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Progress in Eradicating Amalgam from Restorative Dentistry

SUMMARY

This paper sets out the current position with respect to the replacement of dental amalgam as a restorative material. The environmental impact and the question of possible adverse effects of mercury on human health, including that of dental personnel, are reviewed. The literature has been surveyed using Pub Med with the following key words employed: dental amalgam; environmental; disposal; alternative materials. This identified a large number of papers, and more recent ones were selected for inclusion, particularly where they summarised the earlier literature. The findings of this process are that dental amalgam remains a popular and widely used material which, with appropriate hygiene measures, does not pose a threat to human health. However, environmental concerns with the mining, transport and technical uses of mercury led to the Minamata Convention in 2013, one consequence of which is that mining of mercury will cease from the year 2032. This means that dental amalgam will no longer be available for use. This article considers alternative materials. Results from the literature show that neither of the main possibilities, namely composite resins of glass-ionomer cements, compares with amalgam in terms of strength or durability. The impact of this on the dental profession is discussed briefly.

Keywords: Dental Amalgam; Replacement; Environmental; Disposal; Alternative Materials

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Eradication of Amalgam

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Introduction

Dental amalgam has been used successfully as a dental restorative material since the nineteenth century[1]. It is widely recognised as a reliable, cost-effective material for this purpose but, for a variety of reasons, its use is declining. Several countries have banned it altogether and, due to concerns about the environmental impact of mining mercury, a key component, and also about disposing of amalgam waste, there is considerable pressure for other countries to follow suit.

However, eradicating amalgam from use in dentistry is not straightforward, as no material can compete with it in terms of cost-effectiveness, reliability or durability[2]. It is also generally considered easy to use, which also contributes to its reliability and economic attractiveness.

In the current paper, the present state of use of dental amalgams is considered, along with the environmental and health issues that arise from its use. Future prospects for replacing dental amalgam are also reviewed because, unless there are reliable alternatives available, amalgam will continue to be needed. The literature has been surveyed using PubMed as the main source of relevant publications. Key words used were dental amalgam; environmental; disposal; alternative materials. In this way, a large number of papers published over many years were identified, but the focus has been on more recent publications, with the aim of restricting the discussion so far as possible to amalgams with contemporary formulations, in particular the so-called high-copper versions. The reason for this emphasis has been to ensure that concerns over modern types of amalgam are given the necessary attention. In addition to those articles identified by PubMed, other papers previously known to the author have been consulted and their insights included in the current paper.

The development of dental amalgam

Achieving safe and reliable amalgams for dentistry was the work of several individuals[3]. A notable contributor was G.V. Black (1836-1915) who, in 1896, published his famous *Manual of Operative Dentistry*, which included details of a satisfactory amalgam formulation and gave guidance on the preparation of the appropriate cavities in which it could be used. Later, in 1929, the American Dental Association published a specification for dental amalgam, with the requirement that it should be tested under proper conditions. This was instrumental in driving unsatisfactory amalgam formulations out of the market[4].

To prepare amalgams for clinical use, a powdered alloy (mainly silver-tin) is mixed with mercury. The metal powder is made by an attrition process involving either lathe cutting or milling from a solid cast ingot of the parent alloy. This process produces irregularly shaped particles. Alternatively, the liquid alloy may be atomized and the droplets allowed to condense, a process which produces spherical particles. Both types of alloy powders can be used in clinical amalgams, and also blends of them can be used[5].

The early powder formulations were based on silver-tin alloys with compositions corresponding to Ag_3Sn. These were mixed with liquid mercury in a process known as trituration. In the past, trituration was carried out by hand, but this is against modern regulations. Contemporary dental practice is to carry out trituration using capsulated amalgam components mechanically mixed on vibratory mixers[5]. Mixing typically takes 30 seconds, and forms a viscous paste which is extruded from the capsule, where it is pressed by the clinician to squeeze out any excess mercury. This step is called condensation, and once this is complete, the amalgam restoration can be left to set.

Setting is a complicated process involving the reaction of the silver-tin alloy and the formation of a number of new solid metal phases (Table 1). The initial setting reaction takes place between the surface layers of the alloy powder and the liquid mercury. It can be represented as:

$$Ag_3Sn + Hg \rightarrow Ag_2Hg_3 + Sn_{7\text{-}8}Hg$$

Modern amalgams contain large amounts of copper (up to 30%)[6,7]. This reacts with the $Sn_{7\text{-}8}Hg$ component to form an alloy corresponding to Cu_3Sn. The resulting material, known as a high-copper amalgam, is less susceptible to corrosion than the earlier amalgam formulation[8]. This type of material also set quicker and is less prone to creep[9,10]. As a result, high-copper amalgams are now the version employed clinically throughout the world[4].

The phases present in high-copper dental amalgams are listed together with their phase name. As can be seen, these amalgams contain some copper-rich phases that were not present in the former low-copper formulations. These phases are responsible for the resistance to creep and reduced corrosion of high-copper amalgams[9].

Table 1. Phases identified in hardened high-copper dental amalgam[9]

Phase	Chemical formula
γ	Ag_3Sn
γ_1	Ag_2Hg_3
γ_2	$Sn_{7\text{-}8}Hg$
ε	Cu_3Sn
η	Cu_6Sn_5
Silver-copper eutectic	Ag-Cu

Current clinical use of amalgam

Dental amalgam is currently the most widely used restorative material in dentistry, with an estimated 60% of restorations in advanced countries being based on this type of material[11]. If we include restorations from the poorer countries of the world, this proportion almost certainly rises[12].

Dental amalgam is a durable material and shows good survival times[13,14]. However, it is not adhesive, so cavities need to be prepared with undercuts causing the restoration to be retained mechanically. The absence of adhesion means that there may be microleakage around the restoration. Older amalgam formulations produced corrosion products which tended to fill any voids between the filling and the tooth, thereby preventing microleakage. Modern high-copper amalgams do not produce such corrosion products, so the marginal gap has to be filled with something else, typically a layer of copal ether varnish. This is applied to the walls of the prepared cavity immediately prior to placement[5]. Alternatively, bonding agents of the type used with composite resins can be used[5], though these are costlier than copal ether varnish, and do not confer any additional benefit apart from preventing marginal leakage[16]. Certainly, bonding does not seem to be improved[16].

In terms of clinical use, amalgam has a number of desirable features[4]:

- It is cost-effective;
- It is durable in the mouth and shows minimal wear;
- It is relatively insensitive to operator technique.

Against that, it also has some distinct disadvantages[4], as follows:

- It is not adhesive;
- Retention requires mechanical undercuts, necessitating removal of healthy tooth tissue;

- It is not aesthetic;
- There are major environmental concerns with the use of mercury, and steps are being taken internationally to limit this use[17].

Currently, the consensus opinion is that the disadvantages are beginning to outweigh the advantages, and many commentators are now predicting the eventual demise of amalgam as a dental restorative material.

Corrosion of dental amalgam

Corrosion is readily able to occur in the mouth for a number of reasons. The mouth provides an environment that is moist, the saliva present contains salts, and there are fluctuations in temperature and pH [18]. The presence of salts in saliva is probably the most important factor, as it means that any metal in contact with it has an electrochemical potential. In the case of dental amalgam, the occurrence of a number of metal phases within the material means that several different electrochemical potentials can be set up in different regions of the amalgam. Differences in potential drive an electric current between the phases, and this current is partly carried by oxidation of one of the metals phases to produce positively charged ions in solution in the saliva.

Electrochemical studies have shown that the various phases known to occur in dental amalgams have different potentials and hence different susceptibilities to corrosion[18,19]. The phase that most readily undergoes corrosion is $Sn_{7-8}Hg$, whereas the phase that most strongly resists corrosion is Ag_2Hg_3.

In high-copper amalgams, the Cu_6Sn_5 component (the η phase) is the most susceptible to corrosion. The balanced chemical equation for its corrosion reaction is:

$$2Cu_6Sn_5+8O_2+3H_2O + 6Cl^- \rightarrow 3CuCl_2.3Cu(OH)_2+10SnO$$

Unlike the corrosion of low-copper amalgams, this reaction does not release elemental mercury, a feature that makes high-copper alloys safer than low-copper ones. They also have the advantage that the electrochemical potential of the Cu_6Sn_5 phase in contact with saliva is higher than that of $Sn_{7-8}Hg$ [18,19], which means that it is more resistant to corrosion. However, despite this, high-copper amalgams have been shown to release some elemental mercury when stored in a variety of solutions[20-22].

There is also evidence that, following corrosion, amalgams can release mercury vapour[23]. For both forms of mercury (in solution and as vapour), levels of release are low, and the available evidence suggests that using dental amalgams leads to no long-term adverse effects on patients[24]. The question of safety of dental amalgam fillings is considered in more detail later in this paper.

Minamata Convention

The issues of mercury's toxicity and environmental pollution arising from its industrial and technical uses led to the Minamata Convention on Mercury. This is an international agreement dating from 2013 [17] and since the first group of countries signed up, the numbers of countries and regions committing to it has risen to 140 [25]. The most recent signatory was Eritrea, which signed up on 7th February 2023.

The Minamata Convention is a global treaty aimed at protecting human health and the environment from the adverse effects of mercury. The treaty was formally agreed on 19th January 2013 at the fifth session of the *Intergovernmental Negotiating Committee on Mercury*, held in Geneva. It was then adopted by a diplomatic conference, the *Conference of Plenipotentiaries*, that took place in Kumamoto, Japan, in October 2013. After further negotiation, the Convention came into force in August 2017.

The Convention has highlighted the widespread use of mercury in technical applications throughout the world. As a result of this range of uses, mercury has been able to enter the atmosphere, soil and water throughout its lifecycle. This means that extraction, transport, use and disposal all cause release of mercury and hence pose environmental problems[25].

The Convention is named after Minamata, the city in Japan where, in the second half of the 1950s, there was a major outbreak of mercury poisoning[17, 26]. This was the result of mercury being discharged in the industrial waste water from a chemical plant owned by the Chisso company. Waterborne mercury waste entered the waters of the bay on which the city of Minamata stands, leading to its uptake by shellfish. These shellfish were an important part of the local diet, which meant that the population was soon consuming dangerous levels of mercury[26]. Elemental mercury is toxic, especially towards the central nervous system[7]. However, the situation was worse than that, as the company was not releasing elemental mercury but the organic compound methyl mercury[26]. This compound is significantly more toxic than the un-combined element, and can be formed readily by the action of certain bacteria on mercury metal. Hence, poisoning by methyl mercury may occur regardless of the form in which the mercury is released.

The consequences of exposure to methyl mercury for the citizens of Minamata were severe. Various neurological problems occurred, including ataxia, trembling and impaired vision, as well as significant increases in the incidence of mental disorder[27]. The ability of methyl mercury to cross the placenta led to numerous stillbirths, deformities and severe nervous diseases in the newly born.

By the time the cause of the problems had been identified and brought under control, some 2252 residents of Minamata had developed symptoms of severe mercury poisoning. Of these, 1043 died as a direct result of the condition[28]. The conditions caused by mercury became known as Minamata disease.

Given this episode, it was appropriate to name the concerted action against mercury after the city of Minamata. If the Convention achieves its aims, there should be no way that a repetition of the Minamata poisonings could happen. Specifically, the aim of the Convention is to reduce and, where feasible, eliminate the use and release of mercury. One agreed step to facilitate this is to ban the mining of mercury, a ban which is planned to come into force in the year 2032 [4].

These steps are obviously going to change the use of amalgam in dentistry. The current estimate is that dental amalgam is responsible for some 20% of the global consumption of mercury[29]. Countries are therefore taking steps to cope with the loss of dental amalgam as a material for repairing teeth. A number of countries, such as Norway and Sweden, have already banned the use of amalgam in dentistry[2]. Other, such as those in the EU, have drawn up plans to do so with the eventual aim of a complete ban by the year 2030 [29].

Health issues of patients

Mercury is a highly toxic element with a wide range of mechanisms of toxicity. These all relate to its high affinity for sulfur, which means that it binds readily to a number of cellular proteins. This causes changes in the structure and function of the proteins[30, 31], for example altering membrane permeability, increasing oxidative stress and changing the levels of biological signalling molecules produced by the cells. These changes may lead to a variety of symptoms in patients that are typically non-specific and not seen until considerable biochemical damage has been done[32].

Despite these features, studies have generally reported that the presence of dental amalgam fillings is not associated with any toxic effects in patients[33]. These findings have led the International Association for Dental Research (IADR) to consider the issue of the safety of dental amalgam with particular reference to the general population without renal impairment or allergies to the metals present in amalgams. For this very substantial group of patients, they conclude that available scientific literature shows that dental amalgam fillings are completely safe. They have drawn this conclusion by reviewing the evidence from both the literature and from various international regulatory organisations, including the European Union Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the World Health Organization (WHO) and the U.S. Food and Drug Administration (FDA). Their policy statement was adopted in 2014, and no further evidence has emerged that has caused them to reconsider their conclusion.

The IADR considered a number of notable studies. These included a pair of related researches that were carried out in Portugal and America to determine if there were any detectable health effects in children with teeth restored with dental amalgam[34, 35]. Both cohorts used randomized clinical trials that were conducted over at least five years. In each study, over 500 children were randomly assigned to groups receiving either amalgam or composite resin fillings. In both studies, children with dental amalgam were found have higher levels of urinary mercury compared to children treated with composite resin.

In the Portugal study, the level of mercury in the urine levelled out by the second year of the study, and declined slightly as the study progressed[34]. In tests of mental attributes, including memory and ability to pay attention, there were no statistical differences between children in the amalgam group or the composite resin group.

In the related study in the US, there were also no statistical differences between children with amalgam or composite resin in neurological tests, which included measured IQ and memory function[34]. Kidney function was also determined, and found to show no statistical difference between the groups[34].

There have also been studies carried out on pregnant women and their children. These have shown that dental amalgam fillings cause increased levels of mercury in the blood and urine of both the children and their mothers[36-38]. Findings from a study of the relationship between the presence of amalgam restorations in the mothers and stillbirth showed no statistically significant association[39]. A related study showed that amalgam fillings led to higher mercury levels in cord blood of mothers but no difference in birth weight, length or head circumference[40]. Finally, studies have demonstrated that there is no increased risk of child mortality or neurological disorders in the boys of female dental staff[41, 42].

Other studies have considered the impact of amalgam fillings on effects in adult patients. For example, mercury levels in the brains of individuals with and without amalgam fillings were studied using cadavers. A total of thirty-two bodies were sampled, twenty-two of which belonged to amalgam-free patients and ten of which contained teeth repaired with amalgam[43]. The brains of the amalgam-free group contained a mean of 1.06 ± 0.57 μg/g compared with a mean of 0.97 ± 0.83 μg/g for those with amalgam fillings, a difference which was not statistically significant. This suggests that, whatever the fate of mecruy released from dental amalgam fillings, it does not finish up in the brain.

Another study on adults considered the possible link between the presence of amalgam fillings and disease[44]. This involved a cohort of 20000 people, and results were reassuring, with no evidence found of any relationship with amalgams and specific disease. Claims by campaigners of links with neurological disorders such as Alzheimer's or Parkinson's disease were effectively refuted because there were so few cases of either disease, despite the large number of participants[44]. All of these studies suggest that dental amalgam is safe to use and, even though its use leads to slight increases in mercury within patients, these increases do not lead to any adverse conditions.

However, not all researchers agree with these conclusions. A minority have raised concerns about the quality of the statistical analyses applied to data on the effect of dental amalgams[32,45-47], and also about the potential chronic effects of exposure to the levels of mercury that have been observed[48]. Another concern has been with the levels of mercury found in patients with amalgam fillings compared with recommended occupational limits. The World Health Organisation has estimated that the typical dose of mercury from amalgam fillings lies in the range 1-22 μg/day[49]. For the majority of patients, the dose lies towards the lower end of the range, i.e. 5 μg/day or less[49]. However, considerable variation exists, depending on the surface area of the restoration and chewing stresses involved. These dose values can be compared with the limit recommended by US Environmental Protection Agency. In 1995, they set an inhalation limit of 0.3 $\mu g/m^3$ [50], which is equivalent to a daily dose of 4.9 μg/day. This is similar to the WHO estimate, which suggests that the latter has no margin of safety and that large numbers of patients receive mercury doses from their fillings above this recommended level. This situation has raised concerns in some recent scientific publications. However, despite this, the overwhelming consensus among regulators and contributors to the scientific literature is that these materials are safe. This position can be summarised in the positive comments from a paper published in 2011, which reached the following conclusions[3]:

Dental amalgam does not contribute to either systemic disease or systemic toxicological effects;

Allergic reactions from dental amalgam are extremely rare;

Scientific data do not justify the discontinuation of dental amalgam from clinical practice, nor its replacement with other dental restoratives.

Health issues of dental personnel

Given the widespread use of dental amalgam in restorative dentistry it is not surprising that dental personnel are at risk from exposure to mercury[51, 52]. Several conditions have been identified as being associated with occupational exposure to mercury by dentists and their assistants, including neurological and cognitive disturbances[53, 54], fibromyalgia and chronic fatigue syndrome[55-58].

As a consequence of long-term exposure, mercury tends to target the central nervous system[31, 59]. Early stages of mercury toxicity are characterised by weakness, tiredness and loss of weight[31, 58]. Later stages and longer exposure tend to cause motor problems and tremors[31]. Some studies have found that dental staff may have some of these symptoms, especially the milder ones[60-63]. Also, a retrospective study in Denmark showed there was an association between the length of time spent working in dentistry and reported symptoms of mercury exposure[64].

For the last 30 years or so there have been substantial improvements in mercury hygiene in dental surgeries and offices. The aim has been to minimise and preferably eliminate the exposure to mercury of dental personnel. Within the clinic, the main change has been to use pre-capsulated amalgam alloys, with a variety of capsule sizes, so that the appropriate volume can be chosen to match the size of the prepared cavity. As the use of these capsules has increased, so the use of bulk mercury has declined, and is no longer recommended[65].

Pre-capsulated amalgams are mixed on a vibratory mixer ("amalgamator") without the mercury component being exposed to the atmosphere. Mixed amalgam is then extruded from the capsule directly into place within the tooth. This approach minimises the exposure of dental personnel to mercury vapour.

Environmental issues in the use of amalgam

Mercury can be released from amalgam at various stages of the use cycle[66, 67]. These include waste from placement and removal of fillings, and release from humans in excretion. Previously there was an issue at the end of patients' lives, notably with emissions from crematoria[68]. Recent legislation has made the installation of mercury filters mandatory in much of Europe, including the UK[69], regions with a high proportion of cremations, so that this is no longer a significant source of mercury release.

A variety of steps are now practised by dental professionals aimed at reducing the release of mercury and/or amalgam particles into the environment. Typical approaches to this are those listed in the American Dental Association's *Best Management Practices of Amalgam Waste*[65]. Recommendations can be summarised in two series of actions, one that should be followed and the other which should be avoided. These are summarised in Table 2.

Table 2. Recommendations for mercury hygiene, based on ADA guidelines[65]

To follow:	Avoid:
Use pre-capsulated alloys with a variety of capsule sizes;	Using bulk mercury;
Recycle used capsules;	Disposing of amalgam waste in the biohazard waste or regular garbage;
Recycle scrap amalgam;	Rinsing devices containing amalgam over drains or sinks;
Recycle amalgam recovered from old fillings;	Disposing of amalgam-filled teeth in the biohazard waste, infectious waste or regular garbage;
Recycle amalgam-filled extracted teeth;	
Use line cleaners that minimise amalgam dissolution;	Flushing amalgam waste down drains or toilets;
Use amalgam separators to remove amalgam particles from wastewater.	Using bleach or chlorine-containing cleaners to flush wastewater lines.

One problem of increasing concern is that amalgam residues can enter the environment via discharge into wastewater from dental clinics and offices[67]. From wastewater, they can collect into sewage sludge and, in this form, may eventually be disposed of to landfill. Mercury in particular is not confined to the place where such amalgams are dumped, but can leach from them and contaminate the atmosphere and local groundwaters. This would be regarded as poor management of waste[70]. An important way to prevent mercury escaping in this way is to use amalgam separators in the dental surgery.

Within a dental surgery or clinic, amalgam particles may be generated by a variety of processes. They may also be generated at different stages of treatment, including removal of old fillings and finishing of new ones[71]. Pieces can vary in size from around 3 mm diameter to around 0.01 mm. They travel from the operation site into the wastewater system as a result of suction at the chairside. Using traps of the appropriate design causes these particles to be retained and to be prevented from entering the environment.

The use of traps to capture amalgam residues in this way is now mandatory in many parts of the world[71]. Such separators are effective and are able to trap at least 95% of all amalgam particles generated during clinical procedures[72]. There is an ISO standard specifying how such devices should be tested[73] and the best practice is to use amalgam separators that confirm to the requirements of this ISO standard.

Having trapped this amalgam and prevented the particles from entering the sewage system, the waste should then be disposed of in accordance with local regulations on environmental pollution[71, 74]. Overall, the amount of amalgam discharged into the environment can be minimised in this way, and also by minimising the amount produced through having available capsules of various sizes. Where possible, most items involved in amalgam preparation, including empty capsules, should be recycled as much as possible[71]. Increasingly firm regulation throughout the world is making this a matter of high importance.

Alternatives to dental amalgam

As we have seen, the concerns about dental amalgam are mainly environmental rather than health-related. It is these that underpin the Minamata Convention and are the reason that the mining of mercury is to be continued from the year 2032. This leads to the questions, how will the dental profession cope and what will be the consequences for restoring teeth in patients?

Before considering these questions, it is worth noting that dentists typically have a high opinion of dental amalgam[75]. In a survey in the US, the American Dental Association (ADA) surveyed the use of amalgam among general dentists and those specialising in paediatric dentistry, and found that 62% of general dentists and 56% of paediatric dentists reported using amalgam regularly. Although they were happy to take the recommended the precautions with mercury hygiene, such as employing amalgam separators, most of the respondents disagreed with banning dental amalgam[75]. Confirming this widespread support for the use of dental amalgam, data published in 2021 covering the years 2011-2016 showed that 51.5% of the restored teeth in the US population were filled with dental amalgam[76].

The numbers of both general dentists and paediatric dentists reported by the ADA as routinely employing dental amalgam[75] had fallen compared with earlier studies covering the years 2004 to 2009. These earlier studies reported usage rates of 68-81% by general dentists and 57-70% by paediatric dentists[77-79], confirming that the latter are slightly less likely to place dental amalgam restorations and showing that, even though support for the material remains high, its use has undergone a slight decline

One suggestion that is being made by national and international organisations is to improve the quality of oral hygiene in patients[80, 81]. In principle, this would be expected to lead to reductions in the extent of tooth decay, and reduce the need for fillings. There is some evidence that global oral health is improving. For example, in the UK, several indicators of oral health have been found to improve substantially in recent years[82]. Some example statistics to demonstrate this point are shown in Table 3.

Table 3. Indicators of oral health in the UK, 1998-2009 [82]

Year	Proportion of the population with no natural teeth (%)	Proportion of the population with 21 or more natural teeth (%)	Proportion of the population reporting no dental problems in preceding 12 months (%)
1998	12	75	49
2009	3	86	61

The best way of improving oral health is by promoting toothbrushing, and here there have also been some improvements. The recommendation is for the teeth to be brushed twice a day, but surveys show that in actual practice the number of people who do this varies. However, it has risen from a range of 30-62% (depending on the country) in the mid 1990s to between 50 and 72% in 2010 [83]. An alternative measure of oral health is the DMFT (drilled, missing, filled teeth) score. This also shows evidence of slight but positive improvement, with data showing that the DMFT in 24-64 year olds in the US fell from 91.6 in the period 1999-2004 to 89.9 in the period 2011-16 [84]. Although these figures show a positive trend, absolute numbers of teeth needing repair remain high, and improvements in oral health are having only small effects on the demand for tooth restoration. Filling of decayed teeth is going to be an integral part of clinical dentistry for many years to come. Consequently, we have to know what alternative restorative materials there are, and how their performance compares with that of amalgam.

Essentially there are two types of material apart from dental amalgam, namely composite resins and glass-ionomer cements. Some authorities seem to think there are other basic categories, such as giomers[80]. On the contrary, giomers are merely a type of composite resin[85]. Their distinctive feature is that they contain an alternative filler blend, one part of which consists of crushed pre-set glass-ionomer cement. Changing a small proportion of the filler in what is essentially a standard composite resin does not create a new class of material.

Composite resins are more technique-sensitive than dental amalgams[86]. Surface preparation of the tooth requires more care and involves having an optimally dried field for the specific bonding agent being used. Bonding agents are an essential component of a composite resin restoration, and are necessary to ensure that the restorations are retained.

Many authorities are claiming that composite resins are the answer to the question of what can (and should) replace dental amalgam. Much is made of the excellent aesthetics[87, 88]. In spite of these claims, it is not obvious why posterior teeth should be repaired with highly aesthetic materials, particularly as they would previously have been repaired with non-aesthetic silver amalgam. As well as that, the durability of composites is much poorer than that of amalgam.

Numerous published studies have confirmed this point. Composite resins generally have higher failure rates than dental amalgam in all types of filling examined. These studies have been summarised in two Cochrane Database systematic reviews[89], though in both cases, the data were described as "low quality", either because of limited numbers in the populations of restorations examined, or because the time scales of the studies were too short. However, the conclusion of the relatively poor durability of composite resins has been found in a large number of studies. Moreover, at least one review suggested that the data were such that amalgam remained a good choice for posterior restorations where considerations of aesthetics did not apply[90].

The other possible repair material is the glass-ionomer cement. Again, there is misinformation about these materials in the literature, with people citing old papers on less advanced formulations to suggest that glass-ionomers are too brittle to be durable and unsuitable for load-bearing applications, especially in adults. The reality is that modern high-viscosity glass-ionomer cements have been found to have acceptable durability in clinical trials, notably in studies of the ART technique, for which glass-ionomers are the only feasible option for restoration[91, 92]. However, what evidence there is suggests that this durability does not compare with that of dental amalgam.

In summary, neither alternative material has durability or strength of amalgam, and both are more demanding to place. This means that dentists and their patients are going to have to change the expectations of dental restoratives. Placement of materials will be less comfortable and the time until they need replacing shorter. It may also be necessary to change the approach to operative dentistry and for more repairs to be carried out, rather than complete replacement. Either way, the dental profession is going to find the situation challenging when amalgam is no longer available for use.

Conclusions

Dental amalgam remains the most widely used restorative material in all parts of the world. It has been used for well over a century, and is known to be strong, durable and easy to place. Because of this, it remains popular with dentists throughout the world. In spite of these positive aspects, its days are numbered. Environmental concerns associated with the mining of mercury and its ultimate disposal led to the Minamata Convention of 2013, with its commitment to cease the mining of mercury from the year 2032, and to eliminate the technical uses of the element in the years leading up to this date. Amalgam remains the most durable repair material available, and its loss will alter clinical practice.

Specifically, replacement of failed restorations will become more common, with replacements being needed at shorter time intervals. In addition, it is likely to be necessary to carry out more repairs of restorations than with dental amalgam. As a consequence of these changes, patients will have to be advised carefully on what to expect in terms of how well their dental restorations will perform. In some parts of the world, the option of glass-ionomer cements will have to be reconsidered. Changing wholesale from dental amalgam to composite resins, driven by aesthetic considerations only, is not a viable approach as the performance of composite resins is far inferior to that of dental amalgam.

Despite the fact that the date at which mercury will no longer be mined has been known for a decade, and notwithstanding the volume of work done on alternative materials, the dental profession will find the loss of dental amalgam difficult to cope with. Moreover, the evidence presented here suggests that the profession is far from ready for the impact that losing amalgam is going to have on their work.

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