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Dental Amalgam Waste in Dentistry: Sources, Environmental Impact and Management Strategies

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Abstract

Among the restorative materials, dental amalgam is one of the most commonly used due to its superior characteristics, including clinical durability, affordability, and clinically reliable properties. However, its mercury content has raised environmental concerns, especially regarding the waste generated during routine procedures such as placing, removing, finishing, and replacing old amalgam restorations. This waste can enter dental wastewater systems through plumbing and suction, which is why dental clinics are such an important source of mercury for municipal wastewater treatment plants, even though dentistry only contributes a small amount of global anthropogenic mercury emissions. Once released, amalgam particles can build up in sewage sludge or enter water bodies. Mercury can turn into methylmercury and accumulate in living things, which is considered the most hazardous for the environment and public health. As a result, various regulatory bodies have set guidelines to limit the amount of mercury that can be released from dental offices. Best management practices, including separating waste, recycling, and using ISO-certified amalgam separators, have been shown to significantly lower the amount of mercury released. This review provides insights into the recent information regarding the sources of amalgam waste, its effect on the environment, the regulatory framework, and ways to manage it. It also emphasizes how important it is for dental professionals to use environmentally friendly methods to reduce the environmental impact of dental amalgam.

Keywords: Dental amalgam, Amalgam waste, Mercury pollution, Dental wastewater, Amalgam separators.

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1. Introduction

For more than 150 years, dental amalgam has been a popular material for restoring teeth in clinical dentistry. This is because it is strong, easy to work with, and costs less than other materials for restoring teeth [1,2]. Dental amalgam is an alloy of liquid mercury and a powdered mixture of metals like silver, tin, and copper, among others [2,3]. Mercury usually makes up about 50% of its weight [3]. Even though amalgam is known to work well in the clinic, its mercury content has raised more and more concerns because of the health and environmental risks that come with mercury spills [1-6]. Mercury is a bioaccumulative element, and on exposure to the ambient conditions, the mercury vapours may be released immediately due to its low melting point and high vapour pressure [2]. Additionally, it may enter into air, water, and soil, and can affect human health and ecosystems. When elemental mercury is released into water, microorganisms can change it into methylmercury, which is a highly poisonous form that accumulates in aquatic animals and then enters the human food chain [7,8]. Dentistry is a major source of mercury in municipal wastewater systems, especially in countries where amalgam is still widely used. This is even though dentistry only accounts for a small percentage of global mercury emissions compared to major industrial sources [9]. Amalgam particles enter sewage systems from dental clinics during the restorative procedures involving amalgam restoration and while removal of the same as well. Even the release of small amounts of mercury may pollute the environment [10].

To address these concerns, various regulatory agencies and international organizations have developed guidelines to minimize mercury emissions from dental operatories [11,12]. A global agreement, the Minamata Convention on Mercury, emphasized the importance of reducing the dental amalgam usage and enhancing its environmental management [12,13]. Furthermore, various professional organizations like the FDI World Dental Federation and the World Health Organization (WHO) have recommended best management practices (BMPs) for amalgam waste, which include installing amalgam separators that meet performance standards [6,14-16]. These devices decrease the amalgam waste by capturing and eliminating solid amalgam particles from dental wastewater lines, and prevent them from entering public sewage and wastewater treatment facilities. Dental amalgam waste management is still a difficult and evolving issue, despite improvements in separation technology and regulatory systems. Technical solutions, adherence to best management practices (BMPs) by dental professionals, and ongoing support from local, national, and international policies are all necessary for mitigation to be successful. This paper aims to comprehend the most recent information on amalgam waste sources, health and environmental effects, new laws, and best practices in dental settings.

2. Composition of dental amalgam

The amalgam is an alloy of mercury. Based on the copper content, the amalgam alloys are classified as low-copper (less than or equal to 6.0 Wt% of copper) and high-copper (greater than or equal to 6.0 Wt% of copper) alloys [1,2,6]. The amalgam alloys are dispensed in the form of powder and liquid, pre-proportioned capsules and pellets. The low-copper alloy is composed of Silver, tin, copper, and Zinc. Whereas the high-copper alloys contain silver, tin and copper. Additionally, the latter alloy also contains platinum or palladium [1,2]. The compositions of various amalgam alloy powders are presented in Table 1.

3. Sources and types of amalgam waste in dentistry

Dental amalgam waste is produced during standard clinical restorative procedures and consists of several elements that leak mercury into the environment and pose health hazards to humans if not properly managed. Precise identification and categorization of amalgam waste is crucial for executing optimal management strategies in dental facilities.

3.1 Clinical sources

Excess material may remain after dental amalgam is prepared and restored into a tooth cavity. A portion of this leftover amalgam must be gathered as waste because it may end up on tools or in the mixing glass [17]. Particulate debris made of amalgam particles is produced when old or defective amalgam restorations are removed. These particles are regularly extracted from the mouth and suctioned into the wastewater lines of dental offices [18,19]. Sludge and fine amalgam particles are created during carving, finishing, polishing, and other operational processes, and they may get into chairside traps or vacuum systems. Inadequate separation and collection of these retained particles can lead to amalgam discharge through wastewater streams [10,18,19].

Table 1. Composition of various dental amalgam alloys.

Ingredient	Weight %			Functions
	Low-copper	High-Copper Admixed	High-copper Uni-composition	
Silver	67-74	69	40-60	Increases strength, setting expansion, and reactivity with mercury. Decreases creep.
Tin	25-27	17	13-30	Increase creep, contraction, and rate of amalgamation. Decreases the strength, hardness, and speed of setting.
Copper	0-6	13	17	Increase hardness, strength, setting expansion, and tarnish.
Zinc	0-2	1	-	Causes delayed expansion and corrosion. Acts as an oxide scavenger.

3.2 Categories of amalgam waste

Depending on the source and the extent of contact with the patient or dental equipment, dental amalgam waste can be classified into several types [20-22]. Amalgam that has come into direct contact with the patient's oral environment is referred to as contact amalgam. Examples of this type of amalgam include extracted teeth with amalgam restorations, carving scrap from clinical procedures, and amalgam particles caught in chairside traps and filters [20,21]. Contact amalgam needs to be handled and recycled carefully because it is thought to be potentially contaminated [17,20-22]. Another type of amalgam waste is non-contact amalgam (scrap), which is extra amalgam that hasn't come into contact with the patient and is usually left over in the dappen dish or mixing capsule after placement. This kind of waste can frequently be recycled and is typically clean [20-22].

Amalgam sludge, a distinct category, consists of fine solid amalgam particles in suspension. This amalgam sludge may be confined within vacuum pump filters or other amalgam retention devices. Due to their elevated mercury levels and semi-liquid consistency, these sludges are challenging to manage and are typically gathered for recycling or specialist processing [19,23].

Amalgam scrap is the other variety of amalgam waste, which is found in chair-side traps and filters falls into another category. A large amount of amalgam waste from surgical procedures is made up of particles gathered in chairside traps and vacuum filters. Even though these devices prevent amalgam debris from entering the wastewater system, the material that is trapped needs to be handled as hazardous waste and recycled [24,25]. Even if there are capture devices, smaller amalgam particles (wastewater-borne amalgam particles) that get by chairside traps and filters can still get into the wastewater from the dental office and perhaps run into the municipal sewage systems. These tiny particles are a type of amalgam waste that is best kept under control with ISO-certified amalgam separators [10].

4. Fate of amalgam and mercury in dental wastewater

Dental amalgam particles that are made during restorative procedures get into the wastewater stream. They go through a number of physical transport and retention processes in municipal wastewater treatment systems and dental plumbing. The size of the particles, the hydraulic conditions, and the treatment methods are the main factors that affect the fate of amalgam and mercury.

4.1 Particle size distribution in wastewater [26]

Amalgam particles produced during the placement, finishing, and removal are of varying sizes. Research indicates a bimodal distribution, with fine particles measuring approximately 2–90 µm and larger particles spanning 160–5500 µm. Fine particles, especially those that are less than 10 µm, stay in the air longer and are harder to catch with chairside traps. This makes it more likely that they will get into municipal sewer systems.

4.2 Transport through the suction system and plumbing

Dental vacuum systems suck up amalgam debris, which then goes through chairside traps, vacuum filters, and piping before being dumped into the sewage. Experimental simulations show that without amalgam separators, a large amount of amalgam escapes from the body's internal retention systems. A study found that about 60% of the amalgam waste that was made during removal procedures ended up in wastewater effluent, while only about one-third of it was kept in the dental unit. The way plumbing is built and how water flows through it also affects how particles move [27].

4.3 Retention by chair-side traps and vacuum filters

Amalgam particles, especially larger ones, are usually trapped in chairside traps and vacuum pump filters. The efficiency of these devices ranges between 40% and 70%, depending on the size of the particles and the design of the device. However, they are unable to retain the fine particles; therefore, they are seen as extra steps rather than stand-alone solutions [28].

4.4 Behaviour in wastewater treatment plants

Physical setting and adsorption processes are used to treat the amalgam particles and mercury that have reached the wastewater treatment plants. During treatment, the amalgam-associated mercury, due to its high density, is greatly incorporated into grit and biosolids. According to the literature, around 90-95% of Hg from dental sources is found to be retained in sludge rather than discharged in treated effluent [29].

4.5 Mercury accumulation in sludge and effluent

Mercury accumulates in water sludge due to its strong affinity towards solids and organic matter. Increased mercury levels have been documented in biosolids in treatment plants, and are serving areas with high concentrations of dental clinics [30]. Despite the low mercury levels in treated effluent, trace amounts of mercury may still occur, which signifies the importance of source control measures, amalgam separators [14-16].

5. Environmental impact of dental amalgam waste

Dental amalgam waste is a known source of anthropogenic mercury released into the environment. However, dentistry does not significantly contribute to global mercury emissions, but the persistent and localized dental discharges have caused environmental and regulatory apprehensions, especially regarding wastewater systems and aquatic ecosystems.

5.1 Dentistry's contribution to overall mercury pollution

Dentistry introduces mercury into the environment mainly via amalgam particles released into wastewater during the placement, finishing and removal of old amalgam restorations. Various factors that are related to mercury vapour release from dental amalgam filling are listed in Table 2. Numerous mass-balance and environmental monitoring investigations have shown that dental practices are among the primary non-industrial contributors of mercury to municipal wastewater systems. Hylander and Meili indicated that dental clinics contributed between 3–28% of the mercury influx into wastewater treatment facilities in urban regions before the extensive implementation of amalgam separators [31]. Likewise, research undertaken in Europe and North America has recognized dental amalgam as a quantifiable factor in mercury levels within sewage sludge [30,32]. Compared to large-scale industrial operations, dentistry is expected to contribute less than 1% of all anthropogenic mercury emissions worldwide [33]. Despite this small percentage, dentistry is becoming a primary focus of mercury reduction programs due to the controllability of mercury emissions from dental sources.

5.2 Comparison with other Anthropogenic mercury resources

Significant anthropogenic sources of mercury encompass coal combustion, non-ferrous metal smelting, cement manufacturing, waste incineration, and artisanal gold mining. Artisanal and small-scale gold mining is the leading global source of mercury emissions [34]. Conversely, dental amalgam emissions are of lesser volume but are characterized by their high localization, continuity, and direct association with municipal wastewater systems. In contrast to atmospheric emissions from industrial sources, mercury discharged from dental amalgam predominantly enters aquatic systems through wastewater channels. This difference is very important because mercury that gets into water ecosystems is more easily changed into methylmercury, which is a very toxic and bioavailable form [35]. So, even small amounts of waste from dentistry can have a big impact on the environment in wastewater systems that are not well managed or are prone to problems.

Table 2. Factors causing mercury vapour release from dental amalgam restoration

S. No.	Factors
1.	Age of amalgam restoration
2.	Cleaning, polishing, and other dental procedures
3.	Composition of saliva.
4.	Composition of the alloy powder mixed with the mercury.
5.	Dental plaque.
6.	Deterioration of amalgam restoration
7.	Infections in the mouth
8.	Number of amalgam restorations present in the oral cavity.
9.	Patient habits such as brushing, bruxism, chewing, consumption of hot liquids, diet (especially acidic foods), smoking, etc.
10.	Presence of other metallic appliances in the mouth, such as gold alloy restorations or titanium implants.
11.	Size and surface of the amalgam restoration.
12.	Techniques and safety measures used during the placement and removal of amalgam restorations.

5.3 Environmental release pathways

Various routes of dental mercury release into the environment include amalgam waste via wastewater discharge, release of mercury vapours during manipulation, and improper disposal of amalgam waste. Amalgam particles that evade chairside traps, vacuum filters, or separators infiltrate sewer systems and are conveyed to wastewater treatment facilities. During the treatment, the mercury cannot be removed completely from the sludge [36]. The other possible pathways of releasing the mercury include sludge cremation, biosolids application, and landfill disposal. Over time, the mercury released through these channels may spread throughout the ecosystem and contaminate water systems and sediments in ways that are persistent [37].

5.4 Public health and ecological implications

It is well known that methylmercury can be neurotoxic, particularly to developing foetuses and young children [38]. Consumption of methyl mercury-contaminated fish is the major human exposure to methylmercury. Fish, invertebrates, and birds are among the aquatic organisms that suffer ecologically from mercury contamination, which impairs their ability to grow, reproduce, and behave. Although dental amalgam is not the primary cause of mercury toxicity globally, it does contribute to local mercury burdens, underscoring the importance of effective waste management strategies [39]. As a result, it is widely acknowledged that lowering mercury emissions from dental sources is a workable and practical component of more extensive environmental mercury reduction programs.

6. Environmental impact of dental amalgam waste

International and national regulatory bodies and standards aimed to reduce mercury emissions into the environment with utmost management of dental amalgam waste. Regulatory approaches differ worldwide, yet they converge on key principles such as source control, optimal management practices, and the incremental reduction of dental amalgam utilization. The increasing concern about how long mercury stays in the environment and how poisonous it is has led to international efforts to stop mercury from being released from dental practices. The World Health Organization (WHO) says that dental amalgam adds to mercury in the environment and suggests a gradual phase-down through preventive dentistry, the use of appropriate systems for managing amalgam waste and alternative restorative materials [40]. The most important part of these suggestions is collecting amalgam particles before they get into wastewater systems. The Minamata Convention on Mercury also addressed dentistry in Annexe A. It does this by promoting the use of alternatives to amalgam that don't contain mercury, pre-capsulated amalgam, and mandatory amalgam separators [41]. Peer-reviewed studies show that the Convention is more about lowering environmental risks than banning amalgam completely. This is because amalgam is still useful in some situations [42].

The initial regulations on mercury emissions were constituted in the European Union (EU) under the Council Directive 84/156/EEC [43]. On the other hand, Regulation (EU) 2017/852 suggested the usage of amalgam separators in dental practices and also to limit the use of amalgam in at-risk groups. Studies indicate that these strategies have significantly reduced mercury inflows into municipal wastewater treatment facilities across several EU member states [44]. A comprehensive collection of regulations in the United States governs dental amalgam waste, including guidelines for safeguarding the environment, occupational safety, and establishing professional standards. The Environmental Protection Agency's Dental Effluent Guidelines recommend that dental offices install ISO 11143–certified amalgam separators. This initiative led to a considerable reduction in the accumulation of the amount of mercury in wastewater, which is sent to the treatment plants [45]. The Occupational Safety and Health Administration (OSHA) sets limits on how much mercury workers can be exposed to and requires that hazards be communicated, there be enough ventilation, personal protective equipment be used, and spills be cleaned up properly. Studies show that dental professionals are most likely to be exposed to mercury when they handle and remove amalgam. This shows how important it is to follow OSHA guidelines [46,47]. Professional groups help make sure that rules are followed more closely. For example, the American Dental Association (ADA) gives the best ways to handle and recycle amalgam [28], and the Canadian Dental Association (CDA) pushes for national standards that lower mercury emissions while still being practical in a clinical setting [48].

In most of the developing countries, amalgam waste management is still not fully enforced due to the limited wastewater treatment facilities, inadequate amalgam separators, and manpower to monitor. research indicates that dental clinics in low- and middle-income countries may significantly contribute to localized mercury contamination due to ineffective waste capture systems [49]. Smaller clinics are still unable to meet the international and local regulatory guidelines across the globe. These limitations can be attributed to the limited awareness, financial constraints, financial difficulties, limited awareness, and infrastructural constraints, which frequently impede the appropriate implementation of the stipulated guidelines. It is evident from the research that the small clinics are failing in implementing the OSHA guidelines, including proper ventilation and the management of mercury spills. Furthermore, studies also highlight the necessity for enhanced training, consistent monitoring, and more robust integration of environmental and occupational safety policies to fulfil the mercury reduction goals established by the Minamata Convention [50]. The permissible levels of mercury through various media according to the different regulatory bodies are presented in Table 3.

Table 3. Permissible levels for mercury through various media.

Regulatory Body / Standard	Medium / Context	Permissible/Reference level	References
World Health Organization (WHO)	In drinking water	0.006 mg/L (6 μg/L)	51
European Environmental Quality Standards	Surface Water (Priority Hazardous Substance)	0.07 μg/L	52
Occupational Safety and Health Administration (OSHA) – Occupational Air	Airborne mercury (8-hour TWA)	0.1 mg/m³ (100μg/m³)	53
National Institute for Occupational Safety and Health (NIOSH)	Airborne mercury (8-hour TWA)	0.05 mg/m³ (50μg/m³)	53
The U.S. Environmental Protection Agency (EPA)	Drinking water (Inorganic mercury)	0.002 mg/L (2 μg/L)	51
The U.S. Environmental Protection Agency (EPA) – Health Advisories (Short-term)	Inorganic Mercury	0.002 mg/L (2 μg/L)	51
The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) – Chronic Inhalation MRL	Mercury vapour	4 μg/day	54

7. Best management practices (BMPs) for amalgam waste

It is important to use best management practices (BMPs) for dental amalgam waste to prevent mercury release into the environment and to protect dental personnel in dental clinics. BMPs include systematically identifying, separating, handling, storing, recycling, and disposing of waste that contains amalgam. Evidence-based professional guidelines back these practices.

7.1 Waste identification and segregation

There are two types of dental amalgam waste: contact amalgam and non-contact amalgam. Contact amalgam, which has interacted with patients, like extracted restorations and amalgam sludge. Non-contact amalgam includes unused amalgam, such as capsules and trash. The first step in effective amalgam waste management is to find and separate materials that contain mercury. Studies indicate that isolating the source of mercury pollution in wastewater and biomedical waste streams [48] significantly reduces the amount of mercury in those streams. Poorly separating amalgam waste often causes more mercury to get into sewage systems and landfills, which makes treatment processes downstream less effective [55].

7.2 Chairside handling protocols

During the placement and removal of amalgam restorations, chairside procedures are very important for controlling the release of amalgam particles. Using rubber dams, chairside traps, and high-volume evacuation systems has been shown to markedly reduce the release of amalgam particles into dental wastewater [56]. Studies indicate that direct rinsing of amalgam debris into sinks and improper suction techniques markedly increase mercury discharge [27]. Also, using pre-capsulated amalgam and avoiding handling bulk mercury are both highly recommended to lower both environmental pollution and occupational exposure [57].

7.3 Storage, labelling and transport

Amalgam waste must be stored in sealed, corrosion-resistant containers that are typically immersed in a liquid medium such as water or a commercial mercury suppression solution. Studies indicate that airtight storage significantly reduces mercury vapour emissions in dental clinics [46]. Consequently, it is recommended that the container be labelled as “amalgam waste” and comply with hazardous waste transport regulations to ensure safe handling during off-site transit to recycling facilities [58].

7.4 Recycling and disposal procedures

Recycling is the best amalgam waste management practice. It enhances mercury recovery and reduces mercury emissions into the environment. Research indicates that recycling amalgam waste is significantly more environmentally sustainable than incineration or landfilling [59]. Dental clinics must strictly comply with amalgam disposal regulations and refrain from discarding amalgam waste in standard garbage or biomedical waste streams, as such actions may result in mercury emissions during waste processing [58]. Certified amalgam recyclers utilise regulated thermal or chemical methods to safely extract mercury and other metals.

7.5 Professional guidelines and recommendations

Promoting BMPs for amalgam waste management has been greatly aided by professional associations. Comprehensive best management practices describing amalgam waste segregation, chairside handling, separator use, and recycling procedures have been published by the American Dental Association (ADA) through its Council on Scientific Affairs" [28]. Clinical and environmental studies showing quantifiable decreases in mercury discharge after its implementation [60] complement these recommendations. International dental organisations have also released similar recommendations, highlighting the need for regionally standardised techniques in achieving global mercury reduction targets [61].

8. Amalgam Separators

The amalgam particles that are generated during the placement and removal may vary widely in size (from greater than 3 mm to extremely fine particles smaller than 0.01 mm). Using a mass-balance analysis, a study reported that approximately 68% of amalgam particles in dental office wastewater are captured by chairside traps, while an additional 13% are collected by vacuum pump filters [58]. The remaining particles that bypass the vacuum system are discharged into the municipal sewer. Among the amalgam particles that reach wastewater treatment facilities, about 95% are ultimately retained in grit chambers or incorporated into biosolids (sludge) [62]. To further limit the transfer of amalgam from dental clinics to wastewater treatment plants, the installation of amalgam separators in dental practices is increasingly being adopted worldwide.

8.1 Types of amalgam separators

Amalgam particles containing mercury can be removed from dental wastewater using three principal separation mechanisms: filtration, centrifugation, and sedimentation. Centrifugal separators operate in a batch-processing manner, whereby wastewater enters the unit and, once the chamber reaches a predetermined volume, the separation cycle is initiated, with the recovered amalgam collected in a designated tray. However, this approach has become less widely used in comparison with sedimentation-based systems.

Sedimentation devices function by retaining wastewater in a container to allow particulate matter to settle; the clarified liquid is then gradually withdrawn using a low-flow pump, leaving the settled particles behind. Some sedimentation units are additionally equipped with filtration components, and certain systems also incorporate chemical removal columns employing ion-exchange technology to enhance mercury removal [63].

8.2 Testing of amalgam separators as per ISO standards

The International Organization for Standardization (ISO) produced ISO Standard 11143 [64], which is used to evaluate the ability of amalgam separators to prevent the escape of amalgam particles into the sewer system. A simulated test material that closely resembles the particle size distribution of amalgam produced in clinical settings is used in the testing procedure [26]. A standardized 10 g test sample comprises the various particle size distributions, including pulverized, triturated dental amalgam with a specific size distribution, 3 g of particles between 0.5 and 3.15 mm, 1 g of particles between 0.1 and 0.5 mm, and 6 g of particles less than 0.1 mm. To meet the ISO criteria, a separator's removal efficiency for all amalgam particles must be at least 95% by mass.

The suitability of the ISO standard remains subject to debate because data indicate that a number of factors influence amalgam separator performance. These include the initial amalgam concentration in dental wastewater, the discharge system's layout and design before the wastewater enters the separator, and the wastewater's chemical additives. Furthermore, evaluations of separator effectiveness based on concentration reduction [65] rather than particle mass removal alone may be more representative. External factors like the length of the wastewater discharge pathway and the application of disinfectants can also cause variations in performance. Amalgam separators are typically anticipated to considerably lower the quantity of amalgam emitted into the municipal sewer system despite these drawbacks [66].

9. Role of dentists in environmental stewardship

Dentists have an ethical and professional responsibility to lessen the environmental impact of clinical care, particularly the mercury released by dental amalgam. The principles of beneficence and non-maleficence not only protect patients, but they also protect the environment from harm that could place public health at risk. The research indicates that dentistry is a manageable source of mercury pollution, requiring meticulous disposal of amalgam waste [61,67]. Even in places where there are no regulations, choosing to use green dental practices like separating waste, using an amalgam separator early, and recycling through a certified program can greatly lower the amount of mercury that is released

[68,69]. Because of varying information and viewpoints, education is still very important. When sustainability and mercury hygiene are taught in dental school, public trust in the profession is higher, dental personnel are less likely to get exposed to mercury, and compliance is improved [27,46].

10. Alternatives to dental amalgam and future trends

Glass ionomer cements (GICs) [70] and resin-based composites [71] are aesthetic restorative materials that have been developed as alternatives due to the decline in the use of dental amalgam across the globe. Improvements in filler formulae and adhesive technology have made these materials more aesthetically pleasing and clinically effective, allowing for their widespread use in posterior restorations [72-74]. Additional benefits of glass ionomer cements with high viscosity and resin modifications include fluoride release and chemical attachment to the tooth structure, which make less invasive treatment techniques possible [2,70]. However, technique sensitivity and moisture control continue to play a major role in long-term performance [2,70].

Alternative materials eliminate environmental concerns associated with mercury, but a comprehensive assessment is required for their sustainability needs. The environmental implications are associated with energy-intensive manufacturing, components derived from petrochemicals, resin-based restorative products, and the production of microplastics during finishing and removal procedures [59]. Environmentally friendly material development is essential, as concerns regarding the emission of monomers and bisphenol-A derivatives highlight [75]. Dental amalgam should be phased down instead of being completely phased out, as it may continue to be clinically relevant in some populations and circumstances. These circumstances are especially, including cost-effectiveness, durability, and availability to advanced dental care, are especially crucial concerns for the patients [76]. As a result, strict waste management in conjunction with controlled reduction is highly recommended.

Future dental trends will be more in alignment with sustainability practices. These include choosing materials based on their life-cycle effect, minimally invasive care, digital workflows to cut down on waste, and sticking to best management practices. These initiatives promote the shift toward environmentally sustainable oral healthcare while maintaining clinical outcomes [77,78].

11. Conclusion

Dental amalgam waste is an environmental concern because it contains mercury and is produced during many routine dental treatments. Dentistry does not release large amounts of mercury compared to other industries, but dental clinics can still be an important local source. When amalgam particles enter dental wastewater, they may collect in sewage sludge or sometimes reach natural water systems. In these settings, mercury can change into more harmful forms that affect wildlife and may pose risks to human health. Using basic control measures, such as proper waste separation, recycling, and amalgam separators, can greatly reduce mercury release. Regulations and international agreements also encourage safer handling and reduced use of dental amalgam. Overall, better awareness, improved equipment, and responsible daily practices are important for limiting environmental harm and supporting more sustainable dentistry.

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References

1. Anusavice KJ. Dental Amalgams (In) Philips' Science of Dental Materials. 11th Ed., Saunders Elsevier, St Louis, Missouri, USA. 2007: p. 495-544.
2. Alla RK. Dental Materials Science (In) Dental Amalgam. Jaypee Brothers Medical Publishers Pvt. Ltd., New Delhi, India. 2013: p. 78-91.
3. Mackenzie L. Dental amalgam: a practical guide. Dental Update. 2021;48(8):607-18. https://doi.org/10.12968/denu.2021.48.8.607
4. Bharti R, Wadhwani KK, Tikku AP, Chandra A. Dental amalgam: An update. J Conserv Dent Endod. 2010;13(4):204-8. https://doi.org/10.4103/0972-0707.73380
5. Chin G, Chong J, Kluczewska A, Lau A, Gorjy S, Tennant M. The environmental effects of dental amalgam. Aust Dent J. 2000;45(4):246-9. https://doi.org/10.1111/j.1834-7819.2000.tb00258.x
6. Haque N, Yousaf S, Nejatian T, Youseffi M, Mozafari M, Sefat F. Dental amalgam. (In) Advanced Dental Biomaterials Woodhead Publishing, 2019: p. 105-125. https://doi.org/10.1016/B978-0-08-102476-8.00006-2
7. Amalgam Separators and Waste Best Management — ADA overview on environmental impacts of dental mercury and separator usage. https://www.ada.org/resources/ada-library/oral-health-topics/amalgam-separators Accessed on 14.11.2025
8. Brownawell AM, Berent S, Brent RL, Bruckner JV, Doull J, Gershwin EM, Hood RD, Matanoski GM, Rubin R, Weiss B, Karol MH. The potential adverse health effects of dental amalgam. Toxicol Rev. 2005;24(1):1-10. https://doi.org/10.2165/00139709-200524010-00001

9. Muhamedagic B, Muhamedagic L, Masic I. Dental office waste–public health and ecological risk. Mater Socio-medica. 2009;21(1):35-8. https://doi.org/10.5455/aim.2009.21.35-39
10. Shraim A, Alsuhaimi A, Al-Thakafy JT. Dental clinics: a point pollution source, not only of mercury but also of other amalgam constituents. Chemosphere. 2011;84(8):1133-9. https://doi.org/10.1016/j.chemosphere.2011.04.034
11. Sanderson S. The great dental amalgam debate. Brit Dent J. 2022;233(10):874. https://doi.org/10.1038/s41415-022-5217-3
12. Jebur N, Vinall-Collier K, Umair AA, Aggarwal VR. Dental amalgam teaching phase-out-a step too soon? Foundation trainees' experience of amalgam use in dental school compared to practice: a mixed-methods survey. Brit Dent J. 2023;235(5):329-34. https://doi.org/10.1038/s41415-023-6228-4
13. Phasing-down the Use of Dental Amalgam | Global Mercury Partnership — UNEP info on Minamata Convention requirements and global phase-down of amalgam. https://www.unep.org/globalmercurypartnership/our-work/mercury-products/phasing-down-the-use-of-dental-amalgam Accessed on 14.11.2025
14. Geier DA, Geier MR. Dental amalgam fillings and mercury vapor safety limits in American adults. Hum Exp Toxicol. 2022;41:09603271221106341. https://doi.org/10.1177/09603271221106341
15. Chadwick RG, Lloyd CH. Dental amalgam: the history and legacy you perhaps never knew?. Brit Dent J. 2022;232(9):633-7. https://doi.org/10.1038/s41415-022-4204-z
16. Kisumbi BK, Osiro OA, Gathece LW, Maina SW. Dental Amalgam Phase-Down—Status, Alternatives, Strategies and Preparedness for Implementation: A Review. Int J Dent. 2025;2025(1):6688410. https://doi.org/10.1155/ijod/6688410
17. American Dental Association. Amalgam Separators and Waste Best Management. ADA Oral Health Topics. https://www.ada.org/resources/ada-library/oral-health-topics/amalgam-separators Accessed 14.11.2025
18. Mahesh S, Benamanahalli Motaiah K, Shivaswamy M, Nandigunda Subramani M, Kumar Jain Shanthilal V. Dental wastewater treatment using electro-chemical coagulation unit process. Sep Sci Technol. 2025;60(9-10):1171-88. https://doi.org/10.1080/01496395.2025.2483761
19. Sahana M, Krishna BM, Mahesh S. Raw Dental Wastewater Treatment by Electro-Chemical Coagulation Using Copper and Stainless Steel Electrodes: A Comparative Study. Int J Environ Res. 2025;19(6):275. https://doi.org/10.1007/s41742-025-00941-1
20. Sudi SM, Naidoo S. Perspectives on the Minamata Convention and dental amalgam waste management in South Africa. South African Dent J. 2024;79(10):542-6. https://doi.org/10.17159/sadj.v79i10.19172
21. Foláyan MO, Virtanen JI, Gaffar B, Abodunrin O, Sun IG, Duangthip D, Kemoli A, Masumo RM, Vukovic A, Al-Batayneh OB, Mfolo T. Scoping review on the association between early childhood caries and responsible resource consumption and production: exploring Sustainable Development Goal 12. BMC Oral Health. 2024;24(1):98. https://doi.org/10.1186/s12903-023-03831-0
22. Dormen M, Özkan P. Sustainable Dental Approaches for the Environment and Human Health: A Traditional Literature Review. HRU Int J Dent Oral Res. 2025;5(1):51-8. https://doi.org/10.61139/ijdor.1649869
23. Shrikrishna Bhat V, Shrikrishna Bhat T, Balasaheb Chougule M. Biomedical waste analysis in the rural area of Warananagar-Kodoli, Maharashtra, India. Environ Health Eng Manag J. 2024;11(4):429-40. https://doi.org/10.34172/EHEM.2024.42
24. Eshrati M, Momeniha F, Momeni N, Ahmadi E, Hashemian A, Kashani H, Alaeddini M. Clinical Guide Adaptation for Amalgam Waste Management in Dental Settings in Iran. Front Dent. 2024;21:44. https://doi.org/10.18502/fid.v21i44.17053
25. Frost AL. New dental amalgam handling regulations-what every dentist needs to know. Int Dentistry (Afr Ed). 2025;15(2):32-28.
26. Letzel H, de Boer EA, Van T Hof MA. An estimation of the size distribution of amalgam particles in dental treatment waste. J Dent Res. 1997;76(3):780-8. https://doi.org/10.1177/00220345970760031101
27. Adegbembo AO, Watson PA, Lugowski SJ. The weight of wastes generated by removal of dental amalgam restorations and the concentration of mercury in dental wastewater. J Can Dent Assoc. 2002;68(9):553-8.
28. American Dental Association. Best management practices for amalgam waste. J Okla Dent Assoc. 2004;95(1):28-30.
29. Skare I, Engqvist A. Human exposure to mercury and silver released from dental amalgam restorations. Arch Environ Health: An Int J. 1994;49(5):384-94. https://doi.org/10.1080/00039896.1994.9954991
30. Drummond JL, Cailas MD, Croke K. Mercury generation potential from dental waste amalgam. J Dent. 2003;31(7):493-501. https://doi.org/10.1016/S0300-5712(03)00083-6
31. Hylander LD, Meili M. 500 years of mercury production: global annual inventory by region until 2000 and associated emissions. Sci Total Environ. 2003;304(1-3):13-27. https://doi.org/10.1016/S0048-9697(02)00553-3
32. Warwick D, Just A. Dental Amalgam and the Environment. ChampionsGate, FL: International Academy of Oral Medicine and Toxicology (IAOMT). 2014 May.
33. EPA. Locating and estimating air emissions from sources of mercury and mercury compounds. 1997. EPA-454/R-97-012. https://www.epa.gov/sites/default/files/2020-11/documents/mercury.pdf Accessed on 23.11.2025.
34. Pacyna EG, Pacyna JM, Steenhuisen F, Wilson S. Global anthropogenic mercury emission inventory for 2000. Atmos Environ. 2006;40(22):4048-63. https://doi.org/10.1016/j.atmosenv.2006.03.041
35. Ullrich SM, Tanton TW, Abdrashitova SA. Mercury in the aquatic environment: a review of factors affecting methylation. Crit Rev Env Sci Tec. 2001;31(3):241-93. https://doi.org/10.1080/20016491089226
36. Lindberg S, Bullock R, Ebinghaus R, Engstrom D, Feng X, Fitzgerald W, Pirrone N, Prestbo E, Seigneur C. A synthesis of progress and uncertainties in attributing the sources of mercury in deposition. Ambio. 2007;36(1):19-33. https://doi.org/10.1579/0044-7447(2007)36[19:ASOPAU]2.0.CO;2
37. Richardson GM, Wilson R, Allard D, Purtill C, Douma S, Graviere J. Mercury exposure and risks from dental amalgam in the US population, post-2000. Sci Total Environ. 2011;409(20):4257-68. https://doi.org/10.1016/j.scitotenv.2011.06.035
38. Clarkson TW, Magos L. The toxicology of mercury and its chemical compounds. Crit Rev Toxicol. 2006;36(8):609-62. https://doi.org/10.1080/10408440600845619
39. Wolfe MF, Schwarzbach S, Sulaiman RA. Effects of mercury on wildlife: a comprehensive review. Environ Toxicol Chem. 1998;17(2):146-60. https://doi.org/10.1002/etc.5620170203
40. Petersen PE, Baez R, Kwan S, Ogawa H. World Health Organization Future use of materials for dental restoration. In Proceedings of the Report of the Meeting Convened at WHO HQ. pp. 1-67.
41. United Nations Environment Programme. Minamata Convention on Mercury. UNEP; 2013. https://www.unep.org/resources/report/minamata-convention-mercury Accessed 21.11.2025.
42. Mackey TK, Contreras JT, Liang BA. The Minamata Convention on Mercury: Attempting to address the global

controversy of dental amalgam use and mercury waste disposal. Sci Total Environ. 2014;472:125-9. https://doi.org/10.1016/j.scitotenv.2013.10.115

43. Council of European Communities. Council Directive 84/156/EEC on mercury discharges. Official Journal of the European Communities. 1984. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31984L0156 Accessed on 22.11.2025.
44. Hylander LD, Lindvall A, Uhrberg R, Gahnberg L, Lindh U. Mercury recovery in situ of four different dental amalgam separators. Sci Total Environ. 2006;366(1):320-36. https://doi.org/10.1016/j.scitotenv.2005.07.007
45. U.S. Environmental Protection Agency. Dental effluent guidelines and mercury reduction. https://www.epa.gov/eg/dental-effluent-guidelines Accessed on 22.11.2025
46. Ritchie KA, Burke FJ, Gilmour WH, Macdonald EB, Dale IM, Hamilton RM, et al. Mercury vapour levels in dental practices and body mercury levels of dentists and controls. Brit Dent J. 2004;197(10):625-32. https://doi.org/10.1038/sj.bdj.4811831
47. Jones DW. Exposure or absorption and the crucial question of limits for mercury. J Can Dent Assoc. 1999;65(1):42-6.9.
48. Arenholt-Bindslev D. Environmental Aspects. In Biocompatibility of Dental Materials 2008. Berlin, Heidelberg: Springer Berlin Heidelberg. 325-334. https://doi.org/10.1007/978-3-540-77782-3_13
49. Osiro OA, Kariuki DK, Gathece LW. The Minamata Convention on Mercury and its implications for management of dental caries in low-and middle-income countries. Int Dent J. 2019;69(4):247-51. https://doi.org/10.1111/idj.12461
50. Musliu A, Beqa L, Kastrati G. The use of dental amalgam and amalgam waste management in Kosova: An environmental policy approach. Integrated Environmental Assessment and Management. 2021;17(5):1037-44. https://doi.org/10.1002/ieam.4408
51. Toxicological Profile for Mercury. Atlanta (GA): Agency for Toxic Substances and Disease Registry (US); 2024 Oct. Table 7-1, Regulations and Guidelines Applicable to Mercury (Hg). https://www.ncbi.nlm.nih.gov/books/NBK611018/table/ch7.tab1/ Accessed 21.11.2025.
52. Sara Johansson. Tackling Mercury Pollution of EU Waters: Why coal combustion must end by 2027 at the latest. 2021, The European Environmental Bureau (EEB). https://eeb.org/wp-content/uploads/2021/12/EEB_Mercury_Briefing-1.pdf Accessed on 21.11.2025
53. OSHA Instruction. Inorganic Mercury and Its Compounds. CPL 02-02-006. 1978. https://www.osha.gov/enforcement/directives/cpl-02-02-006 Accessed 20.11.2025
54. Cieplik F, Dame-Teixeira N, Priya H, Schmalz G, Scholz K, Tenuta l, et al. Policy Statement on Safety of Dental Amalgam. 2025. https://www.iadr.org/science-policy/safety-dental-amalgam Accessed 20.11.2025.
55. Tibau AV, Grube BD. Mercury contamination from dental amalgam. J Health Pollut. 2019;9(22):190612. https://doi.org/10.5696/2156-9614-9.22.190612
56. Warwick D, Young M, Palmer J, Ermel RW. Mercury vapor volatilization from particulate generated from dental amalgam removal with a high-speed dental drill–a significant source of exposure. J Occup Med Toxicol. 2019;14(1):22. ttps://doi.org/10.1186/s12995-019-0240-2
57. Skare I, Engqvist A. Human exposure to mercury and silver released from dental amalgam restorations. Arc Environ Health: An Int J. 1994;49(5):384-94. https://doi.org/10.1080/00039896.1994.9954991
58. Jokstad A, Fan PL. Amalgam waste management. Int Dent J. 2006;56(3):147-53. https://doi.org/10.1111/j.1875-595X.2006.tb00087.x
59. Smith L, Ali M, Agrissais M, Mulligan S, Koh L, Martin N. A comparative life cycle assessment of dental restorative materials. Dent Mater. 2023;39(1):13-24. https://doi.org/10.1016/j.dental.2022.11.007
60. Bjørklund G, Dadar M, Mutter J, Aaseth J. The toxicology of mercury: Current research and emerging trends. Environ Res. 2017;159:545-554. https://doi.org/10.1016/j.envres.2017.08.051
61. Mackert Jr JR, Berglund A. Mercury exposure from dental amalgam fillings: absorbed dose and the potential for adverse health effects. Crit Rev Oral Biol Med. 1997;8(4):410-36. https://doi.org/10.1177/10454411970080040401
62. Vandeven JA, McGinnis SL. An assessment of mercury in the form of amalgam in dental wastewater in the United States. Water, Air and Soil Pollution. Water Air Soil Pollut. 2005;164(1):349-366. https://doi.org/10.1007/s11270-005-4008-1
63. Fan PL, Batchu H, Chou HN, Gasparac W, Sandrik J, Meyer DM. Laboratory evaluation of amalgam separators. J Am Dent Assoc. 2002;133(5):577-89. https://doi.org/10.14219/jada.archive.2002.0233
64. International Standard ISO 11143. Dental Equipment–Amalgam Separators; 1999. Geneva, Switzerland: International Organisation for Standardisation; 1999. 1–23.
65. Drummond JL, Hathorn RM, Cailas MD. Particle size analysis of dental waste stream components. Dent Mater. 2001;17:322–332. https://doi.org/10.1016/S0109-5641(00)00090-7
66. Drummond JL, Liu Y, Wu TY, Cailas MD. Particle versus mercury removal efficiency of amalgam separators. J Dent. 2003;31(1):51-8. https://doi.org/10.1016/S0300-5712(02)00067-2
67. Jones DW. Putting dental mercury pollution into perspective. Brit Dent J. 2004;197(4):175-7. https://doi.org/10.1038/sj.bdj.4811564
68. Kall J, Robertson K, Sukel AP, Just MA. International Academy of Oral Medicine and Toxicology (IAOMT) Position Paper against Dental Mercury Amalgam Fillings for Medical and Dental Practitioners, Dental Students, Dental Patients, and Policy. 1-91. https://elearning.iaomt.org/wp-content/uploads/2022/05/IAOMT-Position-Paper-on-Dental-Amalgam.pdf Accessed on 20.11.2025.
69. Hiltz M. The environmental impact of dentistry. J Can Dent Assoc. 2007;73(1):59-62.
70. Saridena USNG, Sanka GSSJ, Alla RK, Ramaraju AV, Sajjan MC S, Mantena SR. An overview of advances in glass ionomer cements. Int J Dent Mater. 2022;4(4):89-94. https://doi.org/10.37983/IJDM.2022.4403
71. Gosavi SS, Gosavi SY, Alla RK. Local and systemic effects of unpolymerised monomers. Dent Res J. 2010;7(2):82-7.
72. Alla RK, Sanka GSSJL, Saridena USNG, Ramaraju AV, Raju M, Mantena SR. Fiber-Reinforced Composites in Dentistry: Enhancing structural integrity and aesthetic appeal. Int J Dent Mater. 2023;5(3):78-85. https://doi.org/10.37983/IJDM.2023.5303
73. Dara L, Buchi D, Mantena SR, K MV, D BR, Chandrappa V. Recent Advances in Dental Composites: An Overview. Int J Dent Mater. 2019;1(2):48-54. https://doi.org/10.37983/IJDM.2019.1202
74. Mudunuri S, Madhu Varma K, Kalyan Satish R, Sita Rama Kumar M, Sai Dinesh J, Anil Kumar P. Fiber-reinforced composites in endodontic practice: a review. Int J Dent Mater. 2020;2(4):122-34. https://doi.org/10.37983/IJDM.2020.2404
75. Fleisch AF, Sheffield PE, Chinn C, Edelstein BL, Landrigan PJ. Bisphenol A and related compounds in dental materials. Pediatrics. 2010;126(4):760-8. https://doi.org/10.1542/peds.2009-2693
76. Bengtsson UG, Hylander LD. Increased mercury emissions from modern dental amalgams. Biometals. 2017;30(2):277-83. https://doi.org/10.1007/s10534-017-0004-3

77. Sakchhi S, Elbanna L, Chakor M, Nikferjam AZ, Saeedi N, Badve S, et al. Green Dentistry: Sustainable Practices and Materials for a Healthier Planet. Int J Dent Mater. 2025;7(3):84-92. https://doi.org/10.37983/IJDM.2025.7303

78. Duane B, Stancliffe R, Miller FA, Sherman J, Pasdeki-Clewer E. Sustainability in dentistry: a multifaceted approach needed. J Dent Res. 2020;99(9):998-1003. https://doi.org/10.1177/0022034520919391