Glass-ionomer cements in restorative dentistry

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Abstract
This article reviews the current status and future prospects for glass-ionomer materials. These materials are of two chemical types: the older, self-hardening cements, which set by an acid-base neutralization reaction to give relatively brittle materials; and the newer, resin-modified cements, which set partly by polymerization and partly by neutralization. Compared with the self-hardening cements, the latter materials have improved esthetics, improved resistance to moisture, and greater toughness. Both types of glass-ionomer cement bond well to enamel and dentin and release a clinically useful amount of fluoride. They have been used in a variety of applications: as liners or bases, for luting of stainless steel crowns, for Class V restorations in permanent teeth, and for Class II and Class III restorations in primary teeth. The resin-modified glass-ionomers are particularly promising for these latter uses, although it is too early to be sure whether their long-term durability is sufficient. Self-hardening glass-ionomer materials are likely to retain specific niches of clinical application, including in their metal-reinforced and cermet-containing forms. (Quintessence Int 1997;28:705-714.)

Clinical relevance
This review of the glass-ionomer genre updates the dentist about glass-ionomer and polyacid-modified resin materials, describes their chemistry and potential, and advises the clinician about methods and rationale for their use in restorative and prosthetic dentistry.

Introduction
In recent years, there has been considerable confusion about what type of material should be called a glass-ionomer cement. Strictly, the term should be applied only to a material that involves a significant acid-base reaction as part of its setting reaction, where the acid is a water-soluble polymer and the base is a special glass. Other materials, for example those that some manufacturers have marketed as “light-cured glass-ionomers,” are essentially resin composites, although they do contain the fluoroaluminosilicate glass of a conventional glass-ionomer material. However, these materials lack the characteristic good adhesion of glass-ionomer cements, tend to release little fluoride, and undergo polymerization contraction on setting.

A further source of confusion has been the development of materials that set by polymerization but are based on resins modified to include acid functional groups on them and also contain basic glasses. These materials, such as Dyract (Dentsply), Compoglass (Ivoclar), and Hytac (ESPE), show interesting properties, and are promising as restoratives, but are certainly not glass-ionomer materials. The term comporter has been applied to them by the manufacturers, but this
term has already been incorrectly applied by clinicians to glass-ionomer-resin hybrid materials that set substantially by an acid-base reaction. The term polyacid-modified resin composite has been recommended for these materials, although the word compomer is a useful everyday name. Those glass-ionomer materials that are modified by the inclusion of resin, generally to make them partly photocurable, are recommended to be called resin-modified glass-ionomer materials, the term used here.

Self-hardening glass-ionomer materials

Glass-ionomer materials in their original, self-hardening form, became available in the last quarter of the 20th century. They belong to the class of material known as acid-base cements, and their setting involves neutralization of acid groups on a water-soluble polymer with a powdered, solid base. The base is a special calcium aluminosilicate glass that also contains fluoride, an important feature, because it causes the cement to release clinically useful amounts of this ion and thereby to prevent the development of secondary caries around restorations. The glasses act as bases in the sense that they are proton-acceptors, even though they are not soluble in water.

As the cements set, water becomes incorporated into the material, and there is no phase separation. In fact, water has been identified as having a number of roles: (1) it is the solvent for the setting reaction, because, without it, the polymeric acid would be unable to exhibit its full properties as an acid, (2) it is one of the reaction products, (3) it acts as both coordinating species to the metal ions released from the glass and as hydrating species at well-defined sites around the polyanion, and finally (4) it may act as a plasticizer and reduce the rigidity of the bulk polymeric structure.

A number of factors are known to influence the speed of the setting reaction and the final strength of the cement. These include the molar mass of the polyacid concentration of the acid solution, the powder-liquid ratio, and the presence of chelating agents, such as (+) - tartaric acid, which reduces the setting time and increases the compressive strength of the cement once set.

Glass-ionomer cements undergo gradual maturation processes that are poorly understood. For example, in cements prepared from poly(acrylic acid), compressive strength gradually rises over the first 3 months or so of the cement’s life to a maximum value some magnitude greater than the value at 24 hours. The ratio of bound to unbound water increases, this being defined as the ratio of water that may be removed by chemical desiccation (eg, by storage for 24 hours over silica gel at elevated temperature) to water that is retained in the cement during this treatment. Finally, translucency also changes, gradually becoming greater and more like natural tooth material as the cement ages.

The setting reactions in glass-ionomer materials are as follows:

1. Decomposition of the glass under the influence of the aqueous polyacid, leading to the release of Ca2+ and Al3+ ions. The latter are probably released in the form of complex oxyanions containing several aluminum atoms, a structure that reflects the form they have occupied within the glass prior to acid attack.

2. Rapid reaction of the Ca2+ ions with the polyacid chains, followed by slower reaction of Al3+ species gradually released from the anionic complex. This reaction displaces water from some of the hydration sites and leads to some ionic crosslinking of the polyacid chains; both effects lead to insolubilization of the polymer and stiffening of the material.

3. Gradual hydration of the inorganic fragments released in step 1, to yield a matrix of increasing strength, greater resistance to desiccation, and improved translucency.

Improvements in the strength and durability of glass-ionomer cements have been sought by such means as the inclusion of finely divided silver alloy or of a silver-cermet formed from the glass plus silver in a fusion process. Fibers have also been used to reinforce experimental cements.

A disadvantage of glass-ionomers is that they are sensitive to moisture in the early stages following placement. This may result in either the washing out of reacting ions from the immature cement by saliva or, in patients who tend to breathe through the mouth, in desiccation and arrest of the setting reaction. Both effects are undesirable, and, to overcome the problems, dentists are advised to cover freshly placed cement with an impervious layer of varnish, petroleum jelly, or liquid resin bonding agent.

Glass-ionomers are able to form true adhesive bonds to dentin and enamel and for this reason have found a wider range of applications than other dental cements. These uses are considered in more detail later in this article.
Resin-modified glass-ionomer materials

These materials, the majority of which are cured by visible light, are hybrids that involve the incorporation of polymerizable components into an acid-base glass-ionomer cement. They were first described in the late 1980s. The use of visible light to cure these materials, at least as far as the initial development of structure is concerned, limits the depth of individual layers of cement that can be used, because of limitations in the extent to which light can penetrate these materials. Typically, this depth is of the order of 2 to 3 mm, a feature which restricts the use of these materials to certain areas, such as cavity lining or incisal edges.

Resin-modified glass-ionomer materials consist of a complex mixture of components, including poly(acrylic acid) or a graft-copolymer of poly(acrylic) in which a photocurable side chain has been added; photoinitiators, such as hydroxyethyl methacrylate (HEMA); calcium alumino-silicate glass; and water. These materials are produced by mixing glass and polymer powders and activated by the addition of the appropriate amount of water. The setting profile was almost the same as that of anhydrous zinc polycarboxylate. No pulpal sensitivity has ever been reported for this latter material. It thus seems likely that pH is not the cause of the reported sensitivity.

Biologic studies have shown that different glass-ionomers differ in their ability to develop and sustain a marginal seal that excludes bacteria from the region close to the pulp. Original glass-ionomer restorative cements did not receive widespread acceptance by dentists in the early 1980s, particularly in the United States. These materials had low wear resistance, fractured easily, and were of limited clinical applications. Although moderate inflammatory responses in the pulp have been reported in some human studies, the use of certain glass-ionomers is associated with pulpal hypersensitivity. The particular cements that cause this are the so-called anhydrous cements, which are formulated by mixing glass and polymer powders and activated by the addition of the appropriate amount of water. The reason that these cements cause pulpal sensitivity was initially thought to be due to the slow dissolution of the polyacid, which was assumed to maintain the local pH at low levels for longer than in conventionally formulated glass-ionomers. However, a study of pH change in setting cements showed that the anhydrous cements underwent a slightly more rapid neutralization than conventional ones and that their setting profile was almost the same as that of anhydrous zinc polycarboxylate. No pulpal sensitivity has ever been reported for this latter material. It thus seems likely that pH is not the cause of the reported sensitivity.

Biocompatibility

Biocompatibility is defined as the ability of a material to perform with an appropriate host response in a specific application. It is thus distinct from inertness, which would imply no response from the host. Moreover, biocompatibility is not a single phenomenon, but rather is a collection of processes involving different but interdependent mechanisms of interaction between a material and the tissue. It is also specific to a particular application and location in the body.

Glass-ionomer cements are generally biocompatible with oral tissues and, as restorative materials, result in only mild pulpal irritation at a level similar to that produced by zinc polycarboxylate and zinc phosphate cements. This reaction is so mild that glass-ionomers can generally be used as intracoronal restoratives without a lining or a base, although inflammatory responses in the pulp have been reported in some human studies.

The use of certain glass-ionomers extracoronally, however, as luting cements, has been shown to be associated with pulpal hypersensitivity. The particular cements that cause this are the so-called anhydrous cements, which are formulated by mixing glass and polymer powders and activated by the addition of the appropriate amount of water. The reason that these cements cause pulpal sensitivity was initially thought to be due to the slow dissolution of the polyacid, which was assumed to maintain the local pH at low levels for longer than in conventionally formulated glass-ionomers. However, a study of pH change in setting cements showed that the anhydrous cements underwent a slightly more rapid neutralization than conventional ones and that their setting profile was almost the same as that of anhydrous zinc polycarboxylate. No pulpal sensitivity has ever been reported for this latter material. It thus seems likely that pH is not the cause of the reported sensitivity.

Biologic studies have shown that different glass-ionomers differ in their ability to develop and sustain a marginal seal that excludes bacteria from the region close to the pulp. Original glass-ionomer restorative cements did not receive widespread acceptance by dentists in the early and mid 1980s, particularly in the United States. These materials had low wear resistance, fractured easily, and required unusual handling by the dentist to avoid overhydration or desiccation during the extended initial hardening time. Regardless of the benefits of fluoride ion release and uptake by adjacent enamel and dentin, chemical bonding, and favorable thermal expansion/contraction properties, glass-ionomer restorative cements were simply impractical for use other than for short-term restorations or for people with exceptional susceptibility to caries.
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Glass-ionomer luting cements, however, were more successful. They are used for cementing stainless steel crowns for primary teeth, precision cast crowns and fixed prostheses for permanent teeth, space maintainers, and single orthodontic bands. Dentists treating caries-prone patients are particularly pleased with a luting cement that has leachable fluoride ions and associated preventive dentistry implications. Glass-ionomer luting cements of all types have become quite popular, and their use continues to increase.

Introduction of the glass-ionomer-silver-cermet, Ketac-Silver (ESPE), in 1984 gave dentists an attractive alternative to silver amalgam for Class I restoration of primary teeth. Although fracture strengths remained too low for the material to replace cusps or marginal ridges, Ketac-Silver made a large impact on restorative dentistry for children (Fig 1). A surprising development was that Class I silver-cermet restorations, originally placed for “interim” use in permanent teeth, have routinely lasted for 10 years or more (Fig 2). Ketac-Silver has also been used for “tunnel” restorations, other restorations using unconventional preparations conserving of tooth structure, as an endodontic filling material, and to serve as a core buildup material prior to complete-crown preparation.

More recently the profession has seen the development of resin-modified glass-ionomer materials. These combine advantages of glass-ionomer systems and visible light-polymerized resin technology and are a significant development in restorative dentistry. The set cement has the main advantages of conventional glass-ionomers, i.e. fluoride release and adhesion to dentin and enamel, but also improved fracture resistance and better wear characteristics. Introduced originally as liner/base materials (eg, Baseline VLC, Dentsply/Caulk; Vitrebond, 3M Dental), they are now available as restorative cements. Current commercial materials for this latter application include Fuji II LC (GC), Photac-Fil (ESPE), and Vitremer Tri-Cure (3M Dental), all of which have been useful for Class II and Class V restorations in primary (Figs 3a to 3c) and permanent (Figs 4a and 4b) teeth. For Class I restorations of primary molars intended to last more than 3 years, initial clinical observation is that Vitremer Tri-Cure appears to have the best durability. One author (TPC) has now had more than 5 years’ experience using these materials for the repair of primary teeth and confidently states that the resin-modified glass-ionomer cements will become a mainstay restorative material for pediatric dentistry (Fig 5).

Having been found to be satisfactory in the primary dentition, resin-modified glass-ionomers are now being used to restore permanent teeth (Figs 4, 6, and 7). However, brand selection and material handling are important (Fig 8). Vitremer Tri-Cure restorative cement, mixed at high powder-liquid ratio so that all of the powder is wetted during mixing, appears to perform the best on the occlusal surfaces of permanent teeth. This may be the result of the high powder-liquid ratio, or it may be that Vitremer Tri-Cure has better wear resistance, is less soluble, or both. All three brands of resin-modified glass-ionomer material perform well in Class III and Class V restorations, in many cases holding up well for more than 4 years in permanent teeth.

The use of self-hardening resin-modified glass-ionomer luting cements is growing rapidly. These...
Fig 3a  Sixteen-month-old child with severe lingual caries of the maxillary primary incisors.

Fig 3b  Caries debrided with an inverted cone bur, used in a slow-speed handpiece.

Fig 3c  Resin-modified glass-ionomer restorations, 26 months after placement.

Fig 4a  Sensitive decalcification/carious lesion associated with poor oral hygiene during orthodontic therapy.

Fig 4b  Resin-modified glass-ionomer cement restoration, 1 year postoperatively.

Fig 5  Four-year postoperative view of primary second molar (mesio-occlusolingual) restoration; primary first molar (disto-occlusal) restoration. (Vitremer Tri-Cure Restorative Cement).
Fig 6a  Occlusal and occlusolingual carious lesions of the maxillary permanent first molar in a caries-prone child.

Fig 6b  Initial outline form cut with water-cooled high-speed bur, followed by complete debridement of carious substance.

Fig 6c  Vitremer Tri-Cure Restorative Cement mixed with high powder-liquid ratio and syringe injected into the cavity preparation.

Fig 6d  Excess cement purposely left over the cavo-surface margins acts as an adhesive sealant.

Fig 6e  Enamel and cement surfaces, etched, rinsed, dried, and coated with unfilled resin sealant.

Fig 6f  Restoration 17 months after placement.
materials are not light-activated but contain the necessary monomers to undergo polymerization, together with initiators of the same type as used in cold-cure acrylics, e.g., benzoyl peroxide and amine accelerator. The commercial materials of this type are Advance (Dentsply/Caulk), Fuji Plus (GC; originally called Fuji Duet) and Vitremer Luting (3M Dental).53 These cements are easily handled, cause no significant postcementation sensitivity when luted to dentinal surfaces, and have significant fluoride release and high compressive and fracture strengths. A report published in February 1996 confirmed these observations and predicted that the resin-modified glass-ionomer luting cement will soon dominate the market for routine crown and fixed prosthetic cementation.54 In pediatric dentistry, these luting cements are becoming the material of choice for stainless steel crowns (Fig 9), space maintainers (Fig 10), and individual orthodontic bands. Band cementation can also be carried out with light-curable resin-modified glass-ionomer cements where the radiant light is transmitted through the tooth to bring about the polymerization part of the curing process.55

The future

What does the future hold for the clinical use of glass-ionomer systems? Clearly, the new resin-modified materials will have a major role to play. Although it is
too early to be sure of the long-term durability and reliability of these materials, some predictions can be made. If they prove to have adequate wear resistance and fracture strengths so that a Class II restoration in a primary molar can survive for 6 to 8 years, they will replace silver amalgam for the treatment of such teeth. The logic of this becomes even more compelling considering that resin composite can be used in cosmetically prominent teeth and stainless steel crown restorations are available for severely involved primary molars and canine teeth. The history of glass-ionomer-silver-cermet restorations over the past 10 years also lends credence to predictions of an optimistic future for resin-modified glass-ionomer materials, given their better physical properties and handling characteristics.

Resin-modified glass-ionomer luting cements give every indication of becoming the materials of choice for cementation of stainless steel crowns, space maintainers, and individual orthodontic bands. This could also be true for cementation of precision cast crowns and fixed prostheses to prepared permanent teeth. Although more long-term data are needed concerning resin-modified glass-ionomers, they show remarkable promise for materials at such an early stage in their development.

With all this development on the resin-modified glass-ionomers, it might be tempting to conclude that the original self-hardening glass-ionomer cements are obsolete. However, this is far from the case. These materials, too, are undergoing exciting developments of their own. For example, new restorative-grade materials have been launched recently, such as Ketac-Molar (ESPE) and Fuji IX (GC), which set only by a conventional neutralization reaction but have properties that rival or exceed those of the resin-modified systems. Setting is rapid, early moisture sensitivity is considerably reduced, and solubility in oral fluids is very low. These results have been obtained by altering the particle size and particle size distribution of the glass powder, so that setting occurs more rapidly than in the older formulations. These developments seem likely to be of particular importance in Third World countries, where there is an alarming growth in the incidence of dental caries but where, because supplies of electricity are sparse or nonexistent, sophisticated dental facilities, such as power handpieces and dental curing lamps, cannot be relied on.

Another subgroup of the self-hardening systems is that involving the inclusion of silver metal particles (as opposed to silver fused with glass as a cermet), a strategy that gives cements of good properties, i.e. high compressive strength, radiopacity, and excellent clinical wear. Materials of this type currently on the market include Miracle Mix (GC) and Hi-Dense (Shofu).

Also within the dental field, self-hardening glass-ionomers have been used in bone contact applications. In particular, this has involved their use in augmentation of the alveolar ridge in edentulous patients. Such studies have shown that glass-ionomer materials form intimate bioactive bonds with bone cells and become fully integrated into the bone. It is an excellent material for this application and performs better than, for example, hydroxyapatite, which has been used to date for this purpose. Self-hardening glass-ionomers have also been used in maxillofacial and craniofacial reconstruction surgery. The technique involves the fabrication of custom-made preset implants, cured outside the body to develop their full mechanical strength, and then cemented into place with a self-curing glass-ionomer cement. The material has excellent biocompatibility, and early applications of this technique have been encouraging.

Conclusion

Overall, glass-ionomer cements, both self-hardened and resin-modified, are important materials for modern clinical dentistry and will remain so for years to come. The development of resin-modified materials has opened up new dimensions in restorative dentistry, while the development of metal-reinforced and rapid-setting self-hardening cements has enhanced the properties and extended the usefulness of the well-established original materials. Glass-ionomers of all types continue to combine fluoride release, adhesion, good marginal seal, and reasonable esthetics. No material is perfect, but, with the current level of intensive research on glass-ionomers, the deficiencies that exist seem certain to be eliminated, or at least reduced, resulting in an ever-improving range of materials of this type.

References


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