Dental Materials – Special Edition

Conventional glass-ionomer cements – a guide for practitioners

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Abstract

Glass-polyalkenoate cements, also known as glass-ionomer cements (GICs) are one of the most commonly used bio-interactive restorative dental materials, having been available since the 1970s. With the promotion of minimally invasive operative dentistry (MID) and the reduction in the use of dental amalgam worldwide, the popularity of these materials has grown significantly in recent years. This paper will outline the basics and clinical importance of GIC material science and provide an overview of their use in restorative dentistry.

Clinical relevance

GICs are versatile dental biomaterials that require correct case selection, material handling and placement technique to ensure optimal clinical success.

Objectives

The reader should be able to understand the basics of GIC technology, their delivery systems and how to use them appropriately for the correct case for best clinical results.

1 Introduction

Glass-polyalkenoate cements, also known as glass-ionomer cements (GICs), were invented in the UK by Wilson and Kent in 1965 and commercially introduced in 1972 as ASPA (**A**lumino-**S**ilicate **P**olyacylic **A**cid) cements [1,2]. All GICs consist of the same generic formulation of a polymeric acid, from the polyalkenoate acid family of polymer acids, and an alkaline glass powder, and are defined by this acid-base setting reaction. However, by altering the polymeric acids, alkaline glasses, or by adding different components, industry has created different types or modified-GICs with significantly different properties related to their proposed clinical use [3,4].

GICs are self-adhesive, self-curing, possess fluoride uptake and release properties, can interact with adjacent enamel and dentine resulting in exchange of ions and exhibit cariostatic properties [5,6]. GICs do not specific require tooth preparation/modifications such as an acid-etching or bonding steps like resin-based composites but their physical and mechanical properties of GICs are generally weaker when compared with resin composites [5,7]. The ionic interaction of GICs with adjacent dentine is not as active as that of calcium silicate cements, such as mineral trioxide aggregate (MTA) or Biodentine™ (Septodont, Saint-Maur-des-Fossés, France).

1.1 Acid-base setting reaction

GICs are defined by the acid-base setting reaction between the polyalkenoic acid polymer and alkaline fluoro-alumino-silicate (FAS) glass [8,9]. The polyalkenoic acid polymer could be poly-acrylic, poly-maleic, poly-itaconic acid or their combinations . The reaction is split into three overlapping stages – dissolution, gelation, and maturation – summarised in Figure 1.

Clinically – the acid-base reaction begins as soon as the material is mixed and being placed into the prepared cavity. Care must be taken to ensure minimal moisture loss or contamination to prevent the loss of the ions involved in the setting reaction. If excess water is gained or lost during the setting reaction this will lead to a substantially reduced physical and mechanical properties and ultimately premature restoration failure [6].

The pH of freshly mixed GICs is reported between 0.9 – 2.6 [10,11] immediately after mixing, rising to pH 2.8 – 4.3 [10,11] after ten minutes and pH 5.4 – 6.7 [10,11] after 24 hours. Previous laboratory studies suggested a critical pH of 2 (or less) of the setting cement could cause pulp irritation [10]. However, the clinical implication of the initial low pH remains controversial because the degree of pulp reaction to setting GIC is dependent on a number of factors including quantity of free-acid available within the setting GIC, setting rate and duration, existing histological condition of the pulp and the proximity of the GIC material, degree of bacterial load in the remaining dentine and quality of seal of the final restoration [10,12–14].

Modern GICs are advocated for use in the restoration of large and deep cavity types, particularly where selective caries removal techniques are used due to advances in their chemistry compared with previous older GICs that were the subject of these pH studies[15,16].

1.2 Self-adhesive and self-etching properties

Chemical bonding occurs between GIC and tooth surface. Adhesion of GIC to dentine (and enamel) occurs in different stages - summarised in Figure 2 – consisting of surface wetting, self-etching and micromechanical interlocking, true chemical bonding, and ion-exchange layer formation.

GIC is hydrophilic and self-etching, therefore there is initially both surface wetting and surface etching leading to micromechanical interlocking. True chemical bonding occurs initially consisting of hydrogen bonds rapidly formed between the free carboxyl groups (of the polyalkenoic acid) and the water in the tooth surface. Over time these bonds are replaced by ionic bonds between the polyalkenoic acid polymer and calcium in the hydroxyapatite of the tooth surface – forming an ion-exchange layer [9,17]. This ion-exchange layer (reportedly 1-15 µm thick) is a blended interface between the GIC and the underlying dentine, which can take between 1-10 days to form [18] and forms only within an aqueous environment. Within this ion-exchange layer, there is an exchange of fluoride, calcium, phosphate and other ions between the dentine and GIC [18], and is capable of dynamically breaking and reforming over the lifetime of the GIC restoration. [18]

The clinical importance is that GICs adhere chemically to enamel and dentine. In-vitro bond strengths have been shown to be similar to both sound dentine and caries-affected dentine [19]. Additionally, the initially hydrophilic and acidic properties of GICs result in excellent marginal adaptation at the tooth-restoration interface[20,21]. As a result of the ion-exchange layer there is an antibacterial and bio-interactive property of the GIC when placed on carious dentine [18].

Measuring bond strengths of GICs to dentine and enamel has been notoriously difficult because GICs tend to fail cohesively rather than adhesively and a true comparison with other materials such as resin composites may not be possible and inappropriate [9,18]. However, values for GIC bond strengths have varied from 2.6-9.6 MPa (to enamel) and 1.1-4.1 MPa (to dentine) with 80% of the bond strength achieved 15 mins after GIC placement and this increases as maturation continues [9,22]. Clinical studies have indicated that, depending on the GIC manufacturer, pre-conditioning of dentine improves GIC adhesion and restoration seal [2324,25] (see section 3.1).

1.3 Antibacterial properties

The initial low pH of GICs may confer antibacterial activity particularly when placed over caries-affected dentine. Additionally, laboratory testing indicated both freshly mixed/set GIC and mature GIC inhibit the growth of *S. mutans* and affect the acidogenicity of the overlying plaque biofilm [26,27]. Ions released from GICs including fluoride, aluminium and strontium have exhibited antimicrobial effects, [28–32]. Some studies have suggested the antibacterial properties of GICs could be related to fluoride release [33], the acidity[33,34], or even the zinc[35]. Given there are conflicting reports on this matter, the exact mechanism by which fresh and set GIC exhibit antibacterial properties is still not fully understood [34].

1.4 Bio-interactive properties

The terms “bioactive” and “biointeractive” describe two different properties to a given dental material. “Bioactive” dental materials are able to induce apatite-containing material formation (e.g. hydroxyapatite) in simulated body fluid, or induce a pulpal response to simulate reparative dentine formation. Whilst "biointeractive" dental materials contain and release ions similar to those found within tooth structure (e.g. calcium) that can interact with adjacent tooth structure to drive remineralisation [36–38]. GICs therefore belong in the "biointeractive" category with their ability to release calcium and fluoride into the surrounding tooth structure and environment.

The polyalkenoic acids are a family of acids both ionic and polymeric in nature. Clinically this is important as GICs are both hydrophilic and acidic and can interact chemically with dentine and enamel resulting in chemical adhesion and ion exchange (calcium and fluoride) between GIC and adjacent tooth structure [17,39]. The calcium and fluoride ions found within the GIC can aid in tooth remineralisation and provide cariostatic properties to the GIC which are not observed in conventional resin composites [39].

1.5 Physical properties

As GICs are refined, they have seen success in use in clinical scenarios such as the definitive restoration of primary teeth and stabilisation in adults with high caries susceptibility [40]. However, in comparison to resin composites, GICs' reduced mechanical properties have traditionally limited their comprehensive clinical application as definitive long-term restorations especially as posterior, load-bearing restorations [9,41]. Compressive strength and flexural strength are most commonly used to describe mechanical properties of GICs as they have suitable in-vitro analogues allowing the replication of typical masticatory loading seen clinically [41]. Wear resistance is another requirement in load-bearing scenarios. Conventional GICs have been demonstrated to exhibit lower wear resistance compared with dental amalgam and resin composites, however, the physical and mechanical properties of GICs improve as maturation proceeds [42].

1.6 Aesthetic properties

Aesthetics is a key property that determines the overall clinical success or failure of a tooth-restoration complex. In-vitro laboratory studies found that colour stability of GICs differs for several reasons including the additives in the formulation and contamination from extrinsic sources and the storage solution [43,44].

Clinical trials found that GIC might serve well in terms of colour stability in the long-term. In a 2-year study, EQUIA (GC Corp, Japan) was found to show rare distinct colour mismatch (less than 1%) in Class I and II restorations in permanent teeth [45]. This was later confirmed by a series of studies which demonstrated that EQUIA (GC Corp, Tokyo, Japan) did not exhibit significant colour match and margin discolouration issues at any recall up to five years and no difference was found compared to Gradia Direct Posterior (Dentsply, Pennsylvania, USA) [46,47].

2 GIC classification and presentation

All GICs can be categorised according to how they are formulated, designed, marketed, and sold:

2.1 Clinical use

1. **Restorative** – GICs for restorative and/or preventive purposes
2. **Luting** – GICs for luting/cementation purposes, both temporary and definitive.
3. **Pulp protection** – GICs for the purpose of protecting the pulp floor of cavity preparations, overlying caries-affected or infected dentine

Restorative GICs encompass those that are formulated specifically for use clinically as direct restorations of all types and for preventive clinical techniques such as fissure sealants. Luting GICs are used for the cementation of restorations and base GICs are primarily formulated and marketed for use as pulp protection.

2.2 Delivery system

All GICs are presented with different delivery systems according to clinical use and formulation and are available in a powder/liquid combination either hand-mixed or encapsulated and auto-dispensed. Most manufacturers provide the same GICs with different delivery systems. For example, Fuji IX GP (GC Corp, Tokyo, Japan) and Chemfil Rock (Dentsply, Pennsylvania, USA) are both available as encapsulated powder/liquid and manually mixed powder/liquid containers. Glass-ionomer cements with the same brand name and overall formulation will have subtle differences in the filler:liquid ratio according to their clinical delivery system [5,9].

Hand-mixed GICs allow the clinician to control the quantity of final GIC required for their restoration. It is easier to restore a large cavity using a large quantity of hand mixed GIC compared with using multiple capsules some of which may not be used in their entirety. However, previous research has indicated that there are large inconsistencies in the mixing ratios of powder/liquid and mixing techniques that can influence the mechanical properties and setting time/handling properties of the GIC [48–52]. Pre-dosed encapsulated GICs (powder/liquid) offer the advantage of improved consistency and repeatability of mixing and dispensing. .

3 Conditioners and surface coatings

Some GICs may require use of a conditioner before placement and the application of a surface coat after the GIC has been placed, shaped and cured. [5]

3.1 GIC conditioners

GIC tooth conditioners (also known as surface or cavity conditioners) are not the same as acid-etchants used prior to resin composite placement. They differ according to the acid-type, strength, and effect on the smear layer [5,9]. A smear layer is always created after tooth preparation and contains a mixture of bacteria, necrotic organic tooth tissue, minerals, oils from the handpiece and other debris. This smear layer is susceptible to dissolution under restorations over time, which encourages microleakage, microbial ingress and possibly pulp inflammation [53].

3.1.1 GIC conditioners versus acid-etchants

GIC conditioners modify the smear layer and improve adhesion to enamel and dentine. Many manufacturers use polyacrylic acid in their tooth conditioning protocols at different concentrations (10-25%) and for differing times (10-25s) before being rinsed off with water [5,24,54]. As GIC conditioner consists of polyacrylic acid it is sufficiently acidic to remove the smear layer after rinsing, but, not too acidic to completely remove the smear plugs. The significance of this is that the conditioning helps expose more calcium in the hydroxyapatite enamel/dentine surface which in turn plays a key role in GIC adhesion [9,55]. Using 37% phosphoric acid in a total-etch technique on dentine would remove all remnants of smear layer and plug and decalcify the underlying dentine, this would reduce the amount of exposed calcium ions available for GIC ionic bonding, and possibly increase risk of post-operative sensitivity as the GIC itself is also acidic [24].

If pH of the freshly mixed GIC is sufficiently acidic then the smear layer will be dissolved/incorporated into the GIC itself, and a GIC conditioner is not required [5,56]. This is entirely brand dependent, and clinicians should always check the instructions of use for any GIC material to ensure their correct use and placement.

3.2 GIC surface coating

GICs during the setting reaction are susceptible to excess water loss or gain which can impact significantly on the chemical and mechanical properties of the set material [5,57,58]. The concept of surface protection of conventional GICs has been investigated thirty years ago, initially using the then-available dental adhesives to investigate their adhesion in-vitro [59]. As a result, today manufacturers may recommend the use of a GIC surface coat after placement to help protect the GIC.

These can be of three types:

1) **Emollients** – e.g. petroleum jelly (Vaseline, Unilever, London, UK), cocoa-butter (GC Cocoa Butter, GC Corp, Tokyo, Japan)
2) **Solvent-based waterproof varnishes** – e.g. GC Fuji Varnish (GC Corp, Japan), Ketac Glaze (3M, Seefeld, Germany)
3) **Light-cured resin-based coatings** – e.g. EQUIA Coat (GC Corp, Japan), Riva Coat (SDI, Melbourne, Australia)

Emollients can be petroleum- or lipid-based products [57]. Solvent-based varnishes are simple solutions of different polymers in solvents, which when evaporated with air, leave behind a layer of polymer on the GIC surface [9]. Light-cured resin coatings are generally consisting of a mixture of methacrylate monomers, photo-initiators, with/without filler particles [9].

Comparisons between GIC surface coats have been undertaken primarily in laboratory-based studies studying water loss / gain or the penetration of dyes into the surface of GIC samples coated with different GIC surface coats. Surface emollients have been reported with limited success in protecting GICs as they can be easily wiped/washed off, though offer some protection where no GIC coat is available [57,60]. No differences were reported in the protective effects between solvent-based varnishes and light-cured resin-based coats as all coats tested performed equally well in minimising dye penetration and preventing from water loss, and both types were significantly better than no coating at all [57,61]. A previous study indicated that varnishes might peel from the GIC surface and the use of a light-cured resin-based coat may be preferred [62]. The American Dental Association (ADA) in 1990 stated the importance of coating conventional GICs with either a varnish or a light-cured resin-based coat to limit water movement during the maturation stage [63].

Improved clinical survival rates have been demonstrated for GICs protected with light-cured coats compared with no surface coat [64]. However, the mechanism by which this occurs is not fully understood. [65,66].

4 Clinical indications

The use of conventional GICs classically include the definitive restoration of all paediatric cavity types, definitive restoration of adult Class III and V restorations, temporary restoration of adult Class I and II restorations, core build-ups, endodontic cavity sealing, deep margin elevation/acquisition, coronal perforation repair (supragingival), amongst many others.

Within Paediatric Dentistry and Special Care Dentistry, GICs can be used for the provision of fissure sealants and restoration in those patients with limited cooperation, difficulty attaining adequate moisture control or for partially erupted teeth [67].

Additionally, whilst there are very few companies whose instructions for use state explicitly that their GIC can be used for Class IV restorations, there is no reason that any restorative GIC type could be used for stabilising carious lesions in the anterior dentition.

There is controversy, however, regarding the use of any GIC for the load-bearing areas in permanent teeth and whether these restorations are deemed “definitive” or “provisional”. Rather than considering them according to their supposed longevity, it would be prudent to describe restorations according to their intended clinical purpose – as “stabilising restorations”. For example, a restoration for caries control and disease stabilisation would be any restoration with sufficient chemical and physical properties and clinical longevity, to allow patients (and clinicians) to control the patient risk factors for caries progression, before re-evaluating and either replacing them or using them as part of the definitive restoration.

A clear distinction is therefore required and a discussion to be had with the patient to ensure full understanding and appreciation on the use of GICs. The patient who has undergone a phased personalised care plan will therefore have already been informed of the initial stabilisation of disease, followed by a review and if required, definitive restorative treatment.

4.1 Clinical placement of GICs – technical considerations

The decision to use GIC must be considered before any cavity preparation is undertaken. The decision is made together with the patient with the understanding of why the material is being used and what will likely be required in the future i.e. GIC removal and replacement or cut-back and overlaying with a more durable material such as resin-composite.

Cavity preparation and caries management must be carried out using minimally invasive techniques to ensure full use of the benefits of the GIC material, improved clinical longevity and tooth-restoration complex survival. As the material is moisture-tolerant to a degree the use of rubber dam isolation is not mandatory but is recommended to improve placement due to soft tissue control and cavity field isolation.

The use of a proprietary GIC cavity conditioner and GIC coat is dependent on the GIC being used and its initial pH. As it is not always easy to gain this information from manufacturers, it is recommended that a conditioning step is included in most cases, using a proprietary mild concentration polyacrylic acid (10-25%) for 10-15 seconds on enamel and dentine. This should be thoroughly washed off and the tissue gently air-dried to ensure obvious water droplets are removed off the tooth surface prior to GIC placement.

Another important consideration is when to finish the GIC surface, after placement. Clearly, gross material excess whether occlusal, approximal, or otherwise, must be removed with a sharp instrument to ensure conformity to the existing occlusion and aid patient oral hygiene. The finishing of GICs must only be carried 24 hours (minimum) after placement to avoid dehydration and loss of water from the maturing GIC [68].

Figure 3 provides an overview of the ideal GIC placement for a typical Class II approximal restoration, and the relevant clinical steps clinicians should consider. Each clinical scenario must be considered on an individual basis and manufacturers guidelines followed.

5 Conclusions

GICs are a highly versatile bio-interactive restorative material available in different delivery methods and can be used for many clinical purposes. The key to the successful use of GICs is in the understanding of their chemistry, their limitations and the intended clinical purpose.

Figure 1 – Simplified representation of the GIC setting process. Dissolution occurring within the first few seconds after mixing, Gelation occurs within first couple of minutes, and Maturation occurs after 24 hours and up to couple weeks after placement.

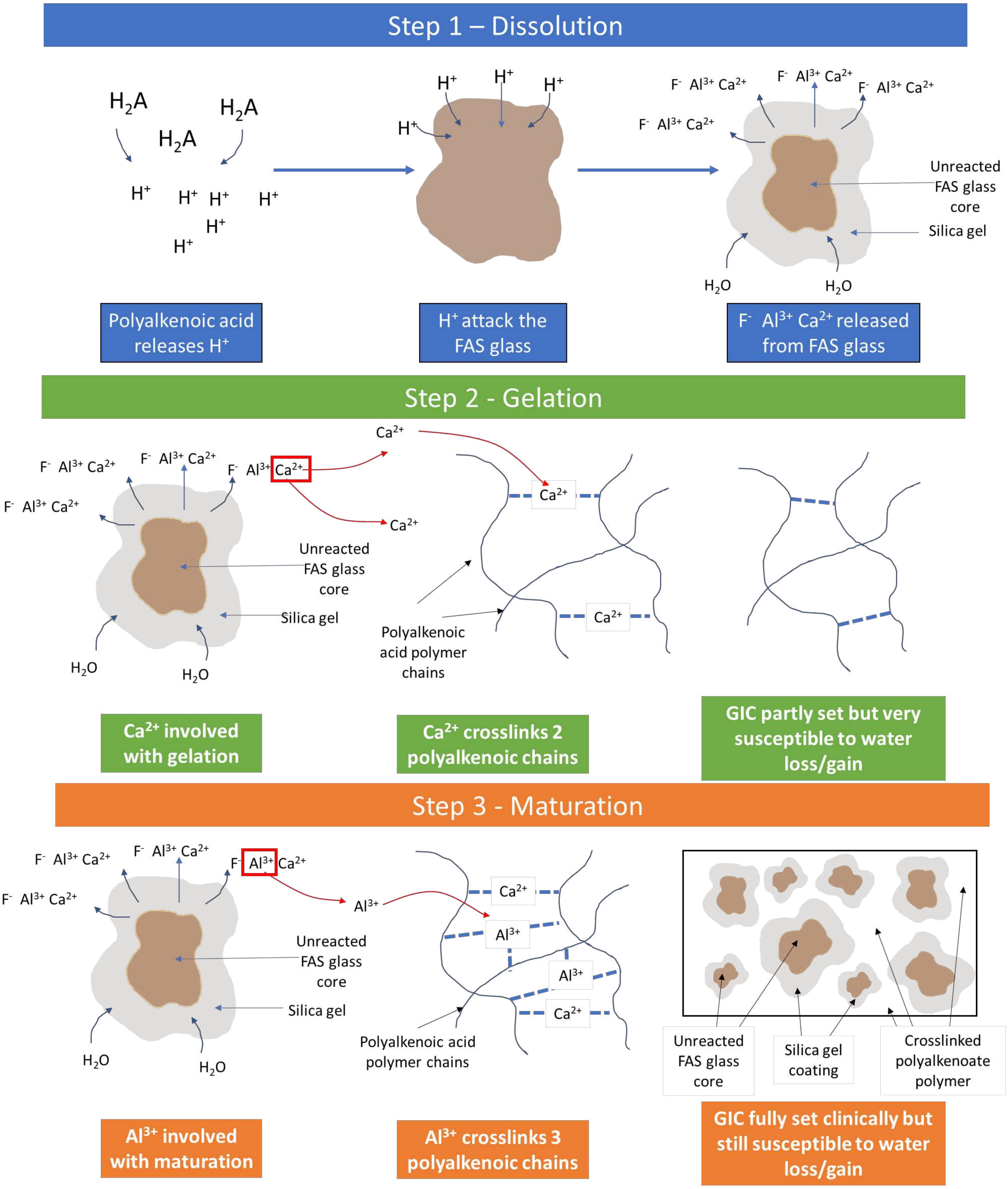


Figure 2 – Simplified representation of the GIC adhesion process

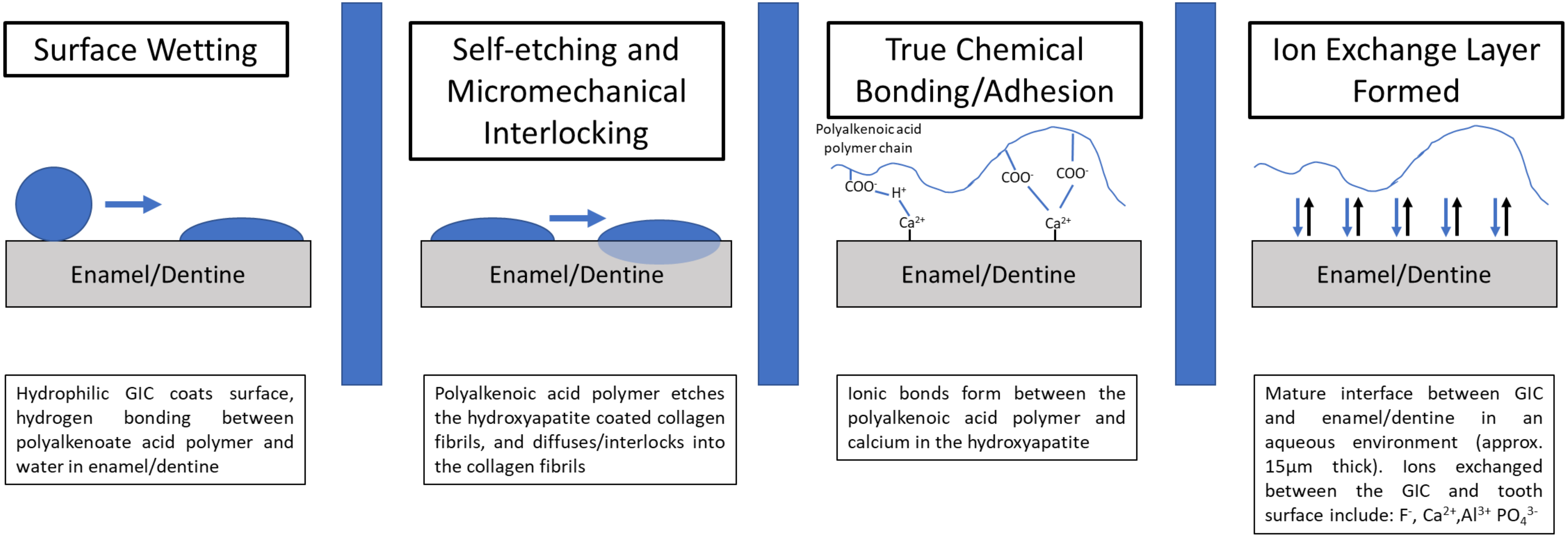
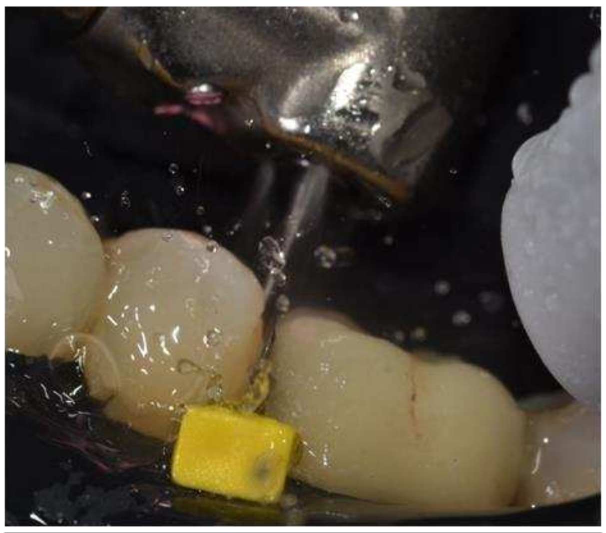


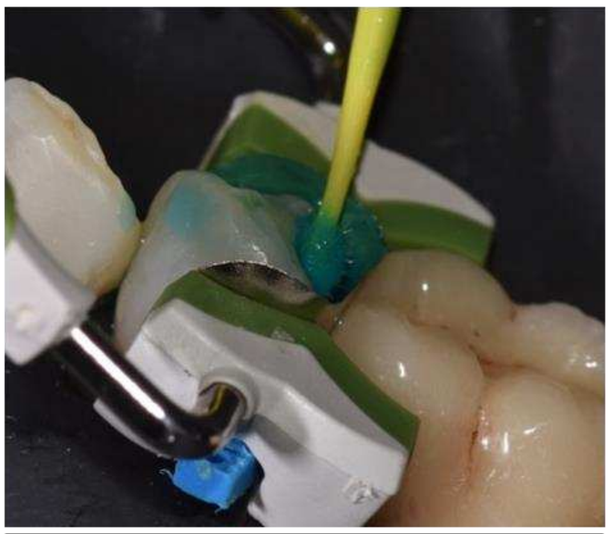
Figure 3 – Clinical example of GIC placement using a cavity conditioner and GIC coat placement

1: Caries identification maxillary premolar, rubber dam isolation (not mandatory)



2: Cavity preparation and caries removal following MI principles

3: Cavity isolation ensuring tight margins



4: GIC cavity conditioner (20% polyacrylic acid used in this example)

5: Encapsulated GIC placed under pressure ensuring minimal bubble formation and maximising cavity fill

6: Whilst GIC setting, excess quickly removed and gross shaping achieved

7: Interproximal margins flossed and checked for overhangs and cleansibility

8: Occlusion checked and any adjustments made

9: GIC varnish or light-cured coat placed

6 References

1 Wilson A. Alumino-silicate polyacrylic acid and related cements. *Br Polym J* 1974; **6**: 165–179.

2 Wilson A., Kent B. The glass-ionomer cement, a new translucent cement for dentistry. J. Appl. Chem. Biotechnol. 1971, 21, 313. *J Appl Chem Biotechnol* 1971; **21**: 313–313.

3 Watson TF, Atmeh AR, Sajini S, Cook RJ, Festy F. Present and future of glass-ionomers and calcium-silicate cements as bioactive materials in dentistry: biophotonics-based interfacial analyses in health and disease. *Dent Mater* 2014; **30**: 50–61.

4 Burke FJT. Dental materials - What goes where? The current status of glass ionomer as a material for loadbearing restorations in posterior teeth. *Dent Update* 2013; **40**: 840–844.

5 Francois P, Fouquet V, Attal JP, Dursun E. Commercially available fluoride-releasing restorative materials: A review and a proposal for classification. *Materials (Basel)* 2020; **13**. doi:10.3390/ma13102313.

6 Banerjee A. The Role of Glass-Ionomer Cements in Minimum Intervention (MI) Caries Management. In: Sidhu SK (ed). *Glass-Ionomers in Dentistry*. Springer International Publishing: Cham, 2016, pp 81–96.

7 Gautam E, Somani R, Jaidka S, Hussain S. A comparative evaluation of compressive strength and antimicrobial efficacy of Fuji IX and Amalgomer CR: An in vitro study. *J Oral Biol Craniofacial Res* 2020; **10**: 118–121.

8 Nicholson JW. Chemistry of glass-ionomer cements: A review. *Biomaterials* 1998; **19**: 485–494.

9 Sidhu S, Nicholson J. A Review of Glass-Ionomer Cements for Clinical Dentistry. *J Funct Biomater* 2016; **7**: 16.

10 Smith DC, Ruse ND. Acidity of glass ionomer cements during setting and its relation to pulp sensitivity. *J Am Dent Assoc* 1986; **112**: 654–657.

11 Wasson EA, Nicholson JW. Change in pH during setting of polyelectrolyte dental cements. *J Dent* 1993; **21**: 122–126.

12 Woolford MJ, Chadwick RG. Surface pH of resin-modified glass polyalkenoate (ionomer) cements. *J Dent* 1992; **20**: 359–364.

13 Tarim B, Hafez AA, Cox CF. Material on Nonexposed and Exposed Monkey Pulps. *Quintessence Int (Berl)* 1998; **29**: 535–542.

14 Modena KC da S, Casas-Apayco LC, Atta MT *et al.* Cytotoxicity and biocompatibility of direct and indirect pulp capping materials. *J Appl Oral Sci* 2009; **17**: 544–554.

15 Duncan HF, Galler KM, Tomson PL *et al.* European Society of Endodontology position statement: Management of deep caries and the exposed pulp. *Int Endod J* 2019; **52**: 923–934.

16 Innes NPT, Frencken JE, Bjørndal L *et al.* Managing Carious Lesions: Consensus Recommendations on Terminology. *Adv Dent Res* 2016; **28**: 49–57.

17 Nicholson JW. Adhesion of glass-ionomer cements to teeth: A review. *Int J Adhes Adhes* 2016; **69**: 33–38.

18 Mustafa HA, Paris S. Forgotten Merits of GIC restorations. *Clin Oral Investig* 2020; **24**: 2189–

2201.

19 Tjäderhane L, Tezvergil-Mutluay A. Performance of Adhesives and Restorative Materials After Selective Removal of Carious Lesions: Restorative Materials with Anticaries Properties. *Dent Clin North Am* 2019; **63**: 715–729.

20 Ebaya MM, Ali AI, Mahmoud SH. Evaluation of Marginal Adaptation and Microleakage of Three Glass Ionomer-Based Class V Restorations: In Vitro Study. *Eur J Dent* 2019; **13**: 599–606.

21 Gjorgievska E, Nicholson JW, Iljovska S, Slipper IJ. Marginal adaptation and performance of bioactive dental restorative materials in deciduous and young permanent teeth. *J Appl Oral Sci* 2008; **16**: 1–6.

22 Powis DR, Folleras T, Merson SA, Wilson AD. Improved adhesion of a glass ionomer cement to dentin and enamel. *J Dent Res* 1982; **61**: 1416–1422.

23 Tyas MJ. Milestones in Adhesion: Glass-ionomer Cements. *J Adhes Dent* 2003; **5**: 259–266.

24 Tay FR, Smales RJ, Ngo H, Wei SH, Pashley DH. Effect of different conditioning protocols on adhesion of a GIC to dentin. *J Adhes Dent* 2001; **3**: 153–67.

25 Rai N, Naik R, Gupta R, Shetty S, Singh A. Evaluating the Effect of Different Conditioning Agents on the Shear Bond Strength of Resin-Modified Glass Ionomers. *Contemp Clin Dent* 2017; **8**: 604–612.

26 Davidovich E, Weiss E, Fuks AB, Beyth N. Surface antibacterial properties of glass ionomer cements used in atraumatic restorative treatment. *J Am Dent Assoc* 2007; **138**: 1347–1352.

27 Klai S, Altenburger M, Spitzmüller B, Anderson A, Hellwig E, Al-Ahmad A. Antimicrobial effects of dental luting glass ionomer cements on streptococcus mutans. *Sci World J* 2014; **2014**. doi:10.1155/2014/807086.

28 Cosgun A, Bolgul B, Duran N. In vitro investigation of antimicrobial effects, nanohardness, and cytotoxicity of different glass ionomer restorative materials in dentistry. *Niger J Clin Pract* 2019; **22**: 422–431.

29 Park EY, Kang S. Current aspects and prospects of glass ionomer cements for clinical dentistry. *Yeungnam Univ J Med* 2020; **37**: 169–178.

30 Nicholson JW, Czarnecka B, Limanowska-Shaw H. The long-term interaction of dental cements with lactic acid solutions. *J Mater Sci Mater Med* 1999; **10**: 449–452.

31 Geurtsen W. Substances released from dental resin composites and glass ionomer cements. *Eur J Oral Sci* 1998; **106**: 687–695.

32 Tüzüner T, Dimkov A, Nicholson JW. The effect of antimicrobial additives on the properties of dental glass-ionomer cements: a review. *Acta Biomater Odontol Scand* 2019; **5**: 9–21.

33 Seppa L, Forss H, Ogaard B. The effect of fluoride application on fluoride release and antibacterial action of glass ionomers. *J Dent Res* 1993; **72**: 1210–1314.

34 Sidhu SK, Schmalz G. The biocompatibility of glass-ionomer cement materials. A status report for the American Journal of Dentistry. *Am J Dent* 2001; **14**: 387–396.

35 Tobias RS, Browne RM, Wilson CA. Antibacterial activity of dental restorative materials. *Int Endod J* 1985; **18**: 1671–171.

36 Gandolfi MG, Siboni F, Botero T, Bossù M, Riccitiello F, Prati C. Calcium silicate and calcium

hydroxide materials for pulp capping: Biointeractivity, porosity, solubility and bioactivity of current formulations. *J Appl Biomater Funct Mater* 2015; **13**: 1–18.

37 Li X, Wang J, Joiner A, Chang J. The remineralisation of enamel: A review of the literature. *J Dent* 2014; **42**: S12–S20.

38 Tomson PL, Lumley PJ, Smith AJ, Cooper PR. Growth factor release from dentine matrix by pulp-capping agents promotes pulp tissue repair-associated events. *Int Endod J* 2017; **50**: 281–292.

39 Mickenautsch S, Mount G, Yengopal V. Therapeutic effect of glass-ionomers: An overview of evidence. *Aust Dent J* 2011; **56**: 10–15.

40 Birant S, Ozcan H, Koruyucu M, Seymen F. Assesment of the compressive strength of the current restorative materials. *Pediatr Dent J* 2021; : 1–6.

41 Lohbauer U. Dental glass ionomer cements as permanent filling materials? -Properties, limitations and future trends. *Materials (Basel)* 2010; **3**: 76–96.

42 De Gee AJ, Van Duinen RNB, Werner A, Davidson CL. Early and long-term wear of conventional and resin-modified glass ionomers. *J Dent Res* 1996; **75**: 1613–1619.

43 Savas S, Colgecen O, Yasa B, Kucukyilmaz E. Color stability, roughness, and water sorption/solubility of glass ionomer-Based restorative materials. *Niger J Clin Pract* 2019; **22**: 824–832.

44 Pani SC, Aljammaz MT, Alrugi AM, Aljumaah AM, Alkahtani YM, Alkhuraif A. Color Stability of Glass Ionomer Cement after Reinforced with Two Different Nanoparticles. *Int J Dent* 2020; **2020**. doi:10.1155/2020/7808535.

45 Friedl K, Hiller KA, Friedl KH. Clinical performance of a new glass ionomer based restoration system: A retrospective cohort study. *Dent Mater* 2011; **27**: 1031–1037.

46 Gurgan S, Kutuk ZB, Ergin E, Oztas SS, Cakir FY. Four-year randomized clinical trial to evaluate the clinical performance of a glass ionomer restorative system. *Oper Dent* 2015; **40**: 134–143.

47 Gurgan S, Kutuk ZB, Ergin E, Oztas SS, Cakir FY. Clinical performance of a glass ionomer restorative system: a 6-year evaluation. *Clin Oral Investig* 2017; **21**: 2335–2343.

48 Freitas MCC de A, Fagundes TC, Modena KC da S, Cardia GS, Navarro MF de L. Randomized clinical trial of encapsulated and hand-mixed glassionomer ART restorations: One-year follow-up. *J Appl Oral Sci* 2018; **26**: 1–8.

49 Al-Taee L, Deb S, Banerjee A. An in vitro assessment of the physical properties of manually-mixed and encapsulated glass-ionomer cements. *BDJ Open* 2020; **6**: 1–7.

50 Akatsuka R, Fukushima S, Sasaki K. Effect of mixing methods on bonding strength of GIC. *J Dent Res* 2012; **91**: 1015.

51 Nomoto R, Komoriyama M, McCabe JF, Hirano S. Effect of mixing method on the porosity of encapsulated glass ionomer cement. *Dent Mater* 2004; **20**: 972–978.

52 Oliveira GL, Carvalho CN, Carvalho EM, Bauer J, Leal AMA. The Influence of Mixing Methods on the Compressive Strength and Fluoride Release of Conventional and Resin-Modified Glass Ionomer Cements. *Int J Dent* 2019; **2019**. doi:10.1155/2019/6834931.

53 Pashley DH. Smear layer: overview of structure and function. *Proc Finnish Dent Soc* 1992; **88**: 215–224.

54 Hoshika S, Ting S, Ahmed Z *et al.* Effect of conditioning and 1 year aging on the bond strength and interfacial morphology of glass-ionomer cement bonded to dentin. *Dent Mater* 2021; **37**: 106–112.

55 Alhalawani AMF, Curran DJ, Boyd D, Towler MR. The role of poly(acrylic acid) in conventional glass polyalkenoate cements. *J Polym Eng* 2016; **36**: 221–237.

56 Hasan AMHR, Sidhu SK, Nicholson JW. Fluoride release and uptake in enhanced bioactivity glass ionomer cement ("glass carbomer™") compared with conventional and resin-modified glass ionomer cements. *J Appl Oral Sci* 2019; **27**: 1–6.

57 Tyagi S, Thomas AM, Sinnappah-Kang ND. A comparative evaluation of resin- and varnish-based surface protective agents on glass ionomer cement – a spectrophotometric analysis. *Biomater Investig Dent* 2020; **7**: 25–30.

58 Causton BE. The physico-mechanical consequences of exposing glass ionomer cements to water during setting. *Biomaterials* 1981; **2**: 112–115.

59 Watson T, Banerjee A. Effectiveness of glass-ionomer surface protection treatments: a scanning optical microscope study. *Eur J Prosthodont Restor Dent* 1993; **2**: 85–90.

60 Faridi MA, Khabeer A, Haroon S. Flexural Strength of Glass Carbomer Cement and Conventional Glass Ionomer Cement Stored in Different Storage Media over Time. *Med Princ Pract* 2018; **27**: 372–377.

61 Nicholson JW, Czarnecka B. Kinetic studies of the effect of varnish on water loss by glass-ionomer cements. *Dent Mater* 2007; **23**: 1549–1552.

62 Hotta M, Hirukawa H, Yamamoto K. Effect of coating materials on restorative glass-ionomer cement surface. *Oper Dent* 1992; **17**: 57–61.

63 ADA. Using glass ionomers. Council on Dental Materials, Instruments, and Equipment. *J Am Dent Assoc* 1990; **121**: 181–188.

64 Klinke T, Daboul A, Turek A, Frankenberger R, Hickel R, Biffar R. Clinical performance during 48 months of two current glass ionomer restorative systems with coatings: A randomized clinical trial in the field. *Trials* 2016; **17**: 1–14.

65 Bonifácio CC, Werner A, Kleverlaan CJ. Coating glass-ionomer cements with a nanofilled resin. *Acta Odontol Scand* 2012; **70**: 471–477.

66 Jevnikar P, Serša I, Sepe A, Jarh O, Funduk N. Effect of surface coating on water migration into resin-modified glass ionomer cements: A magnetic resonance micro-imaging study. *Magn Reson Med* 2000; **44**: 686–691.

67 Gorseta K, Glavina D, Borzabadi-Farahani A *et al.* One-year clinical evaluation of a Glass Carbomer fissure sealant, a preliminary study. *Eur J Prosthodont Restor Dent* 2014; **22**: 67–71.

68 Miličević A, Goršeta K, Van Duinen RNV, Glavina D. Surface roughness of glass ionomer cements after application of different polishing techniques. *Acta Stomatol Croat* 2018; **52**: 314–321.