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FJ Trevor Burke

Louis Mackenzie and Peter Sands

Fifty Years of Glass Ionomers (GICs). Are the Latest GICs Suitable for Restoring Back Teeth?

Abstract: Glass ionomer cements (GICs) have been available for use by clinicians for almost 50 years. Their beneficial properties, such as adhesion to tooth substance, have long been recognized, but early materials suffered from brittleness, lack of translucency, poor wear resistance and solubility in oral fluids. Hence, over the years, new variants have been developed with a view to overcoming these difficulties. If the latest materials were found to be clinically successful in loadbearing situations in posterior teeth, they could hold advantages because of their easier placement than resin composite materials and possibly be more cost-effective. It is therefore the purpose of this article to review recent research into the performance of the laboratory and clinical performance of high viscous GICs and the so-called glass hybrid materials that have developed from the conventional GICs.

CPD/Clinical Relevance: Glass ionomer materials, which, unlike resin composite restorations do not need a separate bonding agent, may hold technique advantages during restoration placement.

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It is the aim of this narrative review to (i) briefly trace the history of glass ionomer materials over the 50 years of their existence and (ii) identify and evaluate articles publishing clinical data (of more than 2 years' duration) on survival of restorations in Class I and II cavities formed in contemporary glass ionomer cement systems.

Early history of glass ionomer materials

Glass ionomer materials were first described in a patent in 1969,[1] with the first publication being in 1972 by Wilson and Kent.[2] They were originally considered to be a development of silicate cement,[3] which comprised a fluoro-alumina-silicate (FAS) glass, mixed with phosphoric acid. The mixed material suffered from many deficiencies, especially solubility in oral fluids, so, for the glass ionomer cements (GICs), an aqueous solution of polycarboxylic acid (a carboxylic acid being an organic acid containing one or more -COOH groups) was substituted for the phosphoric acid. When mixed together, a paste was formed that rapidly hardened into a solid mass bound by a polysalt hydrogel (Table 1; Figure 1).

Commercially introduced in 1975 as ASPA (De Trey/Dentsply Ltd, UK), the ability of these materials to bond to tooth substance brought a new dimension to the properties of dental materials. Further development led to the production of an anhydrous GIC in 1981 (Chemfil, De Trey/Dentsply Ltd, UK), which simply required mixing of the powder with water. This was mainly recommended for use in Class V cavities, and in Class I and II cavities in primary teeth. These materials were based upon polyacrylic acid (PAA), which formed a chemical bond with hydroxyapatite. Another manufacturer (ESPE, Seefeld, Germany) used polymaleic acid in its glass ionomer cement, Ketac Bond, which became available in 1984. Both contained an FAS glass, which had an acid–base reaction with the acid, with the attendant release of fluoride.

FJ Trevor Burke, DDS, MSc, MDS, MGDS, FDS (RCS Edin), FDS RCS (Eng.), FCG.Dent., FADM, Emeritus Professor, University of Birmingham School of Dentistry Birmingham B5 7EG UK. **Louis Mackenzie**, BDS, FDS RCPS, FCGDent, Head Dental Officer, Denplan UK, Andover, and, Clinical Lecturer, University of Birmingham School of Dentistry. **Peter Sands**, MSc, BDS, LDS, MCGD, General Dental Practitioner, Abingdon, England.
email: f.j.t.burke@bham.ac.uk

Glass (base) + polyacid = polysalt + silica gel			
Powder	*Liquid*	*Matrix*	*Particle coating*

Table 1. The acid–base reaction of traditional glass ionomer materials.

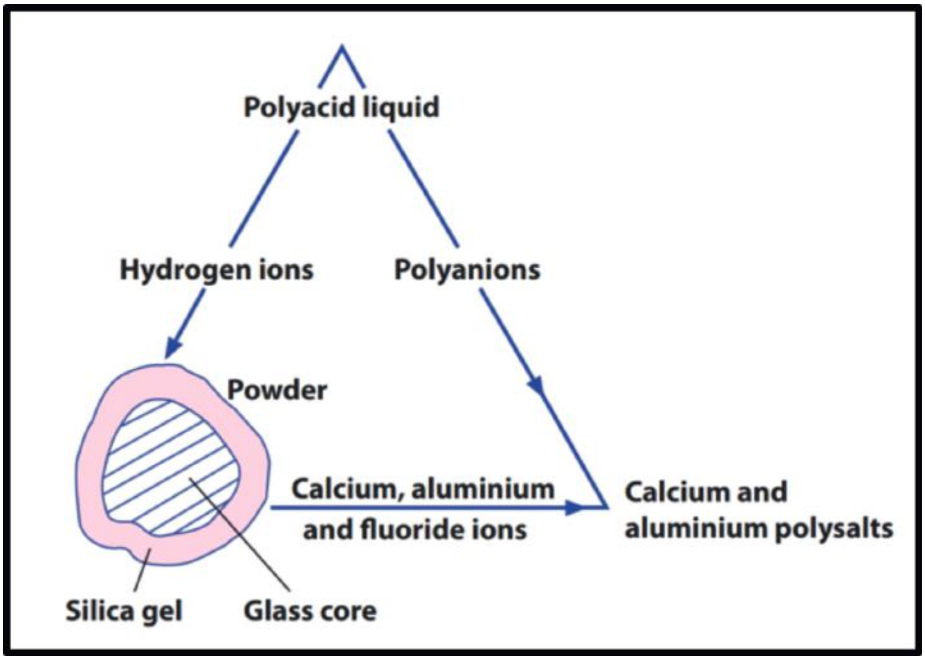

Figure 1. Diagrammatic representation of the setting reaction of an early glass ionomer cement (after Wilson[3]).

Properties of GICs

Glass ionomers have the valuable property of being adhesive to reactive substances, in dentistry, these being enamel and dentine, stainless steel, and non-precious alloys, but not porcelain, gold or platinum. When the GIC is in a fluid state soon after mixing, the -COOH groups wet polar surfaces, thereby forming a hydrogen bridge between the substrate and the polyacid. It is therefore apparent that, if the setting mechanism has proceeded too far and the material becomes dull, there will not be sufficient acid groups present to wet the surface and adhesion will not occur. Later, the hydrogen bridges are progressively converted to stronger ionic bonds as the hydrogen is displaced by calcium, aluminium or other metal ions found in either substrate. GICs were considered, in an early review[3] to be biocompatible.

Concluding a wide-ranging review of glass ionomer materials published in *Dental Update* in 1977, Wilson[3] concluded that these materials were useful for many applications, including filling abrasion/erosion lesions and lining cavities, and, 'since the materials have adhesive properties, only minimal cavity preparation is required', and 'operator time is therefore minimized'. These advantages remain to the present time. However, the material was brittle, and so could not be used in thin sections and early versions had limited translucency, and hence could not be recommended in 'certain visible situations'. Wilson added that the restoration margins must be protected with wax or varnish in order to prevent contamination by moisture (for example saliva) with the setting material.

Glass ionomers release fluoride as part of their acid–base setting reaction, and it was initially hoped that this would provide a cariostatic effect. However, such hopes were dashed by the publication of several reviews, the results of which indicated that, while there was inhibition of caries by glass ionomers in laboratory caries models, this was not replicated *in vivo*.[4,5] More recently, however, Yengopal and co-workers, in a meta-analysis, found no difference between the caries-preventive effect of resin-based and GIC-based fissure sealants.[6]

Wilson[3] concluded part of his review by stating that the glass ionomer cement was not suitable for use in large class IV and II cavities, but adding that 'future developments might overcome these problems'. The aim of the present article is to investigate this.

Resin-modified glass ionomer (RMGI) materials

These were developed to overcome some of the shortcomings of traditional glass ionomers, including their short working time, long setting time, solubility in oral fluids and brittleness. In addition to the FAS glass and poly(alkenoic acid), RMGI materials also contained a monomer, such as 2-hydroxyethyl methacrylate (HEMA) or bis-GMA, together with a photo-initiator that facilitated light curing of the material. These materials, therefore, set by two mechanisms – polymerization of the monomer (either by visible light cure or chemical cure, although some materials contained both) and the GIC acid–base reaction. The general properties of RMGI materials are:[7]

- Biocompatibility similar to conventional GICs;
- Fluoride release similar to, or better than, conventional GICs;
- Adhesion to enamel and dentine;
- Improved physical properties, especially with regard to tensile strength; and
- Satisfactory aesthetics.

However, wear resistance was similar to conventional GICs.

High viscous GICs

The so-called high viscous GICs were developed in the early 1990s, principally in response to the atraumatic restorative technique (ART). These materials are more easily handled than conventional GICs, being of higher viscosity and having faster speed of setting reaction as a result of their finer particle grain size. This group includes Fuji IX GP Fast and Extra (GC, Tokyo, Japan), and Ketac-Molar Easymix (3M ESPE, Seefeld, Germany), now revised as Ketac Universal (*vide infra*). Their physical properties, specifically tensile strength, and also abrasion and wear resistance, are better than conventional GICs.[8] High viscous glass ionomer materials have therefore been considered to have the following properties:[7]

- Smaller particle size, which leads to faster reaction;
- Higher loading, which brings improved physical properties;

Figure 2. Abrasive wear apparent on a high viscous GIC restoration after 4 years, with enamel margins standing proud of the restoration.

- Exhibit plastic features – can be condensed and packed;
- Still a need for improved wear resistance (Figure 2);
- Typical glass ionomer features.

Clinical performance of high viscous GICs

A review published in 2013[9] identified six publications in which high viscosity GICs had been used in loadbearing clinical situations in posterior teeth. It was particularly critical of one paper, that being by Scholtanus and Huysmans,[10] a prospective study carried out by a team of experienced researchers who evaluated 116 Class II restorations in Fuji IX (GC) at 6 years, by which time survival had fallen to 60% (ie a failure rate of 40%, which the present authors consider not compatible with successful clinical practice). No restorations failed because of wear or isthmus fracture. All failures were due to progressive loss of glass ionomer material just below contact areas. In cases where the restoration had no interproximal contact, this did not occur. The authors hypothesized that it was caries-like dissolution of the restorations that occurred, and that high levels of acidogenic plaque might be responsible for this dissolution of glass ionomer restorations at contact areas. Other papers in the review[9] were more favourable, and it was concluded that under certain (favourable) conditions, certain restorations in high viscous glass ionomer materials may provide reasonable longevity. It was considered that the conditions for longevity may include reduced occlusal loading, an absence of cariogenic plaque (ie patients with good oral hygiene), and, possibly the absence of a contact point in Class II restorations. It is worth adding that Opdam and colleagues, in a systematic review on the longevity of posterior composite restorations, concluded that caries risk (and number of restored surfaces) played a role in the survival of restorations.[11]

Given that previous studies showed that the wear resistance of high-viscous GIC was inferior to that of composite and amalgam, it may be of interest to determine whether the concept of application of a resin coating for GIC fillings in Class I and II cavities would improve their clinical performance. Materials that use this concept include EQUIA Fil (GC). A number of clinical evaluations using this material are now available. In the following section of this review, articles publishing data on survival of restorations formed in contemporary GIC systems at more than 2 years have been identified and evaluated.

Clinical performance of earlier glass ionomer variants

To overcome the disadvantages of earlier GICs, while maintaining their core advantages (self-adhesion, bulk application), EQUIA (GC Europe, Leuven, Belgium) was introduced in 2011. This system was a development of the high-viscosity and translucent GIC, Fuji IX GP Extra (GC), combined with a nanofilled light-cured resin coating (and G-Coat Plus, GC, Tokyo, Japan). The individual components were rebranded into EQUIA Fil and EQUIA Coat shortly after their introduction. The application of the resin applied to the surface of the newly placed restoration was considered to provide protection in the early maturation phase, with this, in turn, providing improved flexural strength and an increased wear resistance of the material. The nanofilled resin coating is designed to seal surface defects of the underlying GIC material and protect against abrasive wear. This is of particular importance in the initial days of GIC restoration placement until the restoration has matured and its peak strength has been reached.[12] In this regard, several *in vitro* studies have showed that applying a coating material increased the wear resistance of GIC,[13–15] with higher flexural strength also being noted by one research team.[16]

EQUIA Fil is advertised as a cost-efficient alternative for amalgam in class I and II cavities within the manufacturer's recommended cavity isthmus width. Clinical data on survival of restorations placed in EQUIA Fil are available, as follows:

- In an early study, Friedl and colleagues[17] assessed the performance of 151 Fuji IX GP Extra restorations covered with G Coat Plus (26 class I, 125 class II, and 41 three- and four-surface restorations) for 24 months in six dental practices. As well as measuring restoration performance using USPHS criteria, they also measured the volume loss of restorations, finding that large cavities had more volume loss, given that the original volume of the restoration was retained in 88.5% of the Class I restorations, in 64.2% of Class II and in 53.7% of the largest restorations, indicating that these large restorations were prone to wear, despite the authors' contention that 'wear of the occlusal surfaces of the restorations was not a problem during the period of this assessment'. Marginal deficiencies were not reported as a problem. The authors concluded that EQUIA was suitable for use in Class I restorations of all sizes, but only in smaller Class II restorations.
- Klinke and colleagues[18] carried out a prospective randomized controlled trial containing 1001 fillings placed by 111 general dentists across Germany in 643 patients using the materials EQUIA Fil and Coat (GC), with Fuji IX GP Fast and Fuji Coat LC as control. This was, and still is, a unique approach in dental research, namely, to have a randomized controlled study of this size performed by practitioners, all under the guidance of the Greifswald Clinic in Germany. A total of 503 restorations, placed within the manufacturer's indications, were examined at 4 years, restorations being assessed by three examiners. The results indicated no significant difference in the performance of the two materials, although EQUIA Fil, with its nanofilled resin coating, showed a 'slightly better' overall performance than Fuji IX GP Fast. The authors considered that this was due to the nanofilled resin coating, which allowed an improved primary stabilization of the filling material during the curing stage and improved infiltration and closure of the superficial defects within the GIC. The authors concluded that both materials performed well in Class I cavities, but added that, for Class II restorations, clinicians 'should pay attention to the cavity size, with a higher odds of failure ration being apparent in large cavities and three-surface MOD cavities',

indicating that the manufacturer's recommendations should be followed. Cavities with a large isthmus width (defined by the authors as more than half the intercuspal width) showed the highest incidence of fracture. They also noted 'remarkably fewer' adverse observations when the fillings were limited to Class I and conservative Class II cavities. The study was also funded by GC.

- Gurgan and co-workers[19] initially published a 4-year randomized controlled trial in 2015, using GC EQUIA Fil versus Gradia Direct Resin composite (GC) in Class I and small Class II cavities, including 40 Class I and 30 Class II restorations. In a 10-year follow-up,[20] when 51 patients and 124 restorations were available for examination, there were no differences in marginal discolouration scores or anatomical form, and no secondary caries, but the colour match of the GIC restorations was worse, concluding that 'both materials showed an acceptable success rate' in the restoration of Class I and II cavities at 10 years. However, the paper stated that, while no Class I restorations failed during the 10-year observation period, one Class II restoration was missing for review after fracturing at 3 years and another one at 4 years. The authors stated that a 100% success rate had been achieved because of the absence of the two patients whose restorations had failed! It is the view of the present authors that these failures throughout the study should be included and counted as failures whether the patients attend or not. Nevertheless, the actual cumulative failure rate of the Class II EQUIA GIC restorations at 10 years was 8%, which could be considered a good performance. The present authors therefore consider that these results indicate recent glass ionomer variants, such as EQUIA Fil, appear to have value if used within the instructions for use. The authors of the 10 year study actually discuss the limitations of their work, namely, that the study was carried out in a dental hospital, involved two experienced dentists and motivated patients, that all the restorations were small in size with conservative cavity designs and no cusp replacements in a high proportion of premolar teeth and that the power calculation was not met, adding that there was more margin discolouration around the GIC restorations, but that no restorations required replacement because of wear. The study could indeed be considered to be efficacy (ideal situation) not effectiveness (practice-based, real-world situation). However, this indeed is the set-up of many controlled clinical studies.
- Türkün and Kanik[21] presented a 6-year clinical evaluation of two GICs in Class I and II cavities. In a total of 256 fillings placed (124 Class I, 132 Class II) they compared EQUIA Fil (GC) and Riva SC (SDI, Melbourne, Australia) with two different coatings (EQUIA Coat and Fuji Varnish, respectively) in 54 patients. At 6-year recall, they evaluated 37 patients and included 176 fillings, a 69% recall, with the results indicating that the overall success of EQUIA Fil was better than Riva SC, with Class II cavities in Riva SC being significantly worse in marginal adaptation, anatomical form and retention when compared with the EQUIA Fil group. Many illustrations of restorations were provided to back up the findings. The authors, however, state that 'Riva SC was developed for the restoration of only small and non-stress-bearing Class II restorations, and this could have made it less successful in moderate-size to large restorations'. They added that 'reinforced GICs may be considered as the material of the future in restorative dentistry and minimally invasive dentistry. Their long-term clinical success is making them promising as a definitive restorative material, even in moderate-size Class II restorations', adding that 'further developments are needed to improve their mechanical properties and extend their indications'.
- Most recently, Heck and colleagues[22] carried out a 6-year randomized controlled trial involving 85 Class II restorations (43 EQUIA Fil/EQUIA Coat (GC) and 42 Fuji IX Fast/Fuji Coat LC (GC)) in 34 patients. However, a disappointing number of restorations (44) were assessed at 6 years, because of 'patient relocation, restorations replaced by other dentist, or unwillingness to attend for follow up'. There were eight failures (four in each group) of the 44 restorations examined at 6 years – 81.8% survival. The main reasons for failure were material fractures and retention loss, combined with poor marginal adaptation or poor proximal anatomical form. Two failures were attributed to inadequate application of the materials, with five restorations (three EQUIA Fil and two Fuji IX GP Fast) requiring some intra-oral repair procedures. They added that application issues during the placement of the materials could possibly have contributed to a few later failures. The annual failure rate was 3.0%. In discussion, the authors added that 'In the meantime, the material has been further developed into a glass hybrid and launched as EQUIA Forte. The more voluminous glass fillers are supplemented with smaller, highly reactive glass fillers. This leads to better handling of the material with improved packability and less stickiness and also to increased flexural strength and acid stability'. This study was 'mainly' funded by GC.

In conclusion, the results of these clinical studies indicate that high viscous GICs, such as EQUIA Fil, in combination with EQUIA Coat plus, have been found to perform satisfactorily in Class I restorations and in small/medium Class II restorations, with several researchers considering that the latter cavities should not have a large isthmus width (defined by GC in the respective instructions for use and the authors as less than half the intercuspal width).

Performance of the most recent GIC variants

The most recently introduced GIC variants are the glass hybrids, an example being EQUIA Forte (HT)(GC). These possess the typical GIC setting mechanism, but have a variety of alterations from previous formulations, such as glasses of different sizes that are more reactive, therefore providing improved crosslinking with the PAA, and therefore improved physical properties. The manufacturers, GC, state that the PAA is of higher molecular weight with more chemical stability, leading to improved physical properties of the matrix, and better handling. An improved resin coating is considered to lead to a smoother restoration surface and may improve wear resistance,

Another recent introduction is Ketac Universal (3M Oral Care, St Paul, MN, USA). This is a classical GIC material with no coating or glaze. It is virtually monomer free, with a purified polyacid and no added monomers. An advantage is the simple clinical procedure.

Recent laboratory research on a glass hybrid material

Despite the fact that testing GICs and glass hybrids in a lab setting is technique sensitive, and the maturation that takes place over time in the mouth is not taken into account, there are a number of *in vitro* studies that examine the physical properties of EQUIA Forte (GC).

- Poornima and co-workers[23] made 54 cylindrical 6 x 4 mm specimens and divided these into three groups of 18, comparing EQUIA Forte with an RMGI and conventional GIC. They measured compressive strength and surface microhardness, concluding that EQUIA Forte showed comparatively better mechanical properties than the other groups, adding that 'further clinical research is required to confirm our findings since few studies can be found in the literature over the mechanical properties of bulk filled glass hybrid GIC (EQUIA Forte) compared to resin modified and conventional restorative GIC'. The authors further added that 'it can be suggested for use as a posterior restorative material'. However, the present authors consider that it is dangerous to extrapolate laboratory data into a clinical recommendation.
- Yılmaz and colleagues[24] tested water sorption and solubility, having made 60 disc-shaped 8 x 2 mm specimens of EQUIA Forte, with five groups with different coatings. They concluded that EQUIA Forte Coat and Final Varnish LC were more successful in terms of water sorption, but Final Varnish LC was more successful in terms of solubility. The results also suggested that use of a high-powered curing light, which might provide heat as well as light energy might accelerate setting and thereby minimize exposure to moisture.
- Kutuk and co-workers[25] carried out testing using 12 cylindrical specimens formed in EQUIA Forte and G-Aenial (GC), which were subjected to a fracture resistance test. The fracture resistance of the glass hybrid restorative system (EQUIA Forte) was comparable to the composite resin (G-ænial Posterior),
- Kielbassa and co-workers[26] compared the wear resistance of EQUIA Forte and EQUIA Fil with and without their resin coatings, plus controls of Ketac Fil (3M ESPE) and the resin composite G-Aenial (GC), using a simulated clinical simulation of 78 standardized Class I cavities in plastic teeth over 30,000 cycles, with the specimens being scanned before and after chewing. The results indicated that EQUIA Fil and EQUIA Forte performed similarly, but both showed higher abrasive wear than the composite specimens. As a result, the authors concluded that occlusal loading should be carefully considered when using high viscosity GICs or glass hybrids as amalgam alternatives for restoration of posterior teeth, but, again, the present authors question extrapolation of laboratory data into a clinical recommendation.
- Šalinović and colleagues[27] compared the compressive strength of three GIC materials, Ketac Universal (3M ESPE), EQUIA Forte and EQUIA Fil (GC). They concluded that there were no differences in compressive strength and fracture modes between the three materials, but Ketac Universal had higher hardness values than EQUIA Fil or EQUIA Forte. However, the authors added, correctly, that the EQUIA materials were tested without application of a protective coating, which could also have led to the results being inferior to those obtained by the manufacturer.

In summary, it appears that the manufacturer's claims of 20% improved flexural strength, 21% improvement in acid resistance, 40% improvement in wear resistance are partially confirmed by these studies, although further, independent testing is indicated, and the results of well-designed clinical trials are essential before extended indications may be considered. One recommendation, which might translate readily to the clinical situation, is the use of a high-powered curing light, possibly providing both heat and light energy, that might accelerate setting and thereby minimize exposure to moisture.

Clinical research on the most recent glass ionomer variants

While laboratory research can provide useful information on a material's suitability for use in the mouth, there is no substitute for clinical research on restoration survival *in vivo*.

- Miletić and colleagues[28] carried out a split-mouth, randomized, prospective, multicentre clinical study. They enrolled 180 patients (mean age 34.6 years) identified as in need of two Class II two-surface restorations in the molar region of the same jaw. Restorations were examined by two independent examiners. The estimated survival rates at the 2-year recall were 93.6% (EQUIA Forte) and 94.5% (Tetric EvoCeram, (Ivoclar-Vivadent, Schaan, Liechtenstein), indicating no significant differences between various parameters for the two materials, with the authors concluding that 'both the glass hybrid and resin composite system showed good performance in moderate to large two-surface Class II restorations in a 2-year follow up'. This work is part of a 5-year multicentre evaluation. The present authors are advised that these workers expect to publish the 5-year data in the near future.
- The interim 3 years results from the above split-mouth randomized, prospective multicentre, clinical study were used by Schwendicke and co-workers[29] to assess the cost-effectiveness of two amalgam alternatives, glass hybrid and resin composite. The results indicated that overall costs were lower for glass hybrid restorations than for resin composite in Croatia, Turkey and Serbia, while this difference was minimal in Italy. Glass hybrid restorations tended to survive longer than resin composite in Croatia and Italy, and shorter in Serbia and Turkey, but overall survival time was not significantly different. The authors calculated cost-effectiveness, which indicated that resin composite 'was more expensive at limited or no benefit or complications'. They concluded that glass hybrid was less costly than composite, both initially and over 3 years. Efficacy differences were extremely limited. Given their low initial costs, and as efficacy between glass hybrid and composite did not differ significantly, the glass hybrid had a high chance of being more cost-effective within this specific trial.
- Gurgan *et al*[30] published a 2-year evaluation of 108 extended-size Class II restorations (with the width of the proximal box not interfering with the peak of the cusps and the proximal box in occlusion) in 37 patients. Half

of the restorations were restored with EQUIA Forte, the others with a micro-hybrid composite, and two independent examiners evaluated the restorations. At 2 years, 90 restorations in 32 patients were examined (recall 86.5%). Four glass hybrid restorations were 'missing', three due to bulk fractures and one due to proximal fracture, but no significant differences were noted between the two materials for the other criteria evaluated. The authors concluded that, 'although the glass hybrid materials showed a significant mismatch in colour, both materials exhibited successful performance for the restoration of large Class II cavities at 24 months'. Despite this conclusion, four of the 90 restorations had fractured, hence the present authors sound a warning that the large interproximal box widths employed in this study may be best avoided, and the manufacturer's indications for use should be followed, The other message might be – use a resin composite for wide boxes when the proximal size of the box exceeds the recommendations.

- An IADR abstract from the same authors[31] provided 4-year data on this evaluation. In this, 90 restorations were evaluated in 32 patients: five glass hybrid restorations were 'missing', four due to bulk fractures (three of these at 1 year, one at 4 years) and one due to proximal fracture (mentioned above). Six showed colour differences, while SEM observations showed acceptable surface and marginal adaptation for both the materials in the study. The authors concluded that 'these materials could be considered as permanent restorative materials for the restoration of large Class II cavities'.
- Most recently, Wafaie and co-workers[32] in a well-constructed, independent randomized trial in Egypt, evaluated the performance of three high-viscosity glass ionomer materials in small Class II cavities after 5 years. They compared Ketac Universal Applicap (3M), EQUIA Forte (GC) and Riva self-cure (SDI), with a hybrid resin composite system, Filtek Z250 (3M), as control. Patients recruited were between 20 and 40 years of age, with each needing four or more restorations. A total of 160 restorations, in 40 patients, was placed. The isthmus width of the cavities was not more than one-third of the intercuspal distance, and the operative field was isolated with cotton rolls together with high-volume saliva ejector. Restorations were examined by two independent examiners according to FDI criteria as described by Hickel *et al*,[33,34] and epoxy resin replicas of the restorations were observed for surface characteristics. Thirty-nine patients returned for examination at 5 years, results indicating 100% success for the resin composite restorations, while five failed Class II glass ionomer restorations were observed during the evaluation period: one Ketac Universal (2.6% failure), two EQUIA Forte (5.1%), and two Riva HV (5.1%). This resulted in an AFR of 0.5% for the Ketac Universal group and 1% for both EQUIA Forte and Riva HV groups. The reason for failure was the fracture of the Class II glass ionomer restorations, while one Riva HV restoration failed because of 'partial looseness *in situ*'. It was concluded that, although differences in surface lustre and colour match were apparent after 5 years, the three high-viscosity glass ionomer materials provided successful clinical performance in small to medium Class II cavities.
- While the present work relates specifically to survival of GIC Class I and II restorations, a further cost effectiveness study by Schwendicke and colleagues[35] in Germany on 175 sclerotic non-carious cervical lesions (NCCLs) may be of relevance. In this, the performance of restorations in EQUIA Forte was compared with those in the resin composite Filtek Supreme (3M). After 3 years, 17 EQUIA Forte and 19 resin composite restorations showed total retention loss, which was not significantly different. However, the authors concluded that as the glass hybrid was significantly less costly than the resin composite material, both initially and in the long term, using the resin composite was only cost-effective for payers willing to invest high additional expenses with minimal survival gain.

In conclusion, the results of these clinical studies indicate that the recently introduced glass hybrid material, EQUIA Forte (HT), shows promising results in Class I restorations and in small/medium Class II restorations (generally defined as a cavity isthmus width being not closer than 1–1.5 mm from cusp tips, with better cost-effectiveness than equivalent resin composite restorations, the latter being demonstrated in one multicentre study on loadbearing restorations and one study on Class V restorations. One study has provided good results in a clinical study on Ketac Universal Applicap (3M) in loadbearing restorations at 5 years. The results also indicate a more promising result in comparison to the review published in *Dental Update* in 2013. The results of ongoing long-term clinical evaluations will provide further information on the performance of this material.

An EQUIA Forte restoration at 3 years is presented in Figure 3.

a b

Figure 3. (a) Defective resin composite restoration. **(b)** Restoration in **(a)** replaced by EQUIA Forte, 3-year review. (Courtesy of Prof Matteo Bassi.)

Discussion

While discussions regarding an amalgam replacement material have been ongoing since GICs were introduced, GIC use gained momentum following the Minamata Agreement in 2013, in which 147 countries agreed to reduce, and ultimately phase out, their use of mercury-containing products, materials and devices. This obviously included dental amalgam, which has many positive properties,[36] but its adverse environmental impact will eventually lead to its demise. Added to this is the increased patient enthusiasm to have aesthetically pleasing restorations in both their posterior, as well as their anterior dentition.

Resin composite has become the 'gold standard' amalgam replacement by virtue of its good clinical performance. Many clinical evaluations may be considered relevant here, but two, using practice-based 'real world' data will be used as examples:

Laske and colleagues[37] published details of a massive (358,548 restorations in 75,556 regularly attending patients) dataset established in the Netherlands using data from electronic patient files from 67 general dentists, collected between 1996 and 2011. Their results indicated an overall AFR varying between 2.3% and 7.9% (mean 4.6% at 10 years), with restorations in molars having a higher AFR. The AFR of composites in posterior teeth was 4.4%, amalgam 5.1% and GIC 11.1%. However, this result may be biased by the fact that the material is mostly used for temporary restorations, such as closing the access opening after endodontic treatments and for emergency repairs, with the authors stating that 'By far the most common restorative material used by the participating GDPs was composite' (240,701 composites *vs* 34,510 amalgams) and a majority of restorations being placed in molars rather than premolars (177,015 *vs* 108,359, respectively), a more severe test for a restorative material.

The survival rates of posterior composite restorations have also been evaluated in a recent review,[38] with the results indicating, both from cohort studies and meta-analyses that fulfilled the inclusion criteria (among these being that the studies were based in primary care) that resin composite restorations have acceptable survival rates when placed in loadbearing situations in posterior teeth, with AFRs within the range 2–3% being recorded.

The present review appears to indicate that recent GIC variants are now competitive in specific clinical situations, such as Class I restorations and small-to-medium Class II restorations, with restoration survival rates approaching the reported survival rates of posterior composite restorations. A critique of the clinical evaluations reported in the present work might therefore conclude that they present a useful indication regarding contemporary GICs, but one or more long-term cohort studies or randomized controlled trials (to add to that of Wafaie and co-workers[32]) would be valuable, with an extension of the work of Miletić *et al*[28] to provide 5 years' clinical data on the restorations included in their multicentre clinical study.

Figure 4. (a) Multiple cavities visible on radiographs. **(b)** EQUIA Forte restorations at 1 year. **(c)** Radiographs at 1 year indicate successful stabilization of caries. (The clinician in this case made the patient aware of the progression of the caries in the UR4 mesially: it was suggested that this be investigated. However, the patient's schedule was such that this was not possible before his relocation.)

Regarding ease of placement, the present authors agree that the lack of need to bond glass hybrid restorations with an intermediate bonding agent, and the fact that there is no need to etch with phosphoric acid, is an advantage for clinicians (albeit with the need for cavity conditioning with 20% polyacrylic acid), provided that restoration survival is no different for both types. In that regard, the elegant cost-effectiveness work by Schwendicke *et al*[29,35] on Class II and V restorations cannot be overlooked.

Case report

The following presents the use of EQUIA Forte in multiple cavities in a 25-year-old professional male patient who had not visited a dentist for several years, having relocated, but having attended the practice of one of the authors (PS). His complaint was a broken tooth in the upper left quadrant, but no pain. The patient's history indicated that he had never received fillings in the past, and had not experienced any pain. He advised that he had worked from home since the pandemic and admitted to having a 'sweet tooth'.

Examination showed that the patient's oral hygiene was reasonable, with no significant periodontal disease. A visual tactile examination discovered a fractured upper left first premolar that was grossly carious. Extensive caries was noted clinically in another eight teeth, and bitewing radiographs (Figure 4) revealed several additional early carious lesions. Discussion with the patient summarized the aetiology of caries and, further to this, it became clear that he was in the habit of drinking coffee with sugar regularly through the day and, in addition to this, lots of sweet snacks.

Further to this discussion the patient was offered some remedial treatment at the same visit and, subsequent to the administration of local anaesthetic, the majority of the caries was removed from the upper left first and second molars and the upper left first premolar. Owing to time constraints and the need to deal with the active lesions as quickly as possible, it was decided to use EQUIA Forte because of its ease and speed of handling, compared to resin composites. The patient was advised that the upper left first premolar might require endodontic treatment in due course, but rather than risk a carious exposure, some of the deepest caries might be left behind and sealed into the tooth, as suggested by, among others, Kidd *et al*.[39]

One month later, the patient returned and caries in UR654 was removed under rubber dam isolation. The caries in the UR4 was extensive, and, again a decision was made to use EQUIA Forte as a quick 'semi-permanent' restoration. He was seen again 1 week later and the LLQ was isolated under local anaesthesia and caries was removed from the LL567. These lesions were significantly less extensive than the others and a decision was made to use resin composites in these teeth.

During treatment, the patient had become more aware of the aetiology of caries and so had changed his dietary habits and had been using Fluorigard (Colgate-Palmolive UK, Guildford UK) toothpaste since the first visit. At review after 1 year, the restorations were performing satisfactorily (Figure 4b,c), and hence were left *in situ* as definitive restorations, despite some exceeding the manufacturer's recommendations on cavity size. The patient was advised that the non-functional UR8 should be extracted, but he declined this advice. He has since relocated to a new address over 100 miles away, which precluded further review.

Conclusion

Amalgam and resin composite restorations, placed in loadbearing situations in posterior teeth, have stood the test of time and may be considered to have extensive research to back up their clinical effectiveness.

The present review has indicated that contemporary GICs and their variants, such as glass hybrids, feature in an increasing number of publications, which suggests that their clinical effectiveness in Class I and small-to-medium sized loadbearing Class II cavities holds promise. Accordingly, we conclude that composites, glass hybrids and GICs all have their merits and, when faced with a patient, restoration and clinical scenario, the clinician has to weigh up the options and decide what material to use.

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Compliance with Ethical Standards
Conflict of Interest: The authors declare that they have no conflict of interest.
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