Vitremer™
Tri-Cure Glass Ionomer System

Technical Product Profile
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Introduction

We have chosen to open this technical product profile with a rather technical and historical discussion of glass ionomer technology. It is not meant to be an overwhelming chemistry lesson but rather a logical perspective and framework in which to introduce the latest advancement in glass ionomer technology from 3M ESPE Dental Products, the Vitremer™ Tri-Cure Glass Ionomer System. Glass ionomer cement technology was invented by Wilson and co-workers in the U.K. in the 1970s. The original cements have undergone several modifications depending on the particular products. However all conventional cements have the following essential components:

- An ionic polymer which is a polycarboxylic acid
- A fluoroaluminosilicate (FAS) glass powder
- Water
- Tartaric acid

The above components are formulated to provide a powder and a liquid portion. In use the two are combined and a chemical reaction takes place to provide a set cement. The chemistry of the setting reaction of the conventional cements is shown schematically in Figure 1. The acid groups of the polymer attack the FAS glass releasing simple and complex positively charged metal ions. These ions react with the carboxylic acid groups of the polymer in an acid-base setting reaction. This acid-base setting reaction can be readily followed by spectroscopic techniques, e.g. FTIR (Fourier Transformed Infrared Spectroscopy) since the carboxylic acid groups are transformed to carboxylate anions. A very important by-product of this setting reaction is the sustained release of fluoride ions believed to be responsible for caries resistance. Water plays two important roles in the overall setting. Firstly, it provides for ion transport needed for the acid-base setting reaction and fluoride release. Secondly, water is also chemically bound in the cement and thus it provides for the ultimate stability of the set cement. An important feature of glass ionomer cements is that since the release of fluoride is a direct response of the process of the setting reaction, its release in true glass ionomers does not lead to degradation of the set material. The acid-base reaction can continue indefinitely and hence the release of fluoride also continues for prolonged periods in a sustained manner. Tartaric acid is also added to most conventional cements to help in modifying the working time and provide a hard setting material under oral conditions. Since the conventional glass ionomer setting reaction begins immediately upon mixing the powder and liquid, this reaction can be regarded as a self-cure reaction. The conventional glass ionomers gained popularity because they offer important advantages. These advantages are:

- Sustained fluoride release
- Biocompatibility
- Good adhesion and clinical retention

2 Phillips RW. Glass Ionomers: Boosting Amalgam’s Value. JADA 199.
Fluoride has long been known to have a caries-preventive effect.\textsuperscript{4} The cariostatic effect of glass ionomer cement is reported in a five year clinical study by M. Tyas.\textsuperscript{5} A review has also been published by E. Swift.\textsuperscript{6} The conventional glass ionomer systems however suffer from certain disadvantages. These disadvantages are:

- Short working time
- Long set time
- Technique sensitivity
  - Susceptibility to early moisture contamination
  - Prone to dessication after setting
- Britteness

The foregoing disadvantages had limited the clinical application of these otherwise excellent materials. In order to overcome the limitations of the conventional glass ionomers and yet preserve their benefits, 3M introduced the concept of light-cured glass ionomer cements to the dental community. Vitrebond™ Light Cure Glass Ionomer Liner/Base revolutionized the glass ionomer technology. The setting reaction of this true glass ionomer is depicted in Figure 2.

\textsuperscript{4} Ibid.
\textsuperscript{6} Swift, p. 40.
Two types of setting reactions take place in a true light cured glass ionomer: (1) the acid-base reaction between the fluoroaluminosilicate glass and the polycarboxylic acid, the same reaction as in a conventional glass ionomer, and (2) a light-activated free radical polymerization of methacrylate groups of the polymer and HEMA (2-hydroxyethylmethacrylate). Since the rate of the second reaction, the photo-polymerization reaction, is much faster than the first, the setting time of the cement is much shorter than conventional systems. This curing reaction gives these materials extended working time and optimal physical properties. The benefits of a light-curing glass ionomer are now well recognized. However, they suffer from a disadvantage inherent in all light-curing systems. All light-curing systems allow the penetration of visible light to only a limited depth. Hence layering techniques are necessary which make the procedure time-consuming in deeper filling and core buildup applications. It is essential therefore to use proper light-curing techniques including layering of the material, adequate cure time and use of a good curing light. Conventional glass ionomers do not have this drawback since the acid-base reaction is not dependent on light. It may be thought that since the acid-base reaction also proceeds in true light-cured glass ionomers this would be sufficient to give a dark set. However, all light-cured glass ionomers have constituents with methacrylate groups in them. In the absence of light, these methacrylates would essentially remain uncured. Hence even in these systems it would be essential to incrementally place the material and light-cure in order to obtain a thoroughly cured material. In a liner/base system like Vitrebond™ Liner/Base, this is not a problem since the application calls for only a thin layer of material. However, in application as a filling material or core build-up the need for incremental curing is a major drawback. The new Vitremer™ Tri-Cure Glass Ionomer System overcomes the disadvantages of light cured glass ionomers while maintaining all their advantages. To this end the Vitremer chemistry contains a third mode of cure. The schematic of the cure reactions of Vitremer tri-cure system is shown in Figure 3.
The third reaction is a dark cure of the methacrylate groups of the polymer system and HEMA. This relatively fast reaction is initiated by water-activated redox catalysts which allows the methacrylate cure to proceed in the dark. This reaction produces high physical properties in areas where light access is not possible or is questionable. This dark methacrylate cure is a unique feature of 3M tri-cure-based materials and ensures uniform cure throughout the glass ionomer restorations resulting in enhanced physical properties even when placed in bulk. In summary, the Vitremer™ Tri-Cure Glass Ionomer System has the following three distinct curing reactions:

1. Acid-base glass ionomer reaction
   (initiated when powder and liquid are mixed and can proceed in the dark).

2. Photoinitiated free radical methacrylate cure
   (initiated when the powder/liquid mix is exposed to light and occurs only where light penetrates).

3. Dark cure free radical methacrylate cure
   (initiated when powder and liquid are mixed and can proceed in the dark).

The 3M Vitremer™ tri-cure glass ionomer system offers the best features of conventional glass ionomers and light cure systems without the disadvantages of either.
Composition

The Vitremer™ Tri-Cure Glass Ionomer System is indicated for use as an esthetic restorative filling material and as a core buildup material. It is comprised of the tri-cure glass ionomer powder, the glass ionomer liquid, a dentin/enamel primer and a finishing gloss.

Powder

The Vitremer tri-cure glass ionomer powder is composed of a radiopaque, fluoroaluminosilicate glass. It also contains microencapsulated potassium persulfate and ascorbic acid which make up the patented redox catalyst system that provides the methacrylate cure of the glass ionomer in the absence of light. The powders further contain small amounts of pigments to provide shades appropriate for the products’ intended uses. Four VITA shades, namely A3, A4, C2 and C4, a Pedo shade (lighter than a Vita B1) intended for pediatric restorations and a blue shade, designed specifically for core buildups to contrast tooth shades, are available.

Liquid

The glass ionomer liquid is a light sensitive, aqueous solution of a polycarboxylic acid modified with pendant methacrylate groups. It contains the copolymer also used in the Vitrebond™ Liquid, water, HEMA and photoinitiators. It is similar in composition to the Vitrebond liquid but differs in the concentrations of the components. In use, Vitremer liquid and Vitremer powder are combined within a 45–second period and will form a set cement by the multiple setting reactions described above. The glass ionomer mixture is a true glass ionomer having the major benefits attributed to this category of dental materials, i.e. adhesion to tooth structure and fluoride release.

Primer

The Vitremer primer is a one part, visible light–cure liquid specifically designed for use with the tri-cure glass ionomer. It is composed of the Vitrebond copolymer, HEMA, ethanol and photoinitiators. The components of the primer are similar to those of the Vitremer liquid. The relative amounts of each are different however, and the primer’s viscosity is significantly lower. The primer is acidic in nature. Its function is to modify the smear layer and adequately wet the tooth surfaces to facilitate adhesion of the glass ionomer. In use, the primer is applied with a brush for 30 seconds to both dentin and enamel and air dried. Ethanol present in the primer, aids the drying step. The primer is then light cured for 20 seconds. Adequately air drying followed by light curing of the primer before placement of the glass ionomer enhances adhesion of the glass ionomer to tooth structure particularly when the glass ionomer is placed in bulk thicknesses exceeding those that can be penetrated by light.

Finishing Gloss

The Vitremer finishing gloss is a single component, light cure dental resin. It is the same as Light Cure Enamel Bond Resin #5515. Its use is optional. Its function is to provide a surface coating over a final restoration to level any surface irregularities if needed. It is not recommended for use over core buildups.
Properties

Following is a discussion of the properties of the Vitremer™ Tri-Cure Glass Ionomer System. Much of the information will be presented in graphic form. Data will be presented for Vitremer, Vitremer TC and/or Vitremer SC. Vitremer and Vitremer TC refer to the product when it has cured by all three of its curing mechanisms. Vitremer SC refers to the product when it has cured only by its two self-cure mechanisms, i.e. with no light exposure. Performance of the product is at its best when light cured. However, the properties achieved with the self-cure mechanisms only are significant and especially important when one considers use of the product in thicknesses greater than those which light can penetrate. Comparisons will be made with the major products competitive to the new Vitremer product. These are:

- Conventionally setting glass ionomer restorative products:
  - Ketac™ Fil (3M ESPE)
  - Fuji II (GC International)

- Light cure glass ionomer restorative product:
  - Fuji II LC (GC International)

- Conventionally setting glass ionomer products used as core buildups and in pediatric applications:
  - Ketac™ Silver (3M ESPE)
  - Miracle Mix (GC International)

- Other:
  - VariGlass VLC Multipurpose Glass Ionomer (L.D. Caulk)

As will become evident through the course of this profile, VariGlass is not a true glass ionomer. Therefore, data for it will be shaded differently in most of the bar graphs that follow to differentiate it from the other products which are true glass ionomers. Unless stated otherwise, all test specimens are stored wet until tested.

Fracture Resistance

The fracture resistance of a variety of materials indicated for use as core buildups was determined by Dr. John O. Burgess, University of Texas, San Antonio, TX. Cores of the materials were constructed on dentin with pins. Force was applied to the cores at a 45° angle and the fracture resistance determined. Dr. Burgess's data are presented as Figure 4. The fracture resistance of Vitremer ionomer is significantly greater than that reported for the conventionally setting and light cure glass ionomers, the amalgam, (Tytin) and the composite products tested. When crowns were placed over the various core materials and then subjected to the same type of test, fracture resistance values for all the materials were similar.
Fracture Toughness

Fracture toughness is a measure of a material’s resistance to the propagation of a crack after a crack has been initiated. Shown as Figure 5, the 24–hour fracture toughness values for the Vitremer™ Ionomer and Fuji II LC are significantly greater than those of the major conventionally setting glass ionomers as well as a variety of composite products tested dry. Tested wet, the composites would be expected to show somewhat higher values though not equaling or exceeding that of the Vitremer ionomer.
Compressive Strength

Shown graphically as Figure 6, 24-hour compressive strength values for Vitremer ionomer in the tri-cure and in the self-cure modes are greater than those of the conventionally setting ionomers and equivalent to the light cure products. Viewed as a function of time in Figure 7, it can be seen that the Vitremer compressive strength values at ten minutes are already about equivalent to those of the conventional ionomers at one hour. At one hour, they are greater than or equivalent to those of the others at one day.

Figure 6.

![Compressive Strength](Image)

Figure 7.

![Compressive Strength vs. Time](Image)
Diametral Tensile Strength

As illustrated in Figure 8, the 24-hour diametral tensile strengths of Vitremer™ Ionomer in the tri-cure and self-cure modes greatly exceed those of the conventional restorative and core buildup ionomers and are significantly different from them. They are not statistically different from the Fuji II LC and VariGlass products though their average values are greater than or equivalent to these products.

Graphed as a function of time in Figure 9, it is evident that the tensile strength of Vitremer ionomer in the tri-cure mode is superior even at ten minutes to those of the competitive conventional materials at one hour, and at one hour is significantly greater than that which the others achieve even at three months.

Figure 8.

Figure 9.
Flexural Strength

Flexural strength was determined in a three–point bend test. Twenty-four hour results are shown in Figure 10. The data indicate that the Vitremer ionomer is less brittle than the major conventionally setting ionomers and VariGlass restorative. Fuji II LC is similar to the Vitremer product by this particular measure.

Fluoride Release

Fluoride released from Vitremer™ Tri-Cure Glass Ionomer is measured in vitro in buffer solution using a fluoride–ion–specific electrode. The release of fluoride over time is not affected by variations in the powder/liquid ratio as illustrated by Figure 11, nor adversely affected by the cure mechanisms or coating of the cured material as indicated by Figure 12. Cumulative fluoride released from the Vitremer product, the major conventionally setting glass ionomers, the Fuji II light cure glass ionomer and some other products claimed be glass ionomers is shown as Figures 13 and 14 respectively. While the minimum amount of fluoride release required to produce a cariostatic effect has not been established, the near total lack of such release from Geristore (DenMat) and Fluorocore (L.D. Caulk), both products that carry claims of fluoride release, and the limited release from the VariGlass product are noteworthy.
Cumulative Fluoride Released: Vitremer™ Cure Mechanism

Figure 12.

Cumulative Fluoride Released: Vitremer™ vs. Conventional Glass Ionomers

Figure 13.

Cumulative Fluoride Released: Vitremer™ vs. Competitive Products

Figure 14.
Caries Inhibition

Erickson and Glasspoole have conducted numerous in vitro investigations of secondary caries inhibition. To date, they have found that the only materials inhibiting to lesion formation by this test method are the true glass ionomer compositions. In a most recent study, they found Vitremer™ Tri-Cure Glass Ionomer to be caries inhibiting. The Vitremer ionomer was placed after application and light-curing of the Vitremer primer as is recommended for clinical use. A zone of inhibition adjacent to the material can be seen in the polarized light micrograph reproduced here as Figure 15. The response of this new product is like that seen repeatedly with the conventionally setting glass ionomer, Ketac™ Fil. By contrast and as can be seen in Figures 16 and 17 respectively, Geristore and Fluorocore showed no zones of inhibition. In fact, early wall lesion formations are evident indicating leakage between the cavities and these restorations. While the artificial lesion produced adjacent to the VariGlass product was shallower than those adjacent to the other products tested, the VariGlass restorative did not exhibit the inhibition typical of the true glass ionomers, as can be seen in Figure 18.

The fluoride release data cited above and the results of this investigation indicate that Geristore, Fluorocore and VariGlass do not function as glass ionomers. They do not provide the benefit of fluoride release leading to in vitro caries inhibition associated with glass ionomers and expected by the dental profession.
Adhesion

It should be stated at the outset that adhesion values of the glass ionomers are generally lower than those of adhesive/composite systems. Glass ionomers typically fail cohesively within the ionomer and thus adhesion is not necessarily true bond strength. Further, their inherent lower rigidity compared with composites significantly affects shear bond values. However, the glass ionomers have been shown to be highly retentive clinically. Therefore their use as effective restorative materials should not be ruled out on the basis of in vitro bond strength data.

Adhesion is evaluated in the 3M Dental Products Laboratory by potting bovine or human teeth in methyl methacrylate, then grinding and polishing these to expose enamel or dentin. The enamel or dentin surfaces are then treated in accordance with manufacturers’ instructions for bonding. A PTFE mold 5mm in diameter and 2mm in height is placed over the treated surface. The test material is mixed, placed in the mold to form a button and cured. The light–cure materials are cured by light exposure and the self-cure materials allowed to set for their recommended set times at 37°C and 80% RH. They are then placed into water at 37°C before shear bond strength is determined at a crosshead speed of 1mm/min. in an Instron universal testing machine.

The effect of Vitremer™ Primer on the adhesion of Vitremer ionomer to enamel and dentin is presented in Figure 19. A significant decrease in bond strength occurs when the primer is not used. Thus, Vitremer ionomer is recommended for use with the primer.

Unless otherwise noted in the following discussion, Vitremer adhesion values have been determined on primed dentin and enamel; i.e. the Vitremer primer was applied to the particular substrate for 30 seconds, air dried and light cured for 20 seconds before placement of the ionomer button. For the conventionally setting glass ionomer products, enamel and dentin surfaces were treated with the polyacrylic acid solutions recommended by the respective manufacturers for the recommended time and then rinsed and dried before placement of the ionomers.

Figure 19.
The average bond strength of Vitremer™ ionomer to bovine enamel is 10.3 MPa in the tri-cure mode and slightly lower in the self-cure mode. These values are greater than those of the conventional glass ionomers as is shown in Figure 20 and somewhat less than those obtained with the Fuji II LC and VariGlass products though not significantly so. For the Fuji II LC product, the enamel surface was scrubbed with GC Dentin Conditioner, a polycarboxylic acid solution, rinsed and dried prior to placing the ionomer in accordance with GC’s recommendations. For the VariGlass product, the enamel was etched for 30 seconds with a phosphoric acid gel, rinsed and air dried. A coating of Universal Bond 3 Primer was then applied and air dried followed by placement of the VariGlass material in accordance with Caulk’s recommendations for bonding to enamel.

Figure 20.

The average bond strength of Vitremer ionomer to bovine dentin is 5.5 MPa in the tri-cure mode and somewhat less in the self-cure mode. These values are compared with those of competitive products in Figure 21. Though they are greater than the others, they are not statistically so in some cases. For the Fuji II LC samples, the dentin surfaces were conditioned in the same manner as that for enamel adhesion testing and for the VariGlass samples, Universal Bond 3 Primer was applied and air dried before placement of the restorative material all in accordance with manufacturers’ recommendations.

Figure 21.
Though not included in Figure 21, adhesion of Fuji II LC to dentin was evaluated where the ionomer was not light cured but allowed to cure only by its self-cure, i.e. its glass–ionomer, acid-base setting reaction. Bond strength values were zero. Most of the samples failed before they could be placed in the universal testing machine. Similar testing of the VariGlass product could not be accomplished because VariGlass has no self-cure. It can be set only by light exposure. This is another significant indicator that the material does not function as a glass ionomer. The performance of these two competitive products is highly dependent upon proper light-curing technique. This demands the operator’s close attention to the thickness of materials placed, cure times, light access to the materials, distance of the light from the materials, light intensity output and depth of cure of the selected shade to mention some factors. The assurance provided by a material that will not only light cure but will also undergo significant self-cure as with the Vitremer ionomer, is not afforded users of the Fuji II LC and VariGlass products.

Figure 22 shows the adhesion values of Vitremer ionomer to human tooth structures. It is interesting to note that adhesion of the ionomer in the tri-cure mode to human dentin is significantly greater than that to bovine dentin.

![Figure 22. Adhesion to Extracted Human Teeth](image)

Adhesion values following aging to three months and thermal cycling compared with 24-hour adhesion values are shown in Figure 23. Thermal cycling was done from 5–55° C for 630 cycles. No significant difference in adhesion values was found.

![Figure 23. Adhesion of Vitremer™ to Bovine Dentin](image)
Solubility

The solubility of glass ionomers is commonly determined in vitro by two tests, water leachable content in accordance with ISO Specification 7489 and lactic acid erosion in accordance with ISO Specification 9917. For the former, discs of the test materials are made up, cured, held at 37°C and 90% relative humidity for one hour and then placed in water. After 23 hours, the amount of solid material leached from the samples is determined and reported as a percentage of the sample. The specification calls for an upper limit of 0.7% for Type II, i.e. restorative glass ionomers. For immediate values, the test procedure was the same except the one–hour dwell time at temperature and humidity was eliminated. Tested by both protocols, the Vitremer™ Ionomer falls well below the test limit as shown in Figure 24.

**Figure 24.**

The lactic acid erosion test involves a jet impingement of lactic acid solution against the test material. The Vitremer ionomer exhibits very minimal erosion as indicated in Figure 25. The conventionally setting glass ionomers are significantly more soluble by this protocol. The negative numbers shown for Fuji II LC and VariGlass indicate that these products swell slightly in the acid solution.

**Figure 25.**
Radiopacity

Radiopacity is determined in accordance with ISO Specification 4049. By this specification, the radiographic density of a test material is compared and normalized to that of a 2mm thickness of aluminum. A value of one or more indicates that a material is radiopaque and a value of less than one indicates that a material is radiolucent. Vitremer™ Ionomer is radiopaque. A comparison of its radiopacity is shown with other dental filling materials in Figure 26. The radiopacity of Vitremer ionomer is most similar to that of the former P-30 product, a material judged by Norwegian investigators, Tveit and Espelid5,6 to allow detection of caries and defects adjacent to it.

Surface Roughness

Surface roughness measurements have been made after polishing with Sof-Lex™ Discs and after tooth brushing the polished surfaces of Vitremer ionomer, the major conventional restorative ionomers and representative composite restoratives. The glass ionomer products were coated with an unfilled resin after polishing in accordance with manufacturers’ instructions. Data is graphed in Figure 27. While the surfaces of the Vitremer ionomer are not as smooth as that of the microfill Silux Plus, they are smoother than those of the conventional glass ionomer restoratives tested and comparable by this test to APH, a composite used for esthetic anterior restorations.

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Numerous evaluations of the Vitremer ionomer have been conducted with U.S. dentists. Overall, they have found the surface smoothness very acceptable and in fact, remarkable for a glass ionomer. In the European evaluation reported to date, 94–97 percent of the dentists have indicated that the smoothness of the material is acceptable.

**pH Change**

*Figure 28* is a plot of the change in pH of the Vitremer ionomer and two conventional restorative glass ionomers. The pH of Vitremer ionomer is higher, i.e. less acidic at the onset of mixing than that of the other ionomers at ten minutes.

**Setting Characteristics**

Shown by the following table are the working time/setting characteristics of the Vitremer ionomer compared in general, with the conventionally setting glass ionomers.

<table>
<thead>
<tr>
<th></th>
<th>Conventional Glass Ionomer</th>
<th>Vitremer™ Tri-Cure Mode</th>
<th>Vitremer™ Self-Cure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working Time</strong></td>
<td>1–2 minutes</td>
<td>3 minutes</td>
<td>3 minutes</td>
</tr>
<tr>
<td><strong>Setting Time</strong></td>
<td>4–7 minutes</td>
<td>40 minutes (light)</td>
<td>3.5–4.5 minutes</td>
</tr>
</tbody>
</table>
Use

The Vitremer™ Tri-Cure Glass Ionomer System is indicated for use as an esthetic restorative filling material for:

- Class III and Class V restorations
- Restoration of cervical erosion/abrasion lesions
- Restoration of root caries lesions
- Class I and Class II restorations in primary teeth
- Temporary repair of fractured teeth

It is also indicated for:

- Filling defects and undercut areas in crown preparations
- As a core buildup where at least half the coronal tooth structure is remaining to provide structural support for the crown

The basic procedure for a dentist using the system as a restorative filling material and as a core buildup is as follows:

- Apply primer for 30 seconds, air dry
- Light cure—20 seconds
- Place ionomer mix
- Light cure—40 seconds
- Finish
- If desired, apply gloss, light cure 20 seconds (not indicated for core builds)

While the full instructions for use of the product have been included for your reference and study at the end of this profile, let us review some of the key procedural steps.

Shade Selection

As with composite systems, shade selection for an esthetic restoration should be made when the teeth are fully wet, before isolation. For core buildups, while any shaded powder can be used, the blue shade provides contrasting color to tooth structure, a feature dentists like, and it has greater depth of cure than the darker shades such as A4 and C4.

Priming

The primer is quite fluid so should be dispensed into a well rather than onto a pad. It is applied to both enamel and dentinal surfaces for 30 seconds. We recommend that the tooth surfaces be kept wet with the primer for the full application time. If pins have been placed for a core buildup, the primer should also be applied to the pins. After application, the primed surfaces are not to be rinsed but must be dried using an air syringe and then light cured for 20 seconds. The primed surfaces will still appear shiny after the air drying and after the light curing steps.

Using the primer as instructed is critical to achieving optimal adhesion of the glass ionomer to tooth structure. It should not be eliminated from the procedure.
Dispensing
The standard powder/liquid ratio of 2.5/1 by weight can be obtained with an equal number of level powder scoops and liquid drops. Based on our evaluations, we expect that 2 scoops of powder and 2 drops of liquid will be an adequate amount of material for most restorative filling applications and 4 scoops to 4 drops, an adequate amount for most core buildups. These are only guidelines as users will determine appropriate amounts for specific applications as they become familiar with the product. We recommend that a separate mix be made for each restoration to be placed.

This is based solely on our experience with some evaluators who placed multiple restorations from a single mix and then had inadequate working time to contour them. Again, experience with the product will become the user’s best guide.

Mixing
We instruct the user to mix all of the powder into the liquid within 45 seconds using a cement spatula. Some new users may have difficulty mixing the Vitremer ionomer as it is a fairly high powder-to-liquid ratio and the liquid is fairly viscous. The resulting mix is relatively thick. Use of a large cement spatula will facilitate mixing. For some, incrementally mixing the powder into the liquid will ease mixing. Many evaluators have done this intuitively. Evaluations conducted with experienced dental assistants indicate that the ionomer does mix differently than other materials they are more accustomed to mixing but they were able to mix the material within the recommended time period.

Working time at a room temperature of 73°F (23°C) for the standard powder/liquid ratio is 3 minutes from the start of mix. Excessive time spent mixing will reduce the working time.

Placement
We recommend placement of the ionomer mix with a syringe system. Most of our evaluators reporting on their experiences with the material found this placement technique to be acceptable and have used it. Some preferred to use plastic placement instruments for some applications. The material can be placed in bulk, i.e. in thicknesses greater than those through which light can penetrate. Placement in layers with a separate light cure of each layer is not required. However, should a dentist prefer to use a layering technique, this can be done.

Curing
A 40–second light exposure will cure the A3, C2, Pedo and Blue shades to a depth of 2.5mm and the A4 and C4 shades to a depth of 2mm. The self-cure set time for all the shades is 4 minutes from the start of mix at oral cavity temperature.

Finishing and Polishing
The ionomer can be finished or prepared in the case of a core buildup, immediately after light curing or completion of self-curing. We recommend that the instruments used for these functions be used wet.
Finishing Gloss
A light–cure finishing gloss is part of the Vitremer system. Its use is optional and, if desired, can be applied after restoration has been finished and polished. It then would be light–cured for 20 seconds. It is not recommended to apply the finishing gloss to core buildups. The air–inhibited surface on the gloss would adversely affect the set of some impression materials.

In summary, it can be seen that the Vitremer™ Ionomer System is a relatively fast and easy system to use.

Use as a Liner
More fluid consistencies than the standard powder/liquid ratio have been evaluated with dentists for use of the Vitremer ionomer as a cavity liner. Of these, a ratio of 0.8/1 by weight was found to be the most desirable although the handling and amount of material dispensed for this application are not optimal.

The Vitremer ionomer has not been specifically manufactured for use as a liner. However, if a dentist wants to use it as a liner, and will accept the less-than-optimal handling characteristics and tolerate the anticipated waste, performance of the material is expected to be quite acceptable. Adhesion to dentin was determined to be excellent even without application of the primer. While Vitrebond liner/base remains the material of choice for lining applications, as it was developed specifically for these uses, the use of Vitremer ionomer as a liner could be recommended at the 0.8/1 powder/liquid ratio (1 scoop powder/3 drops liquid). No application of the primer would be required in this use. The material would be dispensed, mixed within a 45-second period, applied to dentin in a thin layer (0.5mm or less) and light cured for 30 seconds.
Competition

Considerable information on products competitive with the Vitremer™ Ionomer System has been presented in the discussion of properties. Most of the data are summarized in the following table for your convenience. Additional comments relative to the advantages of the Vitremer ionomer compared with the competitive products in general and specifically will follow.

The advantages of the Vitremer ionomer system compared in general with composites used as restorative filling materials and as core buildups are:

- Bulk placement versus the time — consuming need to place and cure the light-cure composites in increments
- Bond to tooth structure — no need for the application of a separate adhesive
- Fluoride release supported with in vitro artificial caries inhibition
- Moisture compatibility
- Toughness

The advantages of the Vitremer ionomer system compared in general with amalgams used as restorative filling materials and as core buildups are:

- Esthetics
- Bond to tooth structure
- Allows for more conservative cavity preparations
- Fluoride release supported with in vitro artificial caries inhibition
- Immediate finishing

The advantages of the Vitremer ionomer system compared in general with the conventionally setting glass ionomers used as restorative filling materials and as core buildups are:

- Easier to use — longer working time and rapid set by light exposure
- Tougher
- Less brittle
- Esthetic
- Better bond strength to tooth structure as measured in vitro
- Less sensitive to moisture contamination and dehydration

The advantages of the Vitremer™ Ionomer System compared with the light-cure glass-ionomer restorative is:

- Bulk placement
- Adhesion to dentin in the absence of light
At present, Fuji II LC is the dominant if not only light-cure glass-ionomer restorative filling material commercially available. The product is a true glass ionomer showing the characteristic composition and setting reaction for this category of dental materials. Its major disadvantage is that it must be placed and light cured in increments to achieve adhesion to dentin. By contrast, Vitremer ionomer can be placed in bulk and yet achieve bonding to dentin. Bulk placement affords the user easier, more rapid placement.

The advantages of the Vitremer ionomer system compared with the products claimed to be glass ionomers or fluoride–releasing, eg. Geristore, VariGlass, Fluorocore are:

- Fluoride release supported with in vitro artificial caries inhibition

### Comparison Table

Standard Deviation in parenthesis

<table>
<thead>
<tr>
<th></th>
<th>Vitremer™ TC</th>
<th>Victremer™ SC</th>
<th>Ketac™ Fil</th>
<th>Fuji II</th>
<th>Ketac™ Silver</th>
<th>Miracle Mix</th>
<th>Fuji II LC</th>
<th>VariGlass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture Resistance, Newtons</td>
<td>1800</td>
<td>—</td>
<td>—</td>
<td>650</td>
<td>—</td>
<td>1050</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Fracture Toughness, MN/m^1.5</td>
<td>1.87 (0.03)</td>
<td>—</td>
<td>0.71 (0.09)</td>
<td>0.49 (0.06)</td>
<td>0.65 (0.05)</td>
<td>0.74 (0.08)</td>
<td>1.70 (0.07)</td>
<td>1.15 (0.01)</td>
</tr>
<tr>
<td>Compressive Strength, MPa</td>
<td>219 (7.1)</td>
<td>194 (8.4)</td>
<td>172 (6.0)</td>
<td>156 (21.2)</td>
<td>170 (4.3)</td>
<td>128 (2.9)</td>
<td>216 (4.8)</td>
<td>207 (6.5)</td>
</tr>
<tr>
<td>Diametral Tensile Strength, MPa</td>
<td>40.3 (8.4)</td>
<td>33.1 (2.9)</td>
<td>15.4 (1.7)</td>
<td>7.9 (1.6)</td>
<td>14.1 (1.4)</td>
<td>7.0 (0.9)</td>
<td>30.4 (4.3)</td>
<td>33.8 (1.2)</td>
</tr>
<tr>
<td>Flexural Strength, MPa</td>
<td>61.7</td>
<td>—</td>
<td>12.2</td>
<td>14.3</td>
<td>26.9</td>
<td>10.6</td>
<td>56.6</td>
<td>20</td>
</tr>
<tr>
<td>Adhesion to enamel, MPa</td>
<td>10.3 (3.7)</td>
<td>8.2 (2.1)</td>
<td>4.1 (0.7)</td>
<td>4.1 (0.9)</td>
<td>2.5 (0.7)</td>
<td>2.2 (0.5)</td>
<td>14.1 (4.2)</td>
<td>12.9 (2.6)</td>
</tr>
<tr>
<td>Adhesion to dentin, MPa</td>
<td>5.5 (2.9)</td>
<td>4.6 (2.2)</td>
<td>3.1 (0.5)</td>
<td>3.1 (0.8)</td>
<td>0.9 (0.9)</td>
<td>3.1 (0.8)</td>
<td>3.8* (2.8)</td>
<td>4.5 (4.6)</td>
</tr>
<tr>
<td>Water Leachable Content, %</td>
<td>0.05</td>
<td>0.22</td>
<td>0.71</td>
<td>0.49</td>
<td>0.25</td>
<td>0.4</td>
<td>0.03</td>
<td>0.19</td>
</tr>
<tr>
<td>Radiopacity</td>
<td>1.4</td>
<td>—</td>
<td>0.9</td>
<td>1.3</td>
<td>—</td>
<td>—</td>
<td>1.6</td>
<td>—</td>
</tr>
<tr>
<td>Working Time, from start of mix</td>
<td>3:10</td>
<td>3:10</td>
<td>1:20</td>
<td>1:40</td>
<td>1:20</td>
<td>1:00</td>
<td>3:10</td>
<td>&gt;2 days</td>
</tr>
<tr>
<td>Set Time, from start of mix</td>
<td>0:40 (light)</td>
<td>4:00</td>
<td>4:00</td>
<td>5:30</td>
<td>4:00</td>
<td>2:50</td>
<td>0:40 (light)</td>
<td>0:20 (light)</td>
</tr>
</tbody>
</table>

*Light-cured. When the Fuji II LC material is not light cured but allowed only to cure by its glass ionomer cure, adhesion to dentin has been determined to be zero.
Questions and Answers

Q What does “redox” mean?
A Redox means the same as oxidation-reduction. It is a chemical reaction in which one of the reactants is reduced (gains one or more electrons) and another is oxidized (loses one or more electrons). The redox catalysts contained in the Vitremer™ Powder react in this manner when the powder is mixed with the aqueous Vitremer liquid. This reaction initiates the methacrylate cure of the ionomer mix in the absence of light.

Q Is the Vitrebond copolymer the same as the Vitremer liquid?
A No. The Vitrebond copolymer is the modified polycarboxylic acid which is contained in the Vitrebond liquid.

Q Is the Vitremer liquid the same as the Vitremer liquid?
A No, but they are very similar in their constituents. They both contain the Vitrebond copolymer, HEMA, water and photoinitiator systems. However, the Vitremer liquid has a higher concentration of the Vitrebond copolymer and lower concentrations of HEMA and water.

Q Can the Vitrebond liquid be substituted for the Vitremer liquid in the Vitremer System?
A No, this is not recommended.

Q What are the similarities and differences between Vitremer primer and Scotchbond™ Multi-Purpose Primer?
A They both contain a like concentration of Vitrebond copolymer and HEMA. However, the Vitremer primer also contains ethanol as a drying aid and photoinitiators so that it can be light cured. The Scotchbond Multi-Purpose primer has no ethanol and also no photoinitiator system and thus is not light curable.

Q When the solubility tests were done, was the Vitremer ionomer glazed?
A No, the samples were not glazed.
Questions and Answers

**Q** What is the standard powder/liquid ratio?

**A** The standard powder to liquid ratio is 2.5 to 1 by weight. This ratio can be obtained with an equal number of level scoops of powder and drops of liquid. Because of variability inherent in the dispensing system employed, a range of ratios likely will be obtained by users. Also, dental teams tend to mix powder/liquid systems to their particularly desired consistencies and they appreciate this flexibility. The following table shows some key properties of the Vitremer™ Glass Ionomer at three powder/liquid ratios. It can be seen that while mean values may differ by mix ratio, excellent properties are achieved across the range. It should be noted too that powder/liquid ratios below 2.2/1 are quite fluid and were found to be undesirable by evaluators for use as restorative filling materials and as core buildups. Powder/liquid ratios greater than 2.8/1 are very thick and difficult to mix and thus undesirable.

<table>
<thead>
<tr>
<th></th>
<th>2.2/1</th>
<th>2.5/1</th>
<th>2.8/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear bond strength, MPa</td>
<td>8.7 (2.3)</td>
<td>9.8 (1.8)</td>
<td>6.5 (1.9)</td>
</tr>
<tr>
<td>Compressive strength, MPa</td>
<td>209.7 (8.4)</td>
<td>225.5 (3.0)</td>
<td>232.4 (7.7)</td>
</tr>
<tr>
<td>Diametral tensile strength, MPa</td>
<td>37.8 (0.9)</td>
<td>39.9 (1.3)</td>
<td>30 (2.4)</td>
</tr>
</tbody>
</table>

**Q** How does the Vitremer ionomer handle?

**A** When mixed at the standard powder/liquid ratio of 2.5/1, the mix is nicely thick and putty-like. Current users of the capsulated glass–ionomer products may find the Vitremer somewhat thicker in consistency by contrast. Compared with composite, the Vitremer ionomer may be perceived to be somewhat softer and, depending upon which composite is used, slightly sticky.

**Q** Does Vitremer ionomer bond to itself?

**A** Yes, adhesion studies indicate that the bond strength of Vitremer ionomer to cured, non-contaminated Vitremer ionomer is about 8 MPa.

**Q** Does Vitremer ionomer bond to itself when it has been contaminated by saliva?

**A** Yes. Adhesion studies indicate that additional Vitremer ionomer can be added to cured Vitremer ionomer that has been contaminated by saliva. The contamination should be rinsed away, the ionomer surface dried and then additional material placed.

**Q** Has the new tri-cure ionomer been subjected to histological examination?

**A** Histological examinations of the Vitremer tri-cure glass ionomer were conducted at the Forsyth Dental Center, Boston, MA under the direction of Dr. I. Leon Dogon and at the University of Alabama, Birmingham, AL under the direction of Dr. Charles F. Cox. They were conducted with and without a primer in monkeys in accordance with ISO Standard 7405. This protocol involves sacrificial periods at three to five days, one month and three months. Results from the studies were that the tri-cure glass ionomer revealed no adverse pulpal reaction at any of the sacrificial periods. The investigators from Forsyth presented results of their study at the International Association for Dental Research meeting in Glasgow, Scotland in June, 1992, abstract number 68.
By what mechanism does the Vitremer™ ionomer bond to tooth structure?

The mechanism of adhesion of glass ionomers to dentin and enamel is not well understood and although several hypotheses have been advanced the exact mechanism has not been fully elucidated.

On the basis of infrared and adsorption studies, Wilson and co-workers have suggested that initially there is an wetting of the tooth by the polycarboxylic acid of the cement mix. This is followed by ionic bonding between the matrix polycacid and calcium ions from the hydroxyapatite. Further credence to this hypothesis is offered by the titrimetric work of Iloka et al. An additional theory is that the polyacrylates bond to the collagen molecules of dentin. However there is no evidence to support the latter hypothesis. In light cure glass ionomers, the additional possibility of some penetration into the dentinal tubules cannot be ruled out based on confocal microscopy studies.

The 3M Vitremer tri-cure glass ionomer system is based on the foundation of Vitrebond chemistry. In a clinical study, Powell et al. have reported that the Vitrebond™ System used as a liner and covered with composite, had 100% retention in Class V situations over the course of three years. In general, glass ionomers have performed well in terms of clinical retention compared with composite-based systems even though in any comparison of in vitro bond strength values, the adhesive bonding agents fare better. Since purely resin-based dentin bonding agents are believed to bond by purely mechanical interlocking, only the adhesion of glass ionomers to tooth substrates must involve some additional mechanism. It is also interesting to note from studies by Prati et al that hydrostatic intrapulpal pressure does not affect the bond strength of Vitrebond to dentin. The reason for this is that the water-soluble polycarboxylic acid of Vitrebond is able to absorb any water exuding from the dentin and therefore negate its effect in debonding the overlying layers.

One of the fundamental rules in obtaining a good adhesive bond is to bring together two surfaces that are equivalent in their surface energies. The other rule is that the adherend must intimately wet the substrate to which it has to bond. In the Vitremer tri-cure glass ionomer system, the acidic, low viscosity primer modifies the smear layer and wets the tooth structure so as to provide a constant surface which is ideally receptive to the glass ionomer mix. The acidic polymer of the primer has strong inherent attraction for the dentin and enamel surfaces. Photocuring the primer crosslinks the methacrylate groups of the polymer and provides an integral surface that is ready for the placement of the ionomer mix. As is evident from SEM studies, once the Vitremer mix is placed on the primer the polyacid of the primer reacts with the fluoroaluminosilicate glass of the glass ionomer mix. The primer thus becomes a part of the overall glass ionomer restoration.