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Adhesion of glass-ionomer cements to teeth: A review



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ABSTRACT

This review covers the adhesion of glass-ionomer cements, both conventional and resin-modified, to the enamel and dentine of the tooth. These materials are widely used in modern dentistry, and studies have shown them to bond particularly to the mineral phase of the tooth material, with some evidence of direct chemical bonds between carboxylic acid groups of the polymer and calcium ions in the tooth mineral. With time, conventional glass-ionomers have been shown to develop an ion-enriched interfacial zone with dentine, which is probably responsible for the high durability of the adhesive bonds of this material. Adhesion is exploited in many of the clinical applications of these materials, including ART, class V cavity repairs, and pit-and-fissure sealants. These are described briefly.

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1. Introduction

For many years the repair of teeth damaged by caries was performed with silver amalgam [1]. This material has the advantages of being inexpensive and easy to place, and is durable in clinical service [2]. However, it is not aesthetic. When set, it is an unsightly silver colour and visually obtrusive. It also has the disadvantage that relatively large amounts of healthy tooth tissue have to be removed by the dentist in order to create a retentive cavity shape capable of maintaining the set material in place [3,4].

To overcome these drawbacks, aesthetic materials are increasingly used in the dental clinic [5]. These materials are conservative (*i.e.* allow more natural tooth material to be retained) and they generally match the natural tooth in colour and translucency. Two main classes of material are considered aesthetic, namely composite resins and

glass-ionomer cements [4]. It is the latter that are the subject of this review article. The emphasis of the article is on the inherent adhesion of these materials and its mechanism, and also the clinical applications that follow from this adhesion.

2. Background

Conventional glass ionomer cements are acid–base materials that were first introduced in 1972 by Wilson and Kent [6]. They are prepared from an aqueous solution of polyalkenoic acid, either polyacrylic acid or acrylic/maleic acid copolymer, which is reacted with a powdered glass component that has a basic character. This glass is usually a calcium fluoro-aluminosilicate, though strontium based glasses are also available and used clinically. These glasses are complex materials, and not only contain numerous components (see Table 1) but may also show at least partial phase separation [7].

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In the clinic, the powder and liquid are mixed together to form a stiff paste, and this paste gradually hardens by an acid–base reaction occurs. The acid attacks the glass, which causes ions (Ca^{2+} and Al^{3+}) to be released. These ions crosslink the polyalkenoic acid chains [8,9]. The combined effect of crosslinking by metal ions and neutralization of the polyalkenoate molecules is that the cement hardens [10]. This takes place in a short period of time, typically 2–5 min from mixing, after which the cement can be finished.

The freshly set cement is not completely fit for clinical service. It is susceptible to water exchange across its immature outer surface. This means it can dry out, a process which has been claimed to be responsible for the formation of a network of micro-cracks in the cement surface and the development of an unsightly chalky appearance [11]. Alternatively, it can take in water, with the potential loss of network-forming ions and associated swelling, which may also cause micro-cracks to develop [8]. Covering the newly placed cement with a layer of either petroleum jelly or varnish prevents this water movement, and so stops the occurrence of a chalky appearance [12].

Further slow reactions continue with time. These are generally described as maturation, a term that seems to cover a variety of processes [10]. They include an increase in ionic crosslinking with time [13]. In addition, there is an increase in the proportion of bound water within the cement, which has been attributed to greater binding of water to co-ordination sites around ions, or around neutralised polyanion molecules. There is also some evidence of the formation of silanol groups on the surfaces of the glass particles, a process that involves hydrolysis of Si–O–Si groups [14]. There is also evidence of some sort of inorganic network formation from the ion-depleted glass [15], probably involving phosphate groups from the latter [16]. Finally, it has been suggested recently that the size of the pores trapped within the cement by the mixing process decreases with time [17], though the mechanism of this observed reduction in pore size is unclear.

These variation maturation steps lead to changes in the properties of the glass-ionomer cement. Specifically, compressive and diametral tensile strength increase with time, at least in cements derived from poly(acrylic acid), and also translucency improves. Properties of glass-ionomers vary widely, but must at least the minimum requirements specified in the relevant ISO Standard [18]. These are shown in Table 2.

One of the developments of glass-ionomer cements has been the high-viscosity version [19], which became available in the mid-1990s and which set more rapidly than earlier types of glass-ionomer. They have been called *viscous* or *condensable* by some authors [19], and

Table 1
Composition of a typical ionomer cement glass (G338).

Component	% by mass
SiO_2	24.9
Al_2O_3	14.2
AlF_3	4.6
CaF_2	12.8
NaAlF_6	19.2
AlPO_4	24.2

Table 2
ISO requirements for physical properties of clinical grade glass-ionomer cements [18].

Property	Luting cement	Restorative cement
Setting time/min	2.5–8	2–6
Compressive strength/MPa	70 (minimum)	100 (minimum)
Opacity, $C_{0.70}$	–	0.35–0.90

they were originally developed for use with the atraumatic restorative treatment (ART) technique [20]. This application particularly exploits the adhesion of glass-ionomers, and is considered later in this article.

The second important member of the glass-ionomer family that is widely used in contemporary clinical practice is the resin-modified glass-ionomer. Originally introduced as a liner/base material in 1991 [21], this material includes a polymerizable monomer, 2-hydroxyethyl methacrylate (HEMA) as an additional component. In addition, polymerisation initiators are present to cause the HEMA to undergo addition polymerisation. These initiators are usually light-activated, so that the majority of brands of resin-modified glass-ionomer are light-curable [21].

In resin-modified glass-ionomers, the acid–base reaction is augmented by the HEMA polymerization [22,23]. In their simplest form, these materials contain only the conventional components of glass-ionomers (glass, polyalkenoic acid and water) together with HEMA. However, more complex materials have also been developed in which the polyalkenoic acid is modified with side chains that are terminated in vinyl groups and which can consequently become involved in the addition polymerization reaction. In all cases, however, these materials retain their essential nature as glass ionomer cements because of their ability to set by means of the acid–base reaction [22].

Resin-modified glass-ionomers have similar mechanical properties to conventional glass-ionomers. They also show inherent adhesion to both the enamel and the dentine layers of the tooth. However, because of the presence of HEMA, some of which can be released from the set material, resin-modified glass-ionomers have inferior biocompatibility to conventional glass-ionomers [24], a point not always recognised in the clinical literature.

Both conventional and resin-modified glass-ionomers are used with relatively minimal cavity preparation, which exploits their good inherent adhesion. They are also used in repairs in which good adhesion is a requirement, such as Class V cavities [25]. The rest of this review focuses specifically on their adhesive properties.

2.1. Surface pretreatment

Bonding of restorative dental materials to the tooth is an important topic that has been studied extensively for many years. Bonding to dentine is considered a particular challenge, because this tissue contains more water than enamel and also less mineral phase for bonding. It has fluid-filled tubules running through its structure, and these provide moisture that may possibly undermine the interface between the cement and the tooth [26]. Glass-ionomers of both types have the advantage of being hydrophilic, so have the capability of wetting the freshly cut dentine surfaces and forming durable adhesive bonds.

When the tooth is cut, the result is a surface covered with a thin layer of debris known as the smear layer [27]. This layer is of the order of 1–2 μm thick and attached to the underlying dentine quite tenaciously. It comprises mineral phase embedded in denatured collagen [27], and is effectively a structure with less defined order than either enamel or dentine. Bond strengths and durability of bonding vary according to the precise details of the cutting process applied to the tooth [28].

Removing the smear layer typically modifies this surface. Such cleaning creates a uniform and reliable surface for bonding and may also remove any smear layer blocking the dentinal tubules, which allows freshly placed glass-ionomer paste to penetrate the surface to an extent. The result is a degree of micro-mechanical attachment when the cement has hardened [29].

Removal of the smear layer may be achieved either by treatment with weak acid, such as citric acid, or by treatment with strong acid, such as 37% phosphoric acid, typically as a gel [5]. The former has been called “conditioning” while the latter is known as “total etch”. Total etch is widely used, following its introduction

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