Amalgam: Gone for good?

By **Prof. Dr Falk Schwendicke**, Germany

Prof. Dr Falk Schwendicke *is the Head of the Department of Oral Diagnostics, Digital Health and Health Services Research at Europe's largest university hospital, the Charité in Berlin (Germany).*
Prof. Schwendicke is currently an Associate Editor of the Journal of Dental Research, the President of the German Association for AI in Dentistry, the Topic Driver Dental at the ITU/WHO group AI in Health and the Vice President of the German Society for Oral Epidemiology and Health Services Research. He holds a PhD from Charité – Universitätsmedizin Berlin and a Master of Dental Public Health (MDPH) from the University of Manchester (UK). He received numerous awards, such as the IADR Leader Award, IADR Basil Bibby, IADR Lion Award and the David Sackett Award for Evidence-Based Medicine.

For about a century, dental amalgam has been the standard restorative material for posterior caries lesions. Given the ease of placement, particularly its moisture tolerance, but also its relatively high resistance against masticatory forces and secondary caries, amalgam remains the restorative standard in most statutory or public health insurances until today. Whilst concerns towards its biocompatibility and wider health effects repeatedly entered the public debate, a number of studies were able to refute such assumptions and to showcase the general safety of amalgam, if properly placed.

Notably, the usage of amalgam will likely cease in many countries in the world over the next years – grounded in the so-called Minamata treaty. Emanating from the spoilage of mercury used in an industrial process in the city of Minamata in Japan and a series of widespread health effects due to subsequent mercury uptake, the vast majority of nations worldwide have signed the Minamata treaty, binding the signees to reduce and eventually stop the usage of mercury in any industrial process. In that sense, dentistry is an outlier; only for dentistry, the treaty did not mandate a complete "phase-out" of the material, but a "phase-down". Signing nations promised to undertake measures to reduce the usage of dental amalgam, for example via the reinforcement of prevention or the development and adoption of alternative restorative strategies. In many countries in the world, including all countries of the European Union, policy makers have indeed decided to overachieve this promise and phase-out the usage of dental amalgam completely. For some groups, i.e. pregnant or lactating women, this phase-out has already become reality. Within this reality, dentists are now faced with an important question: Which alternative material to use?

Restorative options in the post-amalgam era

In the course of the last 60 years, a range of amalgam alternative materials have been introduced.

Broadly, they fall into three categories;

1. resin-based composite materials, placed in increments to compensate for polymerization shrinkage and to allow safe polymerization,
2. glass-based materials, i.e. glass ionomers and glass hybrids,
3. materials combining the properties of both material classes (for the latter, terminology is not consistent and the clinical evidence often limited).

Especially resin composites have a long tradition of being used as an alternative to amalgam, in particular for posterior load-bearing restorations extending into the proximal surface. Micro- and nano-hybrid resin composites have shown excellent physical properties, such as high resistance against abrasion and erosion, high flexural strength, polishability and aesthetics. Moreover, these materials can be placed adhesively and therefore do not rely on macroretentive cavity preparation, allowing for minimally invasive dentistry. Notably, the placement of resin composites comes with a number of prerequisites like strict moisture control, stepwise preparation and conditioning of the cavities, e.g. involving acid-etching and adhesive placement. In recent years the trend towards simplifying these application steps has been one focus of manufacturers, for example by combining the etching and the adhesive steps or by reducing the need for increment placement when using "bulk fill" composites instead.

Nevertheless, the placement of resin composites – especially in equigingival or subgingival situations - is technically demanding. Moreover, the material itself is relatively costly when compared to dental amalgam. Hence, resin composites can safely be regarded as one of the contemporary amalgam alternatives, but nevertheless does not "check all the boxes".

Glass ionomers and glass hybrids

For several decades, glass ionomers have not been considered a fully fletched amalgam alternative, mainly because of their limited stability against abrasion and erosion and their low flexural strength, which resulted in limited longevity in occlusal-proximal posterior cavities. More recent generations of this material glass have been developed to specifically address the discussed main weaknesses. A more advanced category of glass-based materials, called glass hybrids, claims to have overcome the most limitations around abrasion and erosion stability, and also to come with significantly improved flexural strength. This has been achieved by alterations in the chemical composition of the material: mainly the introduction of an additional, smaller and highly reactive glass particle and longer acrylic-acid chains. Moreover, the introduction of an additional coating step for the occlusal or other accessible surfaces, with a nano-resin material being placed onto the rougher glass surface protects the porous glass body against acid and abrasion. This coating has also been found to significantly improve the aesthetics of this formerly poorly polishable material. When the coat wears off, the glass hybrid undergoes a unique second maturation, substantially increasing the restoration's hardness.[1]

In the range of laboratory studies, it was confirmed that indeed the glass hybrids come with significantly superior properties compared with their predecessors, while retaining the advantages of this material class, namely the option to place it in bulk, the ease of placement and its high bioactivity (especially the known release of fluoride). Notably, laboratory studies are not necessarily perfect surrogates for clinical behaviour. Only clinical studies can demonstrate the true effects of any material alterations and the potential suitability of a restorative material as an amalgam alternative.

Glass hybrids: Clinical data as hard currency

As with most scientific advances, the development of the glass hybrids was not a revolution but an evolution. A number of studies – some of them even practice-based – investigated the direct predecessors of glass hybrids and confirmed the advances of this material class over the last one and a half decade, refuting the notion of glass-based materials being merely a temporary material [2-4]. The current generation of glass hybrids has been assessed in several studies that are presented in more detail in the subsequent paragraphs. Reassuringly, these studies were not all related to manufacturers and were conducted by a range of groups from all over the world. Moreover, they dealt with different clinical indications and employed robust clinical designs, such as randomized control trials, to compare the glass hybrid material against an accepted standard of care like a resin composite. Two main application fields have been explored, i.e. cervical and posterior, load-bearing lesions.

Fig. 1. A: Multiple cervical non-carious lesions, prior to treatment; **B:** cervical lesions restored with the glass ionomer EQUIA Forte from GC; **C:** Glass hybrid restorations at follow-up after 6.5 years (Courtesy of Prof. Matteo Basso, Italy).

Cervical lesions (Fig. 1)

The cervical placement of glass ionomers, especially resin-modified glass ionomers, has a long tradition and is backed by a wealth of clinical studies demonstrating the usefulness of this material for this purpose. Resin-modified glass ionomers have consistently outperformed alternative materials when it comes to survival and success of cervical restorations [5]. For glass hybrids, two randomized trials were identified comparing this material against resin composites. The first study [6] included a small sample of 25 patients with non-carious cervical lesions and bruxism, i.e., a very specific group. In these (overall rather young) patients, a total of 148 lesions were randomly restored (indicating a massive clustering of the lesions per patient) with either a glass hybrid (Equia Forte, GC, Tokyo, Japan) or a resin composite (Ceram.X One Universal, Dentsply, Konstanz, Germany). After 6, 12 and 24 months follow-up, the restorations were re-evaluated using the modified USPHS criteria. When assessing the 126 remaining restorations (in 22 patients) at the 24-months recall, it was apparent that both materials performed similar. Only for marginal adaptation, a significant difference was found, with glass hybrids showing slightly reduced adaptation. Secondary caries was not observed on any of the restorations.

Another study [7], with a follow-up of 36 months, assessed the survival, quality and costs of glass hybrid (Equia Forte) and resin composite restorations (Filtek Supreme XTE, 3M, St. Paul, USA) for managing cervical lesions; more specifically, sclerotic non-carious cervical lesions. In 88 patients (50–70 years) with 175 lesions, restorations were directly placed without any mechanical preparation (which eventually resulted in high annual failure rates for both groups, see below). Restoration quality was assessed at 1-, 18- and 36 months using FDI-criteria. Costs were evaluated using a so-called micro-costing approach (accounting for the time used for placing the material) and, during follow-up, fee items of the statutory insurance in Germany. Of the 88 patients, 43 received glass hybrids (83 restorations) and 45 resin composites (92 restorations); cluster randomization had been applied. At 36 months, 17 glass hybrids and 19 resin composites showed total retention loss, 5 glass hybrids were partially lost (no significant difference between materials). FDI ratings were not significantly different for any domain except surface lustre (here, composites were superior to glass hybrids – while it should be noticed that the latest generation of glass hybrids addressed such aesthetic effects specifically) (Fig. 4). Costs were significantly lower for glass hybrids, both initially (glass hybrids: 32.57; SD 16.36 € versus resin composites: 44.25; SD 21.40 €) and over the full observational period (glass hybrids: 41.72; SD 25.08 €, resin composites: 51.60; 26.17 €).

In summary, both studies – randomized trials of a robust design – indicate the suitability of glass hybrids for restoring cervical lesions. Moreover, they demonstrate that the material is not only showing similar survival, but also flag the advantageous cost-effectiveness of this material. Notably, and as mentioned above, the fact that glass ionomer materials work well in this indication is not necessarily new. However, aspects around the economic differences between composites and glass hybrids for managing cervical lesions have not been assessed in detail before. The fact that regardless of the used restorative material, a preparation of sclerotic surfaces is likely beneficial, should also be highlighted.

Occlusal-proximal lesions (Figs. 2 and 3)

In contrast to cervical lesions, glass ionomers were not considered to restore posterior, load-bearing and proximally extended cavities in the past. As mentioned, their limited flexural strength and abrasion/erosion resistance have often compromised the success and survival of glass ionomer restorations for this indication. On the contrary, with the glass hybrid materials, a number of clinical studies have now refuted that notion. Two recent randomized trials are particularly noteworthy:
In the first trial [8], a glass hybrid (Equia Forte), a bulk-fill composite resin (Filtek Bulk Fill Posterior Restorative, 3M) and a micro-hybrid composite resin placed incrementally (Charisma Smart, Heraeus Kulzer, Hanau, Germany) were compared. 109 teeth in 54 rather young patients (31 female, 23 male, mean age 22 years) with two-surfaced (mesial-occlusal, occlusal-distal) cavities in permanent teeth were randomly restored. The restorations did not extend towards cusps and all cervical margins were placed in sound enamel (i.e. not subgingivally). After caries removal and minimal invasive preparation, the materials were placed. After up to 24 months, 84 restorations were re-evaluated using the modified USPHS criteria. Composite restorations showed better anatomic form, contact point, colour match, surface texture and overall survival compared to the glass hybrid restorations.

In contrast, another, multinational randomized controlled split-mouth trial [9, 10] in four university hospital centres in Zagreb (Croatia), Belgrade (Serbia), Milan (Italy) and Izmir (Turkey) compared a glass hybrid (Equia Forte) against a nano-hybrid composite (TetricEvoCeram, IvoclarVivadent, Schaan, Liechtenstein) for a similar indication. The study included occlusal-proximal two-surfaced restorations in the molar region in adults with a permanent dentition; each individual needed to have two similar cavities in vital (positive response to ethyl chloride) molars of the same jaw to allow for the split-mouth design. A total of 360 restorations (in 180 patients) were placed. Per patient, one tooth was randomly selected to be restored with glass hybrid and the other was restored with composite material. Pre-contoured sectional matrices (Palodent Plus, Dentsply) were employed and cavities conditioned according to manufacturer's instructions prior to placing the material. For the composite, a two-step self-etch adhesive (AdheSE, IvoclarVivadent) was employed. Patients were followed

Fig. 2 A: Class I restoration on tooth 47 with marginal discoloration and recurrent caries, prior to treatment; **2B:** Class I glass hybrid restoration with EQUIA Forte, right after placement; **2C:** Glass hybrid restoration at follow-up, 3 years after placement (Courtesy of Prof. Matteo Basso, Italy).

Fig. 3A: Class II restoration on tooth 26 with secondary caries; **3B:** Class II glass hybrid restoration with EQUIA Forte on tooth 26, right after treatment; **3C:** Class II glass hybrid restoration, 5 years after treatment (Courtesy of Prof. Matteo Basso, Italy).

up after one week, 1 year, 2 years and 3 years and restorations assessed using FDI-2 criteria (10). Additionally, the costs of each restoration from the patient's perspective were calculated in US Dollar (USD), accounting for direct medical costs. To assess cost-effectiveness, incremental-cost-effectiveness ratios were used, expressing the cost difference per gained or lost effectiveness.

In that trial, patients in Italy were older than in the other centres, and overall, more patients were female than male. 32 patients dropped out over the 3-years period, and 21 received re-treatments (on 27 restorations). The mean survival time of the restorations was high across all centres and did not differ significantly between the two materials (Table 1). In three of the four countries, composite was more expensive both initially (e.g. for its placement) and on the long term (over the 3 years follow-up and accounting for managing complications, too). When assessing the cost-effectiveness (USD and survival in months), composite was usually more costly than glass hybrids in three of the four counties, and overall, composite was more expensive at limited clinical benefit (costing additional 268.5 USD per additional month without complications).

The emerging body of evidence displays that the glass hybrids are also promising for posterior, proximally extended cavities. While there are some inconsistencies around the comparative longevity of glass hybrids versus composites for this purpose between the two described studies, especially the large multinational trial is assuring: In four independent centres, concordant results were generated, confirming that both composites and glass hybrids are suitable materials over the 3-year observational period for load-bearing cavities. Notably, the

Parameter	Croatia	Italy	Serbia	Turkey
Age (years)	26.5 (7.4)	44.6 (15.8)	31.7 (11.4)	30.6 (11.2)
Gender (female/male)	44/16	16/16	16/12	40/20
Glass hybrids costs (USD)	92.7 (7.4)	146.1 (12.9)	44.0 (3.3)	66.2 (11.9)
Composites costs (USD)	126.42 (16.3)	146.2 (19.3)	61.0 (3.5)	128.6 (3.8)
Glass hybrids survival (months)	35.1 (3.4)	35.3 (2.3)	34.1 (6.2)	35.0 (3.0)
Composites survival (months)	34.3 (5.1)	35.0 (4.0)	34.9 (4.6)	35.8 (1.0)

Table 1: Costs and survival of glass hybrids and composites in different countries (mean, SD)

cost-effectiveness of glass hybrids was once more confirmed, deeming it a particular amalgam alternative when cost considerations are important, for example in low- and middle-income countries but also in most statutory or social insurance settings in high-income areas. Using an extrapolation model [11], it was further demonstrated that this cost-effectiveness was likely to be retained on the long term; a recent study found the added effectiveness of composites minimal (tooth retention for a mean (SD) 54.4 (1.7) years) but also more costly (694 (54) Euro) than glass hybrids. In sensitivity analyses, and under certain assumptions, glass hybrids were even more effective and still less costly than composite.

Glass ionomers as essential medicines

Given the advantages of glass ionomers and glass hybrids and the recent advancements, a WHO expert committee, in 2021, declared that "glass ionomer cement has caries-preventive properties due to continued capture and release of fluoride ions, which remineralise carious tooth structures, and have a bacteriostatic effect. Glass ionomer cement results in lower rates of recurring caries compared to composite or amalgam restorations, and also reduces the incidence of new cavities on other teeth. The simplicity of application makes glass ionomer cement suitable for primary health care and field settings, including for "people with special needs" [12]. As a result, glass ionomers were, as one of few dental materials, defined as "essential medicines" [13], i.e. materials needed for a basic healthcare system. Essential medicines are usually the most efficacious, safe and cost-effective materials for a certain condition (in this case dental caries).

In 2019, glass hybrids were recognized by the FDI as a class of restorative materials for permanent teeth, suitable for single-surface restorations and Class II restorations [14, 15].

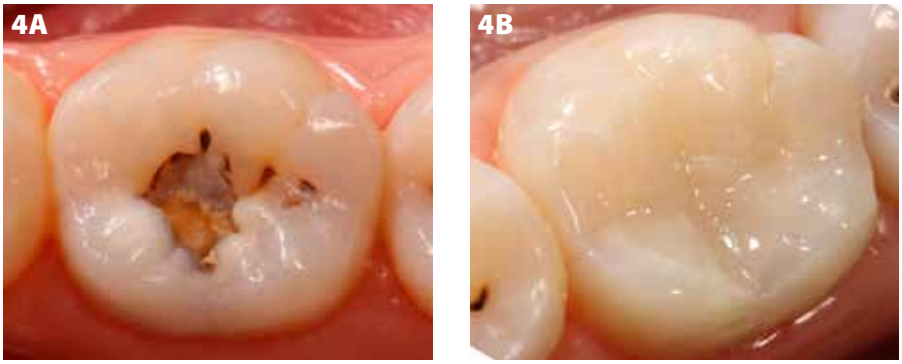

Fig. 4A: Class I cavity prior to treatment; **B:** Glass hybrid EQUIA Forte HT (GC) restoration (Courtesy of Dr. Zeynep Bilge Kütük, Turkey).

Conclusions

The era of dental amalgam is slowly coming to an end – and it can be expected that in the future, the usage of amalgam will fully cease in most healthcare systems. There is not a single material fulfilling all requirements towards an amalgam replacement; instead, a range of materials with different properties are available and dentists will need to make informed choices which material fits which indication best. Glass ionomers and glass hybrids are among the potential amalgam replacements, and have shown a considerable evolution over the last two decades. Evidence supports the usage of glass hybrids for both cervical and posterior load-bearing restorations. The cost-effectiveness and applicability of these materials is likely superior to that of other materials, while improvements in further material characteristics (specifically flexural strength) would be welcome to establish this material as truly universal amalgam replacement material. For most healthcare systems worldwide, though, glass ionomers and glass hybrids are already "essential medicines" according to WHO.

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