Glass ionomer cements in pediatric dentistry: review of the literature

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Abstract

Glass ionomer cement systems have become important dental restorative and luting materials for use in preschoolers, children and teenagers. These materials form chemical bonds to tooth structure, are biocompatible, release fluoride ions for uptake by enamel and dentin, and are able to take up fluoride ions from dentifrices, mouthwashes, and topically applied solutions. Unlike early glass ionomers, the new cement systems are easy and practical to use. Resin-modified glass ionomer cements not only have improved physical characteristics, but the photopolymerizable resin component reduces initial hardening time substantially. This article reviews the development and history of glass polyalkenoate cement systems and their ongoing role in dentistry for children.(*Pediatr Dent*. 2002;24:423-429)

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Glass polyalkenoate cements, are materials made of calcium or strontium aluminofluorosilicate glass powder (base) combined with a water soluble polymer (acid). Kent called such materials "glass ionomer" cements, and that name has become part of the dental vernacular.[1] Glass ionomers were invented in 1969 and reported by Wilson and Kent in the early 1970s.[2,3]

Glass ionomer cement components, when mixed together, undergo a setting reaction involving neutralization of the acid groups by the powdered solid glass base. Without diminution of physical properties of the hardened cement, significant amounts of fluoride ions are released during this reaction.

There has been some confusion as to what dental restorative materials or luting cements can be considered "glass ionomer" cements. McLean, Nicholson and Wilson suggested nomenclature which succinctly defined the respective materials.[4] They noted that polyacid-modified resin-based composites, commonly called "compomers," are light-polymerized resins containing basic glass filler and acid functional groups. Such materials harden by photopolymerization. Once moisture (saliva) saturates the hardened resin, the glass ionomer components do react and release some fluoride, but this reactivity occurs within the polymerized resin.

Another type of material is resin-based composite that incorporates large particles of hardened glass ionomer cement within its mass. This type of material does not bond to tooth structure like a glass ionomer cement, releases little fluoride and has polymerization contraction of the constituent resin. Two other types of true glass ionomer materials are those modified by inclusion of metal (for example, glass ionomer silver cermet cement) and those with a light-polymerized liquid resin component that renders the cement photocurable as part of the overall hardening reaction. These "resin-modified glass ionomer cements" have gained much interest and use in pediatric dentistry over the last decade.

The term "glass ionomer cement" should be applied only to a material that involves a significant acid-base reaction as part of its setting reaction, where the acid is a water-soluble polymer and the base is a special glass.[4-6] Berg,[7] Albers,[8] and Ewoldsen and Herwig[9] expertly elucidated the vast array of modern adhesive restorative materials.

Original self-hardening glass ionomer cements

The setting of these self-hardening glass ionomer materials has been described as follows:[5]

"As the cements set, water becomes incorporated into the material, and there is no phase separation. In fact, water has been identified as having a number of roles:

1. It is the solvent for the setting reaction, because, without it, the polymeric acid would be unable to exhibit its full properties as an acid.
2. It is one of the reaction products.
3. It acts as both coordinating species to the metal ions released from the glass and as hydrating species at well-defined sites around the polyanion.
4. It may act as a plasticizer and reduce the rigidity of the bulk polymeric structure."

The setting reactions of glass ionomer cements are:[6]

1. Initial decomposition of the glass under the influence of the aqueous polyacid, leading to the release of calcium and aluminum ions. The latter ions are less readily released, probably because they have existed in the glass as complex oxyanions.
2. Rapid reaction of the calcium ions with the polyacid chains, followed by later reaction of aluminum ions species, reflecting the more gradual release of the latter ion from its anionic complex. Reaction of metal ions with the carboxylic acid groups displaces water from some of the hydration sites, and leads to some ionic cross-linking of the polyacid chains. Both of these effects lead to insolubilization of the polymer and stiffening of the material.
3. Gradual reconstruction of the inorganic fragments also released in step 1 to yield a matrix of increasing strength, greater resistance to desiccation, and improved translucency.

The original glass polyalkenoate formulations developed in the 1970s failed to gain much interest from dental clinicians treating children. Those materials required extended setting time, were susceptible to dissolution or desiccation during the hardening reaction and, once hardened, had poor wear resistance and poor fracture strengths. Regardless of the advantages of (1) fluoride ion release and uptake, (2) coefficients of thermal expansion similar to that of tooth structure, (3) biocompatibility, and (4) chemical bonding to both enamel and dentin, dentists were not about to adopt materials that took longer to use, were difficult to handle, and proved unreliable in the long term because of poor durability.

The speed of the hardening reaction and ultimate strength of a glass ionomer formulation depends on powder/liquid ratio of the components, molar mass of the polyacid and its concentration, and the presence of chelating agents such as ± tartaric acid. Researchers discovered that inclusion of ± tartaric acid made it possible to use different compositions of glass so that the hardened cements were more translucent. Besides improving tooth-color matching in comparison to the early opaque glass ionomers, incorporation of ± tartaric acid also made the hardening reaction faster and more definitive.[10,11] These improvements made glass ionomer materials more attractive and practical for the clinician.

Classification of glass ionomer materials

Glass ionomer cements used for children and teens can be categorized as restorative cements, including liner/base materials, or luting cements. Restorative cements can be further described as self hardening or partially light hardening, metal modified, and resin modified. Glass ionomer luting cements are self hardening, and some are modified with resin. In addition, there are some instances in which a photocurable resin-modified glass ionomer restorative cement can be used with a lower powder/liquid ratio to serve as a luting cement. Such material is ideal for cementing orthodontic bands and space maintainers.[12]

In the 1980s, with the goal of creating stronger and more durable glass ionomer materials, one manufacturer added silver amalgam powder to the glass powder (Miracle Mix, GC America, Inc., Alsip, Ill). Another combined the glass powder with elemental silver (cermet) by a process of high-heat fusion (sintering) (Ketac-Silver, 3M ESPE, St. Paul, Minn, formerly ESPE, Seefeld, Fed. Rep. Germany).[13-15] Adding fibers to reinforce experimental cements was also investigated.[16]

The addition of silver had the advantage of increasing radiopacity of the cements. In addition, wear resistance of the silver cermet cement was somewhat improved over traditional glass ionomer restorative material. However, fracture resistance and fracture toughness of the metal-modified materials are still too low to recommend the materials for stress-bearing regions of teeth, and the gray color precluded routine use of the cermet in anterior teeth.

Despite its disadvantages, Ketac-Silver did establish a modest niche for itself in pediatric dentistry as a silver amalgam substitute in certain cases.[17,18] Use of the silver cermet cement in children decreased greatly with introduction of tooth-colored, resin-modified glass ionomers in the early 1990s.

Resin-modified glass ionomer restorative cements

An important advancement in glass ionomer technology that has influenced dentistry for children is development of the resin-modified glass ionomer systems. Vitrabond (now spelled "Vitrebond"), a resin-modified glass ionomer base/liner, was introduced by 3M Dental Products Division.[19-21] Vitrebond is supplied in a powder/liquid format and needs to be spatulated by hand. The liquid polyacid component includes a photopolymerizable resin which hardens the material substantially when a visible light beam is applied. Once the resin component has been cured, the glass ionomer hardening reaction continues, protected from moisture and overdrying by the hard resin framework. "On command" light-hardening in about 40 seconds makes Vitrebond a practical and valuable dentin replacement.

This material has been on the market for over 13 years and is known for: (1) preventing postoperative sensitivity when placed under direct application resin-based composite restorations, thus protecting against bacterial access to dentinal tubules, (2) its internal fluoride ion release,[22] and (3) its antimicrobial action.[23-25] Although made for dentin replacement, Vitrebond proved useful in children for nonstressbearing restoration of primary teeth.[26,27]

Light-hardened, resin-modified glass ionomer restorative cements were introduced in the early 1990s. Two of these materials were provided in predosed disposable capsules (Photac-Fil, [3M ESPE, and Fuji II LC, GC), and the other was available only in bottles for hand spatulation (Vitremer, 3M). Fuji II LC was also available in a hand-mixed version. Like Vitrebond, the resin-modified glass ionomer restorative cements harden initially by free radical photopolymerization of the resin component in the formulation. Forty seconds of visible light beam exposure substantially hardens these cements initially, and a chemical resin polymerization reaction and the glass ionomer setting reaction subsequently progress. Addition of the resin component within the glass ionomer formula not only decreases initial hardening time and handling difficulties, but substantially increases wear resistance and physical strengths of the cement.[28-30]

Fracture toughness, fracture resistance, and resistance to wear are all improved in the resin-modified glass ionomers. In addition, the major advantages of glass ionomers (fluoride ion hydrodynamics, biocompatibility, favorable thermal expansion and contraction properties, and physiochemical bonding to tooth structure) are retained.

It was discovered that, to achieve the best physical properties of resin-modified glass ionomer restorative cement, the mixture required the highest powder/liquid ratio possible, but with assurance that all the glass powder was thoroughly wetted with the acid solution during spatulation.[31-34] Such a mixture was possible only with the hand-spatulated cement. It should also be noted that there are differences in physical properties of the various brands that are not related only to powder/liquid ratios.[35] Even though some reports of glass ionomer materials have not been favorable,[36,37] these were related to self-hardening glass ionomer materials whose physical properties vary greatly from the resin-modified glass ionomers. Clinical reports and clinical research articles after 1993 have reported and documented much success with resin-modified glass ionomer systems.[38-47]

Fluoride ion release and uptake

When one considers the role of fluoride in preventive dentistry, it is easy to consider glass ionomer cement systems as therapeutic materials. Fluoride ions are not only released by glass ionomer systems, but also taken up by associated enamel and dentin, rendering that tooth structure less susceptible to acid challenge by a combination of decreased tooth structure solubility and disruption of bacterial activity that produces organic acids.[9,19,22-25,48-67] It has been shown that glass ionomer materials are able to release fluoride at a sustained rate for long periods of time (at least 5 years).[48,62] Also, being water-based systems, they act as continuing fluoride ion reservoirs in the mouth by taking in salivary fluoride from dentifrices, mouthwashes and topical fluoride solutions at the dental office.[66,67] Fluoride ion release and uptake associated with all the glass ionomer systems, while useful for all young patients, are particularly advantageous for those with high susceptibility to dental caries.

Glass ionomer luting cements

Early glass ionomer luting cements were commercially more successful than the restorative cements. Their physical strengths were sufficient for cementing stainless steel crowns, space maintainers, and individual stainless steel orthodontic bands. The added benefit of fluoride ion transfer was also an attractive advantage for caries-prone orthodontic patients.[68,69] Resin-modifed glass ionomer luting cements contain monomers that undergo polymerization together with initiators similar to those used in cold-cure acrylics (eg, benzoyl peroxide with amine accelerator). With increased physical strengths associated with inclusion of the resin component, these easy-to-use, adhesively bonded luting cements have gained much popularity.[5,70,71]

Dentists treating children find the photopolymerized, resin-modified glass ionomer luting cements especially useful for orthodontic bands and stainless steel crown cementation.[12] The curing light beam directed upon the occlusal surface of the tooth irradiates through tooth structure and hardens the cement held by the band against the axial tooth surfaces. Light hardening the luting cement in this manner takes minutes off the time required to cement each stainless steel band. In addition, the cement has high physical strengths and is virtually insoluble, so band loosening is most uncommon. Its only minor disadvantage is that the bonded cement sometimes needs to be cut with a bur for detachment from the enamel surface when the band or orthodontic device is removed. Light-hardened resin-modified glass ionomer luting cement is essentially the restorative cement blended with a slightly lower powder/liquid ratio.

Glass ionomer/resin-based composite stratification

One cannot comprehensively review glass ionomer cement systems for use in children and adolescents without discussing the technique of restoring a tooth with a combination of glass ionomer dentin replacement and bonded resin-based composite enamel replacement. This method has been called "lamination," the "sandwich technique" or "stratification." Since McLean and Wilson first suggested individualized dentin and enamel restoration, there has been much advocacy for the concept.[30,72-90] Development of the light-hardened glass ionomer systems has made placement of a glass ionomer liner/base much easier and quicker and, therefore, more practical.

Based on principles of "biomimesis"[90-92] (replacement of tissue or a part using materials that most closely replicate original essence), it can be argued that the properties of certain glass ionomer cements make them the best direct application dentin replacement material ever available. When overlaid with appropriate adhesively bonded resin-based composite, a resin-modified glass ionomer dentin replacement layer also virtually guarantees that there will be no post-operative tooth sensitivity for the young patient.

The future for glass ionomers in pediatric dentistry

Clinical research is producing scientific evidence that certain resin-modified glass ionomer restorative cement systems can give long-term reliability in dentistry for children.[44,45,47] One might believe that self-hardening glass ionomer restorative cements are now impractical in comparision to their light-hardened counterparts.

However, 2 encapsulated glass ionomer restorative cements have been introduced that harden by the conventional acid/base neutralization reaction, but have much improved physical properties compared to any other self-hardening glass ionomer restorative cement. Ketac-Molar (3M ESPE) and Fuji IX GP (GC) have a rapid set which significantly reduces early moisture sensitivity. Faster hardening has been achieved by altering the particle size and particle size distribution of the glass powder. Even newer versions of these cements are now available (Ketac Molar Quick and Fuji IX Fast) that require only about 120 seconds for significant initial hardening.[93] Such materials are ideal for certain uses in primary teeth, interim restorations in permanent teeth, long-term nonstressbearing restorations in permanent teeth, and in the "atraumatic restorative technique" (ART). ART has gained much interest internationally for patient populations who lack the advantages of modern dentistry.[94]

Bioactivity of glass ionomers

In recent years, the ability of glass ionomers to release ions apart from fluoride, notably calcium and aluminum, has been studied, and there is evidence to show that they promote remineralization of the tooth.[95] This seems to be related to their ability to buffer lactic acid,[96] an effect that was originally thought to be negative, because of its association with loss of cement by erosion.[97] However, very recently, it has been found that lactic acid at the pH of active caries (4.5) can be buffered to the pH of arrested caries (5.5) within less than 30 seconds, and with negligible erosion.[98] This effect is likely to be beneficial, and would inhibit the development of secondary caries around a glass ionomer restoration.

Summary

In the last 15 years, manufacturers have worked diligently to produce glass ionomer cement systems that have overcome the 3 chief disadvantages of this class of materials: (1) difficult handling properties, (2) poor resistance to surface wear, and (3) poor resistance to fracture. They have produced products that are improved to the point that these major disadvantages have either been eliminated or reduced to acceptable levels. The authors expect that improvements will continue and that glass ionomer cement systems will gain even more importance in restorative dentistry, preventive dentistry and orthodontics for young patients.

Disclaimer

The authors have no financial interest in any products or manufacturers identified in this article.

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Glass ionomer manufacturers

It is difficult to make an all-inclusive list of commercially available glass ionomer products because new products are constantly introduced and other products are periodically taken off the market. However, the authors consider it useful to designate the names of manufacturers that offer the various glass ionomer systems in North America. The authors have not considered polyacid-modified resin-based composites (compomers) in this listing:

GC America, Inc
(800) 323-3386
(708) 597-0900
www.gcdental.co.jp

3M ESPE Dental Products
(800) 634-2249
(651) 575-5144
www.3MESPE.com

Shofu Dental Corporation
(800) 827-4638
(650) 324-0085
info@shofu.com

Ivoclar Vivadent, Inc
(800) 533-6825
(716) 691-0010
www.ivoclarna.com