 N. Six specimens of each group were not mechanically aged (NMA).

ANALYSES

Scanning Electron Microscopy

Two teeth of each group, one subjected to mechanical aging and one without mechanical aging, were randomly selected to be studied by scanning electron microscopy (S 520 SEM, Hitachi, Tokyo, Japan). Replicas were produced, and the marginal adaptation of the restorations was assessed.

Fracture Failure Determination

The roots of the teeth were embedded in acrylic resin (Palavit G,Kulzer) and subsequently mounted in a Universal Testing Machine (Zwick, Einsingen, Germany). A continuously increasing force was put on the teeth at an angle of 45° to their long axis (Figure 3). The force was applied 1.5 mm below the incisal edge in the mesial third of the restoration. The forces required to produce failure were noted and statistically analyzed.

Failure Modes

The failure modes were evaluated macroscopically. Dislodgements of the pins were assessed with a pair of tweezers. The failure modes were classified as: loss of filling, pin still in situ (LF); dislodgement of pin (DP); filling fracture (FF); and tooth fracture (TF).

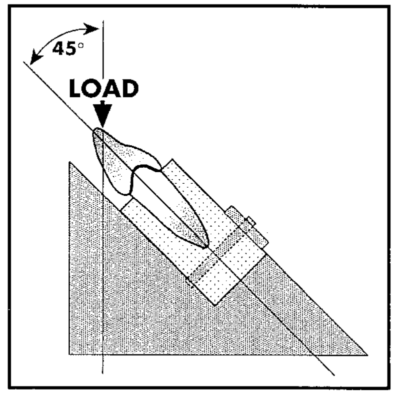

Figure 3. *Specimen mounted in the Universal Testing Machine for the determination of the failure load*

STATISTICS

Design

The effect of using pins and the difference between the pin materials were of main interest. These questions led to four experimental conditions, which could not be examined on the teeth of the same individual. So we decided to use paired samples for the AET versus AET + PCR 2 comparison and for the AET + PCR 4 versus AET + FO 4 comparison. Sample size was determined by using the results of a pilot study with four AET and four AET + PCR 2 teeth. The resulting means (202.5 ± 5.95 [N] versus 233.75 ± 9.17 [N]) led to a sample size of 10 specimens each to detect restoration differences in an unpaired t-test with a power of 90% at a two-sided significance level of 5%.

Analyses

The statistical analysis was performed in two steps. For an orientation, ANOVA was calculated using the factors of mechanical aging and restoration type respectively to develop influences of mechanical aging only. We found that the mean differences between the MA and NMA groups were small (and statistically nonsignificant) as compared to the range of the means over the four restorations. Moreover, there was no indication that these differences depend on the restorations. Hence it seemed to be justified to pool the samples over the mechanical aging for the respective four restorations. However, it has to be noted that the former analysis ignored the dependent structure of teeth of the same animal. Analysis of the differences between the restorations with respect to the dependent structure of the data was performed in the next step. Here the method of all pairwise comparisons between the restoration types [correcting significance levels for multiple inferences according to the method by Shaffer (1986)] was applied. Paired t-tests were used for the AET versus AET + PCR 2 and AET + PCR 4 versus AET + FO 4 comparisons respectively. Unpaired t-tests were used for the remaining comparisons.

RESULTS

SEM Study

The specimens that had not been submitted to mechanical aging (NMA) showed no marginal gaps between enamel and resin. Three of the specimens that had been submitted to mechanical aging (MA) revealed marginal gaps between enamel and the composite resin (Figures 4 and 5).

Fracture Failure Determination

The forces required to produce failure are presented in Figure 6 and in Table 2. *P*-values of all pairwise comparisons between the four restorations are shown in Table 3. No noticeable difference was observed between AET and AET + FO 4. This was also true for the difference between AET + PCR 2 and AET + PCR 4. AET + PCR 2 and AET + PCR 4 required considerably higher forces to produce failure compared to AET and AET + FO 4 respectively.

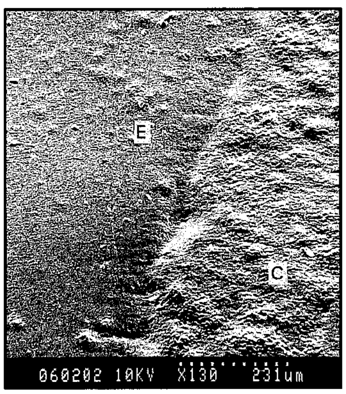

Figure 4. *SEM image of a restoration not exposed to mechanical aging (NMA). No marginal gap could be detected. (C = composite resin; E = enamel)*

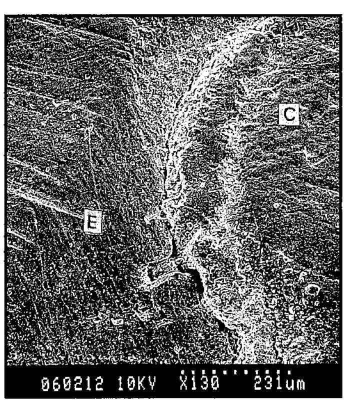

Figure 5. *SEM image of a restoration exposed to mechanical aging (MA), showing a marginal gap (C = composite resin; E = enamel)*

Failure Modes

The evaluation of the failure modes is presented in Table 4. Filling fractures occurred most frequently in group 1 (AET + FO 4). Loss of the entire filling was most frequently noticed in AET (MA), AET + PCR 2, and AET + PCR 4 (NMA). Dislodgement of the pin with concomitant loss of filling was only observed in AET + PCR 2. No tooth fractures occurred. Loss and damage respectively of the opaquer coating was noticed in five restorations of type AET + PCR 2 and four restorations of type AET + PCR 4.

DISCUSSION

The experimental conditions of the present study imitated the clinical conditions very well. Although the bond strength of composite resins to bovine enamel is slightly lower than to human teeth, bovine teeth are suitable for evaluating the retention of restorations retained by acid etching technique (Nakamishi, Iwaku & Fusayama, 1983). The extension of the standardized cavities of the specimens in the present study are similiar to large incisor fractures. Composite resins were inserted according to the recommendations of Exner (1984). Drilling of the pin canals was performed according to Käyser and others (1983).

In the clinical situation self-threading retentive pins tend to create microcracks in dentin (Irvin & others, 1985; Galindo, 1980). Thus the pins were placed at least 1 mm from the dentinoenamel junction (Baum & McCoy, 1984). The storage of the specimens in artificial saliva for a period of 72 hours is in accordance with Koike and others (1990). They found that the main part of water sorption of composites took place in the first 48 hours of water storage of composite resins. In the present study the specimens were submitted to 120,000 mechanical loads. This corresponds to Krejci and others

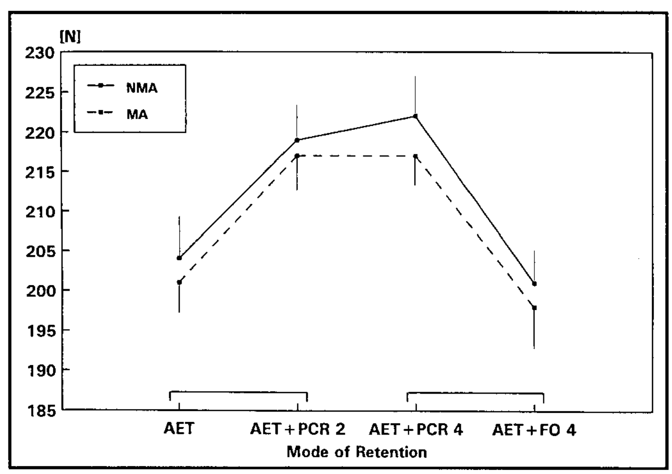

Figure 6. *Mean values and SEM of the forces required to produce failure of the different restorations*
MA: Mechanical aging of the restoration (n = 10 in each group 1-4)
NMA: No mechanical aging of the restoration (n = 6 in each group 1-4)
: Paired samples

Table 2. Forces Required to Produce Failure of Restorations with (MA) and without Mechanical Aging (NMA) and of Pooled Sample

Restoration	Failure Load [N] MA*	NMA*	Pooled Sample*
AET	201 ± 3.8**	204 ± 4.9	202 ± 2.9
AET + PCR 2	217 ± 4.8	219 ± 4.7	218 ± 3.4
AET + PCR 4	217 ± 4.0	222 ± 4.8	219 ± 3.0
AET + FO 4	198 ± 5.4	201 ± 4.0	199 ± 3.6

*Each MA-group consisted of 10 specimens; each NMA-group consisted of six specimens. Pooled sample comprises NMA-group and MA-group respectively.
**Mean ± SEM

Table 3. Test Results of Pairwise Comparisons

Comparison	*P*-value	CISL*
AET -> AET + PCR 4	0.0004	0.0083
AET + PCR 4 -> AET + FO 4	0.0005	0.0167
AET + PCR 2 -> AET + FO 4	0.0006	0.0167
AET -> AET + PCR 2	0.0042	0.0167
AET -> AET + FO 4	0.4964	0.025
AET + PCR 2 -> AET + PCR 4	0.8065	

*Corrected Individual Significance Level by Shaffer (1986) to control the overall significance level

(1990), who found that 120,000-200,000 mechanical forces are suitable for evaluating dental restorations. The loading (7 N) is in the range of the average masticatory force of 2 to 700 N (Anderson, 1956; Krejci & others, 1990). We used a Universal Testing Machine that is recommended for the determination of failure loads of dental materials (Simonson & Khairy, 1988). Forces exerted at an angle of 45° to the tooth long axis cause shear forces that correspond with clinical conditions (Sorensen & Engelman, 1990).

The loads required to produce failure were lower compared with results of previous investigations (Dietz & Mesko, 1980; Simonson & Khairy, 1988). This might be explained by different testing conditions of those studies compared with the testing conditions of the present study. The chemical and mechanical aging of the restorations had no significant influence on the failure loads. However, in the SEM study marginal gaps were more frequently observed with the mechanically aged specimens compared to the not-aged specimens.

Table 4. Frequency of Failure Modes of Restorations with (MA) and without Mechanical Aging (NMA)

Restoration	FF*	LF**	LF + DP***
MA			
AET	0	10	0
AET + PCR 2	1	8	1
AET + PCR 4	5	5	0
AET + FO 2	6	4	0
NMA			
AET	2	4	0
AET + PCR 2	2	2	2
AET + PCR 4	0	6	0
AET + FO 2	6	0	0

*Filling fracture (FF)
**Loss of filling (LF)
***Loss of filling + dislodgement of pin (LF + DP)

This finding is in agreement with clinical long-term investigations that described an increase of marginal gap formation in time (van der Veen, Pilon & Henry, 1989).

The failure loads determined in the present study were significantly dependent on the mode of retention of the restoration. AET + FO restorations showed the lowest resistance against shear forces, AET + PCR restorations the highest resistance. The values of the restorations attached only with acid etching technique were lower compared with the values of the AET + PCR groups but higher than the results of the AET + FO group. The big PCR pins yielded a better result than the small PCR pins. The bonding/opaquer coating (PCR pins) is favorable to the retention of class 4 restorations; it provides a chemical bond between the composite resin and the pin (Musil & Tiller, 1984; Laufer, Nicholls & Townsend, 1988). The assessment of the fracture modes revealed a loss of the opaquer coating as a result of the exerted forces. The opaquer coating seems to act as a parting line that initiates fractures of a restoration. This observation is in accordance with a study showing that experimental (not commercially available) pins, which were only covered with a bonding coating, achieved better initial retention to composite resins compared with pins covered with a bonding/opaquer coating (Neumeyer & Gernet, 1988a). The most filling fractures were observed in the AET + FO group. This is in accordance with Lloyd and Butchart (1990), who found that retentive pins induce a splitting of the surrounding filling material when submitted to heavy forces. Mondelli and Vieira (1972) showed that retentive pins improve the retention of a restoration but increase its fracture susceptibility.

CONCLUSIONS

No tooth fractures were observed in the present study. Photoelastic analyses have proved that PCR and FO pins induce a reduced stress in dentin (Neumeyer & Gernet, 1988b). This minimizes the danger of tooth fractures. In the present study the use of size 4 PCR pins, in addition to acid etching technique, improved the retention of class 4 restorations compared with only adhesive-attached restorations. This improvement amounted to about 10%. The numerous risks when using retentive pins are already described in the introduction. Since retentive pins with a bonding/opaquer coating improve the fracture toughness of class 4 restorations only to a small extent, the following clinical procedure seems to be reasonable:

1. Large class 4 cavities should be restored with acid etching technique exclusively;
2. If these restorations fail, only the use of bonding/ opaquer covered pins should be taken into account.

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The Effect of Pulpal Fluid Flow on Tensile Bond Strength of a Glass-Ionomer Cement: An in Vivo and in Vitro Comparison

M W TYLER • M FITZGERALD
J B DENNISON • D R HEYS

Clinical Relevance
Glass-ionomer bond strengths are weaker in vital teeth than in nonvital teeth.

SUMMARY

Previous studies of the bonding capabilities of glass-ionomer cements have concentrated on the use of in vitro testing conditions. Since early moisture contamination appears to have adverse effects on the physical properties of glass-ionomer cements, and with the probability of pulpally derived dentinal fluid being present under in vivo conditions, the objective of this study was to compare in vivo tensile bond strength with in vitro tensile bond strength of a glass-ionomer cement to dentin utilizing the same teeth under similar test conditions. A glass-ionomer lining cement was placed on freshly exposed labial dentin of the maxillary incisor on 10 Rhesus monkeys. Immediately following placement, an orthodontic button was placed over the cement and left undisturbed for 1 hour. The teeth were then extracted and stored in 100% relative humidity for 23 hours. An Instron testing machine was used to register in kilograms the force required to cause tensile bond failure of the cement. Identical methodology was then used on the same teeth for in vitro testing. The concluding results indicate that a statistically significant difference ($P \leq 0.05$) exists between in vivo and in vitro tensile bond strengths of the glass-ionomer lining cement and that the bond failure was cohesive in character for all cases both in vivo and in vitro. These findings suggest that clinically, tensile bond strengths of glass-ionomer cements to cut dentin can be expected to be weaker in vital teeth than in devital teeth.

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INTRODUCTION

For many years dental researchers have been striving to develop a material that will bond chemically to tooth structure, both enamel and dentin. Wilson and Kent (1972) introduced a new cement composed of a poly(acrylic acid) liquid and an aluminosilicate glass powder. Crisp and Wilson (1973) demonstrated that the poly(acrylic acid) reacted with the calcium and aluminum ions, forming salts and complexes that resulted in a hard setting matrix that bound together the excess unreacted glass particles. Hotz and others (1977), Öilo (1981), Negm, Beech, and Grant (1982), and Coury and others (1982) studied specifically the adhesive bond properties of the various glass-ionomer cements using in vitro methods,showing the glass-ionomer cements to be adhesive to both dentin and enamel under these conditions. However, Causton (1981), Mount and Makinson (1982), and Phillips and Bishop (1985) demonstrated that early moisture contamination can have an adverse effect on the physical properties of glass-ionomer cements. Brännström, Lindén, and Johnson (1968) observed, using in vitro methods, the outward flow of pulpally derived fluid when dentin was invaded using either carbide burs or diamond stones. Lindén (1968) demonstrated through studies utilizing extracted human teeth that fluid did have the capacity of flowing outward from the pulp. Pashley and others (1984) and Maita and others (1991) have demonstrated outward flow of pulpal fluid in dog teeth. These observations suggest that freshly cut dentin surfaces in vivo may become sufficiently wetted by pulpally derived dentinal fluid to adversely affect the setting reaction of a glass-ionomer cement placed on that cut surface. The purpose of this study was to measure the in vivo tensile bond strength of a glass-ionomer cement to freshly cut dentin, and to compare these results with those strengths measured using the same cement against dentin of the same teeth under in vitro testing conditions.

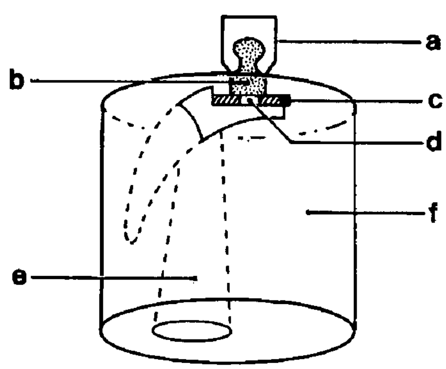

Figure 1. *Cross section line drawing of a sample mounted in Instron testing machine*
a = Instron
b = orthodontic button
c = tape
d = glass-ionomer cement
e = wax
f = stone

MATERIALS AND METHODS

Ten Rhesus monkeys, with maxillary incisor teeth planned for extraction as part of a different study protocol, provided a sample size of 20 maxillary central incisors. The monkeys were sedated with 5-10 mg Ketamine hydrochloride IM (Veterinary Products, Bristol Laboratories, Div of Bristol-Meyers Co, Syracuse, NY 13221) per kilogram of body weight. The labial enamel surfaces of the maxillary central incisors were prepared to expose a flat dentin surface using a 170-L fissure bur (Midwest Dental Products Corp, Des Plaines, IL 60018) in an ultra-high-speed air turbine handpiece (Midwest) with air-water spray, and dried using oil-free air. Four thicknesses of 3M double-faced sticky tape (3M Dental Products, St Paul, MN 55144) with a centrally located 3-millimeter-in-diameter hole that served both as a reservoir for the cement and also as an aid in maintaining a constant area and thickness of cement throughout the experiment were placed on the prepared dentin surface. A glass-ionomer lining cement (G-C Dental Industrial Corp, Tokyo, Japan, Batch #220451) was mixed according to the manufacturer's instructions and placed in contact with exposed dentin in the reservoir of the tape. An orthodontic lingual button 4 mm X 3.5 mm with a concave serrated surface (ORMCO Corp, Div of Sybron Corp, Glendora, CA 91740) was treated prior to use with a technique similar to that described by Powis and others (1982). The concave surface of the button was treated with an air-abrasive material (Type LA, Paasche Air Brush Co, Harwood Heights, IL 60656), placed in a 50%-by-volume hot nitric acid solution for 2 minutes, rinsed with acetone and distilled water, and air dried. The button was placed over the freshly mixed cement in the reservoir with the outer edge of the button resting on the tape. No load was placed on the button after placement into the cement.

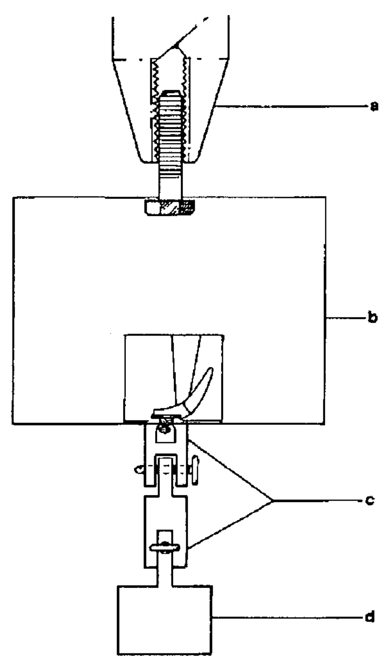

Figure 2. *Cross section line drawing of tooth sample mounted in Instron testing machine*
a = upper jaw of Instron
b = mounting frame
c = mounting jig
d = lower jaw of Instron

After the initial set of the cement (4-5 minutes), a varnish (Ever-Bond V, Sybron/Kerr, Romulus, MI 48174) was placed around the circumference of the orthodontic button to help prevent water uptake by the cement from the surrounding oral environment. The teeth were surgically removed 1 hour later and stored in 100% relative humidity at 37 °C for 23 hours, making a total of 24 hours that the cement had been in place against the dentin.

The teeth were removed from the 100% relative humidity environment and prepared for testing. Figure 1 shows schematically the tooth sample mounted and ready for placement in the testing machine. Figure 2 shows cross sectionally the mounting of the sample onto the Instron testing machine (Instron Corp, Canton, MA 02021). The tensile bond strength of the glass-ionomer cement was measured utilizing a crosshead speed of 0.01 cm/min, and the force necessary to cause tensile failure was recorded in kilograms. After testing was completed, the teeth were removed from the mounting ring and returned to a 100% relative humidity environment at 37 °C.

The in vitro phase of the experiment utilized the same teeth and batch number of lining cement as in the in vivo phase and was conducted 1 week after the in vivo testing was concluded. The dentin surface was freshened, removing less than 0.5 mm of dentin, utilizing a 170-L fissure bur (Midwest) in an ultra-high-speed handpiece. The methodology of cement placement, mounting of tooth samples, and tensile testing utilized in the in vivo phase of the experiment was repeated for the in vitro phase.

The type of bond failure was observed for all samples in both the in vivo and in vitro phase utilizing the naked eye and X2 magnification. Selected cases were observed using scanning electron microscopy (SEM). The raw data (force in kilograms) was converted to MPa and subjected to statistical analysis utilizing the paired *t*-test.

Table 1. Stress Required to Produce Bond Failure of a Glass-Ionomer Lining Cement (MPa)

Sample	In Vivo	In Vitro
1	2.13	2.38
2	1.75	1.78
3	1.82	1.99
4	1.58	2.51
5	2.38	2.38
6	1.93	2.56
7	0.50	2.38
8	1.22	4.02
9	2.06	1.33
10	2.14	3.67
11	2.40	1.63
12	1.26	2.34
13	2.05	4.01
	SD = 0.53	SD = 0.82

RESULTS

Table 1 shows the data from both the in vivo and in vitro tensile bond tests of the glass-ionomer lining cement. A total of 13 samples were used for comparison in the study of the lining cement. Seven samples were not used for comparison due either to (1) orthodontic button dislodgement on removal of tooth, (2) dislodgement of orthodontic button during mounting procedures, or (3) sacrifice of the sample for SEM analysis. Sample 5 showed no difference in tensile bond strength between in vivo and in vitro dentin bonding. Samples 9 and 11 showed a decrease in the in vitro tensile bond strength when compared with the in vivo tensile bond strength. The paired *t*-test in Table 2 indicates that a statistically significant difference exists at $P = 0.0272$ between in vivo and in vitro tensile bond strength of the lining cement.

Figure 3 depicts a representative example that shows the bond failure is cohesive. Figure 4 is an SEM photograph of an in vivo specimen showing the bond failure to be cohesive with a layer of cement remaining on the dentin. Figures 5 and 6 are SEM views of cross-sectioned specimens demonstrating the cohesive bond failure both in vivo and in vitro.

DISCUSSION

Since the advent of glass-ionomer cements in the early 1970s, their capability of bonding to various substrates, especially dentin, has been tested extensively using in vitro conditions. Since early contamination with water appears to adversely affect certain physical properties, the question was raised as to the effect of the pulpally derived dentinal fluid flow in freshly cut dentin on the bonding of the cement to dentin, as well as on the cement mass itself. Certain observations were made while conducting the in vivo and in vitro tests. Ten out of 13 samples demonstrated greater tensile bond strength values for the in vitro phase than the in vivo phase, with one sample showing equal in vivo and in vitro tensile bond strengths. Two of the 13 samples demonstrated a decrease in the in vitro bond strength when compared with the in vivo bond strengths. This may have been due to stresses placed on the button/tooth during extraction of those teeth. These results indicate that there exists a significant difference at the 5% level between the in vivo and in vitro tensile bond strengths of the G-C glass-ionomer lining cement, with the in vivo bond strength being the weaker (Tables 1 & 2).

Indirect evidence from other studies provides insight to the possible mechanisms leading to the reduced bond

Table 2. Paired t-Test Lining Cement (MPa)

Variable	Mean	Mean Diff	Std Dev	*t*-Stat	Signif
In Vivo	1.787	-0.750	1.076	-0.2468	0.0272
In Vitro	2.537	N = 13			

Figure 3. *Photograph of cohesive bond failure*

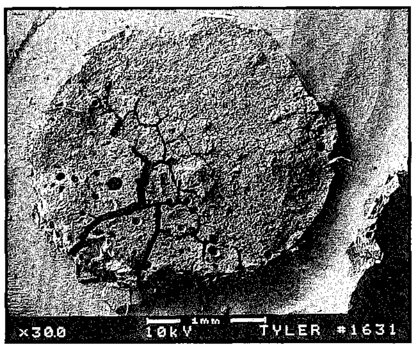

Figure 4. *SEM photograph of cohesive bond failure in vivo*

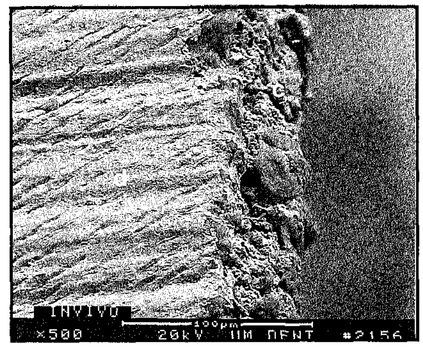

Figure 5. *Cross section SEM photograph of cohesive bond failure in vivo. c = glass-ionomer cement; d = dentin*

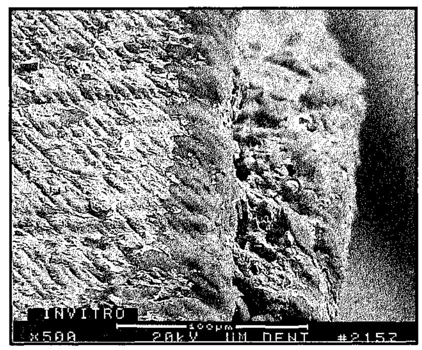

Figure 6. *Cross section SEM photograph of cohesive bond failure in vitro. c = glass-ionomer cement; d = dentin*

strengths. Causton (1981), Mount and Makinson (1982), and Phillips and Bishop (1985) demonstrated that early moisture contamination can significantly lower the physical properties of glass-ionomer cements. Pashley and others (1984) demonstrated that fluid-filtration occurs from the pulpal side to the cavity preparation surface in freshly cut dentin of vital dog teeth. This fluid is presumably pulpal fluid and could act as a source of moisture contamination during the initial set of the freshly mixed glass-ionomer cement. Prati and others (1991) simulated pulpal fluid flow in vitro by applying varying fluid pressures to the pulp chambers of extracted human teeth and measuring the resulting cut dentin surface wetness using a Periotron device (Harco Electronics Ltd, Winnipeg, Manitoba, Canada R3H 0N3). They reported an inverse correlation between the shear bond strengths of Scotchbond 2 with Silux (3M) and dentin wetness, suggesting that increased wetness due to fluid flow from the pulp side of the tooth decreases the bond strength of that system. Our findings in vivo support their in vitro simulation findings. It is interesting to note that the significant reduction in tensile bond strength observed in the present study was measured on bonding to dentin with an intact smear layer, since it is known that the smear layer decreases dentin permeability (Pashley, 1985). Based on the findings of this study and those of Prati and others (1991), it may be reasonable to expect even greater differences between in vitro and in vivo tensile bond strengths in teeth treated to remove the smear layer. Further studies are needed to define the magnitude of this effect.

The type of bond failure was also interesting. Prodger and Symonds (1977) demonstrated adhesive dentinal bond failures, Hotz and others (1977) observed a combination of adhesive and cohesive, and Öilo (1981) found cohesive bond failure when testing the various glass-ionomer cements under in vitro conditions. The type of bond failure observed in the present study for each sample in both the in vivo and in vitro conditions for the lining cement was observed using the naked eye and X2 magnification. Cohesive failure was observed using the naked eye in all cases. The X2 magnification substantiated these initial observations of cohesive bond failure. Scanning electron microscopy was utilized for representative specimens to obtain further observations (Figures 3-6). The two lining cement samples viewed under SEM, one in vivo and one in vitro, showed a thin layer of material (less than 100 mm) present throughout the area of cement placement in both cases, indicating a cohesive bond failure. Since the cement bond failure observed under both in vivo and in vitro test conditions was cohesive, with the weaker tensile strength being in the in vivo group, it seems plausible that moisture from the assumed flow of pulpally derived dentinal fluid affects the physical strength of the cement mass per se more than the adhesive bond of the cement to dentin. Identifying the mechanisms underlying this effect were beyond the scope of the study but deserve further investigation.

CONCLUSIONS

The tensile bond strength of a glass-ionomer lining cement applied to vital dentin in vivo is weaker than tensile bond strength of the same glass-ionomer cement applied to devital teeth in vitro. These findings suggest that clinically this bond strength can be expected to be weaker in vital teeth than in devital teeth. The bond failures were cohesive failures, i e, they occurred within the mass of the cement rather than directly at the dentin-ionomer interface. This suggests that when reapplying a glass-ionomer cement following a bond failure, the area of dentin to be covered should be lightly reinstrumented to remove the remaining ionomer cement, if bonding directly to dentin is desired.

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The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or as reflecting the views of the Department of the Navy.

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