This article will focus on glass-ionomer cement (GIC) and its role in the clinical management of caries. It begins with a brief description of GIC, the mechanism of fluoride release and ion exchange, the interaction between GIC and the external environment, and finally the ion exchange between GIC and the tooth at the internal interface. The importance of GIC, as a tool, in caries management, in minimal intervention dentistry, and Caries Management by Risk Assessment (CAMBRA) also will be highlighted.

The philosophy of minimal intervention density (MI) and the CAMBRA approach is gaining popularity worldwide as both integrate the new understanding that caries is a biofilm-related, multifactorial and lifestyle-associated bi-directional disease. There is now an acceptance that to manage caries disease effectively, it is important to move from the surgical approach to a combined surgical—medical approach, with special focus on engaging patients in changing their lifestyle. The following statement is a consensus of 165 experts, comprising of clinicians, scientists, educators, and health service managers from 15 countries, who gathered in Bangkok for a consultative meeting to discuss the MI philosophy (personal communication, 2009):

“The current surgical model of caries management does not fully address the multi-factorial nature of dental caries. This model often results in unnecessary removal of tooth structure, can impact negatively on general health and quality of life and can impose substantial cost.”

Glass-ionomer cement (GIC) is an important tool in the fight against caries. It can be thought of as a reservoir of fluoride and other ions in the oral cavity, a mechanical barrier that protects the tooth surface against bacteria; most importantly, it can provide a long-lasting seal under the most challenging clinical circumstances.
GIC is very versatile. It may be utilized as a definitive restorative material, a preparation liner, a restorative base material, a luting cement, or a fissure sealant. Recently, it was suggested that GIC also could be useful in the preventive arena as therapeutic coating. This new terminology is utilized to describe a material that can be painted on a susceptible surface and form a long-lasting coat to protect, both mechanically and chemically, against accumulation of plaque where patients are unable to render effective hygiene in certain parts of the oral cavity. Clinical examples of these applications will be given at the end of the article.

HISTORICAL PERSPECTIVE

There is a spectrum of tooth-colored restorative materials, spanning from GIC at one end to the resin-based materials at the other end. Wilson and McLean introduced the GIC family of materials to the dental profession in 1988. The four families of acid–base materials used in dentistry are: silicate, zinc phosphate, polycarboxylate, and glass-ionomer. They all utilize acid and base components (Table 1). It was over 100 years ago when silicate cements were introduced to dentistry as a restorative material. There was anecdotal evidence that silicate cements were an effective anticaries agent that was attributed mainly to the high level of fluoride release from the silicate material. The material’s solubility was high, however, and the search for its replacement led to the development of polycarboxylate cements, and eventually GIC. Currently, glass-ionomer is the only restorative material that is water-based and like silicate has an anticaries effect.

Current esthetic high-strength GICs are considered to be durable restorative dental cements.

<table>
<thead>
<tr>
<th>Acid-Base Cement</th>
<th>Acid</th>
<th>Base</th>
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<tbody>
<tr>
<td>Silicate</td>
<td>Calcium-fluoro-alumino-silicate</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>Zinc Phosphate</td>
<td>Zinc oxide</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>Polycarboxylate</td>
<td>Zinc oxide</td>
<td>Polyalkenoic acid</td>
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<tr>
<td>Glass-Ionomer</td>
<td>Calcium-fluoro-alumino-silicate</td>
<td>Polyalkenoic acid</td>
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HOW DO GIC ACQUIRE THEIR ANTICARIES EFFECT?

GICs are true acid–base cements where the base is the fluoroaluminosilicate glass powder and the liquid containing acid comes from the polyalkenoic family. In some glass formulations, the F-rich phase of the glass can be visible (Fig. 1) and physically distinct. Apart from the base and acid, the third major component is water, the major component of the liquid. The total water content of the set cement is somewhere between 11% and 24%. Being a true water-based material, GIC also is recognized as the only biological active restorative material that is currently available.

The precise glass composition varies from one material to another. Traditionally, GIC powder was based on calcium (Ca); however, there are several materials where the calcium has been substituted by strontium (Sr). This was done to impart radiopacity to the material. It is interesting to note that because of their similarity in polarity and atomic size, these two elements are interchangeable in the composition of GIC as well as hydroxyapatite (HAP). Some of the Ca in HAP can be substituted with Sr without any significant disadvantage. It is interesting to note that, at a population level, there is some evidence to show that Sr has anticariogenic properties. Curzon reported on the caries-reducing effect of drinking water containing strontium. He noted a reduction...
in DMFT in a population exposed to drinking water containing strontium. The importance of this information will become apparent in the discussion of a study relating to the internal remineralization technique, where both F and Sr from GIC were found to migrate from GIC to the soften dentine left at the base of cavities.

For restorative GIC, approximately 60% of the liquid is water, which plays an important role in the setting reaction and in the final structure of the set cement, as well as contributing to the observed biocompatibility and the well known ionic exchange. Water allows the acid–base reaction to occur and the migration of the various ions out of and into the matrix of the set cement. When the powder is brought into contact with the liquid, the acidity allows the matrix-forming cations, Ca or Sr and Al, to leach out of the glass. These will cross-link with the polyalkenoic chains to form metal polyacrylate salts, which form the matrix and solidify the mix.

MOISTURE CONTROL AND THE CLINICAL PERFORMANCE OF GIC

The setting reaction of GIC is a two-phase process. In the first phase, immediately after mixing, there is cross-linking of the poly-acid chains by either the Ca or Sr ions. This cross-linking during this first phase is not stable and can be easily affected by excessive water loss or gain. Clinically, this means that the restoration must be protected, against initial water contamination and desiccation, immediately after placement. In the second phase, within the solidified cement, the poly-acid chains are further cross-linked by trivalent Al ions. This second phase gives the material increased physical properties and reduced solubility.

In the set GIC, water molecules can be classified as either loosely bound or tightly bound. As the material matures, the ratio between the loosely bound and tightly bound water decreases, and the material will show increased in physical properties. This is important for two reasons. First, the loosely bound water is essential for ion release and uptake, and second, it is important to maintain the water balance right through the life of a GIC restoration. Early exposure to excess water during setting and desiccation, at any stage, will lead to poor clinical performance.

ION EXCHANGE BETWEEN GIC AND THE EXTERNAL ENVIRONMENT

Because of the combined effect of release and uptake of ions, GIC is a rich reservoir of apatite forming ions such as fluoride, calcium, strontium, and phosphate. In the
aqueous environment of the oral cavity, these are released through an ion exchange process with the environment. There is a natural exchange between Sr and Ca ions.\textsuperscript{11} As Sr leaves the set cement, an equivalent number of Ca ions from saliva enter the matrix of the cement to maintain electrolytic balance (Fig. 2). Nicholson postulated that this leads to the hardening of the surface, and this was confirmed by Okada when it was found that the surface hardness of a GIC can increase by 39\% after 40 days storage in natural saliva.\textsuperscript{11–13} This was demonstrated by immersing 24 hours-old buttons of strontium containing GICs in an artificial saliva solution, and then a distribution map of Ca was acquired using electron probe micro analysis (EPMA), which clearly showed that Ca was exchanged for Sr in the matrix of the surface layer of the GIC buttons (see Fig. 2). It was postulated that the increase in surface hardness was related to the exchange of Sr by Ca in the matrix; however, the mechanism involved has not yet been identified. This phenomenon means that an exposure to Ca-rich saliva is beneficial to the long-term clinical performance of GIC.

One of the major advantages of GIC is the long-term release of fluoride and other ions. This is characterized by an initial high peak that will decline rapidly to a lower level and sustained over a number of years.\textsuperscript{14} It has been shown that there is a topping-up effect\textsuperscript{15,16} with the material up-taking fluoride from external sources such as toothpaste and topical fluoride gel. Wilson studied this over a period of 20 months and found that these species still were being released at the end of the experimental period, although at a diminished rate.\textsuperscript{17} This fluoride release also can suppress the acidogenicity of the biofilm.\textsuperscript{18} From the above observations and what is known about the importance of fluoride in the demineralization and remineralization process, one can understand the protective effect that GIC has on tooth structure in its immediate

![Fig. 2. An elemental distribution map showing Ca (purple) in the matrix of a Sr-based GIC that was stored in saliva for 7 days.](image)
vicinity. As the level of fluoride, and other ions, in GIC can be recharged, this class of material can be used as a reservoir for fluoride and may act as a slow F release device. GIC also can provide protection by the combined effect of mechanical and chemical means. For example, GIC can be used successfully to protect fissures, and despite a lower retention rate than resin-based fissure sealants, there is evidence that it reduces caries incidence in permanent teeth. In addition, a long-term clinical trial reported an effective rate of 80.6%, and suggested traditional retention is not essential for caries prevention. This is probably due to the effect of the chemical protection the material provides, and the fact that GIC tends to fail cohesively, so there is always a remaining layer on the surface, even when GIC is no longer clinically detectable.

This ion exchange is not only restricted to fluoride. The essential elements in a GIC include Ca, or Sr, Al, Si, and F. After the completion of the setting reaction, a portion of these ions is available for transfer from the matrix to the surrounding environment. As shown in (Fig. 3), the level of release of Sr far exceeds that of F or Al ions. It is well accepted that the release is caused by an exchange process, so it is unlikely to adversely affect the clinical performance of the material.

The following segment looks at some new clinical indications where the biocompatibility effect of GIC is important for clinical success.

ION EXCHANGE BETWEEN GIC AND CARIOUS DENTINE

The term internal remineralization was introduced to describe the interaction between GIC and carious dentine, and to suggest that GIC is an essential tool in the vicinity.
management of deep caries lesions in permanent teeth as it supplies apatite-forming ions to the partially demineralized dentine at the base of cavity.

Since the time of GV Black, cavity designs have been classified and standardized. Regardless of the size and extent of the original lesions, the final shape and dimensions of the prepared cavity were designed to accommodate the shortcomings of the early restorative materials. In the 1970s, the author was taught that removing caries meant accessing the soft dentine and removing it until the floor and the walls of the cavity were stain-free and hard. Anything that did not resemble sound dentine had to be removed. The objective was to ensure the elimination of all remaining microorganisms, which led to many unnecessary pulp exposures. This approach was justified at the time for the following reasons. First, any soft dentin left under the filling would lead to insufficient support and could be detrimental to the longevity of the restoration and second, any bacteria left under the filling was thought to be detrimental to the pulp.

The first suggestion that the profession should move away from this concept was proposed by Fusayama and then Massler. They both suggested that there were two layers in carious dentine. The outer layer was heavily infected by microorganisms and was broken down to the extent that it could not be remineralized at all. However, there was also an inner layer, immediately adjacent to sound dentine on the floor of the lesion, that could be partially remineralized even though it contained some bacteria, because it still retained some of the original dentine tubule structure. This was called

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**Fig. 5.** Presentation during preparation for access.

**Fig. 6.** The periphery of the cavity is prepared to sound dentin or enamel to ensure a good seal. Only a minimal amount of demineralized dentin was removed.
the affected layer, and it was suggested that it should not be removed during cavity preparation as it could be remineralized. However, this suggestion was not widely accepted by the profession, because there was no reliable method to differentiate the infected from affected layers in the dental office. Therefore, there was a need to simplify this technique further, and the next logical question is: how important is it to differentiate between the two layers so that only the infected layer is removed during cavity preparation?

In a clinical trial conducted by Mertz-Fairhurst and colleagues,23 10 years after completely sealing a lesion where the “soft, wet, demineralized dentine was left on the floor of a lesion,”24 the lesion did not progress or jeopardize the restoration placed above it. Recently, a review of the literature confirmed that it is acceptable to leave soft and wet dentine at the base of cavity preparations, providing a complete seal is established and maintained.25 There is now evidence suggesting that the partly demineralized component of the soft and wet dentine can be remineralized when it comes into contact with GIC.3 It is a biocompatible material that delivers a long-lasting seal through the development of an ion exchange adhesion with both enamel and dentine, with low technique sensitivity.

Therefore, the two keys to clinical success when leaving soft dentin behind are, first, to ensure that the tooth does not show signs of irreversible pulpitis and, second, the establishment of a long-lasting seal.

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Fig. 7. Initial radiographic presentation.

Fig. 8. “Soft and wet” dentine; it is difficult to differentiate between infected and affected dentine.
When GIC is placed in direct contact with affected dentine, the migration of apatite-forming elements F and Sr from the GIC to carious dentine can be extensive. In a clinical trial study, these two elements were found to have accumulated deep into the lesion with the maximum depth reaching over 1.5 mm. The controlling factor was the depth of the lesion and the physical state of the demineralized dentine.

The clinical application of the internal remineralization concept is illustrated in the following clinical case. A patient presented with a proximal cavity and reported mild symptoms consistent with reversible pulpitis. There was no evidence of periapical involvement. The initial presentation can be seen in Fig. 4, with only enough enamel removed to gain proper access to the cavity (Fig. 5). Note that the entire enamel margin and dentino-enamel junction have been cleaned to leave 2 mm of sound hard dentine to ensure a seal can be achieved and maintained long-term (Fig. 6). Only hand instrumentation was then used in the removal of the soft dentine immediately above the pulp to minimize the risk of direct pulp exposure. The cavity was then conditioned using 10% polyacrylic acid for 10 seconds. Following conditioning, a small amount of high fluoride-releasing GIC was applied over the soft dentine as a liner. The cavity then was restored with composite resin in the conventional manner. The selection of composite resin for the final restoration was based on the fact that there was sufficient enamel still available right around the periphery of the cavity (see Fig. 6).

Fig. 9. The gingival margin is entirely in dentine; a margin of 2-mm wide was created in sound dentine and the soft dentine, over the pulpal wall, was removed by hand and conditioned using 10% polyalkenoic acid.

Fig. 10. A high fluoride-releasing GIC liner is applied to the discolored portion for internal remineralization.
It is suggested that GIC, through its self-adhesive characteristics, will provide a complete and long-lasting seal, preventing the ingress of bacteria and potential nutrients. GIC can be placed in close proximity to the pulp without the risk of inducing irreversible inflammation and the placement of calcium hydroxide is no longer needed, unless there is a direct pulp exposure. Providing that the restoration is completely sealed then there is no risk in leaving the demineralized dentin under the GIC lining.

THE SANDWICH TECHNIQUE

This technique uses two different materials for the final restoration, and some clinicians use the following analogy to describe the rationale for its use; GIC is used as a dentine replacement, while composite resin acts as an enamel replacement. The indication is badly broken down teeth or when part of the gingival margin is located on dentine, because there is doubt on the long-term performance of a dentin adhesive in the absence of enamel. The following clinical case is an example of combining the internal remineralization, to treat carious dentine, and sandwich techniques, to restore the tooth. This patient presented with a large proximal lesion and reported mild symptoms over a brief period (Figs. 7 and 8). A clean margin of 2 mm wide was created using a round bur, and only hand instruments were used to remove carious dentine. The finished cavity was treated with 10% polyacrylic acid for 10 seconds. Note that the enamel transverse ridge was retained so not to weaken the tooth crown (Fig. 9).
The discolored dentine was treated with a high F-releasing GIC liner (Fig. 10). A high-strength GIC was laid down as a base in preparation for the composite resin restoration. This was done to ensure a long-lasting seal along the gingival margin (Figs. 11–13), The three practical advantages of this technique are that it

- Minimizes the risk of pulp exposure
- Minimizes the number of increments of composite resin to be placed, offering time savings
- Results in a longlasting seal around the dentine margin.

SURFACE PROTECTION FOR ROOT SURFACES IN ELDERLY PATIENTS

One of the new challenges clinicians are facing is the maintenance of good oral health in the older patients. Reinhardt predicted that by the year 2030 the number of retained teeth in people living in the United States, aged between 45 to 84, will be approximately 2.2 billion compared with just over 1 billion in 1990. He recognized these teeth will exist in a more hostile oral environment.

Root caries can be defined as caries lesions initiated on exposed root surfaces. At an early stage, they are difficult to detect visually, because the first changes are in surface hardness and texture of the affected areas. Unlike enamel lesions, discoloration comes much later, and they are usually masked by plaque and inflammation of the surrounding soft tissue. Once established, the lesions can spread incisally by

Fig. 13. Radiograph of final restoration.

Fig. 14. An exposed and arrested root caries that required protection as the patient could no longer maintain good oral hygiene because of arthritis.
undermining the thin enamel at the CEJ, but more often, they spread below the gum level. These lesions quickly become cavitated, because dentin contains much less mineral than enamel, and more is permeable because of the presence of dentinal tubules. In the following clinical case, GIC was applied as a therapeutic coating to protect the exposed root surfaces and lesions. The original caries lesion had been arrested for many years (Fig. 14). This had been achieved with a combination of good oral hygiene, use of a high fluoride-containing toothpaste, and daily application of a calcium and phosphate-containing paste to saturate the biofilm. The lesion displayed the three characteristics of a remineralized dentine surface; it was discolored, shiny, and hard. However, with the onset of arthritis, the task of keeping the area clean became too much of a challenge for the patient. After a period of assessment, it was decided that the area should be protected with a thin coat of high fluoride-releasing GIC, Fuji Triage (Fuji VII, GC Corp, Tokyo, Japan) (Fig. 15). Being a conventional GIC, this thin film GIC adheres well to the root surface and acts as a mechanical barrier to protect the area and minimize plaque accumulation. It releases significantly much more F than the traditional restorative GICs and if recharged with a daily exposure to fluoridated toothpaste, then the F release can be maintained indefinitely. A thin film of half a millimeter or less will allow ions such as calcium and fluoride to cross from saliva to the underlying root surface and remineralize it further.

**SUMMARY**

GIC is an important tool in the fight against dental caries, and it should be used in conjunction with other traditional tools:

- It can be thought of as a reservoir of fluoride and other ions in the oral cavity. Externally it can be used as a therapeutic coating to protect the tooth surface against acid and to modulate bacterial activities.
- It assists in preserving carious dentine at the base of restoration, by delivering F and other apatite-forming ions, and providing a long-lasting seal to both dentine and enamel.
- GIC can be used as a restorative material, a liner, a base, a luting cement, a fissure sealant, and a surface protectant.

The dental profession has come to the realization that to control caries effectively, it is necessary to move from the surgical-only approach to a combined surgical–medical approach with special focus on engaging patients in changing their lifestyle. GIC, as
a family of materials, is part of the armamentarium that the clinician has for the
treatment of dental caries, as it can contribute to the surgical and medical manage-
ment components.

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