

# GLASS-IONOMER CEMENTS

## Col David Charlton

### History

Development of the glass-ionomer cements (GICs) was first announced by Wilson and Kent in 1972.<sup>1</sup>

Glass ionomers were first marketed in Europe in 1975 and became available in the United States in 1977. The first commercial glass ionomer was made by the De Trey Company and distributed by the Amalgamated Dental Co in England and by Caulk in the United States. Known as ASPA (**A**lumino-**S**ilicate **P**oly-Acrylate), it consisted of an ion-leachable aluminosilicate glass and an aqueous solution of a copolymer of acrylic acid. ASPA was intended for use in restoring class V abrasion/erosion lesions.

Glass ionomers are hybrids of the silicate cements and the polycarboxylate cements. The intention was to produce a cement with characteristics of both the silicate cements (translucency and fluoride release) with those of the polycarboxylate cements (ability to chemically bond to tooth structure and kindness to the pulp).

### General Composition

#### Powder

Consists of an ion-leachable calcium aluminofluorosilicate glass.

Modern cement powders (by weight) are composed of silicon dioxide (41.9%), aluminum oxide (28.6%), and calcium fluoride (15.7%). Also present may be aluminum phosphate (12%), aluminum fluoride (8%), and sodium fluoride (9%).

These powders are combined and fused (at temperatures up to 1300°C for 2 hours) with a fluoride flux that serves to reduce their fusion temperature. The molten glass is then poured onto a steel tray. To fragment it, the mass is plunged into water and the resulting fragments are crushed, milled, and powdered. The particles are then sieved to separate them according to size.

Particle size varies according to manufacturer, however sizes usually range from 20 microns for luting forms to 50 microns for restorative products. For cementation purposes, a glass particle size of from 13 to 19 microns is optimal.

The powder contains fluoride in a 10% to 23% concentration resulting from the calcium fluoride, sodium fluoride, and aluminum fluoride. The fluoride flux also contributes to the final fluoride concentration.

#### Liquid

The liquid is an aqueous solution of polymers and copolymers of acrylic acid. A copolymer is a chain consisting of two molecules. For glass-ionomer liquid, such a copolymer might be a

molecule with a polyacrylic acid segment and an itaconic acid segment. In addition to polyacrylic acid, which is the most important acid contributing to formation of the cement matrix, three other acids are present. Each plays an important role in the chemistry and handling of GICs.

Itaconic acid promotes reactivity between the glass and the liquid. It also prevents gelation of the liquid which can result from hydrogen bonding between two polyacrylic acid chains.

Polymaleic acid is often also present in the liquid. It is a stronger acid than polyacrylic acid and causes the cement to harden and lose its moisture sensitivity faster. This occurs because polymaleic acid has more carboxyl (COOH) groups which lead to more rapid polycarboxylate crosslinking. This also allows more conventional, less reactive glasses to be used which results in a more esthetic final set cement.

Tartaric acid is also found in the liquid and is an extremely important ingredient of GICs. It is a reaction-controlling additive. It acts to extend the working time and promotes a snap set by facilitating ion extraction from the glass particles; it then complexes with the ions, preventing them from crosslinking the polymer chain until the chains become more linear when crosslinking can occur more readily. Tartaric acid also strengthens and hardens the cement. This acid plays such an important role in improving the manipulative characteristics of GICs that it is called the "fourth important component" of GICs. The other three are the powder, polyacids, and water.

### Compositional Forms

The composition described above for GICs is actually only one of three forms they may take: water mixed (water hardened); nonwater mixed (nonwater hardened); or a combination of the two.

Water-Mixed GICs: Some manufacturers take the polyacids (primarily polyacrylic and polymaleic), vacuum- or freeze-dry them and incorporate them into the powder. These cements are called "water mixed" or "water hardened." The manufacturer does this to maximize shelf life (because there is then no possibility of gelation occurring) and to reduce viscosity (which makes the cement easier to handle). The term "anhydrous" is an inappropriate one to use when referring to these forms of the GICs because it implies that water is not present during their chemical reaction. That is not the case, because water is crucial to their chemistry and proper setting. The liquid component of the water-mixed cements is distilled water or an aqueous solution of tartaric acid. Products of this type include Chelon-Fil (3M ESPE) and the nonencapsulated forms of Ketac-Cem (3M ESPE) and Ketac-Bond (3M ESPE).

Nonwater-Mixed GICs: Other GICs have liquids that contain the polyacids (generally polyacrylic, polymaleic, itaconic, and tartaric). These products are somewhat viscous and may exhibit a gelation of their liquid due to hydrogen bonding between polyacrylic acid chains, which can occur over as short a period as 6 weeks. The bottles of liquid of these forms of the GICs should not be refrigerated because they become too viscous for use. Examples of this type of cement include the older version of Fuji Ionomer Type I (GC America) and the encapsulated products Ketac-Cem Aplicap (3M ESPE) and Ketac-Cem Maxicap (3M ESPE).

Combination Water-Mixed, Nonwater-Mixed GICs: These GICs consist of powders that contain dehydrated polyacrylic acid and liquids that contain polyacrylic and tartaric acids. These forms of glass ionomers have physical properties of viscosity and shelf life that are intermediate to those of the water-mixed and nonwater-mixed forms. Products of this type include the new version of Fuji Ionomer Type I (GC America) and the encapsulated glass ionomer Fuji Cap I (GC America). In the Fuji products, approximate 5% polyacrylic acid is dehydrated and added to the powder; the remainder of the polyacrylic acid is in the liquid.

#### Classification of GICs Based on Use

Type I Luting cements which contain glass particles from 13 to 19 microns in diameter. Powder-to-liquid ratio is approximately 1.5:1.

Type II Restorative cements which contain glass particles up to 50 microns in diameter. Powder-to-liquid ratio is approximately 3:1. The Type II products also include the metal-added glass ionomers.

Type III Chemically-set liners/bases or pit and fissure forms.

Type IV Visible light-activated liners/bases.

A subset of GICs were introduced in the mid-1990s called the "Condensible" or "Viscous" GICs. These products such as Ketac Molar (3M ESPE) and Fuji IX GP (GC America), are characterized by having smaller glass particles and a higher powder-to-liquid ratio. This is said to give them higher strength, greater wear resistance, and greater flexural strength than traditional GICs. They have many uses, including as a long-term temporary.

Compared to the Type I cements, the Type II cements are generally harder and stronger. In addition, they are less sensitive to moisture contamination and leach more fluoride. These property differences are due to the higher powder-to-liquid ratio for the Type II cements.

The visible light-activated glass-ionomer liners/bases (Type IV), introduced in the mid-to-late 1980s, were the first hybrid resin/glass ionomer materials. They consist of the traditional glass-ionomer cement powder and a modified polyacrylic acid liquid. Often both the powder and liquid contain a photoactivator which makes them light sensitive. Five such Type IV GICs are available on the market: Vitrebond (3M ESPE), XR Ionomer (SDS/Kerr), Zionomer (Den-Mat), Fuji Lining LC (GC America), and Photac-Bond (3M ESPE). They bond to resin as well as to dentin, leach fluoride, are biocompatible, and acid resistant. In addition, they are less moisture sensitive and are light-activated for easier clinical handling. Compared to the autopolymerizing Type III GICs, these light-activated forms bond stronger to dentin, leak less,<sup>2</sup> and may leach more fluoride. They can be difficult to polymerize in layers thicker than 2 mm and many shrink up to 7% over 24 hours.

#### Recently-Introduced Hybrid Forms

Since the early 1990s, other hybrid resin/glass-ionomer products have been introduced that are intended for other clinical purposes. Hybrids are now available that are used as direct restorative materials, dentin bonding products, and luting agents. This wide variety of hybrids has caused a great deal of confusion among clinicians. Because the hybrid resin/glass-ionomer materials have different characteristics, it has been suggested that appropriate terminology be used to describe them and to distinguish them from other types of glass-ionomer materials.<sup>3</sup> There are now three terms used to describe glass ionomers and related materials:

glass-ionomer cement: consists of an acid-decomposable glass and an acidic polymer and sets via an acid/base reaction that is fully capable of occurring in the dark (e.g., Ketac-Fil, Fuji Ionomer Type II)

resin-modified glass ionomer (RMGIC): sets via an acid/base reaction as well as a photo- and/or chemical-initiated free-radical resin polymerization reaction; the reaction can occur in the dark (e.g., Fuji II LC (GC America), Vitremer (3M ESPE), and Photac-Fil (3M ESPE)).

In general, the powder of RMGICs is similar to that in glass ionomers; the liquid is water, HEMA, and a polyacid with or without pendent methacrylate groups. Several distinct differences exist between the RMGICs. Specifically with regard to composition, the liquid of Fuji II LC and Photac-Fil consist of polyacrylic acid mixed with 2-hydroxyethyl methacrylate (HEMA) while Vitremer's liquid contains HEMA mixed with polyacrylic acid chains to which polymerizable side methacrylate groups have been

added.<sup>4</sup> The amount of fluoride released from Photac-Fil, for example, is greater than that released by the other materials.<sup>5</sup> Photac-Fil is significantly rougher than the other two after polishing and after toothbrush abrasion.<sup>4</sup> In addition, bond strength to dentin differs. In one study, the bond strengths of Fuji II LC and Vitremer were reported to be 11.6 MPa and 8.8 MPa, respectively while Photac-Fil's bond strength was extremely low (0.16 MPa).<sup>6</sup> It should be noted that in January 1997, ESPE introduced Photac-Fil Quick and claimed that it addresses two known shortcomings of the original Photac-Fil: lack of radiopacity and poor bond strength to dentin.

Differences also exist between the RMGICs and traditional GICs. Compared to traditional GICs, the fluoride-release pattern from these materials is about the same; the majority of fluoride is released in the first few days to weeks and then drops to a low level that is released for a long time.<sup>7,8</sup> They release an equivalent (or slightly smaller) amount of fluoride than conventional GICs, however they are just as effective in imparting in vitro resistance to dentin against recurrent wall carious lesions.<sup>9</sup> Their wear resistance is significantly less than that of traditional GICs, probably because of differences in their matrix formation.<sup>10</sup> Both types of materials exhibit an improvement in wear resistance over time, thought to be due to the long-term continuation of their acid/base glass-ionomer setting reactions. Based on their physical properties, Photac-Fil more closely resembles a glass-ionomer cement than Fuji II LC and Vitremer.<sup>4</sup>

The RMGICs also differ from composite resins in certain ways. In general, they exhibit more wear than composite resins, although their wear resistance increases over time.<sup>10</sup> An in vitro study found these materials to be significantly rougher than the composite resins Z100 and Silux Plus after toothbrush abrasion.<sup>4</sup> None of the RMGICs can be polished as smoothly as composite resins.<sup>4</sup> One study found that they shrink more than composite resins after polymerization, but they expand over time with water storage.<sup>11</sup> Whether they exhibit a net expansion or contraction is material specific. They also exhibit color stability and opacity differences compared to composite resins. One accelerated color and opacity test showed that, compared to light-activated composite resins, they undergo a darkening and an increase in translucency;<sup>12</sup> another accelerated aging test found that they become lighter.<sup>13</sup>

Be aware that many of these differences were identified using the original versions of the three products. Two of the products have undergone compositional changes (Fuji II LC, Photac-Fil) and all have new names. Fuji II LC Improved is the new version of Fuji II LC and is supposedly more polishable than the original because of smaller glass particle size. Bond

strength has also been improved by changing the pre-treatment conditioner from 10% polyacrylic acid to 20% polyacrylic acid and 3% aluminum chloride. Photac-Fil Quick is the new version of Photac-Fil and is purported to be radiopaque and to bond more strongly to dentin than the original Photac-Fil. Vitremer is now known as Vitremer Core Buildup/Restorative.

polyacid-modified composite resin (PAMCR): may contain one or more glass-ionomer components but does not undergo an acid/base reaction or undergo one in a clinically-relevant period of time. Products introduced thus far that fit this category have not exhibited the ability to set in the dark (e.g., Dyract AP, Compoglass F, Hytac Aplitip, F2000, élan)

It is important to note that just because a "glass-ionomer" material sets in the dark does not mean that it is, in fact, a glass ionomer because the dark-setting capability may be due to a chemically-caused, free-radical, resin polymerization. However, if a "glass ionomer" does not set in the dark, you can be sure that it is not a glass ionomer because it does not undergo an acid/base reaction.

#### Differences Between the GICs, RMGICs, and PAMCRs

Besides the rather obvious difference of method of polymerization (setting), other differences exist between the three types of products. For example, fluoride release differs. Generally, the GICs release the greatest amount of fluoride while the RMGICs release the same amount or slightly less.<sup>9</sup> Fluoride release from PAMCRS is minimal. However, some differences exist between brands of PAMCRS. For example, Dyract and Variglass VLC release relatively little fluoride, while Compoglass releases more.<sup>14</sup> The ability of these materials to act as fluoride-releasing reservoirs also differs. Traditional GICs and RMGICs act similarly in their ability to take up externally-applied fluoride and release it over time. One PAMCR (Dyract) exhibits little ability to take up and release fluoride.<sup>14</sup> A recent in vitro study found that Dyract and Compoglass provided inferior anticaries protection than a GIC.<sup>15</sup>

To summarize the differences between the three types of materials:

#### *Fluoride Release and Rechargability*

GICs>RMGICs>PAMCRs

#### *Wear Resistance*

PAMCRs>GICs>RMGICs

### *Strength*

PAMCRs>RMGICs>GICs

### *Ease of Handling*

PAMCRs>RMGICs>GICs

### *Polishability and Esthetics*

PAMCRs>RMGICs>GICs

### Hybrid Luting Agents

The latest development involving the use of glass ionomers as luting agents has been the introduction of self-cured hybrid resin/glass-ionomer products such as Fuji Plus (formerly Fuji Duet, GC America), FujiCem (GC America), and RelyX (formerly Vitremer Luting Cement, 3M ESPE). Hybrid resin/glass ionomers were initially introduced as light-activated liners/bases and later as dual-activated restorative materials. These new cements have several advantages compared to traditional glass-ionomer luting agents such as Ketac-Cem, Ketac-Cem Aplicaps, and Fuji Cap I. They have greater tensile strength and are less brittle. In addition, they release at least as much fluoride as traditional glass ionomers,<sup>16</sup> are less soluble, and are less sensitive to moisture contamination and desiccation.<sup>17</sup> Although the three brands are similar in that they are all self setting (i.e., self curing), differences exist between them in many ways (e.g., how the prepared tooth is treated prior to luting and the number of clinical uses for the cement). For example, no additional treatment is performed prior to using RelyX. With Fuji Plus, however, the prepared tooth surface must be treated immediately before luting with an acidic conditioner. While RelyX is used only for luting, Fuji Plus is used for luting as well as a liner/base. FujiCem is the only one of the three that is a two-paste system; the other two are powder and liquid. It is important to know that these cements should not be used to lute all-ceramic crowns such as IPS Empress (Ivoclar) or In-Ceram (Vident) because of clinical fractures. Most researchers believe this is due to post-placement hydrolytic expansion of the cement caused by water sorption. In fact, one study found that the hybrid cements take in many times the amount of water that resin cements do.

### Chemical and Physical Properties

#### Constituents

The composition of the powder and liquid varies from manufacturer to manufacturer. It is therefore recommended that powders and liquids not be interchanged.

#### Chemistry

The setting reaction, initiated by the mixing of the powder with the liquid, consists of three phases that overlap each other.

Phase 1: When the powder and liquid are mixed, hydrated protons (hydrogen ions) are formed from the ionization of the polyacrylic acid in water. These ions attack the peripheries of the glass particles which causes the release of calcium, aluminum, and fluoride ions and the formation of a silica-based hydrogel around the involved glass particles.

Phase 2: In the second phase of the reaction, the  $\text{Ca}^{+2}$  and  $\text{Al}^{+3}$  ions migrate from the silica hydrogel into the aqueous cement phase where, as the pH increases, they precipitate out as polysalts (specifically as polycarboxylates). The polycarboxylates ionically crosslink the polyanion chain and cause the cement to harden. Calcium polycarboxylates form first for several reasons: 1. they are released in greater quantity by the action of the hydrogen ions because attack on the glass particles occurs preferentially at the calcium-rich sites; 2. the calcium ions have a bivalent, rather than trivalent, charge which allows them to migrate faster into the aqueous cement phase; and 3. the calcium cations do not form stable complexes with the fluoride ions as do the aluminum cations. This means that the calcium is more readily available to crosslink the polyanion chains. The calcium polycarboxylates form over the first 5 minutes while the stronger and more stable aluminum polycarboxylates form over 24 hours. As a result, the cement has relatively poor physical properties at first. These properties improve, however, as the aluminum polycarboxylates form. The fluoride ions initially released from the glass particles along with the calcium and aluminum ions do not take part in the matrix-forming stage, but remain available in the matrix.

Phase 3: A slow hydration of both the silica-based hydrogel and the polycarboxylates occurs which results in a further improvement in the cement's physical properties. This phase of the reaction may continue for several months.

Two clinically important results of this reaction are that the physical properties of the glass-ionomer cements take a relatively long time to fully develop because of the cement's long setting reaction and that the cement is sensitive to moisture contamination and to desiccation because the glass particles are covered with a hydrogel.

#### Physical Properties

GICs can be described as moderately hard, brittle materials, with a relatively high compressive strength, but low fracture toughness, flexure strength, and wear resistance.

Since their fracture toughness, flexure strength, and wear

resistance are low, they should not be used to restore teeth in high stress-bearing areas.

Their physical properties develop slowly; for example, compressive strength of a Type II GIC has been shown to increase over a one-year period.<sup>18</sup>

Glass ionomers expand under moist conditions and contract under dry ones.<sup>19</sup> They undergo little dimensional change if allowed to set in an environment of 80% relative humidity.<sup>20</sup>

GICs possess good color stability.

Their coefficient of thermal expansion is 0.8 that of tooth structure while their thermal diffusivity is approximately the same as that of dentin.

GICs exhibit approximately 10 times as much two-body wear as do composite resins.<sup>21</sup>

Tensile strength is only 1/10 that of compressive strength.

Film thickness for the Type I GICs is reported to be from 18 to 23 microns, which is acceptable.<sup>22</sup>

GICs have compressive and tensile strengths that are higher than those of zinc phosphate cement, but their moduli of elasticity are only ½ those of zinc phosphate cements.

#### Fluoride Release

As noted earlier, GICs contain fluoride in a 10% to 23% concentration; the fluoride is located primarily in the glass particles although some is present in the matrix.

The fluoride that is released is sodium fluoride which does not take part in matrix formation, therefore its release does not result in a deterioration of the cement's physical properties.

Research reports vary regarding the amount and rate of fluoride released from the GICs.

Fluoride release is greatest immediately after placement and diminishes over time.<sup>23</sup> A large release occurs over the first 24 to 48 hours which is then followed by a rapid decline.<sup>24</sup> The initial burst release is from surface fluoride while the long-term, lower-level release comes from the bulk of the material.

Release probably occurs for the life of the restoration.<sup>25</sup> Release rates at 5 years have been found to be the same as release rates measured at 5 months.<sup>26</sup>

Fluoride has been found in enamel up to 7.5 mm from the margin of Type II GIC restorations.<sup>27</sup>

Over a three-week period, GICs have been found to release 2.5 times the amount of fluoride that a comparable silicate cement restoration releases.<sup>28</sup>

The amounts of fluoride released increase with a decrease in pH,<sup>18,29,30</sup> probably as a result of surface dissolution.<sup>31</sup>

When stored in artificial saliva, GICs release less fluoride than when they are stored in deionized water.<sup>30,32</sup>

Evidence indicates that GICs can act as rechargeable,

fluoride-releasing systems. GICs that are exposed to fluoride gels in vitro take up a large amount of the fluoride and subsequently release it.<sup>33</sup>

Fluoride release is greater from Type II than from Type I forms because the higher powder-to-liquid ratio of the Type II cements means that they contain more fluoride-releasing glass particles.<sup>34</sup>

Hand-mixed GICs release significantly less fluoride than mechanically-mixed ones.<sup>35</sup>

Covering GIC restorative materials with a sealant reduces the amount of fluoride they release.<sup>36</sup>

GICs can reduce enamel solubility by up to 52%.

Although some in vivo work indicates that fluoride release from GIC restorations can reduce caries adjacent to them,<sup>37</sup> a detailed review of 28 studies found a positive effect against secondary caries, but no conclusive, overall evidence.<sup>38</sup>

#### Sensitivity to Moisture and Desiccation

**Moisture contamination:** Although at least one source suggests that GICs are sensitive to moisture contamination for up to 24 hours,<sup>39</sup> others recommend protecting them from moisture for 10 to 30 minutes after placement. Ketac-Fil, for example is sensitive to moisture for 10 minutes after placement, while Fuji Type II is sensitive for 20 minutes. Changes made in the chemistry of Ketac-Fil, however, have reduced this period of moisture sensitivity. If contaminated, calcium and aluminum ions leach out of the aqueous cement phase and are prevented from forming polycarboxylates. This causes the matrix to turn chalky and erode and produces a rough surface. It also causes a significant decrease in surface hardness.<sup>40</sup> Moisture sensitivity is lost as the calcium and aluminum ions take part in polycarboxylate formation and become less susceptible to leaching.

Once set, the glass-ionomer cements are one of the least soluble luting agents.<sup>22</sup>

**Desiccation:** Susceptibility varies from 1 to 15 days depending on the material.<sup>41</sup> Mount reports that sensitivity to desiccation lasts for up to six months.<sup>39</sup> Early desiccation robs the cement of water necessary for the setting reaction and, therefore, retards the rate of setting. Later desiccation prevents strength from developing because hydration of the silica-based hydrogel and the polycarboxylates cannot occur. Drying of the cement can also lead to crazing, loss of esthetics, and accelerated deterioration. Susceptibility of the cement to desiccation decreases over time as water becomes chemically bound to the hydrogel and polycarboxylates.

Proper placement technique for a chemically-set Type II GIC involves application of a low-viscosity, visible light-activated, single-component bonding resin to any areas of exposed cement as soon as possible following placement. Some researchers even recommend that margins of castings cemented with a Type I GIC be protected in this way. This helps to prevent water transport (both moisture contamination and desiccation) across the surface of the GIC. Varnishes supplied by the manufacturers of the GICs can be used but are generally less effective in preventing water transport than are the light-activated bonding resins.<sup>42,43</sup> Varnishes are also less effective than light-activated resins in preventing color change in the cements.<sup>44</sup> If a manufacturer's varnish is used, do not air dry it after application because this can cause hydration and crazing of the cement. Do not use copal varnishes or chemically-activated unfilled resins because they are too porous.

#### Biocompatibility

Certain characteristics of the chemistry of GICs should make them a very biocompatible cement:

- polyacrylic acid, which forms a major portion of the liquid component of most brands of GIC, is a weak acid
- what few dissociated hydrogen ions that are present are electrostatically bound to the polymer chains
- the polymer chains are long and, therefore, entangle on each other which prevents them from migrating down the dentin tubules and having an adverse effect on the pulp

Despite these factors, cases of sensitivity following the use of certain glass-ionomer cements for cementation began to surface in the early 1980s. The pain was usually delayed in onset, progressive in nature, and severe enough to require removal of the casting and recementation with a more bland cement. The sensitivity was most often seen after use of the "water-mixed" forms of the GICs. They were probably involved because of their low viscosity and low initial pH. Another reason may involve the fact that they contain unreconstituted acid. Because the cements set in 7 minutes and it normally takes 18 minutes for the dehydrated acid to be fully reconstituted, unreconstituted acid remains that is rehydrated slowly by dentin tubule fluid. This has the effect of exposing the pulp to a low pH for an extended period of time.

As noted, sensitivity has almost exclusively been limited to the Type I (luting) cements. This is probably related to the fact that the luting forms of the GICs are placed under pressure

over a large surface area of cut dentin.

Polycarboxylate cements, while somewhat similar in composition to the GICs, do not exhibit this problem, probably because they are not as acidic after mixing, are not as moisture sensitive, and are more viscous.

Several factors have been implicated in postcementation

sensitivity:

- microleakage secondary to early moisture contamination
- pressure generated during seating of the casting
- low initial pH; this may be exacerbated by use of a low powder-to-liquid ratio mix and removal of the smear layer
- fluoride release which may have a cytotoxic effect in the presence of low pH

Recommended techniques to help prevent postcementation pain:

- use a base material on deep areas of the preparation
- use the proper powder-to-liquid ratio
- do not remove the smear layer
- do not desiccate the tooth
- apply a one-step, resin dentin-desensitizer (e.g., Gluma Comfort Bond + Desensitizer, Heraeus Kulzer) to the exposed dentin; do not apply it to the margins;<sup>17</sup> recent research has found that this type of desensitizer does not adversely affect crown retention<sup>45,46</sup>
- avoid overfilling the casting with cement; just line it with a thin layer of the cement
- seat the casting gently
- allow the bead of excess cement that is expressed at the margins to remain in place where it will act as a barrier to moisture contamination
- protect the cement from moisture contamination
- clean up excess cement only after it has fully set (usually about 10 minutes); this prevents the cement from being pulled out from underneath the margins
- line any exposed margins with a low viscosity, single-component, light-activated bonding resin to prevent moisture contamination and desiccation of the cement

### Adhesion

A full 80% of the ultimate bond strength of a GIC to tooth structure develops within the first 15 minutes following placement.<sup>47</sup>

Tensile bond strength to untreated enamel ranges from 2.6 to 9.6 MPa while most of the values range from 4 to 6 MPa; tensile bond strength to dentin is about half that of enamel and ranges

from 1.1 to 4.5 MPa.

The bond strength of GICs to enamel exceeds the cohesive strength of the cements themselves. That is, failure normally occurs within the cement.

The actual mechanism by which GICs bond to tooth structure is unknown although Smith, writing about the zinc polycarboxylate cements in 1968, felt that chelation between the carboxyl groups of the cement and calcium of the tooth structure was the primary mechanism.<sup>48</sup> Beech also believed that interaction between the carboxyl groups and calcium accounted for bonding, however, he argued against chelation saying that it led to the formation of an unstable, eight-membered ring.<sup>49</sup> Wilson has advanced the theory that adhesion of the GICs is due to displacement of calcium and phosphate groups in the tooth structure caused by the action of the cement's carboxylate ions ( $\text{COO}^-$ ).<sup>50</sup> This leads to the formation of an intermediate aluminum and calcium phosphate layer that mediates bonding at the tooth/cement interface. Recent work has been published that supports this mechanism, namely that carboxyl groups replace phosphate ions in the tooth structure and then form ionic bonds with the calcium ions of the hydroxyapatite.<sup>51</sup>

Many believe that both ionic and hydrogen bonding are involved.

No evidence exists that GICs bond to dentinal collagen (the 33% organic phase of the dentin).

GICs chemically bond to enamel and, to a lesser extent, to dentin<sup>52</sup> and cementum; they also bond to stainless steels, base metals and to tin-plated noble metals, but not to pure noble metals or to glazed porcelain. Some evidence indicates that GICs bond to high-copper amalgam alloys with a bond strength greater than that with which they bond to dentin.<sup>53</sup> Slightly stronger bonds form between the VLA glass-ionomer liners/bases and high-copper amalgams.<sup>54</sup>

### Optical Properties

Early GICs were extremely opaque because of their high fluoride content which was necessary to improve their handling characteristics.

The reduction in fluoride and the use of more translucent glasses made possible when tartaric acid's reaction-controlling effects<sup>55</sup> were discovered resulted in the production of a more translucent cement. The addition of polymaleic acid also produced a more translucent cement because more conventional, less reactive glass particles could then be used.

Translucency generally improves over the first 24 hours but does not reach a maximum until at least a week after placement of a GIC restoration.<sup>56</sup>

### Conditioning the Tooth Surface to Increase Adhesion

Purpose: Dentin conditioning prior to placement of a Type II, III, or IV GIC is done primarily to remove the smear layer. This promotes stronger bonding for several reasons: by removing the smear layer, the GIC is better able to wet the dentin surface; the cement also bonds to dentin and not to the smear layer (bonding to the smear layer is undesirable because premature bond failure can occur cohesively within the smear layer or adhesively between the cement and the smear layer). Conditioning is also recommended because it promotes ion exchange, chemically cleans the dentin, and increases surface energy. The goal is to remove the smear layer without removing smear layer plugs from the dentin tubule orifices or reducing bond strength through depletion of surface ions.

Many practitioners use polyacrylic acid for dentin conditioning. Either a 10% (GC Conditioner), 25% (Ketac-Conditioner), or a 40% (Durelon liquid) concentration can be used. Do not use the liquid component of water-mixed GICs because they are not polyacrylic acid solutions.

Many researchers recommend a passive 10-second application of 10% polyacrylic acid,<sup>57</sup> however a passive 10- to 15-second application of a polyacrylic acid solution having a 10% to 25% concentration is acceptable. If using the liquid of Durelon, apply it for only 5 seconds and then rinse liberally with water.

### Dispensing and Mixing

The powder-to-liquid ratio is important and varies from manufacturer to manufacturer. A reduction in powder-to-liquid ratio can result in poor physical properties.

A glass slab is recommended for mixing and may be chilled to lengthen the working time (almost doubling it in some cases). It should be noted that an excessively chilled slab can cause a reduction in the cement's compressive strength and modulus of elasticity.

It is not necessary to mix the cement over a large area on the glass slab because the setting reaction is only mildly exothermic.

Prior to mixing, divide the dispensed cement powder into two equal portions. Mix the first portion into the liquid in 20 seconds and then add the remaining powder and mix for another 20 seconds. Mixing should be completed within 40 seconds and the cement should be used before it loses its glossiness. If the glossiness is lost, the cement won't wet the tooth surface well and bond strength will be reduced. It will also be too viscous for easy use and film thickness may be excessive.

### General Information

The main indication for the use of a Type I GIC is in a situation where the patient would benefit from fluoride release.

A contraindication is the presence of hypersensitive teeth.

The high rate of retention for glass-ionomer restorative materials is surprising considering the relatively weak bonds they form to enamel and dentin. The high rate of retention may, in part, be related to the fact that GICs exhibit a slow setting reaction and have a coefficient of thermal expansion similar to that of tooth structure. Both of these properties minimize stress formation at the GIC/tooth structure interface.

Certain Type II GICs show good bond strengths when repaired. The shear bond strength of new Ketac-Fil added to old exceeds the cohesive strength of the material. When repaired at 3 months, however, the bond strength is significantly less than when repaired within hours or days following initial placement.<sup>58</sup> Bond strengths of repairs done at 20 minutes also exceed those done at 24 hours.<sup>59</sup>

Etching a Type II or Type III GIC in the "sandwich" technique as a means of increasing bond strength to composite resin has been shown to be unnecessary if the GIC is placed with an instrument. As a matter of fact, etching can actually result in a lower bond strength between the GIC and composite.<sup>60</sup> If etching is done, however, the GIC should be no thinner than 0.5 mm. The etching should not be done too early after placement (i.e., less than 4 minutes) nor should the acid be applied for more than 10 seconds.<sup>61</sup>

GICs are an excellent choice for luting orthodontic bands to teeth because of their fluoride release and ability to chemically bond to both the metal band and tooth structure. They also exhibit higher retention rates than zinc phosphate cements.<sup>62,63</sup>

GICs compared to resin cements have several advantages for the luting of orthodontic brackets. These include an anticariogenic effect, easier bonding, and less potential for damage during debonding. While one study found that GICs provided significantly less retention for brackets than did a resin luting agent, it was concluded that one GIC (Ketac-Cem) provided enough bond strength for successful clinical use.<sup>64</sup>

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