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REVIEW ARTICLE

Glass-ionomer Cements in Restorative Dentistry: A Critical Appraisal

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ABSTRACT

Glass-ionomer cements (GICs) are mainstream restorative materials that are bioactive and have a wide range of uses, such as lining, bonding, sealing, luting or restoring a tooth. Although the major characteristics of GICs for the wider applications in dentistry are adhesion to tooth structure, fluoride releasing capacity and tooth-colored restorations, the sensitivity to moisture, inherent opacity, long-term wear and strength are not as adequate as desired. They have undergone remarkable changes in their composition, such as the addition of metallic ions or resin components to their composition, which contributed to improve their physical properties and diversified their use as a restorative material of great clinical applicability. The light-cured polymer reinforced materials appear to have substantial benefits, while retaining the advantages of fluoride release and adhesion. Further research should be directed towards improving the properties, such as strength and esthetics without altering its inherent qualities, such as adhesion and fluoride releasing capabilities.

Keywords: Adhesion, Dentin bonding, Fluoride release, Glass-ionomers, Resin-modified glass-ionomers, Restoration.

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INTRODUCTION

Glass-ionomer cements (GICs) are clinically attractive dental materials that have certain unique properties which make them useful as restorative and luting materials. Glass-ionomer (GI) material was introduced by Wilson and Kent in 1972 as a "new translucent dental filling material" recommended for the restoration of cervical lesions. It consists of a powdered fluoroaluminosilicate glass and a polyalkenoic acid. Polyacrylic acid is often incorporated into the powder in its dehydrated form, leaving the liquid to consist of water or an aqueous solution of tartaric acid. The positive characteristics of the GICs include chemical adhesion to enamel and dentin in the presence of moisture, resistance to microleakage, good marginal integrity, dimensional stability at high humidity, coefficient of thermal expansion similar to tooth structure, biocompatibility, fluoride release, rechargeability with fluoride, and less shrinkage than resins upon setting with no free monomer being released. Originally the GICs were brittle water-based materials which set by an acid-base reaction between a polyalkenoic acid and a fluroalumino silicate glass. Subsequently the properties of GIC's were enhanced by the addition of either metal particle, such as silver or gold, by fusion process resulting in a "cermet" (ceramic-metal), or amalgam alloy particles by a simple addition ("admix").[1]

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CLASSIFICATION OF GICs

Based on Clinical Indication

- Type I GICs are the luting cements, characterized by low film thickness and rapid set[2]. Type I ionomers are indicated for the cementation of inlays, crowns, fixed partial dentures, orthodontic appliances, and endodontic filling. They are fluid materials, also identified as type I, CEM, C or luting.
- Type II GICs are ionomers indicated for restorations, presenting particles larger than those of type I, also identified as R or FIL, with subtypes 1 and 2.

Type II–1 GICs are esthetic cements (available in both conventional and resin-modified presentations) and Type II–2 GICs are "reinforced" (however, despite their description, are not necessarily stronger than type II–1 products). However, they are more wear-resistant.

- Type III GICs are the lining cements and fissure sealants, characterized by low viscosity and rapid set also known as bond and lining or F.

Based on Composition of GICs

Conventional GICs

Glass-ionomers are derived from organic acids and a glass component, and are referred to as acid-base reaction cements. In anhydrous cements, the liquid acid component was freeze-dried (dehydrated) and incorporated into the powder. It is mixed with distilled water or in an aqueous solution of tartaric acid, which accelerate the setting reaction. It is also available as powder and liquid. The glass components and the fluoride are inside the powder and the acid components inside the liquid.

Resin-modified Glass-ionomer Cements (RMGICs)

The RMGICS were introduced as an attempt to overcome the problems such as moisture sensitivity and low physical properties associated with the conventional GIC. The resin modified cements improved the physical properties while maintaining the clinical advantages of the traditional GICs, such as adhesion and fluoride release and offering some protection against caries. These materials generally set via a dominant acid-base reaction and auxiliary photo polymerization. The addition of hydrophilic resin monomers (2-hydroxyethylmethacrylate (HEMA)), about 4.5 wt%, and a photo-initiator, RMGIC are polymerized with visible light.[3] The RMGICs contain a basic ion-leachable glass, a water-soluble polymeric acid, organic monomer/s and an initiator system.[4] The advantages of RMGICs are control of working time, ease of handling, fast setting time, less sensitive to syneresis and imbibition. Due to the micromechanical adhesion to the hydroxyapatite, these cements showed stable bonding to the dentin and enamel.[5] The mechanical properties of the RMGICs can be improved further by the addition of spheroid silicate fillers. The addition of silanized particles improved the compressive strength by 17%, whereas the use of non-silanized particles increased the compressive strength only by 9%. A 17% increase of flexural strength was observed by both filler types.[6]

Polyacid-modified Composite Resin (Compomer)

The term "compomer" is an acronym derived from "composite" and "glass-ionomer," and it reflects the intent to produce a restorative material that combines components and properties of both materials.[7] These materials have a superior esthetic value along with the fluoride-release capabilities of GI. Compomers are in fact light-polymerized composite resin restoratives, modified to contain ion-leachable glass particles and anhydrous (freeze-dried) polyalkenoic acid.[8] The compomers have relatively lower rates of fluoride release due to the presence of the resin bonding agents required for compomer-tooth adhesion.[9] Mechanical properties of compomers are inferior to those of conventional composite resins, thus limiting their use for restoration of noncarious cervical lesions.[10]

Metal Reinforced GICs

Researchers have investigated the influence of the addition of a range of metallic powders to GICs, such as Silver alloys, gold, palladium, and titanium oxide.[11,12] The addition of a spherical amalgam alloy powder (Lumi Alloy; GC Corporation) to Fuji II (GC Corporation) was tried and a variant was subsequently marketed as "Miracle Mix" in 1983 by the GC Corporation.[11,13] The liquid is similar to that of the conventional ionomers, while the powder consists of a mixture of conventional powder with amalgam alloy particles or silver particles sintered with the glass. The sintering of a precious metal with the GI glass constituent was used as an alternative approach to metal reinforcement of GIs and was marketed by ESPE GmbH as glass-cermet cements under the trade names of Chelon Silver which was hand-mixed and Ketac Silver which was encapsulated.[14] The cermet powders were prepared by mixing equal volumes of silver powder (mean particle size 3.5 mm) and a GI glass powder. The blended powders were compressed at 350 MPa to form metal-glass powder pellets which were sintered at 800°C and ground to fine powder. In an attempt to improve the esthetics, 5 wt% of titanium dioxide was added and the blended powders were mixed with a 46% solution of acrylic, maleic and tartaric acids at powder: liquid mixing ratios of 4:1 (Chelon Silver) and 4.5:1 (Ketac Silver).[1] The cermet materials were not tooth-colored owing to the silver in the powder constituent which caused discoloration of the cermet restored teeth. The poor esthetics of cermets limited their range of clinical applications to pediatric dentistry.[15] The inclusion of metallic particles brought damage to materials in relation to fluoride release, adhesion to tooth structure, as well as the esthetic damage arising from the darkening of the edges of the cavities. Cermet type GIC has been employed in invasive sealing of posterior teeth and some cases of crown reconstruction.

High-viscosity GICs

The high-viscous or condensable GICs, with better mechanical properties than traditional GICs were developed for atraumatic restorative treatment (ART).[16] They have a high powder-liquid ratio and fast setting reaction. The high viscosity GICs have improved physical properties by chemical modifications to the heat history of the glass powder that allow higher powder-liquid ratios than earlier conventional restoratives. The characteristics include the adhesion and ion exchange common to all GIs as well as fast setting times, and high levels of compressive and tensile strength, surface hardness, and fluoride release.[17] These attributes render these materials an excellent choice for bases, emergency temporary restorations, long-term provisional restorations, and final restorations in non-stress-bearing areas, particularly in high-caries-risk patients.[18]

Zirconia Reinforced glass-ionomer (ZIRCONOMER)

Recently, Zirconia reinforced glass-ionomer (ZIRCONOMER, Shofu Inc., Japan) a novel material was introduced that could overcome the drawbacks of previously used tooth colored restorative materials. It contains zirconium oxide, glass powder, tartaric acid (1–10%), polyacrylic acid (20–50%) and deionized water as its liquid. Zirconium oxide, the main powder component of ZIRCONOMER results from Baddelyite (ZrO_2) that contains high levels of zirconia ranging from 96.5 to 98.5%.[19] In the early 1990s, Zirconia was popularized into dentistry as endodontic posts,[20] later on as implant abutments[21] and hard framework cores for crowns and fixed partial dentures.[22] The accessible zirconia powders have different grain sizes and different additives such as yttrium oxide and alumina that can be distributed homogeneously throughout the whole material or higher concentration at grain borders.[23] Grain size variety affects the resulting porosity as well as the translucency of the material. The glass component of ZIRCONOMER is subjected to controlled micronization to acquire optimum particle size and characteristics.[19] The grain size has an effect on an exclusive characteristic of zirconia called transformation toughening, which gives it higher strength, toughness, high hardness, and corrosion resistance, thus when homogeneously incorporated in the glass component, further reinforces the material for lasting durability and high tolerance to occlusal load.[19] Hence, this biomaterial promises to show outstanding strength, durability and sustained fluoride protection thus combining and retaining the benefits of both popularly used restorative materials: amalgam and conventional GI.

Biocompatibility

The pulpal response of GICs are better than the other restorative materials such as zinc oxide and zinc polycarboxylate cements.[24] The better biocompatibility is due to the weak nature of the polyacrylic acid with macromolecules of high molecular weight which is prone to bind to calcium of the tooth. Glass-ionomer cement has also better response to the periodontal tissues and is capable of reducing subgingival biofilm compared with resin composite restorations, not irritating the tissues if the biological principles are followed.[25] The initial low pH is responsible for the sensitivity following crown cementation and it increases as the cement sets.[26] However, studies revealed that the dentin buffers the hydrogen ions released from GIC, and also has shown that GIC was not associated with postoperative sensitivity.[27] With regards to the systemic effects, the aluminum leached in varying degrees from GICs has been studied and concluded that this ion is largely excreted and poses a negligible health hazard.[28]

Fluoride Release and Storage

Fluoride is effective against caries and it acts by inhibiting the metabolism of cariogenic bacteria and enhancing the resistance of enamel and dentin by helping in the demineralization of enamel and dentin. The mechanism of release of fluoride from the glass particles on mixing with the polyalkenoic acid is complex and not fully understood. Most of the fluoride is released as sodium fluoride, which is not critical to the cement matrix, and thus does not result in weakening or disintegration of the set cement.[29] The sustained, long-term fluoride release especially in marginal gaps between filling material and tooth help prevent secondary caries of the dental tissues.[30] The conventional GIC's releases up to 10 ppm and a constant long-term release of 1 – 3 ppm up to 8 years.[31] This ability to release and store fluoride, makes GIC an excellent choice of restorative material in treating patients at high risk for caries. The release of fluoride occurs mainly in the first 24 – 48 hours, but decreases and stabilizes over time, although it can occur throughout the life of the clinical restoration, with the possible reintroduction of fluoride ions.[32,33]

Adhesive Bonding Mechanism

The adhesive mechanism of the GICs to the tooth structure is an ionic bond between the GI and the calcium within the tooth structure. Basically an ionic bond occurs between the carboxyl (COO^-) ions in the cement acid and the calcium (Ca^{++}) ions in enamel and dentin.

Adhesion of GICs to the tooth can be considered to result from two inter-related mechanisms, such as micromechanical interlocking and true chemical bonding. The micromechanical interlocking is by the formation of short cement tags within the surface of the dentin and also a thin hybrid layer between hydroxyapatite-coated collagen fibrils at the tooth surface and the surface of the freshly placed GIC.[34] The slightly higher bond strength of the RMGICs is due to the presence of HEMA which enhances the micromechanical interlocking.[35] The true chemical bonding involves the formation of ionic bonds between the carboxylate functional groups on the polyalkenoic acid molecules and calcium ions in the hydroxyapatite surface.[36]

Clinical Applications of GICs

Glass-ionomer cements are the most versatile direct restorative materials, with many potential clinical indications, especially in the context of minimally invasive dentistry because of its chemical, mechanical and biological properties. Glass-ionomers used in restorative dentistry can be classified into 3 groups according to their applications: restorative (filling), lining, luting agents. The clinical applications are summarized below.

Clinical applications for direct-placement GI restoratives are as follows[37]:

- Class V restorations
- Caries control as provisional restorations
- Blockout of undercuts in crown and onlay preparations
- Dentin substitute as a base material
- Small core/foundation build-ups where at least 50% of the tooth structure is remaining
- Posterior restorations in primary teeth
- Temporary restoration of endodontic access preparations
- Temporary restorations in anterior/posterior teeth
- Orthodontic band cementation
- Orthodontic bracket adhesive
- Non-stress-bearing restorations
- Repair adjacent to crown margins due to subgingival caries
- Repair of endodontic root perforations
- Repair of external root resorptive lesions
- ART technique.

GICs in Endodontics

Glass-ionomer cements are bioactive and adhesive materials with a therapeutic action; they act as antimicrobial materials with a high degree of biocompatibility. Glass-ionomer cements are used as root end filling material. Because of its compatibility with soft tissue and bone, it is suitable filling material during endodontic surgery as a root canal sealing.[38]

DISCUSSION

Glass-ionomer cements were introduced in dentistry by Wilson and Kent (1972). Since then, several modifications have been introduced with the purpose of enhancing their mechanical properties.[39] The salient features of the GIC, include adhesive properties, marginal adaptation, biocompatibility, moisture sensitivity, fluoride release and strength. The intoduction of the resin-modified GIs with superior mechanical strength were used in the posterior resorations.[40] The newer generation of GI retained the most desirable qualities of conventional versions, namely fluoride release, ion exchange adhesion to conditioned enamel and dentin, and low interfacial shrinkage stress.[41] They also have greater working time which can be controlled by the light source and esthetics closer to resin-based materials.[42] Resin-modified and highly viscous versions of GI restorative materials can be used alone or in combination with composite resins to effectively treat many common restorative situations.

Due to the dimensional changes, marginal leakage can occur as a result of lack of adaptation of the restoration to the cavity. The resin-modified version exhibits more rapid setting contraction through the polymerization of the polymer component.[43] One of the concern about the traditional GICs were the low pH which could cause pulpal irritation. However, with the completion of the setting reaction, the pH gradually increases and reaches 6.7 – 7. Once the acid groups are bound to polymer molecules that have limited diffusivity, any potential effects to the pulp from initial pH are limited to areas immediately adjacent to the material. If the material is closer to pulp chamber it is desirable to protect it with calcium hydroxide liner.[33]

Glass-ionomer cements are highly versatile materials in restorative dentistry with great clinical potential mainly because of their natural adhesion to the tooth and also for their reasonable esthetics. The bonding of GICs to the tooth surface has been shown as a result of a good initial wetting, which reflects the hydrophilic nature of the freshly mixed cements, followed by long-term chemical and mechanical interactions leading to a strong interface. Glass-ionomer cement is considered as a biomimetic material, because of its similar mechanical properties to dentin.

The major applications of GICs are as long-term temporary restorations for caries control, to seal access openings of endodontically treated teeth, for core build-ups and for restoring primary teeth. The conventional GICs are not recommended as definitive restorations for the permanent dentition in stress-bearing areas because they do not have the wear resistance and resistance to chemical erosion. Resin-modified glass-ionomers cements have reduced moisture sensitivity and are more moisture tolerant. The zinc-reinforced GI improved the fluoride release and enhanced the wear resistance, flexural strength and fracture toughness.[33,44]

With the introduction of the new generation of GICs, there have been significant improvements to GICs that allow them to be used for routine restorations and provisional restorations. Glass-ionomer cements can be used to successfully restore both permanent and primary teeth based upon these clinical implications. Although advances have been made through different glass powder and polyacid liquid formulations during the past several years, further improvements in the mechanical properties of the current GICs are required to be indicated for the restoration of posterior dentition.[45]

CONCLUSION

Glass-ionomer cements are useful materials in restorative dentistry, and have a wide range of uses such as lining, bonding, sealing, luting or restoring a tooth. The RMGICs appear to have properties intermediate to the conventional GICs and resin composites and are often considered a hybrid of the two materials. However, the currently available commercial compositions represent a modified form of the conventional GICs in terms of adhesion and fluoride release which requires further elucidation. With the introduction of newer generations, the GICs are getting wider applications. There is further scope for improving the properties of these materials, making them even more efficient to compete with the other restorative materials in terms of strength and esthetics.

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