▶ Review article ◀

Glass-ionomer cement: from basic knowledge to application for coronal seal in endodontic treatment: a narrative review

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Abstract

Glass-ionomer cements (GICs) are widely used in dentistry as a lining/base for pulpal protection in a deep cavity or a fluoride-releasing material for restoration in high caries risk cases. Two types of GICs are currently used: high powder-liquid ratio GICs and resin-modified GICs. GICs bond to enamel and dentine via chemical adhesion, which prior surface conditioning with 10-25% polyacrylic acid is recommended. For an endodontic field, due to their sealing ability from the chemical adhesion, GICs lining/base are commonly placed covering on filled root canals to create a coronal barrier before a bonded permanent restoration (i.e. resin composite or core build-up). From laboratory studies, placing GICs lining/base on the filled canal orifices tends to decrease coronal leakage compared to resin composite restorations without the lining/base. According to clinical studies, placing GICs lining/base, either with or without intra-orifice extension, improves the clinical success of endodontic treatment compared to restorations without GICs. Therefore, this narrative review summarizes the benefit of placing the GIC barrier in improving coronal seal and endodontic success.

Keywords: coronal seal, endodontic treatment, glass-ionomer cement, outcome

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Literature review

Introduction

Glass-ionomer cements (GICs) are a fluoride-releasing material widely used in restorative dentistry for liner/base and restoration. GICs are commonly produced in two components- fluoroaluminosilicate glass particles (in either powder or paste) and polyacid liquid, which the two components are mixed and set by acid-base reaction to form GICs structure (1). GICs are particularly used in high caries risk patients due to their ability to release fluoride, which is believed to have a benefit in the protection of secondary caries formation (2). In addition, GICs lining/base in a deep cavity is recommended for pulpal protection (3). GICs have a chemical adhesion to enamel and dentine providing a durable sealing by ion-exchange interaction between the materials and the tooth substrates to form the intermediate layer (1). Conditioning the tooth surface with 10-25% polyacrylic acid is recommended to pre-activate the surface for chemical reaction with the freshly mixed GICs (4).

In the field of endodontics, GICs have been used for many purposes, e.g. lining/base as a coronal or intra-orifice barrier after root canal obturation (5, 6). For endodontically treated teeth, root canal obturation cannot prevent bacterial leakage and reinfection into the root canals; therefore, a sealed coronal restoration is required (7, 8). Covering the obturated canal orifices with GICs lining/base may be beneficial from their chemical adhesion in reducing coronal leakage and may improve the clinical success of root canal treatment (9-11). However, many dental practitioners have believed in the non-base concept in restorative dentistry and omitted the use of GIC lining/base (12). In the endodontic point of view, no lining-base beneath the bonded resin based restoration or core build-up has been also proposed (13). However, adhesive bonding to deep dentine of pulp chamber and pulpal floor tends to be not as reliable as that to superficial coronal dentine (14, 15).

Therefore, the objective of this review article was to provide basic information on GICs and specifically encourage the use of GICs in creating a coronal seal after root canal obturation, which is likely to reduce coronal leakage and improve the clinical outcome of root canal treatment.

Components and types

Glass-ionomer cements (GICs) are a water-based material conventionally composed of fluoro-aluminosilicate basic glass powder and polyacid liquid. The two components are mixed to achieve a polyacid salt matrix containing partially reacted glass fillers by a chemical acid-base reaction (1). From the limitation in a low powder-liquid mixing ratio, a traditional GIC was slowly set and very sensitive to water absorption or loss, which surface protection and delay finishing/polishing were recommended (16). Basically, GICs products are divided into (A) conventional GICs set by the acid-base reaction, and (B) resin-modified GICs set by both acid-base reaction and polymerization of resin components (1).

Later, traditional GICs are improved and modified by adding resin monomers (e.g. methacrylate groups) into the liquid components to achieve resin-modified GICs (RM-GICs) (1). RM-GICs are set by both the chemical and polymerization reactions, usually from light curing. The set RM-GICs consist of the polyacid salt matrix, the glass fillers, and the polymer chains. The polymer structure increases the strength of GICs and reduces the water sensitivity of the materials (16). In addition, RM-GICs can be initially set by light curing and then be polished immediately.

Another modification of conventional GICs is to increase a powder-liquid mixing ratio by adding different particle sizes of fluoro-aluminosilicate glass powder and different molecular-weight polyacids (17, 18). By this modification, the chemical reaction of GICs is higher and more accelerated when compared to the traditional GICs (19). In addition, a higher amount of glass fillers in the set material is detected. Hence, the high powder-liquid ratio GICs (HPL-GICs) are set faster and have flexural/compressive strength than the traditional version (20). The initial set of HPL-GICs is approximately 3-5 min depending on each product compared to the 24 h setting of traditional GICs. Moreover, the water sensitivity of HPL-GICs has been reduced; however, the HPL-GICs restorations still need a surface coat for protection (21, 22).

Mixing ratio

A mixing ratio between the powder and the liquid is critical for GICs (23). When mixed correctly, GICs must be shiny (**Fig. 1**) representing the remaining free acid that is important for chemical interaction to enamel and dentine. Thus, a measuring scoop of powder provided by the manufacturer should be used to obtain a correct powder-liquid ratio. Otherwise, an encapsulated form of GICs can be used and mixed by a mixing machine. Recently, GICs in a paste-to-liquid form (modification of the glass powder into the paste by adding resin components) dispensed from a clicker have been released, with a more well-controlled mixing ratio. However, long-term adhesion of GICs may be negatively affected by increasing resin components in these paste-to-liquid GICs with the laboratory results are still controversial (24, 25), in which adhesion of paste-to-liquid GICs may be similar or lower than the original resin-modified GICs.

The consistency of GICs should not be too thick until dry or in a putty cement (by increasing too much powder) since the chemical bond to tooth substrate is compromised and potentially affects the adhesion and sealing of GICs (26). Conversely, the consistency of the mixed materials should not be too thin (liquid) after mixing (by reducing the amount of powder or increasing too much liquid) because the acid-base reaction has dramatically decreased, which affects the properties of mixed GICs (27). In addition, the radiopacity of GICs is much lower than usual compared to the dentin (**Fig. 2**).

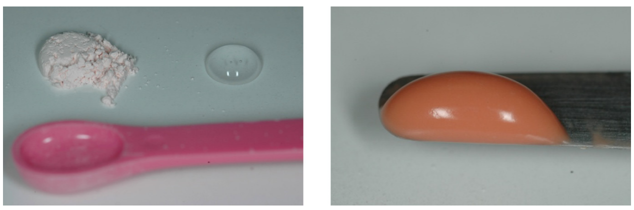

Figure 1 After mixing the powder and liquid (left image), GICs must be shiny representing the remaining free acid (right image) for chemical interaction to enamel and dentine. (Courtesy Assoc. Prof. Watcharaporn Kuphasuk)

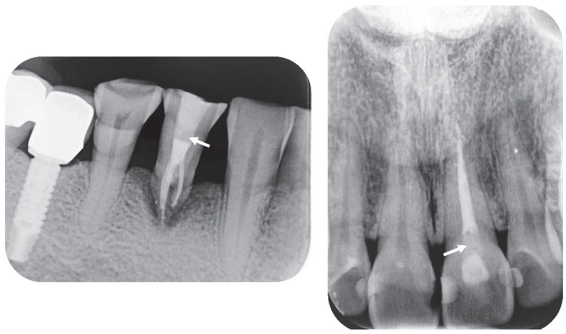

Figure 2 GICs in a proper mixing ratio showed greater radiopacity than that of dentin (left image, white arrow). In contrast, the radiopacity of improperly mixed GICs decreased (right image, white arrow), which was close to that of dentin.

Adhesion to enamel and dentine

GICs can bond to tooth substrate by a chemical reaction between the freshly mixed material and enamel/dentine (28, 29). The free polyacid from the mixed material interacts with the surface hydroxyapatites and induces the release of calcium and phosphate ions. These released ions later interact with the polyacid salt matrix to create a chemical bond between GICs and the tooth surface. As previously mentioned, the consistency of GICs after mixing should not be too thick in a dry, putty form in an attempt to carry them into a cavity by using a hand instrument (26, 30). The mixed GICs should be glossy and flowable representing available free polyacid in the material for adhesion interaction. Conversely, the consistency of GICs after mixing should not be too thin that negatively affects their physical and mechanical properties as well as their radiopacity, as already mentioned (31).

The tooth surface normally is covered with a smear layer after caries removal and tooth preparation. In addition, the surface is also contaminated with remnants of root canal irrigants (e.g. NaOCl) or sealer (e.g. eugenol). Pre-treatment of the surface before GIC application is mandatory to achieve reliable chemical adhesion and seal (32, 33). Using a conditioner containing 10-25% polyacrylic acid or polyalkenoic acid (e.g. Dentine Conditioner, GC Corp., Tokyo, Japan) to treat tooth surface for 10-20 sec (depending on the products) is recommended before rinsing off (**Fig. 3**). Moreover, the conditioned surface should not be blown too dry after rinsing since the moist surface enhances the adaptation of GICs on the cavity walls (26).

Figure 3 Build-up coronal restoration with HPL-GIC to provide coronal seal during endodontic treatment. After caries removal (left image) and covering the exposure areas with hard-setting calcium hydroxide (as a marker for re-access opening and prevent extrusion of the material into the pulp chamber), the cavity was applied with a dentine conditioner (10% polyacrylic acid) for 20 sec (center image) before rinsing off and keep the dentin moist. GIC was filled into the cavity by injecting from a tip of encapsulated product and shaped until the initial set (right image).

Using GICs as a coronal barrier after endodontic treatment

GICs can be used in endodontic treatment for many purposes, e.g. wall build-up, root resorption or perforation repair, root canal sealer, or lining/base as a coronal barrier on the filled canal orifices (9, 34). To achieve the highest success, the coronal seal from post-endodontic restoration is as important as the apical seal from root canal obturation (7). Currently, an adhesive restoration is preferred for achieving a post-endodontic coronal seal. Direct resin composite or indirect cuspal-coverage restoration (i.e. crown or overlay) is selected after complete root canal treatment depending on the remaining tooth structure and loading force (35). A core build-up material (e.g. resin-based) may fill the pulp chamber before resin composite filling or crown fabrication. A fiber-reinforced prefabricated post may be required in severely damaged teeth. However, the post-placement only shows a benefit when no-wall or one-wall tooth structure remains (36).

During the restorative procedures, there is a risk of recontamination into root canals (37). This can occur if the root canals are re-entered without proper rubber dam isolation. Hence, the post-space preparation must be performed under a rubber dam. Nevertheless, endodontically treated teeth are usually referred to restorative dentists, in which rubber dam isolation may not be used during the procedures. The studies have shown that the success rate of post-retained, root canal-treated teeth was lower when the posts were placed without rubber dam isolation (38). Therefore, it is recommended that endodontists can minimize the chance of re-infection by sealing any other canal orifices that do not require a post whenever possible (**Fig. 4**).

When a post is not required, core-build up or resin composite restoration is used to fill the pulp chamber and cover the obturated canal orifices. If endodontists can place an 'immediate' coronal seal after root canal obturation, the risk of recontamination during the restoration is prohibited. In addition, restorative dentists can perform the restorations without rubber dam isolation, which may be difficult in severely damaged teeth. However, the 'immediate' coronal seal after obturation has been omitted by several endodontists; a temporary restorative such as CAVIT or IRM is used to fill the coronal access before referring to the restorative dentists. Loss or inadequate thickness of temporary sealing is also a risk of recontamination into the root canals. (39)

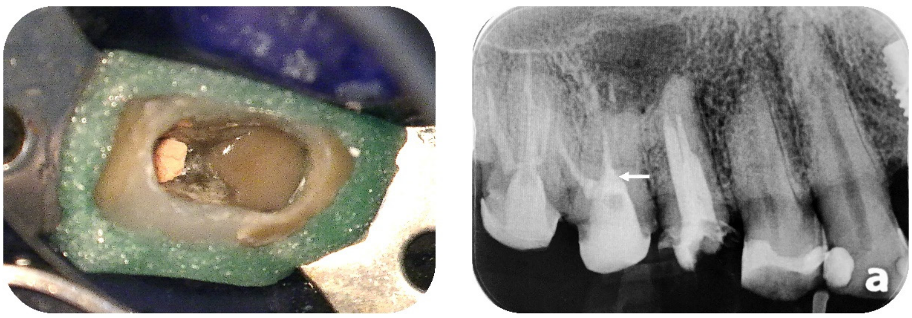

Figure 4 The GIC base was placed as a coronal barrier, approximately 2 mm thick (white arrow), on the filled mesiobuccal and distobuccal canal orifices but not on the palatal canal orifice (left image), which was further planned for a prefabricated fiber post insertion (right image, after the post insertion by a restorative dentist).

An adhesive restorative material can be placed like a lining/base on the filled canal orifices to create a coronal seal or barrier. GICs are usually used for this purpose because of their chemical adhesion to dentine and antibacterial properties (1). In an animal study, A GIC is the best in sealing the cavity from bacterial penetration compared to a resin composite or a core build-up material used in this study (40). Other *in vitro* leakage studies have also confirmed the benefit of GICs in reducing coronal leakage into the filled root canals, as explained below.

Effect of GICs on coronal seal *in vitro*

There are many laboratory methods to test leakage in endodontic experiments. The widely used methods are dye and bacterial leakage tests. However, it is widely accepted that dye-penetration leakage tests are unrelated to clinical implications (41, 42). The dye leakage tests had limitations such as different penetration abilities from dye particle sizes, air-filled gaps, or dye absorption into the tested materials. These limitations made comparisons between the studies and clinical applications inappropriate. Bacterial leakage tests are more clinically relevant and commonly used to test sealing ability in endodontics; nonetheless, the study protocol must be well controlled (43, 44). However, the number of leaked bacteria may vary among the leaked specimens, e.g. 10, 100, or 1,000 bacteria can induce a positive leakage result. Clinically, a small amount of bacteria reinfection into filled root canals may not induce new periapical pathosis because of the defense mechanism from the immune response (45, 46). Thus, a positive bacterial leakage result should not be interpreted as a clinical failure.

The sealing ability of coronal and intra-orifice barriers on filled root canals has been tested using a bacterial leakage model (5, 9). Resin composite (RC), GICs, MTA, and Cavit were commonly tested by placing them on obturated canal orifices or as intra-orifice plugs into 2-3 mm of root canals. A positive control was the obturated root canals without a coronal barrier. Most studies showed that placing these barrier materials on filled root canals significantly reduced the leakage and should be performed after root canal obturation (5, 9). However, GICs usually showed the best results compared to the other materials.

From a recent systematic review and meta-analysis, comparisons of coronal leakage prevention between the barrier materials were statistically performed (9). From the combined results of two laboratory studies using bacterial leakage models (47, 48), a trend of better sealing of GICs compared to RC has been reported even though the statistical analysis was marginally insignificantly different. However, using GICs lining/base to seal the orifices still has other benefits such as reducing polymerization shrinkage of resin composite restorations (49, 50) or easy for retreatment procedure if required. In contrast, restoring endodontically treated teeth with resin composite and no lining-base showed higher fracture resistance than restoring them with a presence of lining/base (51). This can be explained by the monoblock effect of bonded resin composite restorations. Therefore, a lining/base coronal barrier should not be placed too thick (51).

From the combination of two bacterial leakage studies (47, 52) in the systematic review (9), RM-GICs and HPL-GICs showed comparable results in reducing the leakage, in which both materials can be used to seal the filled orifices. Even polymerization volumetric shrinkage from resin components of RM-GICs is a concern (53), the generated shrinkage stress does not affect their sealing ability. Nevertheless, HPL-GICs may be preferred because of no require of light curing in such deep endodontic cavity and no concern of limited light-curing depth (thickness), compared to those of RM-GICs (54).

Compared to calcium silicate cements (e.g. MTA), the GICs reduced the leakage as well as MTA did (9). However, in clinical point of view, MTA is expensive and can cause tooth discoloration, so MTA is not usually used as a barrier material on filled root canals before coronal restorations. In addition, adhesion between MTA and resin-based materials is limited (55).

The proper thickness of the GICs coronal barrier is still controversial (9). The thicker a barrier is, the higher resistance to the leakage. The thickness in laboratory tests varied between 1-4 mm, in which the minimal effective thickness of GICs was 2-3 mm. Therefore, a GIC coronal barrier should be placed at least 2-3 mm thick (5, 9). Occasionally, GIC may be additionally placed as an intra-orifice barrier by removal of gutta-percha 2-3 mm from the coronal third of filled root canals (56). The purpose is to increase the seal by increasing the thickness of the barrier material. However, its benefit may be limited by the risk of gap/void formation in GICs from difficulty in loading the materials into the small root canals. This problem can be fixed by minor enlargement of root canals with an ultrasonic endodontic tip (e.g. ED18D tip in Endo Sucess Retreatment Kit, Acteon, Satelec, France) and using a small injection tip (e.g. Centrix syringe, Centrix Dental, Shelton, CT, USA) for loading GICs. The intra-orifice barrier can be used when the remaining coronal structure is inadequate in retaining the coronal barrier, or achieving the adequate thickness of GICs.

Effect of GICs coronal barrier on clinical success of endodontic treatment

From a cross-sectional study by Hommez, et al. (2002) (10), the placement of base (such as GICs or others, which were not specific in the study) as a coronal barrier increased the success of root canal treatment (no periapical lesion 74% approximately) compared to the restorations without the base (no periapical lesion 59% approximately) in the teeth with good root canal fillings from radiographic images. It has been explained that the base (or coronal barrier) provided more protection to the filled root canals from bacterial leakage via defective margins of direct and indirect restorations especially at the gingival areas.

In a more recent randomized controlled clinical trial by Kumar, et al. (2020) (11), the effect of GICs coronal barrier under resin composite restorations was tested in two manners: intra-orifice barrier (3-mm intracanal depth and 2-mm thick base) and coronal barrier (2-mm thick base only) compared to that without any barrier in well endodontically treated mandibular molars. HPL-GIC (Ketac Molar, 3M-ESPE, St. Paul, MN, USA) was used after cavity conditioning with polyalkenoic-acid-containing liquid for 30 sec. The teeth with intra-orifice barrier and coronal barrier showed higher healed periapical lesions (92% and 97% respectively) compared to those without the barrier (84%) (**Fig. 5**). However, the healed rates were not statistically significantly different in that study. Nevertheless, this 8-13% difference is likely to be clinically significant.

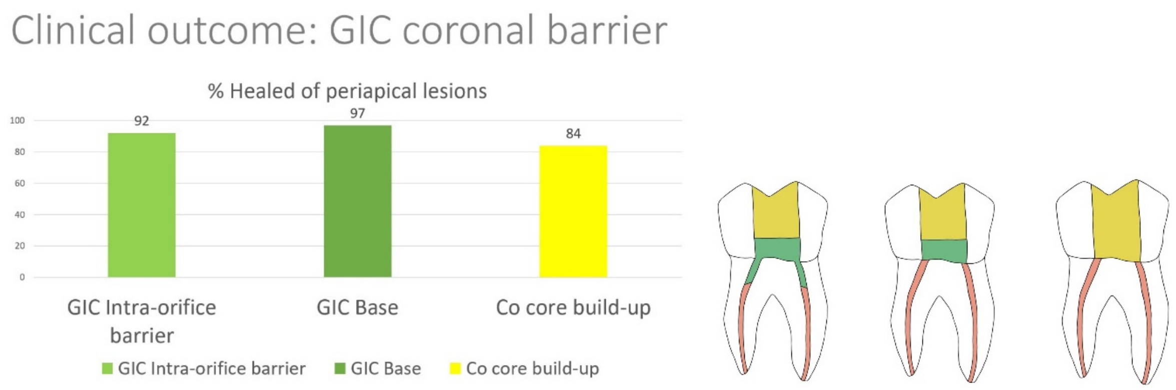

Figure 5 From Kumar, et al. (2020) (11), the GIC base group (2-mm thick base only) showed the best periapical status (97% healed), followed by the GIC intra-orifice barrier group (3-mm intracanal depth and 2-mm thick base) (92% healed) and the Co core build-up (no GIC) group (84% healed) in well endodontically treated mandibular molars (a modified version of figures from Kumar, et al. (2020) (11)).

From the current evidence, it is still emphasized the use of an at least 2-mm thick GIC barrier as a base beneath resin composite restorations to protect the filled canal orifices. However, the thicker the GIC base is, the higher the risk of coronal fracture due to less bonded areas for resin composite restorations (51). A balance between the sealing from the barrier and the tooth-strengthening effect from the restorations must be considered. If a post is not required, GIC coronal barrier should be placed immediately after root canal obturation in just 2-3 mm thick that provides adequate seal on the filled root canals. The remaining pulp chamber and access cavity are then restored with a bonded resin composite for reinforcing the teeth. Intra-orifice GIC barrier technique may be used if the height of pulp chamber is inadequate to retain the resin core build-up (57).

A hybrid material in between resin composite and GICs (e.g. Giomer) may be used as a coronal barrier. Giomer is a resin-based (fluoride-releasing) material containing surface pre-reacted glass-ionomer that can bond to tooth structure using a dental adhesive and possess antibacterial activity (58, 59). Nevertheless, no study in using Giomer as a coronal barrier in endodontically treated teeth has been found.

Conclusion

Based on the limitations of currently available evidence, a GIC barrier 2-3 mm thick should be placed after root canal obturation to protect the filled root canals from coronal bacterial leakage before permanent restorations, which is likely to improve the success of endodontic treatment. GIC coronal barrier can be placed as a base if the pulp chamber is adequate to provide a 2-3 mm thick barrier. However, GICs may be placed additionally as an intra-orifice barrier to achieve adequate thickness, especially at the gingival margin of the cavity (**Fig. 6**).

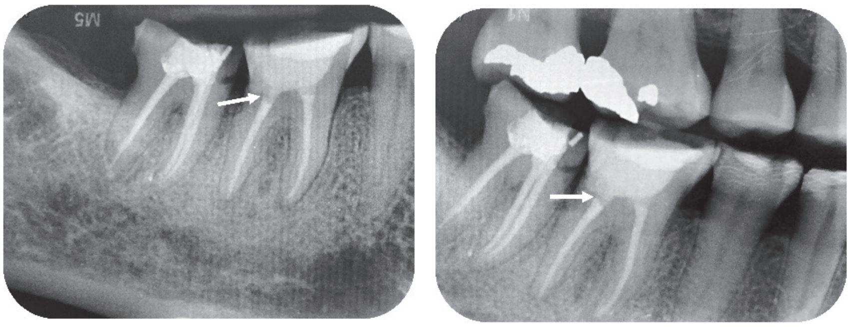

Figure 6 Endodontically treated mandibular first molar was restored with interim resin composite restoration while waiting for a permanent restoration (i.e. crown with no post). GIC was filled at the gingival margin (as an open sandwich technique or, more recently namely, deep margin elevation) and extended into the distal canal as an intra-orifice barrier to prevent any coronal leakage from the proximal side, which the thickness of restoration was much less than that of the occlusal side.

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