

BASES AND LINERS IN CLINICAL DENTISTRY

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INTRODUCTION

A variety of cements have been used in dentistry through the years for two primary purposes: as a restorative filling material, either alone or with other materials, and to retain restorations or appliances in a fixed position within the mouth. In addition, certain cements are used for specialized purposes in the restorative, endodontic, orthodontic, periodontic, and surgical fields of dentistry.

When the properties of dental cements are compared with those of other restorative materials, such as amalgams, resin composites, gold, or ceramics, cements exhibit less favorable strength, solubility, and resistance to oral conditions. As a result, the general use of cements for restorations exposed to the oral environment is quite limited.

THE INSULATING CAPPING. The insulating capping sits between the filling and the dentin of the cavity. The insulating strip is divided into a base and a liner. Base capping can withstand chewing pressure and workload associated with the condensation of materials (amalgam). The optimum thickness is 0.75–1.0 mm. Liner (thin strip) prepared from the cement protects the pulp from chemical influences of the permanent restorative material, but does not protect the pulp against thermal stimulation.

THE MEDICATED CAPPING. Lining strip on the bottom of the carious cavity is used for drug effects on the pulp, as the remaining microflora decreases mineralization of transverse section of dentin. It contains an active medicinal substance and is used most often in the form of paste. It has a medical effect, inhibiting the infection of the carious cavity, which can lead to recurrence of caries and development of pulpitis. Lining is necessary to stimulate the natural defense mechanisms of the dentin and pulp.

Zinc phosphate, glass-ionomer, and zinc oxide-eugenol (ZOE) cements can be applied as a base in deep cavities to insulate the pulp from a possible chemical and thermal trauma. A metallic, ceramic, or composite filling material may then be placed over the cement base in sufficient bulk and in proper adaptation to the cavity walls to form the final restoration. The sedative effect of ZOE mixtures has made them valuable for a variety of applications. The ability of the glass and hybrid ionomer and compomer cements to release fluoride and to bond chemically to tooth structure has resulted in their use as bases and for cementation. Resin cements are used for retention of orthodontic brackets, all-ceramic veneers, crowns and inlays, and resin-bonded bridges because of their strength and ability to bond to acid-etched enamel and dentin treated with a dentin bonding agent.

Currently, a number of different material types are being used as substitutes to dental amalgam, and these include:

- composite resins;
- glass-ionomer cement;
- compomers;
- giomers.

Selection of a material is based on aesthetics, fluoride release, wear resistance, strength and ease of use.

Composites are aesthetically pleasing, strong, and wear-resistant. However, they have low or no fluoride release. Compomers are less wear-resistant but they have good aesthetic properties and release fluoride. Resin-modified glass-ionomer cements release more fluoride than compomers but they are not as wear-resistant and they are not used in posterior restorations. Conventional glass-ionomers release the most fluoride and are best for patients with high risk carries in low-stress applications (Powers and Wataha, 2008).

The following is a classification of dental cements, based on their chief chemical ingredients and application:

1. Zinc oxide-eugenol.
2. Zinc phosphate.
3. Zinc polyacrylate.
4. Glass and hybrid ionomers.
5. Calcium hydroxide.
6. MTA.
7. Biodentin.

REQUIREMENTS FOR CEMENTS

1. They should be non-toxic, and non-irritant to the pulp and other tissues.
2. Insoluble in saliva and liquids taken into the mouth.
3. Mechanical properties — these must meet the requirements for their particular applications, for example, for a cavity lining, a cement should develop sufficient strength rapidly to enable a filling material to be packed on it.
4. Protection of the pulp from the effects of other restorative materials.
5. Thermal insulation — a cement is used under a large metallic restoration (e. g. amalgam) to protect the pulp from temperature changes.
6. Chemical protection — a cement should be able to prevent penetration into the pulp of harmful chemicals from the restorative material.
7. Electric insulation under a metallic restoration to minimize galvanic effects.
8. Optical properties — for cementation of a translucent restoration (for example, a porcelain crown) the optical properties of the cement should be parallel to those of tooth substance.
9. A cement should ideally be adhesive to enamel and dentin, and to gold alloys, porcelain and acrylics, but not to dental instruments.
10. A cement should be bacteriostatic if inserted in a cavity with residual caries.
11. Cements should have an obtundent effect on the pulp.
12. For luting purposes, cements should have a low film thickness.

ZINC OXIDE-EUGENOL CEMENTS

When certain types of zinc oxide are mixed with eugenol, the mix sets to a hard cement that is compatible with both the hard and soft tissues of the mouth. Cements of this type have been used extensively since the 1890s. Simple mixtures of this material do not have great strength when compared with zinc phosphate cements, and their use has been limited to situations in which strength is not important. Quite early it was found that they had a sedative effect on exposed dentin. For many years, ZOE cements have been used as provisional restorations, soft tissue packs in oral surgery and periodontics, and root canal sealers. Because eugenol acts as an inhibitor for free-radical polymerized materials, select other materials for provisional restorations when bonding of the permanent restoration is anticipated.

Composition

The powder is mainly zinc oxide, with added white rosin to reduce the brittleness of the set cement, zinc stearate as a plasticizer, and zinc acetate to improve the strength of the cement. The liquid is eugenol with olive oil as a plasticizer. Two compositional changes have been used to increase the strength of the cement for luting purposes. In one, methyl methacrylate polymer is added to the powder, and in the other, alumina (Al_2O_3) is added to the powder and ethoxybenzoic acid (EBA) to the liquid.

A typical polymer-reinforced cement has 80 % zinc oxide and 20 % poly (methylmethacrylate) in the powder and eugenol in the liquid. These cements are sufficiently strong for final cementation of fixed prostheses and are used also as cement bases and provisional restorations. A typical EBA-alumina-reinforced ZOE cement contains 70 % zinc oxide and 30 % alumina by weight in the powder. In some cases, rosin and copolymers may be added to reduce the brittleness and film thickness and improve the mixing qualities. The liquid of the EBA-alumina-reinforced cements contains 62.5 % ortho-EBA by weight and 37.5 % eugenol by weight.

Setting reaction

The setting of ZOE cements is a chelation reaction in which an amorphous, zinc eugenolate is formed (fig. 1). The setting reaction is shown below, where two molecules of eugenol react with ZnO in the presence of water to form the chelate, zinc eugenolate. Excess zinc oxide is always used, so the set material consists of a matrix of amorphous zinc eugenolate that binds the unreacted zinc oxide particles together. The setting reaction is accelerated by increases in temperature or humidity.

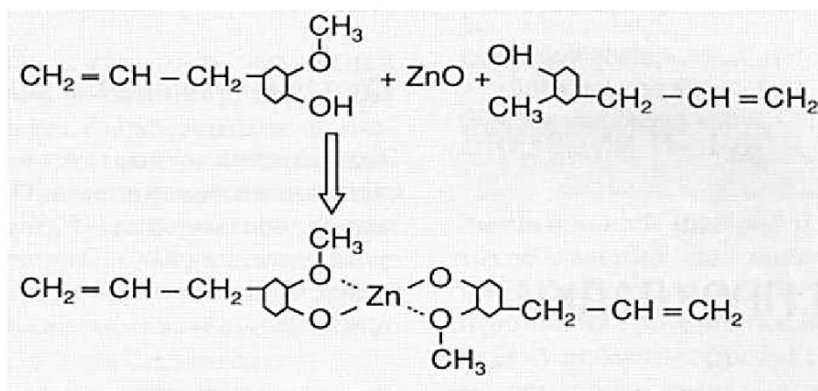


Fig. 1. Setting reaction of ZOE cements

Manipulation

Dispensing the unmodified ZOE is typically two-paste systems. Equal lengths of each paste are dispensed and mixed to a uniform colour. For some cements used for temporary cementation or for provisional restorations, powder is often incorporated into a dispensed amount of liquid until a suitable consistency is achieved for the operation at hand. The dentist makes this determination from experience. A considerable amount of powder can be incorporated into the liquid by heavy spatulation with a stiff spatula.

In general, the more powder incorporated, the stronger the cement and the more viscous the mixed cement. Cements intended for final cementation of restorations carry manufacturers' directions and measuring devices that are important to use. Because of the deceptive flow qualities of these cements, adding powder until the operator feels the mix is of suitable consistency for cementing a restoration will lead to a cement deficient in powder and a lowered strength in the set cement. To those accustomed to the handling qualities of zinc phosphate cement as a luting medium, a correctly proportioned and mixed ZOE luting cement appears far too viscous.

Mixing procedures

Because the setting reaction is not significantly exothermic, a cooled mixing slab is not required. Usually a paper mixing pad with disposable sheets is used, which facilitates the cleanup procedures after cementation. A glass slab is recommended for mixing the EBA-alumina-modified cements. There is no need to incorporate the powder in small increments; usually the bulk of the powder is incorporated in the initial step, the mix is thoroughly spatulated, and a series of smaller amounts is then added until the mix is complete. The mix is thoroughly kneaded with the spatula (a stiff-bladed steel spatula is the most effective type). The EBA-alumina-modified cement is dispensed according to the instructions, kneaded for 30 seconds, and then stropped for 60 seconds to develop a creamy consistency. Oil of orange can be used to clean eugenol cements from instruments.

Applications

A range of ZOE and modified ZOE cements are suitable for many uses in restorative dentistry, and the practitioner should become familiar with each type and its application (fig. 2).



Fig. 2. ZOE cement materials

Base materials having a compressive strength of 5.5 to 39 MPa are used as a cement base, and the strength reaches a maximum in about 12 to 15 minutes. They are normally used under zinc phosphate cement, which acquires about three times the strength at the same time. The ZOE cements have the advantage that the thermal insulating properties of the cements are excellent and are approximately the same as those for human dentin. ZOE products tend to be weaker and less rigid than calcium hydroxide pastes that set. Because the base is used in thin layers, it provides little thermal insulation. The eugenol has a sedative (obtundent) effect on the pulp. The base should not be used when a composite is to be placed, because eugenol can inhibit polymerization of the bonding agent and composite.

Temporary Cementation

Unmodified ZOE cements are also used as luting materials for provisional crowns and temporary cementation of metal restorations in crown and bridge prosthodontics. Laboratory studies have shown that the retention of metal restorations with unmodified cements is proportional to the compressive strength of the cements. Unmodified ZOE cements are available in compressive strengths varying from 1.4 MPa to 21 MPa. A clinical study of the use of various unmodified cements for luting provisional crowns indicated that a cement with a compressive strength of 15 to 24 MPa was the most appropriate cement, based on:

- retention;
- taste;
- ease of removal;
- ease of cleaning.

Another clinical study indicated that an unmodified ZOE cement with a compressive strength of 6.9 MPa was the most commonly used material for the temporary cementation of complete crown and bridge restorations, although a range of cements with compressive strengths from 1.4 to 21 MPa was found to be desirable.

The EBA-alumina-modified cements have been tried as provisional restorations based on their physical properties. Clinical studies showed these cements

were handled easily and had improved carvability, which prevented chipping during trimming, and that symptomatic teeth without pulp exposure showed no symptoms. The EBA-alumina-modified cements, despite their low solubility in water, disintegrated and wore excessively in the mouth. A thick mix, 2.6 g/0.4 ml of polymer-modified ZOE, was more serviceable than the EBA-alumina-modified type, and although some chipping was observed at the margins, all provisional restorations of ZOE were serviceable for 2 to 10 months of observation.

Permanent Cementation. The use of EBA-alumina-modified ZOE cements has been clinically successful for the permanent cementation of crowns and bridges.

Endodontic Sealers. Endodontic ZOE preparations have been used as a root canal sealer alone and with gutta-percha.

ZINC PHOSPHATE CEMENTS

Composition. These materials are generally supplied as a powder and liquid which are mixed together by hand (fig. 1). Encapsulated products are available but are rarely used due to the extra cost involved. The major reactive component of the powder is zinc oxide. Small quantities of other oxides such as magnesium oxide may also be present. The liquid is essentially an aqueous solution of phosphoric acid buffered by adding small quantities of zinc oxide or aluminium oxide. These compounds form phosphates which stabilize the pH of the acid and reduce its reactivity.

Setting reaction. On mixing the powder and liquid together a vigorous reaction occurs, resulting in the formation of a relatively insoluble zinc phosphate as follows:



Only the surface layers of the zinc oxide particles react, leaving unconsumed cores bound together by the phosphate matrix. The reaction is rapid and exothermic although its rate is tempered somewhat by the presence of buffers in the acid and a special process of deactivation of the zinc oxide powder involving heating and sintering with other, less reactive, oxides.

A zinc phosphate cement is supplied as a white powder containing primarily zinc oxide and a colourless liquid which is an aqueous solution of phosphoric acid. Mixing typically is performed on a glass mixing slab of the type shown (fig.3).



Fig. 3. Zinc phosphate cement

Peculiarities. The mechanical properties of the cement play a part in determining the retentive properties of a cement luting agent. Phosphate cements are not adhesive to tooth substance or to restorative materials. The cement flows into the myriad of fine undercuts naturally occurring on the fitting surface of the restoration and on the cut tooth surface. The importance of an element of surface roughness on these two surfaces which are to be joined is clear. Polished surfaces are not easily joined by cement luting agents. Tags of set cement, along with a correct design of taper to the preparation, prevent displacement of the restoration. It is important therefore that the tags should resist fracture in function. Experience suggests that phosphate cements are sufficiently strong to resist such fracture.

The set material has a small, though significant, solubility in water and cement lute margins may erode slowly in the mouth by a combination of dissolution and abrasion. The cement lute is, potentially, the weak link of any indirect restoration since it normally joins two resistant materials, for example, gold and enamel or dentin, or porcelain and dentin. Erosion, leading to loss of the cement lute and failure of the restoration, is not, however, a problem particularly associated with zinc phosphate cement. Loss of restorations is more likely to occur due to a poorly retentive design of the preparation.

Zinc phosphate cements may have an irritant effect on the dental pulp, particularly when used as cavity lining materials. The pH value of the cement at the time of application to the tooth is between 2 and 4 depending on the particular brand and the powder/liquid ratio. The degree of irritation depends on the depth of the cavity and the thickness of residual dentin. It is necessary to remember that attitudes towards the acid tolerance of the dentin and pulp are changing, although many experts still feel that zinc phosphate cements are unsuitable for use as linings in deep cavities unless a sublining of a less irritant material such as calcium hydroxide or zinc oxide eugenol cement is used.

The phosphate materials have adequate thermal insulating properties when used under metallic restorations. They are not able to form an effective chemical barrier, however, due to their inherent acidity.

The set material is opaque due to a high concentration of unreacted zinc oxide. This may detract from the aesthetic appeal of a porcelain crown having a zinc phosphate lute, particularly if the cement lute margin is visible. Consequently crown margins should be placed within the gingival crevice if they are going to be visible in order to hide any exposed cement lute.

POLYCARBOXYLATE CEMENTS

Two types of cement based on polyacids are in common use for both luting and cavity lining applications. The first products to be developed were the polycarboxylate cements which rely on the reaction between zinc oxide and a polyacid. The second-group products are described as glass-ionomer or polyalkenoate ce-

ments. The setting reaction takes place between a polyacid molecule and cations released from an ion-leachable glass.

These materials may be supplied as a powder and liquid or as a powder which is mixed with water. For powder/liquid materials, the powder is finely ground zinc oxide which sometimes contains minor quantities of other oxides such as magnesium oxide. The liquid is an aqueous solution of polyacrylic acid of about 40 % concentration. In the powder/water materials the powder contains zinc oxide and freeze-dried polyacrylic acid. On mixing the powder with water, the polyacrylic acid dissolves and starts to react with zinc oxide. The setting reaction is similar to that for glass ionomers. Zinc oxide behaves as a basic oxide and undergoes an acid–base reaction with acid groups in the polyacid to form a reaction product which consists of cores of unreacted zinc oxide bound together by a salt matrix in which polyacrylic acid chains are cross-linked through divalent zinc ions.

Polycarboxylate cement contains two main reactive ingredients, zinc oxide and polyacrylic acid and both are in the powder; the bottle is filled with water by the dentist. Powder and water are dispensed onto the mixing pad and mixed with a spatula. In other products the powder contains only zinc oxide and the liquid is an aqueous solution of polyacid (fig. 4).



Fig. 4. Polycarboxylate cement

The polycarboxylate materials are acidic though not as irritant as phosphate cements, for two reasons. Polyacrylic acid is a weaker acid than phosphoric acid and the polyacid chains are too large and lack the mobility required to penetrate dentinal tubules. Despite a more biocompatible nature of these materials they are not widely used as linings in very deep cavities unless a sublining of a calcium hydroxide or zinc oxide/eugenol material is used. One reason for this is that they are difficult to handle well in a clinical setting. They tend to be rubbery during their setting reaction and they also adhere to stainless steel instruments, making their placement complex.

Laboratory tests show that the solubility values of polycarboxylate cements are greater than those for the zinc phosphate and glass-ionomer materials. As for most other cements, strength and solubility are optimized by achieving a high powder/liquid ratio. For polycarboxylate materials however, two restricting factors

should be remembered. First, some free polyacid is required to form an adhesive bond and this will not be possible if a very dry mix is used. Secondly, a relatively low viscosity is required to allow setting of restorations during luting.

The set materials are opaque due to a high concentration of unreacted zinc oxide cores. This may detract from the appearance of porcelain crowns, particularly if the cement lute margin is visible.

Glass-ionomer cements

Glass-Ionomer Cements (GICs), frequently also referred to as glass polyalkenoate cements, are restorative materials that consist of a powder and a liquid which are mixed to produce a plastic mas. That subsequently sets to a rigid solid.

The glass-ionomer cements were first described by Wilson and Kent in 1971, and, at the time, presented a natural extension to the zinc polycarboxylate cements that had become available in the late 1960s. The zinc polycarboxylate cements had evolved from the zinc phosphate cements by the ingenious replacement of the phosphoric acid with polyacrylic acid. The glass-ionomer cements were immediately seen as a potential replacement for the silicate cements that had been around for some 80 years and which were gradually being ousted by the resin-based composites.

The two main features of glass-ionomer cements that have allowed them to become one of the accepted dental materials are their ability to bond to enamel and dentin and their ability to release fluoride from the glass component of the cement. Thus, glass-ionomer cements combine the adhesive qualities of zinc polycarboxylate cements with the fluoride release of silicate cement. The relationship between different materials is shown in fig. 5.

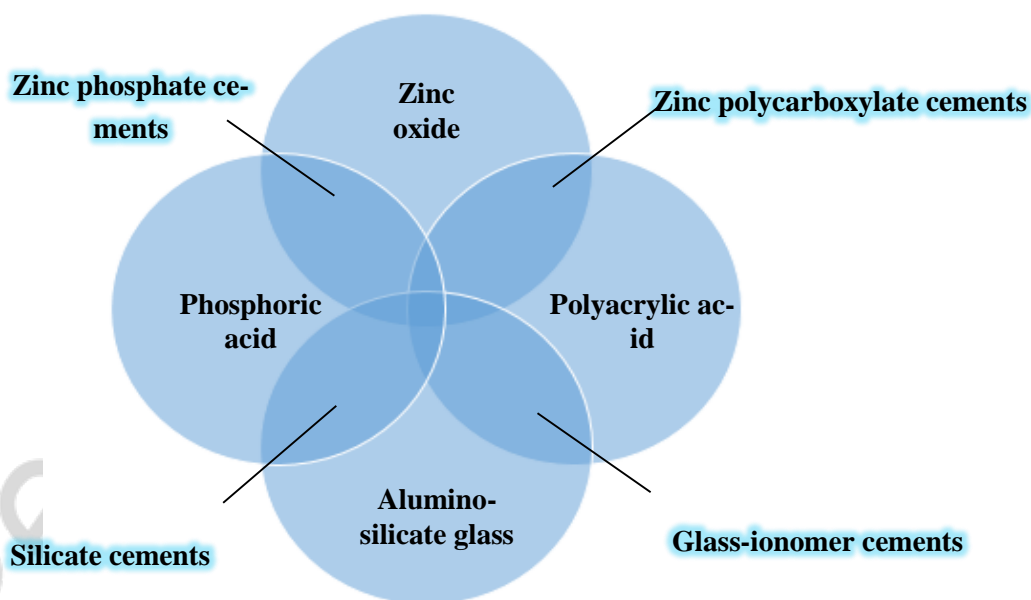


Fig. 5. Schematic of various dental cements based on powders of zinc oxide and alumino-silicate glass, and liquids consisting of phosphoric acid and polyacrylic acid

Glass-ionomer cements were used mainly for the restoration of abrasion/erosion lesions and as a luting agent for crown and bridge reconstruction. Their clinical application has now been extended to include the restoration of proximal lesions, occlusal restorations in the deciduous dentition, cavity bases and liners and core material by the introduction of a wide variety of new formulations.

A recent innovation was the modification of the glass-ionomer cement by incorporation of a resin, which allowed the material to be set by light activation. These new materials are, not surprisingly, known as resin-modified glass-ionomer cements (RMGICs), although sometimes they are referred to as glass-ionomer resin hybrids; however, the preferred description is resin-modified glass-ionomer cements.

CHEMISTRY OF GLASS-IONOMER CEMENTS

Composition

What makes the glass-ionomer cement such an interesting material compared to the zinc phosphate cements is an enormous variety of compositions that can be achieved. The main components of a glass-ionomer cement are glass, polyacid, water and tartaric acid.

The composition of the glass can vary widely, giving many different properties, and, in addition to this, there are numerous combinations of polyacids that are suitable for copolymerization. In contrast, for the zinc phosphate cements, once the composition is optimized in terms of the powder liquid ratio and the concentration of the phosphoric acid, there is little scope for improvement. Of course, such a variety can be as much of a hindrance as a help, and this is reflected in the development of the glass-ionomer cements, which began in the early 1970s.

It could never be claimed that the glass-ionomer cements have had a smooth passage since their inception. The proof of this statement is based on the observation that the materials currently marketed are quite different from those originally made available for clinical use. The early materials consisted of a glass powder to which a concentrated solution of a polyacrylic acid was added. ASPA (Dentsply De Trey Ltd, Weybridge, UK) was the first commercial product, and was made available in 1976.

Glass

The glasses for the glass-ionomer cements contain three main components: silica (SiO_2) and alumina (Al_2O_3) mixed in a flux of calcium fluoride (CaF_2), as shown in fig. 6. The composition of the glass is largely restricted to the central region of the phase diagram by the desire to have a translucent glass. The mixture (which also contains sodium and aluminium fluorides and calcium or aluminium phosphates as additional fluxes) is fused at a high temperature, and the molten mass is then shock-cooled and finely ground to a powder before use. The particle

size of the powder is dependent upon its intended application. For filling materials the maximum particle size is 50 μm , while for the luting and lining materials it is reduced to less than 20 μm . The rate of release of ions from the glass (which is an important factor in determining the setting characteristics, the solubility, and the release of fluoride) is a function of the type of glass employed. The glass also plays a major role in the aesthetics of the restoration, as this is dependent on both the refractive index of the glass and the presence of pigments within it.

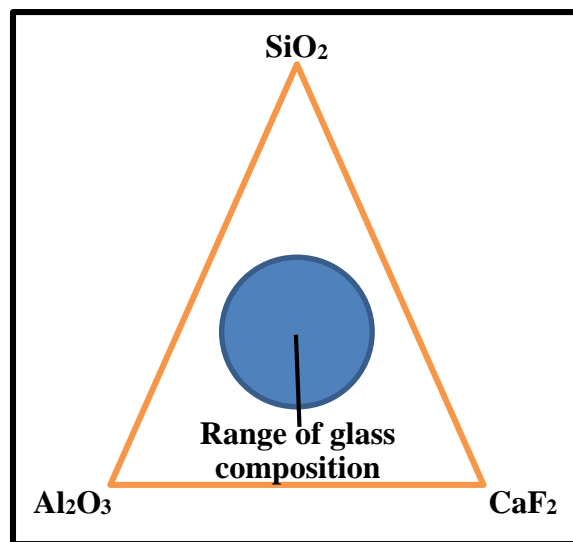


Fig. 6. Composition of glass used in glass-ionomer cements

Polyacid

There is a wide range of polyacrylic acid analogues, which, when combined with variations in molecular weight and configuration, means that a large variety of formulations are possible. The polyacids most used in current formulations are copolymers of acrylic and itaconic acid or acrylic and maleic acid (fig. 7).

A relative newcomer is a glass-ionomer cement based on a copolymer of vinyl phosphonic acid. This is a much stronger acid than the others used in glass-ionomer cements, and the composition has to be carefully controlled to produce a cement with suitable handling properties; however, it is believed to give higher long-term strength and enhanced moisture resistance.

There is an optimum acid concentration in the case of the silicate cements, but the glass-ionomer cements are not so dependent upon this. The strength and the resistance to aqueous attack both steadily increase with polyacid concentration, so the limiting factor is the consistency of the cement paste. The viscosity of the liquid depends both upon the polyacid concentration and the molecular weight, which can vary from 10000 to 30000, depending upon the formulation selected.

Tartaric acid is an important component of the glass-ionomer cement, as it has a significant influence on the working and setting time.

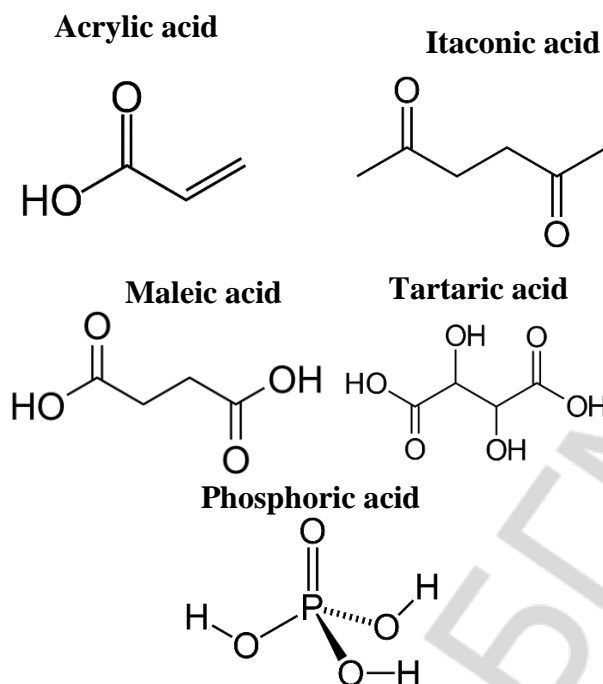


Fig. 7. Acid components used in a glass-ionomer cement

Presentation Powder/Liquid

Many glass-ionomer cements consist of a glass powder to which is added a proprietary liquid. The powder is much as described above, and the liquid is an aqueous solution of polyacrylic or polymaleic acid and tartaric acid. A number of deficiencies were soon recognized with this mode of presentation and brought about a change in formulation.

One of the problems is the excessive solubility of the cement in saliva coupled with the slow setting reaction, and another is concerned with judging the correct powder-liquid ratio. There is a tendency to reduce the powder content of the cement in order to obtain a smooth creamy paste, but this results in a slower setting, weaker cement that is more susceptible to dissolution (fig. 8).

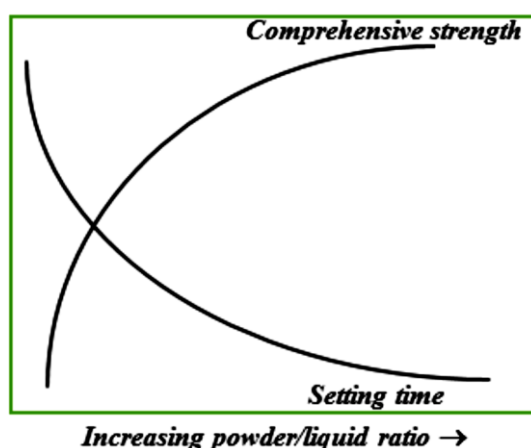


Fig. 8. Effects of changes in powder-liquid ratio on the properties of glass-ionomer cements

Anhydrous Cements

Nowadays, many glass-ionomer cements are of a water hardening type, and the cement is formed by the addition of the correct amount of distilled water. The glass powder is blended with freeze-dried polyacid and tartaric acid powder. The first product that used this approach became available commercially in 1981. The new formulations, described as anhydrous systems present as a powder and a liquid. The powder contains alumino-silicate glass, polyacid powder and tartaric acid, and the liquid is just distilled water (fig. 9).

Some manufacturers of dental materials present GICs with proportioning of the powder, which is achieved by using a scoop and the liquid is proportioned according to the number of drops. Powder and liquid are mixed on a mixing pad (fig. 10).



Fig. 9. Anhydrous cement



Fig. 10. A glass-ionomer cement (Ketac Molar, 3M ESPE) restorative material supplied in the form of a powder and liquid

Capsules

It is well recognized that achieving the correct powder-liquid ratio can still be a problem, and a vigorous mixing process is required to ensure that all the powder is incorporated in the liquid. One way in which this may be overcome is by the use of proportioned capsules.

The contents of different capsules do not necessarily have the same constituents, so it is inadvisable to mix them. For example, to ensure the most appropriate handling and physical properties, the filling materials have much larger glass filler particles than the luting agents. Similarly, the liquids used can vary in composition to suit the particular glass formulation and to give the correct working and setting time. It is also influenced by the application of different formulations. The difficulty of dispensing and mixing the correct amount of powder and liquid for these materials means that preproportioned capsules are preferable for consistency of performance (fig. 11).



Fig. 11. A glass-ionomer cement filling material provided in encapsulated form. The powder and liquid are brought into contact and mixed for about 10 seconds before extruding the mixed material through the nozzle directly into the cavity

Setting Reaction

The setting reaction of the glass-ionomer cements is via an acid-base reaction (fig. 12).

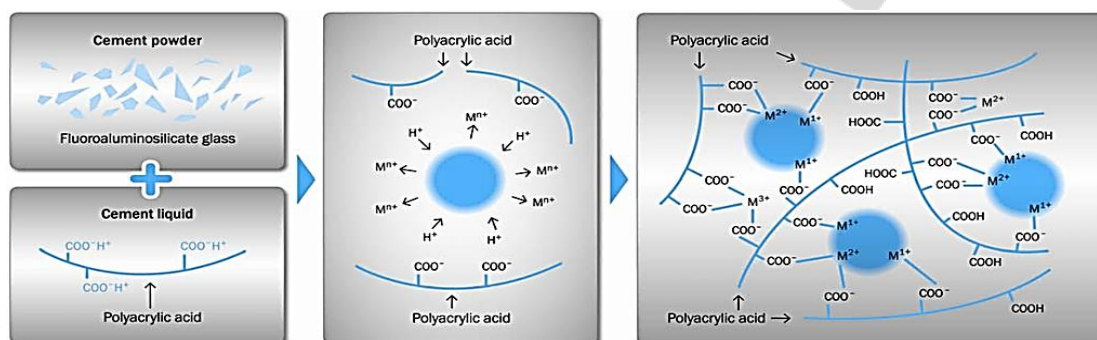


Fig. 12. A glass-ionomer cement setting reaction

The setting process involves three overlapping stages:

- dissolution;
- gelation;
- hardening.

This happens because of the different rates at which the ions are released from the glass and the rate at which the salt matrix is formed (fig. 13); as it is apparent from this curve, the calcium ions are more rapidly released than the aluminium ions. This is because the calcium ions are only loosely bound in the glass structure, while the aluminium ions form part of the glass network, which is more difficult to break down. It is the calcium and the aluminium ions that will eventually form the salt matrix. The sodium and fluoride ions do not take part in the setting process, but combine to be released as sodium fluoride.

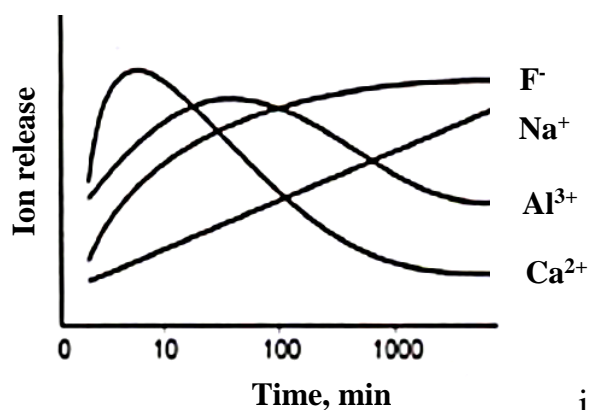


Fig. 13. Variation of the rates of ion release from the glass

Dissolution

When the proprietary solution or the water is mixed with the powder, the acid goes into solution and reacts with the outer layer of the glass. This layer becomes depleted in aluminium, calcium, sodium and fluoride ions, so that only a silica gel remains (fig. 14).

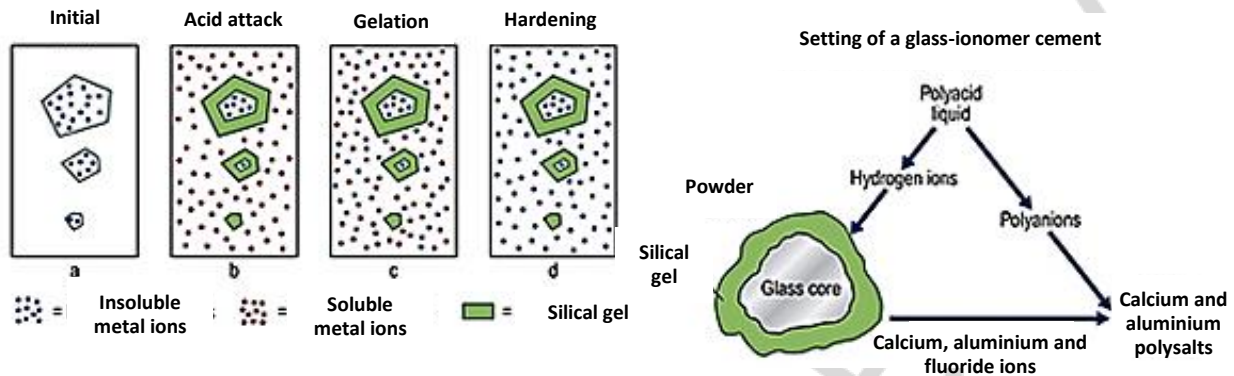


Fig. 14. Initial stages of the setting reaction in a glass-ionomer cement

The hydrogen ions that are released from the carboxyl groups on the polyacid chain diffuse to the glass, and make up for the loss of the calcium, aluminium and fluoride ions. The setting reaction for the cement is a slow process, and it takes some time for the material to stabilize; the final translucency of the material is not apparent until 24 hours after placement.

Although the material appears hard after its required setting time (usually 3–6 min, depending on whether it is a filling or a luting cement), it has still not reached its final physical and mechanical properties and will continue to set for up to 1 month.

Gelation

The initial set is due to the rapid action of the calcium ions, which, being divalent and more abundant initially, react more readily with the carboxyl groups of the acid than do the trivalent aluminium ions. This is the gelation phase of the setting reaction. The efficiency with which the calcium ions crosslink the polyacid molecules is not as good as it might be, because they are also able to chelate carboxyl groups on the same molecule.

Various things can happen if the restoration is not protected from the outside environment during this critical phase. Aluminium ions may diffuse out of the material and be lost to the cement, thereby being unable to crosslink the polyacrylic acid chains. If the water is lost, the reaction cannot go to completion. In both instances, a weak material will result. Alternatively, additional moisture may be absorbed, which may be contaminated with blood or saliva, leading to compromised aesthetics, with the restoration looking exceptionally dull and white. The contaminating moisture will also weaken the material and may even cause it to crumble. Hence, it is essential that contamination by moisture and drying of the restoration are both avoided, at least during the initial period of setting, when the material is at its most vulnerable.

Hardening

After the gelation phase, there is a hardening phase that can last as long as 7 days. It takes some 30 minutes for the uptake of aluminium ions to become significant, yet it is the aluminium ions that provide the final strength to the cement, as

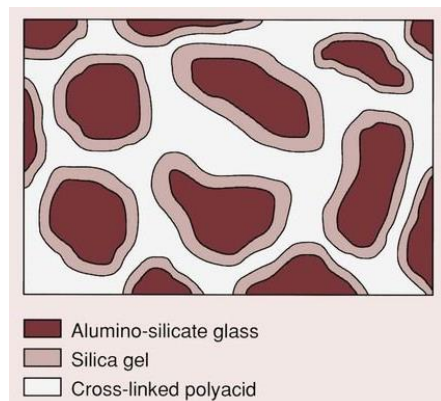


Fig. 15. Structure of glass-ionomer cement

they are responsible for the introduction of the crosslinks. In contrast to the calcium ions, the trivalent nature of the aluminium ions ensures that a high degree of crosslinking of the polymer molecules takes place. There is a continuation of the formation of aluminium salt bridges, and water becomes bound to the silica gel, which now surrounds the residual core of each of the glass particles. Once the cement has fully reacted, the solubility is quite low. The final structure is as shown in fig. 15, and consists of glass particles, each of which is surrounded by a silica gel in a matrix of crosslinked polyacrylic acid.

Whereas normally it is desirable for glasses to resist ion release, in the case of glass-ionomer cements a controlled release of the ions of calcium and aluminium is essential. The skill in choosing the correct glass and the correct formulation is to balance the various requirements of good handling characteristics, low solubility, adequate fluoride release and aesthetics. Glass-ionomer cements are slow to set and need protection from the oral environment in order to minimize dissolution or contamination.

PROPERTIES

Handling Characteristics

The effects of the composition of the glass on the setting process are very pronounced and of a considerable importance in determining the acceptability of the final handling characteristics of the cement. The Al/Si ratio of the glass for the glass-ionomer cements is higher than that for the silicate cements, because the polyacrylic acid and its analogues are much weaker than phosphoric acid. One of the effects of this increased ratio is that the working time is reduced.

However, glass-ionomer cements were previously inclined to have prolonged working and setting time. This was certainly a serious problem with the earliest formulations of this cement until it was overcome by the inclusion of the optimum concentration of tartaric acid. Tartaric acid is believed to have a twofold function. First, it reacts rapidly with the calcium ions being released from the glass with the formation of calcium tartrate, which has the effect of extending the working time. This is followed by an enhancement of the rate of formation of aluminium polyacrylate crosslinks, which speeds up the set.

By manipulation of the glass composition and particle size, and the incorporation of tartaric acid, the handling characteristics have been much improved over the years, and are now far superior than those of the first commercially available products.

Adhesion

One of the most attractive features of the glass-ionomer cement is that it is a bulk placement restorative material (no need for incremental placement), which is able to bond directly to dentin and enamel. It has been suggested that the polyacrylate ions either react with the apatite structure (displacing calcium and phosphate ions, and creating an intermediate layer of polyacrylate, phosphate and calcium ions) or bond directly to the calcium in the apatite, as shown in fig. 16.

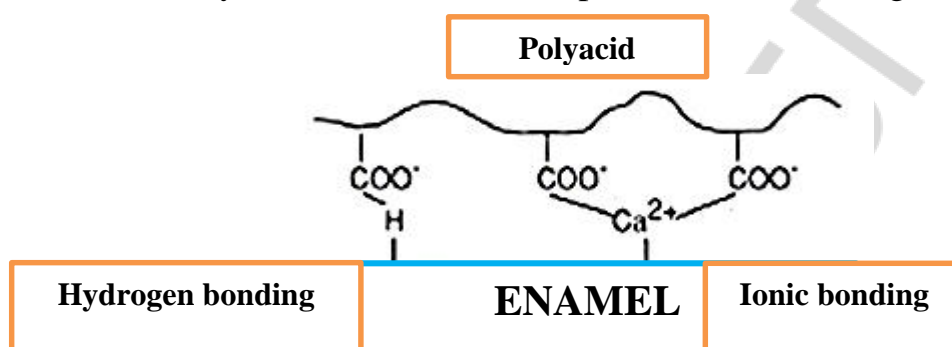


Fig. 16. Adhesive mechanisms for glass-ionomer cements

The bond to dentin may be a hydrogen bond type of adhesion to the collagen combined with an ionic bond to the apatite within the dentin structure. The bond strength, as measured in shear bond strength tests, would suggest that it is not particularly strong (2–7 MPa), but clinical experience would indicate that it is durable when the material is used for the restoration of erosion lesions. Whatever the details of the bonding process may be, the bond created is strong enough so that when a glass-ionomer cement is debonded the fracture will generally run through the cement and not along the interface. The major limitation on the bond strength of the glass-ionomer cement therefore appears to be its low tensile strength, which is only of the order of 7 MPa and is due to the brittle nature of these materials.

Table 1

Typical tensile bond strengths measured for the bond to dentin and enamel

| Surface Treatment | Bond strength (MPa) |
|-------------------|---------------------|
| Enamel | |
| None | 3.2 |
| Citric acid | 5.6 |
| Polyacrylic acid | 7.1 |
| Dentin | |
| None | 3.1 |
| Citric acid | 3.7 |
| Polyacrylic acid | 6.8 |

To obtain a good bond to dentin, the surface must first be treated with a conditioner. The best conditioner appears to be polyacrylic acid, although tannic acid has also proved to be effective. Typical tensile bond strengths that have been measured for the bond to dentine are presented in Table 1.

The major purpose of the surface treatment is to remove debris and to produce a smooth, clean surface. Citric acid should not be used as it opens up the dentinal tubules, increasing the dentin permeability and the potential for pulpal reaction. Additionally, it demineralizes the dentin, which may compromise the bond to the apatite component.

Aesthetics

A major requirement for any restorative material intended for use in anterior teeth is that it must blend in well with the surrounding tooth tissues, so as to be barely distinguishable. The factors governing this are the colour and the translucency of the restorative material. In glass-ionomer cements the colour is produced by the glass. This can be controlled by the addition of colour pigments such as ferric oxide or carbon black.

Whereas colour does not present a major problem, the translucency of the glass ionomer cements was inadequate in the early materials, being more comparable to that of dentin than enamel. This lack of translucency has meant that the aesthetic appearance of glass-ionomer cements has always been considered inferior to that of composite resins. The cements appeared dull and lifeless, and this limited their application to that of a filling material for the treatment of erosion lesions and non-critical class III cavities.

There are essentially two causes for the opacity of glass-ionomer cements:

1. *Separation phase of the glass.* To some extent this problem can be overcome by reducing the aluminium, calcium and fluorine content of the glass, but this reduces the strength of the material and extends the working and setting time.

2. *Mismatch of the refractive index.* This problem can be minimized by reducing the aluminium content and increasing the fluorine content; however, the latter leads to separation phase. In general, optically good glass-ionomer cements tend to have poor setting characteristics.

The translucency of a restorative material can be described and measured by considering its inverse -opacity. Opacity is defined as being zero for a transparent material and 1.0 for a white opaque material.

The opacity, or *contrast ratio*, is defined as the ratio between the intensity of the reflected light from the material when placed against a dark background and that obtained for a white background of known reflectivity (70 % in the case of dental cements).

The opacity is affected by the absorption of water, causing a decrease in the opacity. Thus, clinically, the restoration can darken when it comes into contact with saliva.

Selecting the appropriate colour and translucency is a difficult problem as these are affected by the optical properties of the underlying material. On some occasions, the translucency has to be forsaken, and a relatively opaque material must be used in order to mask out a particularly dark substructure. In these cases, the glass-ionomer cements can prove to be particularly beneficial.

While the initial match in colour and translucency between the enamel and the glass-ionomer cement is important, it is also important that this close match is maintained in the severe environment of the oral cavity. A loss of aesthetic quality of the restoration can arise from staining, and, if excessive, would be considered a clinical failure and would need replacement.

The glass-ionomer cement appear less susceptible to staining than the silicate cements, which preceded them. This has been ascribed to the superior adhesion between the matrix and the glass in the glass-ionomer cement when compared to the bond between the resin and filler in the composite. However, the composites have been improved considerably in recent years and are now far less susceptible to surface staining. Staining of the margins around glass-ionomer cements has also been found to be far less pronounced than for the composite resins. This may be a reflection of the excellent bond that can be achieved between a glass-ionomer cement and the tooth tissues. Another contributory factor may be that shrinkage on setting for glass-ionomer cements should be considerably less than that for composite resins. In effect, glass-ionomer cements set by an acid-base-mediated cross-linking reaction of the polyacid chains, which inherently produces less shrinkage than polymerization. Hence, the local interfacial stresses generated will be less and the bond stands a better chance of survival.

Solubility

Due to their high solubility, the dental silicates had a reputation for loss of material in the mouth. To some extent this can be attributed to incorrect preparation and handling, but it is an inherent feature of all dental cements, and, as such, the glass-ionomer cements are no exception.

Nevertheless, this negative aspect of the material's behaviour can be minimised by an appreciation of the mechanisms involved and the adoption of proper clinical technique. The processes giving rise to loss of material are complex, as there are many variables involved, such as the cement composition, the clinical technique used and the nature of the environment. The loss of material from a glass-ionomer cement can be classified into three main categories:

1. Dissolution of the immature cement.
2. Long-term erosion.
3. Abrasion.

Dissolution of the immature cement occurs before the material is fully set, which can take up to 24 hours. The temporary protection of a layer of nitrocellulose, methyl methacrylate or amide resin acting as a varnish should be sufficient to minimize this effect. This protection must survive for at least 1 hour, as it takes

this much time for the glass-ionomer cement to approach the properties that are achieved when it is fully set. At present, there is some controversy as to the quality and duration of protection offered by the different varnishes available, and some clinicians advocate the use of an unfilled light-activated resin, as this will give longer protection. A high powder-liquid ratio helps, because it accelerates the setting process, whereas a thin mix has the opposite effect, and also adversely affects the mechanical properties.

Once the cement has fully-set (usually within 2–3 days, manifested by a dramatic drop in the amount of water-leachable material), this particular form of material loss will stop. From this point onwards, loss of material can be considered long term, and is a function of the conditions in the oral environment.

Loss of material in the long term may arise either from *acid attack* or *mechanical abrasion*. This is hardly surprising, given that the main application of glass-ionomer cements is the restoration of lesions that have themselves arisen because of the combined effect of acid and abrasion. The potential for acid attack tends to be very marked in stagnation regions, such as around the gingival margin. Here, plaque accumulates and a highly acidic environment develops due to the formation of lactic acid. The glass-ionomer cements are more resistant to this form of attack than the silicate cements, as indicated by a reduction in the extent of surface markings.

Glass-ionomer cements are extensively used in applications where they will be subject to mechanical abrasion, such as toothbrushing. Their resistance to abrasion is poor, which limits their application to low stressing conditions and certainly prevents their use as permanent posterior restorative materials.

An *in vitro* test, in which cement samples are arranged in small holders and subjected to a jet of liquid consisting of a dilute acid, attempts to assess loss of material by a combination of abrasion and acid attack. Using this method, the indications are that the polyacrylic acid-based cements are more resistant to abrasion/erosion than the polymaleic acid-based cements. However, it should be remembered that this observation is based on a laboratory test and would need to be confirmed clinically before its validity can be established.

Fluoride Release

The fact that dental cements dissolve in the oral environment is usually regarded as an adverse effect, as it leads to degradation of the material. However, fluoride is also released, and it is believed that this significantly increases the caries resistance of enamel adjacent to the restoration (fig. 17). Whether fluoride release or other factors (e.g. the release of other ions, antibacterial properties and adhesive capabilities) have a role to play in the anticarcinogenic characteristics of glass-ionomer cements is still a matter of debate.

Nevertheless, attempts have been made to impart this property to amalgams and composites as well as the glass-ionomer cements.

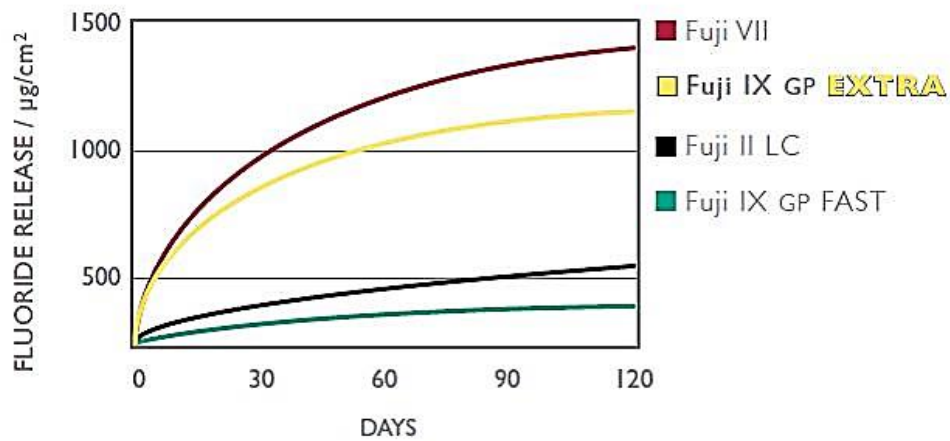


Fig. 17. Fluoride release in different types of GICs (Fuji, GC)

This presents the dentist with an interesting dilemma in making the choice between a glass-ionomer cement or a composite, with the former being most definitely weaker but providing some protection of the surrounding tissues, and the latter being more stable and stronger but not providing such protection.

Release Forms

The materials are available in three formulations:

1. The traditional powder liquid systems with the polyacids in an aqueous solution
2. The anhydrous systems with the dried acid incorporated in the powder
3. Encapsulated versions.

The encapsulated versions require activation of the capsule, and mixing in of an amalgamator, which ensures an accurate powder-liquid ratio, like the amalgam capsules.

The main feature of all of these materials is their low diametral tensile strength, which is an indication of their low tensile strength. Thus, glass-ionomer cements should not be used where they are going to be subjected to high tensile loads, such as incisal tip restorations, cuspal replacement or pin-retained cores. In situations where the restoration is supported all around by tooth tissue, the glass-ionomer cement is protected (to some degree) from tensile loading conditions.

The size of the glass powder particles ensures that a very high powder-liquid ratio can be achieved, and this is reflected in the compressive and diametral tensile strengths of these materials. (These strengths are much higher than for the luting and lining cements described later.) It also affects the solubility which is reduced as the powder liquid-ratio is increased.

There are differences in the working and setting time of the different cements: some have much shorter setting time than others (which is desirable in limiting the early solubility), but the working time is also much reduced, which may present a problem to some clinicians.

Shade Selection

The aesthetic quality of the tooth-coloured glass-ionomer cements has long been considered a drawback, but recent changes in formulation have resulted in a marked improvement (fig. 18).



Fig. 18. Vitremer (3M ESPE). Different shades of material are available

The choice of shade of the restorative material should be carried out before the isolation of the tooth or any other form of preparation. The colour of the rubber dam, if used, alters the colour of the tooth. This change in shade is increased still further when the enamel is allowed to dehydrate during isolation.

For the restoration of lesions that involve an extensive amount of the labial surface, the use of glass-ionomer cements may not give an aesthetically adequate result, and the use of composites should be considered. Nevertheless, for those patients who are known to have a high caries rate, it may be better to forsake some of the aesthetic quality of the composites in preference to the fluoride protection provided by the glass-ionomer cements.

Another aspect of the glass-ionomer cements aesthetics is the observation that there is a colour change during the setting process. Generally, the shade is somewhat darker after the material has fully set than at the time of placement. This darkening is believed to be associated with an increase in translucency on setting and may take up to 24 hours to develop.

Cavity Preparation

The adhesive quality of the glass-ionomer cements dictates that an *ultraconservative approach should be adopted*. This means that minimal removal of tooth substance is required, and it should be stressed that the excessive removal of tooth tissues for the provision of undercuts or dovetails is not necessary. However, for situations where the restoration may be subjected to high stresses, some undercut may be advantageous. In the case of a replacement restoration, the original restoration should be carefully removed without removing any tooth tissue, unless it is carious. The cavo-surface margins should be butt jointed and not bevelled.

Isolation

Although the glass-ionomer cements are hydrophilic materials, it is recommended that careful isolation of the field of operation is carried out. The presence of blood or saliva will not only impair the formation of a strong bond but may also lead to contamination of the restoration, thereby reducing both bond strength and aesthetics. A well-placed glass-ionomer cement should not fail adhesively, as the bond to dentin and enamel is at least as strong as the cohesive strength of the cement.

Preparation of the Dentinal Surfaces. The nature of the dentin surface varies from site to site, with the major distinction being between cut dentin after caries removal and sclerotic dentin.

Abrasion/Erosion Lesions. Lesions at the cervical margin need to be restored to provide direct protection of the pulp, to prevent the development of pulpal sensitivity and to improve appearance. Since the glass-ionomer cements are adhesive it should not be necessary to cut any finishing lines or undercuts in the dentin. Preparation prior to placement of the material should only improve the cleaning and conditioning of the dentin surface. The cleaning procedure should be carried out by scrubbing for a few seconds only with a slurry of pumice and water in a soft rubber cup or bristle brush, and is aimed at removing any surface contaminants, such as plaque or pellicle, which obscure the dentin surface. The surface should be thoroughly washed to remove any debris. A conditioner consisting of an aqueous solution of polyacrylic acid may then be applied to the surface for 30 seconds, using a pledget of cotton wool and a light rubbing action. This procedure will ensure that the surface is clean, but will also result in some opening of the dentinal tubules. Some argue that exposure of the dentinal tubules is contraindicated, as it increases dentin permeability and thus raises the likelihood of a pulpal reaction. This is probably not a problem in the case of patients who have no history of sensitivity, as the tubules will have sclerosed, and secondary dentin will have been laid down. However, for those patients with sensitivity, acid treatment of the dentin surface should not be undertaken. There is still some controversy as to the need for the prior application of polyacrylic acid to the dentin surface. Some studies have shown that this will improve the dentin bond strength, whereas others have shown that it has no effect.

Class III, Class V and Other Carious Lesions

It is not necessary to clean the cavities with pumice and water in the case of carious lesions, as the surface will consist of freshly exposed dentin. However, there is still the dentin smear layer to consider, which is present in any cavity preparation. While the smear layer is strongly bonded to the underlying dentin, surface debris needs to be removed in such a way as to avoid opening of the dentinal tubules. Again, the use of polyacrylic acid is recommended. A variety of other dentin conditioners have been advocated from time to time (e. g. citric acid, EDTA and ferric chloride), but these should not be applied to freshly cut dentin

for the reasons already mentioned. The simplest and most effective dentin surface conditioner appears to be polyacrylic acid.

Pulpal Protection

The increased application of glass-ionomer cements in recent years has raised some interesting problems, not least being the pulpal toxicity associated with these materials and whether or not a lining material should be used. If the cement is in direct contact with the pulp, this will result in a localized zone of pulp necrosis, which inhibits calcific repair. However, in those instances where there is a residual dentin layer, dentin bridge formation will occur. If the cavity is very deep, and there may even be a microexposure of the pulp, then it is recommended that a calcium hydroxide lining is placed on the pulpal aspects of mechanically prepared cavities prior to the insertion of the glass-ionomer cement (fig. 19).

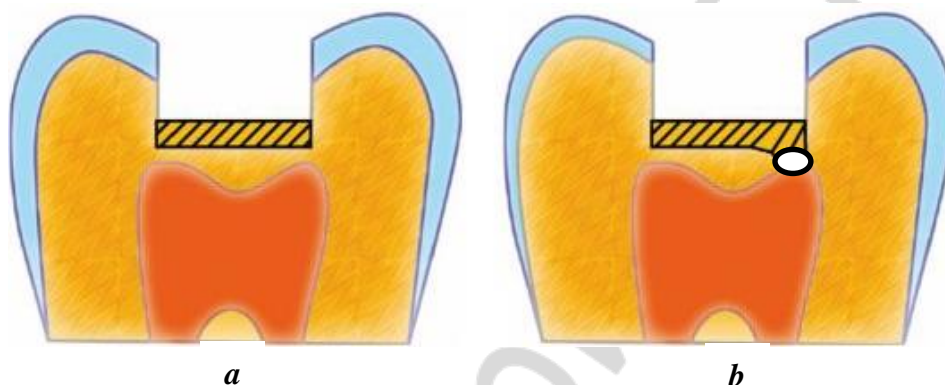


Fig. 19. Different variants of pulp protection with GICs:

a — insulating pulp cap from the GIS; *b* — medicated pulp cap (direct pulp capping) with both calcium hydroxide material and GIC

The potential cause of pulpal sensitivity when using glass-ionomer cements has been suggested to be due to differences in techniques of manipulating the cement (fig. 20), or some other, unknown patient-related factors. As yet, it is not clear what gives rise to the small number of cases of pulpal sensitivity, nor is it clear what the role of bacterial contamination or invasion may be.

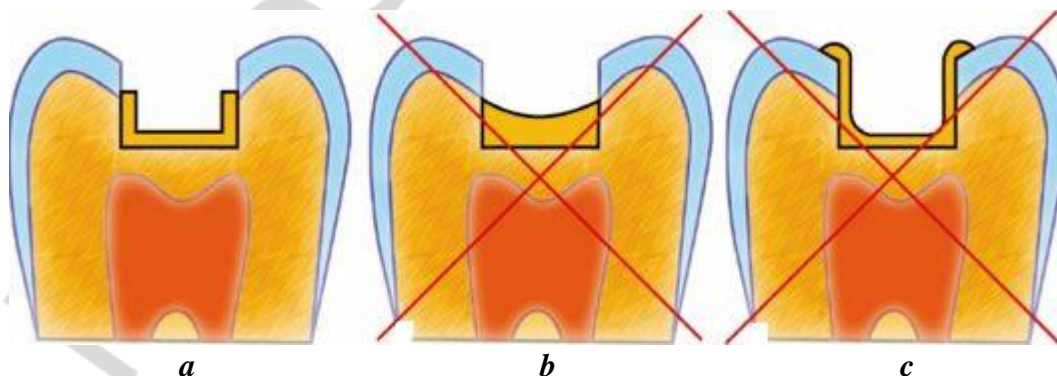


Fig.20 Application of base with GIC:

a — correct; *b, c* — incorrect

Lower levels of bacteria are associated rather with glass-ionomer cements than with zinc phosphate or zinc polycarboxylate cements. This may be because glass-ionomer lining cements have a pronounced antimicrobial effect. Nevertheless, for all types of glass-ionomer cement (including the silver cermets), lining the dentin is recommended, especially if the tooth is symptomatic or the cavity preparation is particularly deep.

There are situations where a small amount of caries may be left in the deepest portions of the preparation if there is the danger of a microscopic pulpal exposure if it were removed. The ability of calcium hydroxide to activate the formation of secondary dentin and its alkalinity are of great value under these circumstances. However, this material should be used sparingly to ensure that the maximum amount of dentin remains exposed for bonding to the glass-ionomer cement.

In general, if there is any doubt about the thickness of the remaining dentin, it is advisable to line the cavity of freshly prepared dentin with calcium hydroxide. For sclerotic dentin, it is not usually necessary to use a calcium hydroxide cavity base, but the use of citric or phosphoric acid should be avoided.

Dispensing, Mixing and Insertion

For the powder liquid systems, great care must be exercised to ensure that the correct amount of powder is mixed with the liquid. It is important that the manufacturer's instructions are carefully followed.

Tapping the bottle before use will ensure that the powder is not compacted. Any excess powder should be scraped off with a spatula and not against the side of the bottle. The powder should be spatulated quickly into the liquid in no more than two increments. The maximum mixing time is 20 seconds. The incorporation of a large amount of powder initially should be avoided, as this will appear to give a satisfactorily thick mix even though the powder liquid ratio may be too low.

In the case of the preproportioned capsules, the capsule should be shaken before activation. The mixing should be carried out in a high speed amalgamator, typically operating at around 4000 rpm, for a period of 10 seconds (fig. 21). The



Fig. 21. A rotary mixing device which can be used for mixing a number of materials including dental cements. In this instrument the capsule is rapidly rotated and centrifuged and the aim is to attempt to produce a mix which contains lower levels of porosity

whole process of activation, mixing and application should be carried out without any delays.

Contamination of the filling materials with saliva should be avoided during insertion, setting and finishing. The cavity and surrounding area should be dry, although excessive desiccation must not occur.

Moisture Control during Placement

There is a dichotomy between the use of the best moisture control techniques (isolation with rubber dam) and the risk of desiccation of the restoration if a rubber dam is used. It is usually adequate to isolate a tooth carefully using cotton rolls or dry guards during the placement of GIC restorations. Obviously, great care is required to avoid contamination of a prepared cavity with saliva prior to placing the cement as the salivary pellicle will interfere with bonding. Salivary pellicle can be removed by treating the dentin with poly (acrylic) acid for 15 seconds.

Finishing and Polishing

Glass-ionomer cements are water-based and hence are highly susceptible to either desiccation or excessive moisture contamination during the early phase of their setting reaction. They achieve a clinical set part way through the chemical process of cement formation. Maturation continues for at least an hour and, with some materials, up to 24 hours. The surface of the cement should be protected during that time period.

A variety of materials have been suggested for moisture protection – from cocoa butter through copal-ether and resin varnishes to unfilled methacrylate-based resins. This latter group is by far the most effective at delaying water flow into and out from the cement. The unfilled resin should be applied to the surface of the cement as soon as the matrix is removed. Light-activated resins are easiest to use for this purpose because of their command set after placement. Any finishing that is required will remove this protected layer; consequently early finishing should be confined to removal of gross excess alone (this can usually be avoided with careful matrix placement). If gross excess is present it should be removed either with a sharp-bladed hand instrument or, if necessary, a bur in a handpiece. It is best to use steel burs in slow handpieces lubricated with petroleum jelly for this purpose. Water cooling should be avoided. As soon as the gross excess has been eliminated the finishing procedures should stop and a protective layer of resin or varnish should be re-applied to the surface of the material.

Once the material is fully mature any final finishing that is required can be undertaken. This is achieved using the same range of burs, strips, discs and abrasive points that are used for composites. However, care should be taken to avoid excessive heating of the cement if at all possible. All abrasives should be lubricated with petroleum jelly if water cooling is not being used.

After the material has been allowed to set for the required time, the matrix can be removed and the restoration should be protected immediately from contam-

ination or dehydration, by placing a waterproof varnish. The best surface finish is achieved at this stage, and the removal of excess material will be detrimental to the finish; however, it is virtually impossible to place a glass-ionomer cement without having to do some trimming and polishing.

Gross excess may be trimmed with a sharp blade. As the material is still fairly weak and the bond to the tooth tissues tenuous, the trimming process should be performed from the restoration towards the tooth and not the other way round. It has been shown that the use of hand instruments for carving can damage the marginal integrity of the restoration. In fact, one manufacturer specifically recommends that hand instruments are not used.

It has been suggested that, after the initial set, finishing may be performed with rotary instruments, such as a white stone, or with flexible discs lubricated with a grease, such as vaseline or petroleum jelly. The use of a water spray at this stage is not recommended as the material is still highly soluble. Final finishing should not be attempted, and is best left to a later visit by the patient, preferably within 24 hours.

A number of studies have shown that if finishing is carried out after only 8 minutes the resultant surface finish is very poor when using either abrasive discs, impregnated rubber wheels, tungsten carbide blanks or white stones even in the presence of petroleum jelly. This situation may change with the more recent rapid-setting materials, but so far the early finishing of glass-ionomer cements is contraindicated. After 24 hours the material is set sufficiently for final finishing to be carried out using either a fine diamond or a 12-bladed tungsten carbide bur. This should be carried out in the presence of a copious supply of water to avoid dehydration, and is now possible as the early susceptibility to dissolution in water has subsided. Final polishing can be performed with the range of abrasive discs, again in the presence of water.

Whichever method is used, it is not possible to obtain a smooth surface finish for a glass-ionomer cement. This is due to the large particle size of the glass used in the production of these cements.

Surface Protection

Whilst GICs are not as susceptible to desiccation once setting is complete, it is sensible to coat a GIC restoration with a protective layer of resin-based varnish or unfilled bonding resin if restorations are likely to be subject to a desiccating environment for a protracted period, e.g. if a tooth containing a GIC restoration is isolated using a rubber dam during a restorative procedure or endodontic care elsewhere in the mouth.

The use of a varnish is extremely important. Solutions of natural (Copal) and synthetic resins (cellulose acetate) dissolved in an organic solvent such as ether, acetone or chloroform are generally recommended. Polyurethane varnishes, which polymerise on contact with water and nitrocellulose (nail varnish), are a less permeable and less soluble alternative.

The light activated enamel bonding resins or dentin bonding agents that are supplied with the composites provide a particularly effective seal and last sufficiently long to offer the necessary protection. The disadvantage with their use is that a small ledge may be left, especially at the gingival margin, which has to be dealt with at a later stage. Also, they suffer from an oxygen-inhibited set, so that the surface layer remains tacky. However, if only a thin layer is applied, it is too readily removed. The problem can be overcome by the use of a matrix strip but this is very cumbersome to use. Further finishing should be carried out within 24 hours.

The use of greases or gels such as Vaseline offers little protection, as these are rapidly removed by the action of the lips and the tongue.

Glass-ionomer restorations that have been in place for some time still need to be protected from dehydration during any prolonged isolation of the dentition when carrying out other restorative procedures. This is especially the case when using rubber dam, when dehydration of the cement can be very pronounced and the resultant shrinkage can lead to fracture of the restoration. Thus, all known or suspected glass-ionomer cement restorations, crowns, inlay margins and cermets should be protected with a layer of varnish (fig. 22).



Fig. 22. Materials for protection of the GIC surface

CLINICAL APPLICATIONS

It must be appreciated from the outset that the glass-ionomer cements are designed to suit a wide variety of applications, their range encompassing materials with widely different properties.

Hence, although they are all based on the same principles outlined above, each formulation has features which make it more suited to a particular application, and it is important that these are not confused.

The major applications of the glass-ionomer filling materials reflect the advantage of their adhesive nature coupled with an inherent brittleness and a less than perfect aesthetic quality. They are widely used to restore loss of tooth structure from the roots of teeth either as a consequence of decay or the so-called cervical abrasion cavity. Both of these lesions tend to occur close to the gingival margins of teeth. Root caries tends to spread laterally across the root as well as centrally towards the pulp. Once it has been removed the resultant cavities tend to be

broad and shallow. Abrasion cavities were once thought to be the product of over-zealous tooth brushing, possibly in association with the use of an abrasive dentifrice. It is now recognized that both dietary factors and functional loading of teeth (causing the teeth to bend) can be co-factors in their etiology. The morphology of such lesions is variable: some are relatively dish-shaped and shallow whilst others are more v-shaped and tend to be deeper. In both cases the tooth surface is likely to be caries free and highly burnished.

Cavities for glass-ionomer cements should be of sufficient depth at their margins to give adequate bulk to the restorative material. A knife-edge finish is not suitable and hence both abrasion and carious cavities may need to be modified to give a butt joint margin of 0.75 mm depth or greater.

The use of glass-ionomers for restoring class III cavities has been advocated. The early materials were far from ideal, being more opaque than either silicates or composites. Newer products are more satisfactory and are now sometimes used for this type of cavity.

Glass-ionomer cements are gaining wide acceptance as filling materials for deciduous teeth, often being used in preference to amalgam in deciduous molars. They allow the trauma of cavity preparation to be reduced to a minimum and, although they are probably not durable enough to withstand forces of mastication in adults, they are probably adequate for the limited life of deciduous teeth.

Some new restorative techniques offer alternatives to traditional class I and class II cavities in posterior teeth in adults. Cavity preparation takes the form of a tunnel with its origin either from the occlusal surface a short distance away from the marginal ridge or from the buccal aspect. The tunnel leads into the area of carious dentin which is removed using rotary and hand instruments. An injectable glass-ionomer cement is then inserted into the cavity with an appropriate matrix as required. The principal advantage of this approach is maintenance of the marginal ridge of the tooth. The clinical manipulation of glass-ionomer cements should be designed to maximize their clinical acceptability whilst doing minimal damage to the set material. One of the key issues is to take care to maintain an appropriate level of hydration of the material's exposed surface.

The primary applications of the glass-ionomer cements have always been as a filling material for the treatment of abrasion and erosion lesions, and as a luting agent for crowns, bridges and inlays. With the advent of newer and better materials, their use is being extended to include class III restorations, occlusal restorations (particularly in deciduous teeth), a core material, and a dentin adhesive lining cement under composite restorations.

Most of the interest in the clinical evaluation of glass-ionomer cements has centred around their use as restorative filling materials. Their ease of placement in bulk, their adhesive qualities and their fluoride protection are seen as important advantages over the aesthetically more pleasing composites.

The higher viscosity has been attributed to the addition of polyacrylic acid to the powder and a reduced grain size (3~m). One of the main attractions of these

materials is their amalgam-like handling characteristics. Although their strength properties are little changed from those of the conventional glass-ionomer cements, their abrasion resistance does appear to be superior, which has been attributed to the reduced particle size of the glass. Commercial examples of these materials include:

1. CHEMFLEX (Dentsply, Weybridge, UK)
2. Fuji IX (GC UK Ltd, Newport Pagnell, UK)
3. HI-FI (Shofu, Tonbridge, UK)
4. KETAC-MOLAR (ESPE UK Ltd, Knutsford, UK)

Dentin Surface Treatment

Glass-ionomer cements are frequently placed in non-undercut cavities, with reliance being placed upon their adhesive characteristics to ensure their retention. Dentin surfaces that are burnished (e.g. those from cervical wear lesions that have not been mechanically prepared) and both dentin and enamel surfaces that are contaminated with saliva are not receptive to bond formation. Even transient wetting with saliva during cavity preparation will inhibit good bond formation. These surfaces should be prepared to remove the precipitated salivary protein and/or the eburnated dentin surface. A variety of agents have been used for this purpose, including citric acid. However, the most effective agent seems to be 10–15 % poly (acrylic) acid. This is applied to the tooth surface for 30 seconds, then washed off and the tooth dried, but not dessicated, to achieve a receptive surface for bonding.

Matrix Techniques

Generally, glass-ionomer cements are used to restore proximal cavities on anterior teeth and defects on root surfaces, whether the product of wear or decay. The matrix technique for proximal cavities on anterior teeth is very similar to that for composites, using transparent flexible film made from either cellulose acetate or polyester. The matrix is inserted between the teeth adjacent to the prepared cavity usually before any dentin surface conditioning. Once the material has been placed in the cavity to slight excess, the matrix is drawn round the tooth root and held in place using firm digital pressure until the material sets.

The problems of adapting preformed, curved matrixes to teeth for cervical cavities have already been mentioned. An alternative that is available for these chemically-setting materials is an aluminium cervical matrix. These are malleable at room temperature and hence can be pressure formed around the root face of the tooth using hand instruments giving a custom matrix for each tooth. This is particularly useful where a cervical cavity extends into the junction between the roots of molar teeth. The cavity margin in this area will be concave towards the furcation. This form of malleable matrix offers the only possibility of achieving a reasonable contour of the restoration with a matrix rather than by post placement finishing. The matrix is adapted to the tooth surface at the completion of cavity preparation. It is then set to one side, and the dentin prepared for bonding and the material

placed in the cavity to slight excess. The matrix is then replaced, taking care to ensure that the gingival portion of the matrix is lying on the outside of the tooth, not sitting on the cervical floor of the cavity (fig. 23). These relatively rigid metal foils are very good for insertion into the gingival crevice to help to form the restoration in that area but care must be taken to ensure that the inferior portion of the matrix does not get caught on the gingival floor of the cavity. If this happens then a negative ledge will be formed, i.e. the tooth will be wider than the restoration. It can be helpful to control the position of the gingival tissues using an appropriate retraction cord or by *troughing* the gingival crevice using an electrosurgery unit to assist with this process.

The matrix should be left undisturbed until the material has set fully and can then be removed carefully using a sharp probe or an excavator. Matrix techniques for tunnel preparation require a thin metal strip to be passed between the teeth and then adapted to conform to the tooth using wedges.

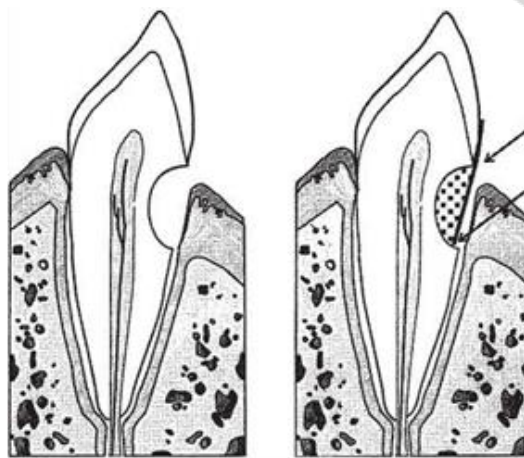


Fig. 23. Adaptation of a matrix for a cavity with subgingival margins can be complicated by negative ledge formation. The left-hand diagram illustrates a large cavity on the root face of a tooth, extending beneath the gingival margin. When a matrix is adapted to that cavity (b) it is important to ensure that it extends beyond the gingival extent of the cavity, otherwise a negative ledge will be formed (a)

Use as Fissure Sealants

Another suggested use of glass-ionomers is as *fissure sealants* (fig. 24). The material is mixed to a more fluid consistency to allow flow into the depths of the pits and fissures of posterior teeth. Early cements were found to be unsuitable as fissure sealants if the fissures were less than 100 μm wide. The large glass particles of the cement prevented adequate penetration of the fissure pattern and it was necessary to consider enlargement of the fissures with a bur. Luting cements having much smaller glass particles may be a more sensible choice of material for this application. Studies show that whilst the retention of glass-ionomer fissure sealants generally does not compare favourably with the resin types, their caries inhibiting effect is significant. This has been attributed to the presence of fluoride with-

in the cement and its ability to change the composition of the enamel with which it comes into contact.



Fig. 24. Sealing of the fissures is the important procedure in caries preventive measures

GICs as an Adhesive Cavity Lining (*the sandwich technique*)

GICs have a number of advantages as a cavity lining as they bond to dentin and release fluoride which may help to reduce recurrent decay. They can be used beneath either a composite resin or an amalgam.

The so-called *sandwich technique* involves using a GIC as a dentin replacement and a composite to replace enamel (fig. 25). The purpose designed lining materials set quickly and can be made receptive for the bonding of composite resin simply by washing the material surface if the material is freshly placed (excess water results in some of the GIC matrix being washed out from around the filler particles, giving a microscopically rough surface to which the composite will attach in an analogous manner to etched enamel). This surface should be coated with either an unfilled resin or a DBA to optimize attachment. It is only necessary to etch a GIC with acid if the restoration has been in place for some time and has fully matured.

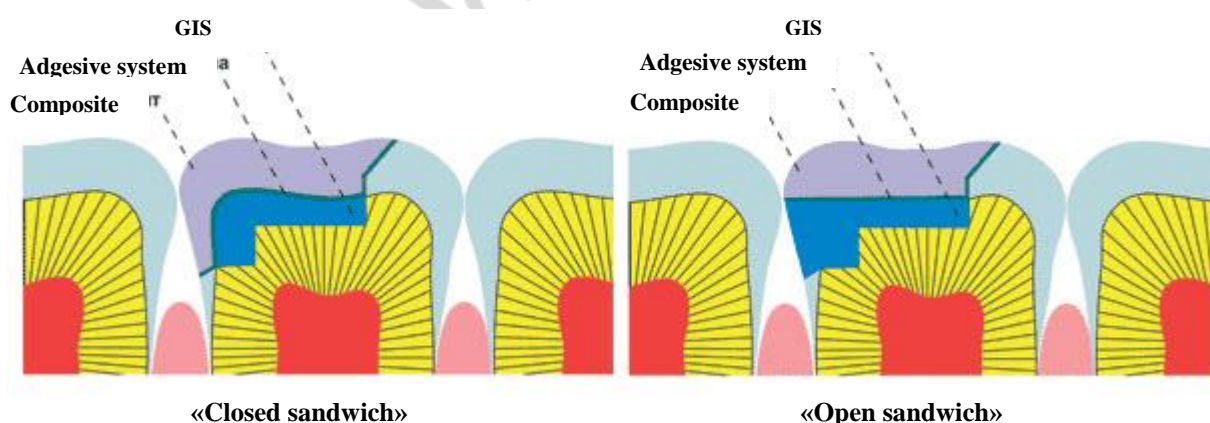


Fig. 25. Diagram illustrating the use of composite and glass-ionomer cement for the restoration of a class II cavity – the sandwich technique. This combines the adhesive characteristics of glass-ionomer cements with the better durability of composites.

The sandwich technique has a number of attractions, but it should be undertaken as a planned procedure rather than as a method to improve the appearance of an unsatisfactory GIC restoration. The principal reason for this is that most restorative-grade GICs are radiolucent; if these are cut back and a radiopaque composite placed over the top then the radiographic appearance is indistinguishable from recurrent decay beneath a restoration. This unfortunate coincidence could result in an otherwise perfectly satisfactory restoration being replaced. The purpose designed GIC base materials are radiopaque, alleviating this problem. Conversely these lining materials are not designed to survive exposed in the oral environment so should not be brought to the surface of the tooth even at a dentin interface.

ART

ART (the atraumatic restorative technique) (fig. 26) is a method of caries management developed primarily for use in the Third World where skilled dental manpower and facilities are limited and the population need is high. The technique uses simple hand instruments (chisels and excavators) to break through the enamel and remove as much caries as possible. The cavity is isolated using cotton rolls. When excavation of caries is complete (or as complete as can be achieved) the residual cavity is restored using a modified GIC. These GICs are reinforced to give increased strength under functional loads and are radiopaque. Their aesthetic properties are poorer with the materials being optically opaque.

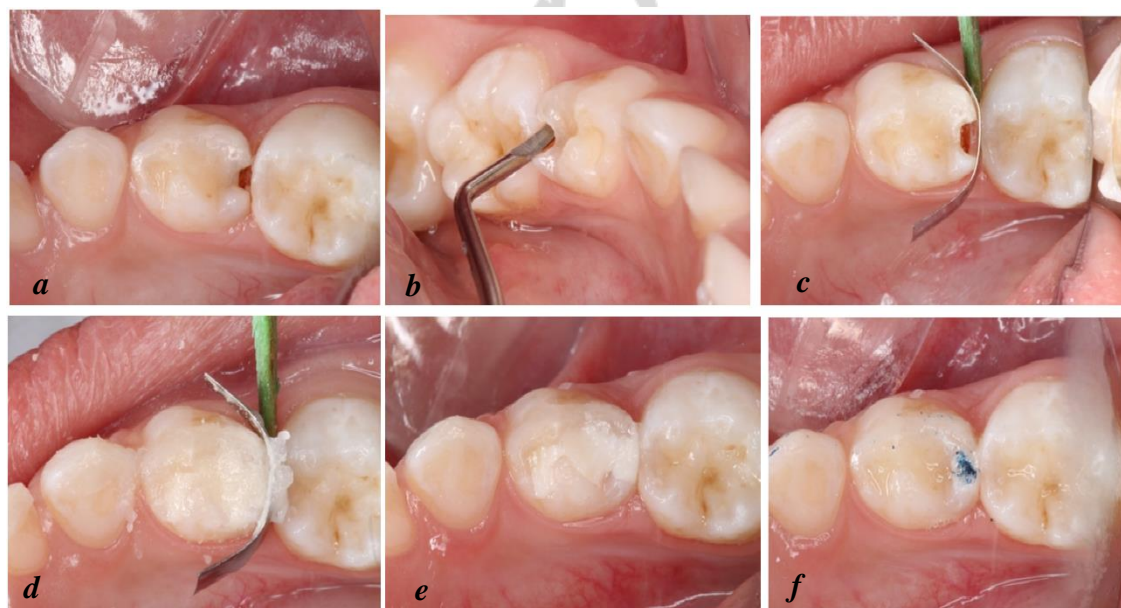


Fig. 26. Step-by-step of an occlusoproximal restoration based on atraumatic restorative treatment, using partial caries removal and high-viscous glass ionomer cement (GIC): a — cavity into dentin; b — accessing the cavity using a manual instrument; c — preparing for restoration — to restore the contact point and avoid marginal excess; d — after inserting the GIC and using finger pressure over the material; e — final restoration; f — checking the occlusal contacts. (by Dr. Isabel Olegario)

SILVER CERMETS

By its nature, glass is extremely brittle, and tends to fracture relatively easily compared to metals. The idea is that the incorporation of silver in the glass will increase the toughness of the resultant material by acting as a stress absorber and will improve wear characteristics. This has been attributed both to the increase in toughness of the material and to the very low coefficient of friction of the surface, with the silver imparting a polished metallic finish. In terms of the other properties of the material, such as compressive strength, flexural strength and solubility, the silver cermets seem no better than the glass-ionomer cements.

Naturally the silver cermets have the ability to bond to enamel and dentin to the same degree as the glass-ionomer cements. As with the glass-ionomer cements, it is recommended that a surface conditioner such as polyacrylic acid is applied to the dentin before placing the cement.

Composition and Presentation

The silver cements are available either as a powder liquid composition, presented in two separate bottles which have to be mixed by hand, or are dispensed in a preproportioned capsule which has to be placed in a high speed amalgamator. In some formulations, the powder is presented as a simple mixture of glass and silver, whereas in others the silver is incorporated in the glass powder.

The latter is produced from a mixture of glass and silver of equal volumes (17.5/ 2.5 wt 0/0). The particle size of the silver is approximately 3–4 μm . The mixture is formed into pellets and then sintered at 800 °C until the glass and the silver fuse together and form an intimate mixture. The sintered solid substance is then ground to produce the right particle size for mixing and manipulation. The particles are rounded by the grinding process, which aids mixing with the polyacid. Thus, each particle consists of a mixture of glass and silver particles tightly bonded to each other by the sintering process. In addition, approximately 5 % TiO_2 is added to improve the aesthetics by acting as a whitening agent. The liquid consists of an aqueous solution of a copolymer of acrylic and/or maleic acid (37 %) and tartaric acid (9 %).

The wear resistance of the silver cermets is adequate for small Class I cavities, but anything bigger should be treated with caution. Unpublished information would suggest that the cermets do not stand up to the wear in large multiple surface restorations. Thus, its use is very much limited to the treatment of the early carious lesion. Because of the large amount of silver in the powder particles, the final restoration is sufficiently radiopaque to allow ready detection of recurrent caries.

As with the glass-ionomer cements, the release of fluoride also occurs with the cermets, which should provide protection to the enamel adjacent to the restoration. However, there is evidence to suggest that the fluoride release from silver cermets is not as high as that for glass-ionomer cements and that these materials do not provide the same degree of protection from caries as do the glass-ionomer

cements. The silver cermets have not lived up to expectation, especially as an occlusal restorative in the deciduous dentition. Their performance has been such that their continued use is highly questionable, especially in the light of the continuing improvements made with the conventional glass-ionomer cements and the introduction of the resin-modified glass-ionomer cements.

RESIN MODIFIED GLASS-IONOMER CEMENTS

Certain resin modified cements were developed in the early 1990s to improve functionality and to address inferior mechanical properties (i. e., bending and tensile strength and fracture roughness) of glass-ionomer cements (fig. 27). As explained above, in the original form, when the powder (i. e., sodium-calcium-alumino-fluoro-silicate glass) and liquid (i. e., polyacrylic acid and tartaric acid) are mixed together, a three-phase acid-base reaction occurs, involving calcium and aluminium ions leaching as the acid attacks the glass powder particles, hydrogel formation as the polyacrylic acid molecules crosslink, and polyalkenoate salt gelation as the polyalkenoate salt captures unreacted glass (SCENIHR, 2008).



Fig. 27. A resin modified glass-ionomer used for luting and lining purposes. The material consists of a powder and liquid which are mixed together on the pad shown. Setting takes place by a combination of both an acid-base reaction and chemically activated polymerisation

However, in the resin modified cements, water-soluble resin monomers (e. g., 2-hydroxyethylmethacrylate or HEMA, which is capable of free radical polymerization) are added into the aqueous solution of polyacrylic acid to improve functionality with respect to higher strength and water resistance. Thus, resin-modified glass-ionomer cement is a material that undergoes both the polymerization reaction and acid-base reaction. In the settling reaction, when the powder and liquid are mixed, the H^+ ion in the liquid attacks the glass surface. The metal ion released from the glass particles reacts with polyacrylic acid while HEMA cures concurrently and the surface layer of the glass particle forms a silica gel layer (Davidson and Mjör, 1999).

One of the main disadvantages of traditional glass-ionomer cement is that when it comes into contact with water during the early stage of settling, the settling reaction is inhibited, damaging the surface of the cement. Water sensitivity could be prevented or reduced by incorporating photopolymerization, which promotes faster setting, which is also an advantage for colour stability. That is why the polymerization of HEMA is aided by an oxidation-reduction or a photopolymerizing catalyst or initiator so that light-curing in addition to chemical curing can occur. The setting of resin-modified glass ionomer cement is identical to the polymerization of composite resin (Davidson and Mjör, 1999).

The ionic reactivity of a resin-modified glass-ionomer to the tooth (an indicator of adhesion of cement to tooth structure) surface is presumed to be lower than that of a conventional glass-ionomer cement. However, this can be significantly increased by treating the tooth surface with an acid conditioner (e. g., aqueous solution of citric acid-ferric chloride or polyacrylic acid-aluminum chloride). This treatment increases bond strength of resin-modified glass-ionomer cement due to improvement in tensile strength of the material (Davidson and Mjör, 1999).

There are several types of resin-modified glass-ionomer cements utilized for different clinical applications. Some of these include:

- *Restorative materials:* As noted above, one of the main disadvantages of conventional glass-ionomer cement as a direct restorative material is the need to avoid polishing immediately after placement in order to prevent deterioration of the material's physical properties caused by water sensitivity during the initial stage of the setting process. The incorporation of monomers and photo polymerization resulted in improvements in four major areas: decreased water sensitivity; improved mechanical properties; manipulability; and translucency.

- *Base and liner:* This was the first clinical application of resin-modified glass-ionomer cement. The base and liner applications are often followed by restorative and temporary filling procedures, including prior to placement of a composite resin restoration.

- *Fissure protection:* Although both conventional and resin-modified glass-ionomer cement is used for this purpose, the merits of conventional cement as protection material were not accepted in some countries due to their retention rate not being as high as that of a resin sealant and the requirement of moisture prevention in the early stages of setting.

- *Luting:* The bond strength of conventional glass-ionomer cement for luting is not as high as that of resin cement due to frequent failures related to cohesive fractures occurring within the cement. There are many resin-modified types of cement that contain a monomer component in the liquid to strengthen the matrix of cured material. Additionally, a major feature of all types of resin-modified glass-ionomer cements is the early development of mechanical strength contributing to the reliability of the resin-modified cement clinically.

- *Orthodontic cementing material:* Significant improvements made in adhesion of resin-modified glass-ionomer cement allowed its use as cementing material in orthodontic applications (Davidson and Mjör, 1999).

Resin-modified glass-ionomers are supplied as powder-liquid or encapsulated forms and are used for restorations in low-stress bearing areas and are recommended for patients with high risk of caries. These restorations are more aesthetically appealing than glass-ionomers because of the resin content. Resin-modified glass-ionomers release more fluoride than compomers and composites, but release less fluoride than conventional glass-ionomers. They have good aesthetic qualities, medium wear resistance, and medium-to-high fluoride recharge ability when exposed to fluoride treatments or fluoride dentrifices (Powers and Wataha, 2008).

Most resin-modified glass-ionomers contain activators which enable polymerization to occur both in the presence or absence of the activating radiation. Where the chemically activated polymerization plays an important part, the presence of three setting mechanisms may be claimed by the manufacturer:

1. Acid-base setting.
2. Light-activated polymerization.
3. Chemically-activated polymerization.

The latter is sometimes described as a *dark cure*, but in essence it is similar to the chemically activated setting achieved with conventional two-component composites. In one product, mixing releases a previously microencapsulated per-sulphate/ascorbic acid redox catalyst system which activates polymerization in the absence of light.

The glass components of both modified composites and resin-modified glass-ionomers have been modified in most materials in order to incorporate a heavy metal (e.g. strontium) which imparts radiopacity.

Some examples of resin-modified glass-ionomer cements:

1. FUJI-IHC Improved (GC UK Ltd, Newport Gagnell, UK).
2. VITREMER (3M Dental, Loughborough, UK).
3. PHOTAC-FIL QUICK (ESPE UK Ltd. Knutsford, UK).
4. RESTORE-PF VIC (First Scientific Ltd, Abertillery, UK).

COMPOMERS

They were introduced in 1995 and combine some of the benefits of both resin composites and conventional glass-ionomer cements. In search of a new restoration material, an acid monomer was polymerized in the presence of fluoroaluminosilicate glass. This resulted in the development of a new compound that releases fluoride slowly in the oral environment (fig. 28). A compomer is a single-paste formulation in compules and syringes consisting of fillers and a matrix, similar to a composite resin. The filler usually contains fluoro-alumino-silicate glass powder and releases fluoride into the environment by a mechanism similar to that of conventional glass-ionomers and resin-modified glass-ionomers.



Fig. 28. An illustration of an acid modified composite material, often referred to as compomers, supplied in single dose syringes called compules. The material can be injected from the compule directly into the cavity using the device shown in the picture. Setting of the material is then activated by light

Metal fluoride is also included in some materials for the same purpose. The glass powder contains strontium or some other metal to make the material radio-paque. A compomer undergoes an acid-base reaction between the acidic monomer (e. g., polymerizable dimethacrylate resins such as urethane dimethacrylate and TCB, which is a reaction product of butane tetracarboxylic acid and hydroxyethylmethacrylate) and ion-leachable basic glass filler in the presence of water from the saliva. The polymerization reaction of the monomer components, initiated by photo polymerization, forms the basis of the setting reaction of the compomer. The acidic monomer is polymerized with other monomer components of the matrix to the acidic polymer, or the polymer with acidic group in the initial setting. During the setting reaction, HEMA is released while fluoride release occurs after setting. Because there is lower amount of glass-ionomer present in compomers, the amount of fluoride released and its duration are lower than those of glass- and hybrid-ionomers. The acid- base reaction is inhibited until the material hardens and absorbs water. The compomers do not contain water and do not self-adhere or bond to hard dental tissue or tooth structure. They require a bonding agent to bond to tooth structure because of their resin content. These characteristics distinguish compomers from resin modified glass-ionomer. The compomer is often deemed as a resin composite with fluoride releasing potential (SCENIHR, 2008; Davidson and Mör, 1999; Powers and Wataha, 2008).

Because compomers do not bind to enamel and dentin directly, a specific priming and bonding system was developed. This system includes the use of a tooth conditioner (34 % phosphoric acid) and a light curing adhesive consisting of di- and trimethacrylate resins, functionalized amorphous silicon dioxide, dipentaerythritol penta acrylate monophosphate, photoinitiators, stabilizers, cetylamine hydrofluoride and acetone (SCENIHR, 2008).

The primary clinical application for compomers is restorative filling because they are not adhesive and require a separate bonding agent. However, they have better mechanical properties and manipulability than glass-ionomer filling materials and their flowability in the cavity is better than that of resin composite.

However, the necessity for a bonding agent prior to filling is a disadvantage and mechanical properties of compomers are inferior to those of resin composites. The compomers are classified as an intermediate material between the glass-ionomer for filling and the resin composite (Davidson and Mjör, 1999), and are recommended for Class I and II restorations in adults in low-stress bearing areas and for patients with medium caries risk.

GIOMERS

They have been recently introduced and feature the hybridization of glass-ionomer and composite resins (fig. 29). They contain an adhesive promoting monomer and a bonding polymer catalyst, which allow bonding to hard tooth tissues.



Fig. 29. An illustration of a giomer material supplied as a light activated paste in a syringe. This material contains filler particles consisting of a pre-reacted glass ionomer blended into a paste with resin polymerization

These products are similar to the acid-modified composites except that the acid-base reaction is completed before blending the filler with resin. The aluminosilicate glass is reacted with polyacid in order to form a pre-reacted glass-polyalkenoate complex. Two distinct products are produced. The first, known as surface reaction type, involves breakdown of only the surface layers of the glass particles. The second, known as full reaction type, involves almost complete breakdown of the original glass particles. Following this initial reaction, the product is ground and blended with a dimethacrylate resin to form a composite structure. A notable feature of the full reaction type materials is the fact that some hydroxyethylmethacrylate is required in order to enable mixing of the hydrophobic resin with the fully reacted glass. The principle of the formulation and manufacturing process is that fluoride is released from the glass particles during the acid-base reaction and when the glass-polyalkenoate complex is blended with resin the fluoride becomes available for release. In the surface reaction products only the surfaces of the glass particles are consumed and for these products the mechanical reinforcing effect of the filler particles is given priority over fluoride release. For the

full reaction products fluoride release is prioritized at the expense of mechanical properties.

Both the full reaction and surface reaction type products are provided to the dentist as single paste materials which set through light-activated free radical addition polymerization of methacrylate groups in the usual way.

The modified composite materials and giomers may have an ability to be recharged with fluoride in a similar manner to that described for conventional glass-ionomers. This may be another example of the potentially «smart» behaviour of materials with some glass-ionomer structure (fig. 30).

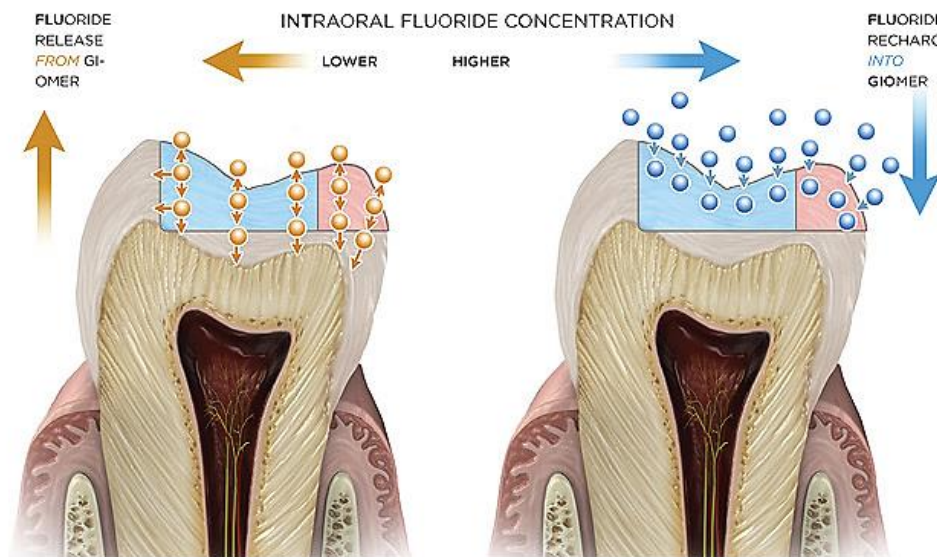


Fig. 30. Fluoride release and recharge reactions with giomers

The effectiveness of fluoride release as a form of prevention or protection is a matter of some debate. After the first few days of initial 'fluoride burst' which is seen for conventional glass-ionomers and some resin-modified materials, the rate of release becomes very low and it is debatable whether this long-term release can be beneficial. However, a sustained long-term release promoted by a continual release, recharge and re-release may well provide the positive therapeutic effect which dentists require. Hence, it is likely that the long-term pattern of recharging and re-release is much more important than the high initial release. On the other hand there is some evidence that the materials which have the greatest initial fluoride release also have the greatest ability to be recharged.

Fluoride release of materials changes in response to changes in pH. Lower pH generates greater levels of fluoride release and this may be another example of «smart» behaviour since the benefit of fluoride is particularly required in regions subjected to plaque acids. However, the mechanism of fluoride release at low pH is likely to involve some dissolution of the material and so the increased fluoride release may be at the expense of material durability and longevity.

Summary of the nature of the available materials are presented in Table 2.

Summary of the nature of available materials

| Material | Number of components | Require mixing | Active ingredients |
|-------------------------------|----------------------|------------------------------|--|
| Modified composites | 1 or 2 | 2 components – yes | Fluoroalumino silicate glass |
| | | 1 component – no (compomers) | Methacrylate resin* (acid modified) Activators/initiators/stabilizers |
| Resin-modified glass ionomers | 2 or 3 | Yes | Fluoroalumino silicate glass |
| | | | Methacrylate polyacid |
| | | | Hydroxyethylmethacrylate (HEMA) |
| | | | Water Activators/initiators/stabilizers |
| Giomer | 1 | No (single paste) | Aluminosilicate glass pre-reacted with poly acid |
| | | | Dimethacrylate resin matrix |

* Acid — modified products referred to as *acid-modified composites*.

Clinical Handling Notes. The handling characteristics and clinical techniques used for these materials are different to those for the conventional GICs, not least because they become hard, as a consequence of the visible light-activated reaction, well before the acid–base reaction is complete.

Matrix techniques are similar to those used for composites with transparent cellulose acetate or polyester strips on proximal surfaces. Again, cervical cavities pose a problem because of the need for transparent matrix to permit light activation. One possibility is to use a small piece of kitchen film (*cling film*) as a physical separator that will allow contouring using hand instruments prior to light activation or to use a celluloid matrix special in form (fig. 31).



Fig. 31. Isolation of the operative field in class V restoration with celluloid matrix special in form

These materials are not as susceptible to desiccation as the chemically setting types and consequently surface finishing can be undertaken immediately after placement.

CAVITY VARNISHES

A cavity varnish is used to provide a barrier against the passage of irritants from cements or other restorative materials and to reduce the penetration of oral fluids at the restoration-tooth interface into the underlying dentin. Varnishes help reduce postoperative sensitivity when applied to dentinal surfaces under newly placed restorations. Cavity varnishes are rapidly being replaced by bonding agents.

Composition

A cavity varnish is a solution of one or more resins from natural gums, synthetic resins, or rosin. Copal and nitrated cellulose are typical examples of a natural gum and synthetic resin, respectively. The solvents that may be used to dissolve these materials are chloroform, alcohol, acetone, benzene, toluene, ethyl acetate, and amylacetate. Medicinal agents such as chlorobutanol, thymol, and eugenol also have been added. The volatile solvents evaporate quickly when the varnish is applied to the prepared tooth surface, thus leaving a thin resin film. The addition of fluoride to cavity varnish has not been established as effective.

Manipulation

Varnish solutions are usually applied by means of a small cotton pledget at the end of a wire or root canal reamer. Apply thin layers of the varnish with a partially saturated pledget. Use a gentle stream of air for drying, but take care to avoid forming ridges. Add a new layer only to a previously dried one. Two thin layers have been found more protective than one heavy layer. To prevent contamination of the cavity varnish, use a new cotton pledget for each application. Tightly cap varnish solutions immediately after use to minimize loss of solvent. Most varnishes are supplied with a separate bottle of pure solvent. This solvent may be used to keep the varnish from becoming too thick. Replace the loss from evaporation by adding solvent to keep the bottle at least half full by diluting the contents with the solvent. Eventually the solvent will be exhausted and a new supply should be purchased. The solvent is also useful for removing varnish from external tooth surfaces.

Properties

Cavity varnishes reduce but do not prevent the passage of constituents of the phosphoric acid cements into underlying dentin. Variations in results and the mere reduction rather than the prevention of the passage of acid appear to be a result of pinpoint holes in the varnish film formed during volatilization of the organic solvent. Greater continuity of the dried varnish film is possible by the use of successive layers of thin varnish; this technique is more effective than using just one layer of thicker varnish.

Thin films of resinous cavity varnishes significantly reduce leakage around the margins and walls of metallic restorations. Although the effect of the cavity varnishes is not completely known, it can be hypothesized that this reduction of fluid penetration around cavity margins would minimize postoperative sensitivity. These varnishes are applied to prepared cavity walls, including the margins. The integrity of the resin film is destroyed when composite restorative materials are placed in contact with them. The monomer contained in these resin materials dissolves the film. Varnishes neither possess mechanical strength nor provide thermal insulation because of inadequate film thickness. Values of film thickness have been measured at between 1 and 40 μm for different commercial varnishes. Con-

tact angles of varnishes on dentin range from 53 to 106 degrees. Improved integrity of a varnish film might be achieved by improvement in the spreading of the varnish on the tooth surface.

Applications

Cavity varnishes are indicated for use

(1) on dentinal surfaces to minimize the penetration of acid from zinc phosphate cements, and

(2) on enamel and dentinal walls to reduce the penetration of oral fluids around metallic restorations.

Cavity varnishes appear also to retard the penetration of discoloured corrosion products from dental amalgam into dentin. Varnishes are not used under composite restorations, because bonding agents effectively seal the dentin tubules. A cavity varnish is applied to the dentinal walls of those tubules in direct contact with the pulp when a base of zinc phosphate cement is used. When therapeutic action is expected from a low-strength base or liner or when the cement base material itself is bland in its action on the pulp, a cavity varnish is not used on the underlying dentin. The varnish may be applied over the cement base in these situations.

CAVITY LINERS

A cavity liner is used like a cavity varnish to provide a barrier against the passage of irritants from cements or other restorative materials and to reduce the sensitivity of freshly cut dentin. Unlike a varnish, a liner may provide some therapeutic benefits to the tooth. Liners, however, do not set as the calcium hydroxide pulp-capping agents do.



Fig. 32. A calcium hydroxide cement.

The material is provided as two pastes. Approximately equal amounts of each paste are dispensed onto the mixing pad and mixed with a spatula. One of the active ingredients is a salicylate compound which has a very distinctive 'medicated' odour

Composition. Cavity liners are suspensions of calcium hydroxide in an organic liquid such as methyl ethyl ketone or ethyl alcohol or in an aqueous solution of methyl cellulose (fig. 32). The methyl cellulose functions as a thickening agent.

Liners also may contain acrylic polymer beads or barium sulfate. Fluoride compounds such as calcium monofluorophosphate have been added to some liners. On evaporation of the volatile solvent, the liner forms a thin film on the prepared tooth surface.

Manipulation. Cavity liners are fluid in consistency and are easily flowed or painted over dentinal surfaces. The solvents evaporate to leave a thin film residue that protects the underlying pulp. Certain products are claimed to have better integrity and pulpal protection when used with composite restorative materials.

Calcium hydroxide bases are supplied as two-paste systems. Equal lengths of the different-coloured pastes are dispensed on a paper pad and then mixed to a uniform colour. Calcium hydroxide preparations, similar to those used for cavity lining and pulp capping but containing retarders, are now available as root-canal sealing pastes. The retarders are required to extend the working time of the materials whilst they are being manipulated in the warm, humid environment of the root canal.

Properties. Like varnishes, cavity liners neither possess mechanical strength nor provide any significant thermal insulation. The calcium hydroxide liners are soluble and should not be applied at the margins of restorations. Fluoride compounds have been added to some cavity liners to reduce the possibility of secondary caries around permanent restorations or to reduce sensitivity. Effectiveness of fluoride for either purpose would depend on its availability to enamel and dentin through its solubility. Although in vitro studies with one material have shown reduced solubility of tooth tissue, clinical studies have not yet demonstrated its efficacy. However, such an investigation has shown absence of bacteria at the resin composite-tooth tissue interface when a cavity liner containing calcium monofluorophosphate is used.

Calcium hydroxide cements are used for lining deep cavities or for direct pulp capping. The antibacterial action of calcium hydroxide makes these cements useful in indirect pulp-capping procedures involving carious dentin. One more advantage of calcium hydroxide products over some of the alternative pastes is that they have effective antibacterial properties without being irritant to apical tissues.

The high solubility and low strength of calcium hydroxide cements render them unsuitable for luting purposes.

Composition and Chemistry of Setting. Some calcium hydroxide preparations consist simply of a suspension of calcium hydroxide in water. This is applied to the base of the cavity and dries out to give a layer of calcium hydroxide. A solution of methyl cellulose in water or of a synthetic polymer in a volatile organic solvent can be used instead of water. These additives produce a more cohesive cement but the compressive strength remains very low at about 8 MPa.

The set materials have a relatively high solubility in aqueous media. Calcium hydroxide is readily leached out, generating an alkaline environment in the area surrounding the cement. This is thought to be responsible for the proven antibacterial properties of these materials. This characteristic is utilized in very deep

carious lesions, sometimes involving exposure of the pulp, or occasionally in cases of traumatic exposure of the pulp during cavity preparation. The calcium hydroxide cement is used as a pulp capping agent in such situations. It is sufficiently biocompatible to be placed adjacent to the pulp and capable of destroying any remaining bacteria. The material is also able to initiate calcification and formation of a secondary dentin layer at the base of the cavity. This calcification process is a product of irritation of the pulp tissues by the cement, possibly mediated by the activation of TGF β , a cellular growth factor.

Calcium from the cement does not become bound into the mineralized tissues of the calcific barrier/secondary dentin. In pulp capping procedures the calcium hydroxide material is generally overlaid with a strong cement base material such as glass-ionomer cement before completing the restoration of the tooth.

Most calcium hydroxide products in current use are supplied in the form of two components, normally pastes, which are set after having been mixed to form a more substantial cavity lining.

The mixed materials have very low viscosity and setting can be relatively slow for some products. Moisture has a dramatic effect on the rate of setting however, and the materials set within a few seconds of being placed in the cavity, even when the cavity has been «dried». Setting of the light-activated materials is more under the control of the operator and residual moisture in the cavity does not have the same influence on setting time. An exposure to activating light for only a few seconds is required to activate polymerization of the thin layer of cement. One characteristic of these cements which has been largely ignored is the relatively high temperature rise produced on setting. This results from the heating effect of the light source and the exothermic setting reaction.

The resin-based calcium hydroxide materials are far less soluble than the conventional products. This is advantageous providing that the rate of calcium hydroxide release remains great enough to maintain the antibacterial and dentin regeneration properties of the material. One problem with resin-based materials is that unreacted methacrylate groups can become attached to a freshly placed composite resin restoration. The composite shrinks during its setting reaction and this can pull the calcium hydroxide material away from the tooth, leaving a void.

The need for a lining material beneath a composite is controversial. As stated previously, some authorities would suggest that with modern dentin adhesives there is no need for a lining as the cavity margins are sealed by the adhesive, making microleakage unlikely. Obviously any lining that is placed will act as a barrier between the bonding agent and the dentin, reducing the potential area available for bonding. Indeed, it has been suggested that even exposed pulps can simply be etched and then coated with a resin adhesive to give a primary seal.

BIODENTIN

Biodentin is a bioactive dentin substitute from the “Active Biosilicate Technology” (fig. 33).

Composition. Powder of tricalcium silicate. Aqueous solution of calcium chloride, and fillers.

Properties. The mechanical properties of Biodentin are similar to the properties of natural dentin. Biodentin can replace dentin in the crown of the tooth and root without the prior treatments of mineral tissues.



Fig. 33 Biodentin™ material

The Biodentin tricalcium silicate synthesized at the plant Septodont, mainly consists of ultrapure minerals that do not contain monomers. High biocompatibility of Biodentin reduces the risk of reaction of the pulp and tissues. Thanks to its mechanical and physical properties, Biodentin can be applied directly to the tooth surface without prior processing.

Biodentin creates optimal conditions for the preservation of pulp vitality, thanks to solid cohesiveness of dentin. This lack of contraction helps prevent micrococci, to provide long-term coverage of the surface and to avoid secondary destruction. Biodentin guarantees the absence of postoperative sensitivity and increases longevity of restorations in vital teeth.

Biodentin is a bioactive material that stimulates the remineralization of dentin. Biodentin stimulates pulp cells and allows to provide optimal protection due to the formation of reparative dentin and dentin bridges. The pH of Biodentin is basic (pH 12) when mixing, which reduces the risk of caries spread in the deep cavities because it prevents the growth of bacteria. Biodentin creates necessary conditions for the pulp healing.

Indications. *In a crown:*

1. Permanent restoration of dentin under the composite fillings, or inlay/onlay
2. Temporary restoration of tooth at the level of enamel and dentinal border
3. Restoration of deep or/and larger defects of a crown caries
4. Restoration in treatment of cervical lesions or root carious destructions
5. Pulp capping
6. Pulpotomy

In a root:

1. Elimination of roots perforations
2. Elimination of perforations in furcation area
3. Elimination of perforations in case of internal resorption
4. Elimination of external resorption
5. Apexification
6. Closing of the root apex after its resection (retrograde sealing) (fig. 34)

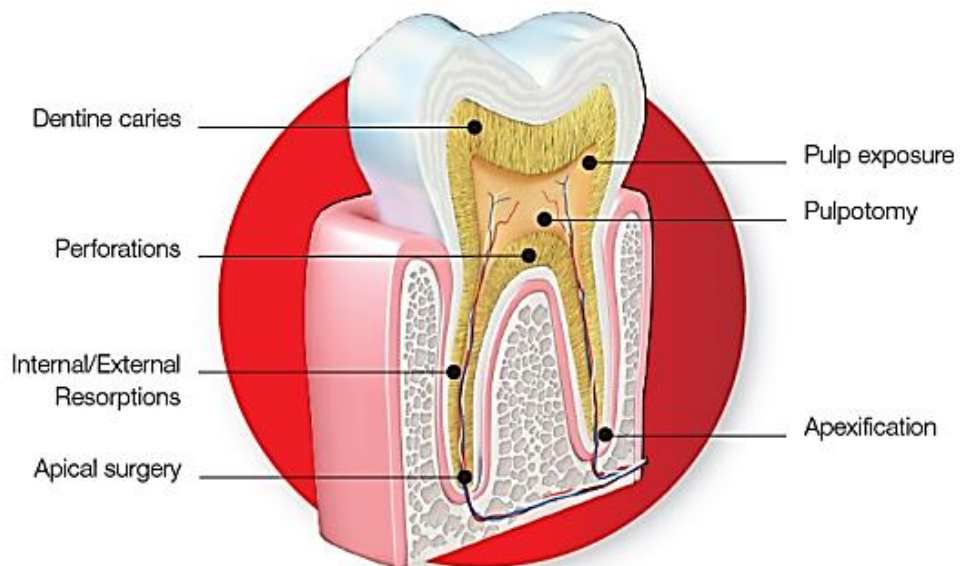


Fig. 34. Indications for using Biodentin™

Restrictions in use:

1. Restoration of teeth under high pressure with a big missing part of the tooth
2. Aesthetic restoration of frontal teeth
3. Caries management in case of irreversible pulpitis
4. Any signs of the tooth periapical pathology

MTA cement (ProROOT MTA, Trioxident) (fig. 35) is the endodontic cement consisting of several mineral oxides. It consists of thin hydrophylic particles. When mixing with water (fig. 34), MTA cement originally forms gel which then hardens. It is especially shown in cases of lateral perforation of teeth roots or at perforations in the field of bifurcation, internal resorption, reverse sealing of the root canal, a sheeting of the tooth pulp and on pulpotomy in teeth with incomplete formation of roots (fig. 35).

MTA cement has a series of advantages in comparison with amalgam and Zinc oxide eugenol cements, such as.

Magnificent marginal closing; it prevents bacteria and tissue liquids from getting into the root canal. Biological isolation of the root canal and perforations in the area of the root bifurcation by inducing the formation of periradicular cement. MTA promotes creation of dentin bridges to cover the open pulp of the tooth.

Unlike other cements which demand absolutely dry surface MTA cement can be used when it is impossible to achieve absolutely dry surgery field (reverse sealing of the canal) without loss of its properties.



Fig. 35. Pro Root MTA material

Indications and ways of use are similar (fig. 36, 37).

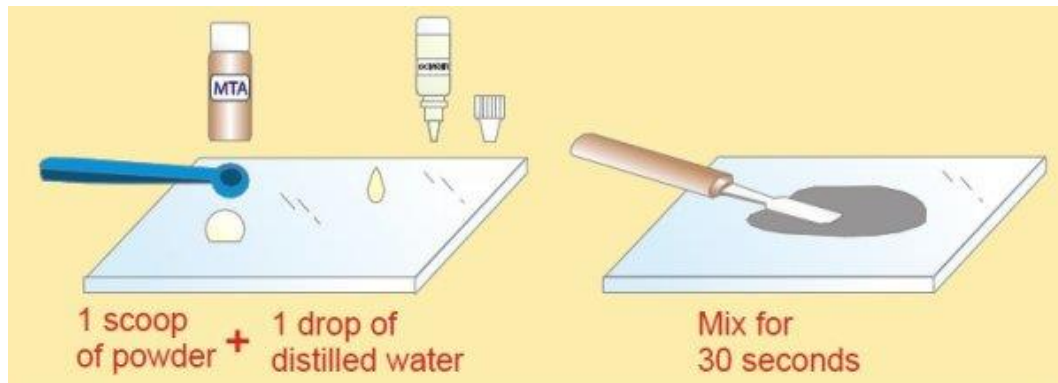


Fig. 36. MTA material mixing

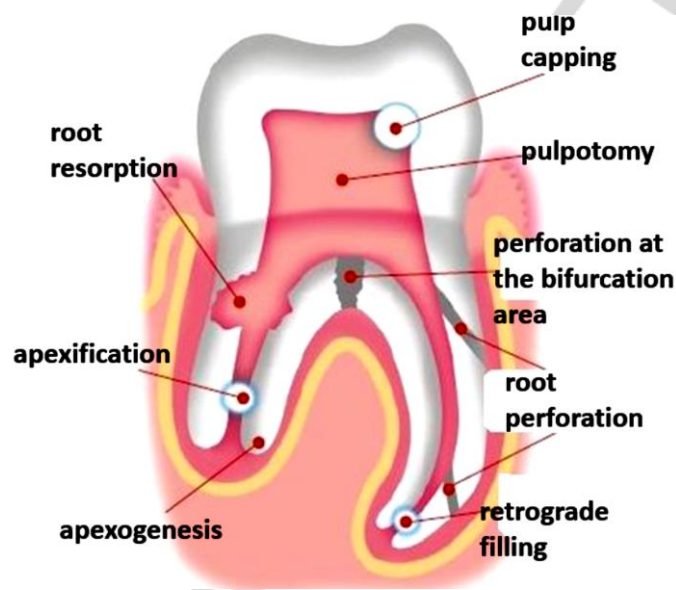


Fig. 37. Indications for using MTA material

SUMMARY

Glass-ionomer cements have had a major impact on restorative dentistry. A wide variety of formulations, designed for a broad range of applications, are now available. The new resin-modified glass-ionomer cements have produced materials with superior properties. However, these improvements are as yet insufficient for them to compete with the resin composites in such high stress bearing situations as incisal tip restorations and posterior occlusal restorations in the permanent dentition. Glass-ionomer cements have improved immensely compared with the original ASPA cements. They have shown themselves to be efficacious dental restorative materials and are still evolving dental materials, as shown by the recent introduction of condensable glass-ionomer cements and resin-modified glass-ionomer cements, which suggests that more improvements can be expected.

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