Glass Ionomers in Contemporary Restorative Dentistry — A Clinical Update

Edmond R. Hewlett, DDS, and Graham J. Mount, BDS, DDSc

Abstract

Glass ionomers are applicable to many restorative situations, both as stand-alone restoratives and in conjunction with composite resins. This article reviews the clinically relevant properties of glass ionomers, the differences between them and composite resins, and their clinical applications. An understanding of these concepts is essential for the optimal incorporation of these materials into common restorative procedures.

The glass-ionomer family of restorative materials has evolved during the past 30 years into a diverse group of products that includes direct restoratives, luting agents, liners, and bases, as well as pit and fissure sealants, all available in both the conventional and resin-modified varieties (Table 1). Such a broad array of choices may pose a dilemma to the clinician with respect to selecting and utilizing these materials over their composite resin-based counterparts. Glass ionomers differ from composite resins on several fundamental levels, including composition (water-based vs. resin-based), setting reaction (acid-base reaction vs. resin polymerization), and nature of the tooth/restoration interface (chemical adhesion and ion exchange vs. micromechanical attachment to acid-demineraled enamel and dentin). These and other attributes of glass ionomers render them applicable to many restorative situations, both as stand-alone restoratives and in conjunction with composite resins. This article reviews the clinically relevant properties of glass ionomers, the aforementioned differences between them and composite resins, and their clinical applications. An understanding of these concepts is essential for the optimal incorporation of these materials into common restorative procedures.

Terminology

The use of the term “cement” in reference to glass ionomers can be confusing. “Cement” as it applies to restorative dentistry typically connotes a luting agent, i.e., an intermediary material that serves to bind two objects together. The term has also been used in reference to liners and bases, temporary restoratives, and certain permanent direct restoratives (silicate and glass-ionomer). A general definition explains this multiple usage, describing cement as “any substance which sets to a hard mass on being mixed with water or other medium.” A glass ionomer is thus appropriately referred to as a dental cement in the traditional sense and, like other cements, falls into several categories of clinical use. It is, however, the only dental cement currently represented in the permanent direct restorative category of available materials. The term “cement” is nonetheless not always necessary in common usage.

Author / Edmond R. Hewlett, DDS, is an associate professor and vice chair of the Division of Restorative Dentistry at the University of California at Los Angeles. Graham J. Mount, BDS, DDSc, is in general dental practice and is a visiting research fellow at the University of Adelaide, Australia.
### Table 1

**A Representative Sampling of Glass-Ionomer Products**

<table>
<thead>
<tr>
<th>Material type</th>
<th>Conventional glass ionomers</th>
<th>Resin-modified glass ionomers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luting agent</td>
<td>Fuji I&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Fuji Plus&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Glassionomer CV-Plus&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Fuji Cem&lt;sup&gt;1&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>Ketac-Cem&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Rely-X Luting Cement&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Restorative/core buildup</td>
<td>Fuji II&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Fuji II LC&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Glassionomer Cement Type II&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Fuji II LC Core&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Ketac Aplicap II&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Vitrebond&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Liner/base</td>
<td>Glassionomer Lining Cement&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Fuji Lining LC&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Glassionomer Base Cement&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Vitrebond&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Lining Cement&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ketac-Bond&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Silver/glass-ionomer cement restorative</td>
<td>Ketac-Silver&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Silver/glass-ionomer admixture restorative</td>
<td>Miracle Mix&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>High viscosity restorative</td>
<td>Fuji IX GP/Fuji IX GP Fast&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Ketac-Molar Aplicap&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pit/fissure sealant</td>
<td>Fuji Triage&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Root canal sealer</td>
<td>Ketac Endo Aplicap&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>Composite bonding agent</td>
<td>Fuji Bond LC&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>G.C. America
<sup>2</sup>Shofu
<sup>3</sup>BM ESPE

### Conventional Glass Ionomers

The first glass-ionomer material was introduced by Wilson and Kent in 1972 as a “new translucent dental filling material” recommended for the restoration of cervical lesions. This original formulation was the product of efforts to develop a replacement for silicate cements, which had been used for decades in cervical restorations. The components of a glass ionomer are a powdered fluoroaluminosilicate glass similar to the one used in silicate cements and a polyalkenoic acid. The latter component is a complex polymeric blend of (primarily) acrylic, itaconic, and maleic acids chosen for their ability to form a cement when mixed with glass and effect ion-exchange adhesion to tooth structure. Depending on the product, the liquid component does not necessarily contain all of the acid. Polycrylic acid is often incorporated into the powder in its dehydrated form, leaving the liquid to consist of water or an aqueous solution of tartaric acid. These various composition characteristics are reflected in the more accurate and scientific term for glass ionomers, namely “glass-polyalkenoate cements.”

Mixing of the glass-ionomer powder and liquid generates an acid-base setting reaction (Figures 1 and 2) commencing with partial dissolution of the surface of the glass particles by the acid. Positive ions (Ca<sup>2+</sup> and Al<sup>3+</sup>) released into solution act to crosslink the acid polymer chains, forming an increasingly rigid matrix as the crosslinked network becomes tighter and more complex. Fluoride ion (F<sup>-</sup>) is also released from the glass particles, becoming available for both uptake by adjacent tooth structure and release from the matrix into saliva. Fluoride neither plays a role in the glass-ionomer setting reaction nor is it incorporated into the matrix structure. Glass ionomer is thus not weakened significantly by fluoride release.

### Limitations

Since the introduction of glass ionomers, numerous modifications have been made to the liquid and powder components to improve the handling and physical properties of the set material. As with all restorative materials, there are strict rules for the clinical handling and placement of glass ionomers. The powder-to-liquid ratio is specific for each application, and mixing techniques are demanding. Consequently, the use of encapsulated materials is strongly recommended to guarantee routine success. The setting reaction is not unlike amalgam in that there is an initial “snap” set within three minutes for all glass-ionomers, but the chemical reaction continues thereafter for a prolonged period. There is a tendency in the earliest stages for the material to take up additional water, but later the main risk becomes water loss leading to dehydration and cracking.
Early water sorption causes swelling (hygroscopic expansion) of the immature material and dissolution of reactive components, while dehydration allows loss of some of the water critical for continuation of the setting reaction. Both situations result in disruption of the setting reaction and resultant nonmature cement with unacceptable properties such as crazing, cracking, and loss of translucency. These untoward occurrences can be prevented by sealing the restoration surface immediately after removing the matrix to maintain the water balance using a light-polymerized unfilled resin enamel bond.\(^6\)

The problem of water balance maintenance was most pronounced with the original glass-ionomer restorative materials but has been largely overcome in recent times. In fact, for the modern high-viscosity auto-cure materials, loss of water through dehydration is the greatest problem; and its prevention in the oral environment is not difficult. It is nevertheless recommended that final polishing of glass-ionomer restorations be delayed for about 24 hours to allow further maturation of the material. Other properties such as compressive and flexural strength and fracture toughness will limit glass-ionomer use as a restorative material to areas not subject to occlusal stress unless well-supported by surrounding tooth structure. Wear resistance improves markedly as the restoration matures, and clinical results suggest that wear is not a problem.\(^9\)

**Advantages**

In spite of their limitations, glass-ionomer restoratives possess several compelling characteristics that merit their inclusion in the adhesive restorative armamentarium.

**Ion Exchange**

It must be noted that ion migration within or through any material can only occur in the presence of water. Since glass ionomer is water-based, it is not surprising that numerous studies have reported continuing release of fluoride from set glass ionomer over prolonged periods;\(^10\)\(^-\)\(^12\) and higher levels of fluoride release from glass ionomers as compared to other fluoride-containing restorative materials.\(^13\)\(^-\)\(^15\)

Additionally, uptake of fluoride by enamel and dentin walls adjacent to glass-ionomer restorations has been demonstrated in both in vitro\(^16\)\(^-\)\(^18\) and in vivo\(^19\)\(^,\)\(^20\) studies. The high levels of fluoride release observed in the days immediately following restoration placement reflect release of fluoride from the exposed glass particles at the outer surface of the restoration. Initial fluoride release levels also likely reflect dissolution of small amounts of the material mass from the surface during the minimally mature stage when solubility of the material is highest. Furthermore, a recent study
also implicates early permeability of some glass ionomers as an explanation for high initial fluoride levels. This phenomenon reflects slow fluoride release from the glass particles and slower diffusion of released fluoride from deeper areas of the matrix. It is generally accepted that both the short- and long-term levels of fluoride release are nonetheless adequate to inhibit demineralization in adjacent tooth structure and to increase the fluoride concentration in saliva. Fluoride release levels have also been shown to temporarily rise following exposure of glass-ionomer restorations to topical fluoride preparations, suggesting a “rechargeable” quality to the fluoride release and giving further credence to the notion of glass ionomer’s inherent anticariogenic properties. The aforementioned higher permeability of resin-modified glass ionomers likely accounts for the higher exchange potential of these materials as compared with the conventional types.

There is gathering evidence that caries inhibition by glass ionomers not only is a question of fluoride release but also involves a continuing ion exchange among the restoration, the surrounding tooth structure, and the saliva. It has been shown that the steady improvement in wear resistance results from movement of fluoride ions out of the restoration surface followed by the uptake of calcium and phosphate ions from the saliva to maintain the electrolytic balance in the restoration. There is further evidence of the transfer of calcium, phosphate, and strontium ions from the glass-ionomer restoration deep into demineralized dentin and surrounding enamel. This remineralization capability renders glass ionomer particularly useful as a long-term provisional restoration in the presence of a high-caries risk inasmuch as it will help to heal damaged tooth structure.

These properties of glass ionomers give rise to a variety of clinical indications not enjoyed by other restorative materials. Of course, no material can be regarded as a prevention or cure for caries. Once the etiologic factors for caries have been eliminated or controlled, however, glass ionomer is most valuable in assisting the healing of remaining tooth structure that has been demineralized and damaged.

**Adhesion to Tooth Structure**

Unlike adhesive resins, which bond micromechanically to partially demineralized enamel and dentin, glass ionomers bond chemically to mineralized tooth structure through an ion exchange mechanism (Figures 3 and 4). The cavity surface must first be conditioned by applying a 10 percent solution of polyacrylic
acid for 10 seconds. A thorough wash of the cavity with air/water spray then removes the smear layer and enhances the wettability of the cavity surface. In contrast to the aggressive demineralization produced with phosphoric acid, the action of this milder conditioning is largely limited to smear layer removal (Figures 5 and 6). Mineral content of the underlying tooth surface will remain relatively intact, and there will be a more consistent and predictable substrate for bonding. Following conditioning and rinsing, cavity surfaces should be dried but not dessicated. Insofar as a mineralized tooth substrate is essential for chemical bonding with glass ionomers, and as these cements are unable to infiltrate and “hybridize” the exposed collagen fibers of acid-etched dentin, conditioning with phosphoric acid prior to glass-ionomer placement is strictly contraindicated.

Ion exchange adhesion between tooth structure and the restoration develops because, in the presence of the polyalkenoic acid in the freshly mixed cement, ions are released from both the glass particles (calcium and aluminum) and the tooth structure (calcium and phosphate). These released ions serve to buffer the acid, effect the initiation of setting, and produce an ion-enriched interfacial layer firmly attached to both the restoration and the tooth. Once the material has matured, any failure will be cohesive within the glass ionomer (the weaker material), leaving behind the ion-enriched layer bonded to the dentin and enamel at the restoration/tooth interface. One investigator has reported findings suggesting some degree of chemical adhesion to the collagen fibers. If the glass ionomer is properly placed, microleakage between the restoration and the cavity walls will be decreased. This in turn ensures absence of post-insertion sensitivity when glass ionomer is used as a base under composite resin.

Glass-ionomer restoratives undergo a small setting shrinkage; but, providing the water balance is maintained, the slow progression of the setting reaction combined with water uptake from the oral environment will counteract the volumetric change and minimize shrinkage-induced stresses at the restoration/tooth interface. They also exhibit a low coefficient of thermal expansion that is similar to that of tooth structure.

Resin-Modified Glass Ionomers

Historically, the first significant modification to glass ionomers came through the addition of small quantities of light-polymerizable resin groups. This has proven to be a successful strategy for simplifying the water balance maintenance while preserving favorable characteristics and improving physical properties and translucency of glass ionomer. The resultant materials have been identified by several terms, including “resin ionomers” and “hybrid ionomers,” but
“resin-modified glass ionomer” is most commonly used to differentiate these materials from those that set solely by acid-base reaction, i.e., the conventional autocure glass ionomers.

“Resin-modified” specifically refers to the addition of polymerizable resin groups (usually 2-hydroxyethylmethacrylate, or HEMA) by grafting them to molecules of the acidic liquid component. The result is a complex liquid that maintains acid reactivity independent of the newly acquired ability to be light polymerized. It is important to recognize that the traditional acid/base setting reaction of the autocure glass ionomer is still present and will continue as normal. Only about 5 percent of the mixed cement will be resin, and when polymerized it will impart strength as well as protection to the ongoing acid-base reaction from dehydration and water sorption (Figures 7 and 8). Resin-modified glass ionomers are thus occasionally referred to as “dual-cure” in reference to these two distinct setting modes. Some manufacturers additionally include a chemical initiator for the HEMA that, along with the usual photoinitiated and acid-base reactions, gives rise to the “tricure” terminology (Figure 8).

Originally marketed in the form of cavity liners, resin-modified glass-ionomer product lines expanded to include restoratives and luting agents. All of these materials retain the most desirable qualities of conventional versions, namely fluoride release, ion exchange adhesion to conditioned enamel and dentin, and low interfacial shrinkage stress. The enhancements over conventional types, particularly in the case of restoratives, include significantly improved resistance to microleakage, on-command hardening and immediate finishing as with composite resins, improved mechanical properties and translucency, and reduced water sensitivity. Despite the transient resistance to water movement in and out of the restoration, post-finishing sealing of a resin-modified glass-ionomer restoration with light-polymerized unfilled resin is recommended to protect acid-base reactive components at the restoration's outer surface. Recent studies additionally suggest that delayed finishing/polishing of these materials may improve resistance to microleakage.

**High-Viscosity Autocure Glass Ionomers**

Other attempts at improving glass-ionomer properties have involved metal reinforcement (addition of amalgam alloy powder) as well as sintering of silver particles to the glass component to form a cermet (ceramic-metal). Data on improvements in physical properties and clinical performance, however, is
equivocal; while other reports suggest diminished caries resistance compared to conventional glass ionomer restoratives.\textsuperscript{34,35}

More recently, high-viscosity, high-strength versions of conventional autacure glass-ionomer restoratives have been introduced. Originally aimed at remote or underdeveloped regions lacking access to dental care,\textsuperscript{56} these materials also have many applications in the traditional restorative setting. Improved physical properties result from chemical modifications and alterations to the heat history of the glass powder that allow higher powder-liquid ratios than earlier conventional restoratives. Characteristics include the adhesion and ion exchange common to all glass ionomers as well as fast setting times, and high levels of compressive and tensile strength, surface hardness, and fluoride release.\textsuperscript{57} These attributes render these materials an excellent choice for bases, emergency temporary restorations, long-term provisional restorations, and final restorations in nonstress-bearing areas, particularly in high-caries-risk patients.\textsuperscript{58,59} Contouring and finishing can begin five minutes after placement, using water spray to prevent dehydration, followed by surface sealing with resin to protect the continuing acid-base reaction.

**Polyacid-Modified Composite Resins (Compomers)**

"Compomers," originally introduced in Europe, have been available since 1993. The term "compomer" is an acronym derived from "composite" and "glass-ionomer," and it reflects the intent to produce a restorative that combines components and properties of both materials. Specifically, compomers purportedly possess the esthetic attributes of composite resins along with the fluoride-release advantage of glass ionomers.\textsuperscript{60} Unlike true glass ionomers, however, compomers are resin-based materials containing no water; and the setting/polymerization of compomer restoratives involves neither mixing nor an acid-base reaction. Compomers are in fact light-polymerized composite resin restoratives, modified to contain ion-leachable glass particles and anhydrous (freeze-dried) polyalkenoic acid. The term "polyacid-modified composite resins" was thus proposed by McLean and colleagues\textsuperscript{61} and is used commonly in the scientific literature to distinguish these materials from glass ionomers.

In the absence of water, the compomer composition prevents the aforementioned glass particles and anhydrous acid from reacting.\textsuperscript{62} Eventual water uptake in the oral environment, however, initiates an acid-base reaction between these components with resultant diffusion of low levels of fluoride ion from the restoration.\textsuperscript{62} Numerous in vitro studies have shown these fluoride release levels to be significantly lower than those measured for conventional and resin-modified glass-ionomers.\textsuperscript{63-65} One recent study,\textsuperscript{66} however, demonstrated equivalent rates of fluoride release for compomers and glass ionomers after three years. This finding, though, does not take into account the higher fluoride recharge/re-release capacity of glass ionomers compared with compomers.\textsuperscript{21,29} The resin bonding agents required for compomer-tooth adhesion act as barriers to fluoride uptake from compomers into cavity walls and margins.

Mechanical properties of compomers tend to be somewhat inferior to those of conventional composite resins, thus limiting their use to areas subjected to low stresses.\textsuperscript{62,67,68} Specifically, compomers (and microfill composite resins) are often recommended for restoration of noncarious cervical lesions as their flexibility (relative to hybrid composite resins) presumably renders them more resistant to detachment during tooth flexure.\textsuperscript{69}

**Clinical Applications for Glass-Ionomer Restoratives**

Resin-modified and highly viscous versions of glass-ionomer restorative materials can be used alone or in combination with composite resins to effectively treat many common restorative situations.
**Sandwich Technique**

The term "sandwich technique" refers to a laminated restoration using glass ionomer to replace dentin and composite resin to replace enamel. This strategy combines the most favorable attributes of the two materials, i.e., caries resistance, chemical adhesion to dentin, fluoride release, and lower interfacial shrinkage stress of glass ionomer with the enamel bonding, surface finish, durability, and esthetic superiority of composite resin. Additionally, composite resin bonds micromechanically to set glass ionomers and chemically to the HEMA in resin-modified versions. Either resin-modified or highly viscous glass ionomers may be used, depending upon anticipated mechanical stresses and esthetic considerations.

The sandwich technique is applicable to Class II lesions in particular using either the "open" or "closed" variations (Figures 9 and 10). The open sandwich is specifically useful for deep Class II proximal box forms where the cervical margin lacks enamel. Numerous in vitro studies have reported improved resistance to microleakage and caries with this technique as opposed to resin bonding at dentin margins. Additionally, replacement of dentin in either the open or closed technique with glass ionomer minimizes the complexity of incremental build-up with composite resin. It will also eliminate acid etching of dentin and thus has potential to reduce or eliminate postoperative sensitivity caused by incomplete sealing of etched dentin.

**Class III and Class V Lesions**

Simple one-surface restorations that are not under occlusal load can be successfully restored with a glass ionomer alone, generally without lamination. The original autocure materials are very suitable, producing satisfactory esthetic results provided that water balance is maintained at insertion.

**Fissure Sealing**

Long-term success with fissure sealing has been demonstrated using normal restorative glass ionomers. Proper conditioning prior to placement will ensure the ion exchange adhesion, and maturation over time allows acceptable longevity. The modern high-viscosity glass ionomers are now the preferred materials, and these can be placed under finger pressure to adapt the cement into the depths of the fissure.

**Root Caries**

Glass ionomer, given its aforementioned attributes, is clearly the material of choice for root caries restorations. In particular, excellent ion exchange adhesion to dentin, caries inhibition, and simplified placement protocol as compared with composite resin render glass ionomer
ideally suited to these situations. Relative esthetic limitations of glass ionomers tend to be inconsequential in root caries sites, and longevity of glass-ionomer restorations in these sites is excellent.8

High Caries Risk
High-viscosity glass-ionomer restoratives lend themselves well to short- and long-term management of patients at high risk for developing caries. In addition to sealing ability and ion exchange, these materials have abrasion resistance adequate for provisional restoration of occlusal and proximal surfaces. Frequent fluoride recharge of such restorations will likely occur via the topical fluoride regimens typically prescribed for such patients, and calcium and phosphate ions are constantly available from the saliva. There is a glass ionomer designed as a lining for high-caries-risk patients that exhibits a very high fluoride release, making it useful when demineralized dentin is to be left on the cavity floor.

Emergency Temporary Restorations
Fractured cusps/restorations can be quickly and predictably stabilized with glass ionomers pending definitive restoration. Adhesion properties of glass ionomer impart adequate retention even if mechanical undercuts are absent. Coverage of exposed dentin and sharp margins to provide enduring patient comfort is accomplished with minimal chair time.

Summary
Glass ionomers have evolved to become more user-friendly while retaining unique characteristics applicable to many contemporary restorative situations. An overview of glass ionomers is presented in an effort to acquaint the clinician with the material's attributes and utilization.9


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