

# From the Oral Cavity to the Environment: The Creation and Fate of Evacuation System Contaminants

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### The Role of Dental Evacuation Systems in Infection Control and Environmental Protection

Although the placement of new amalgam restorations has become increasingly infrequent, the removal of existing, defective, or corroded amalgam fillings continues to generate a substantial proportion of mercury-laden particulates within dental wastewater [1]. These compounds enter the environment through the dental evacuation system which leads to public wastewater facilities. The dental office evacuation system represents a critical component for not only patient treatment but also environmental stewardship beyond the office to safeguard groundwater, soil, septic systems, and aquatic ecosystems from pollutants generated during varied dental procedures.

These systems provide the means for aerosol control, debris removal, and infection minimization by preventing cross-contamination during dental procedures [2,3]. Vacuum handpieces, tubing, lines, and separators continuously collect a complex mixture of oral fluids, particulates, and cooling water generated by handpieces, ultrasonic instruments, and air-water syringes. By effectively removing these fluids from the operative field, evacuation systems maintain a clean working environment, provide required water-free restorative sites, enhance patient comfort, protect the clinical team, and significantly reduce airborne pathogen transmission. Dental evacuation systems also serve a significant role in environmental stewardship as the first line of defense against the uncontrolled release of contaminants, including amalgam restorative metals, plastics, organic tissue, and microbial matter, into wastewater stream [4,5]. Paramount to the complexity of aspirated dental effluent is the presence of mercury, primarily derived from the ablation and removal of amalgam fillings. Through effective management, dental evacuation systems not only prevent environmental contamination but also contribute to environmental remediation and biome enhancement.

### The Composition, Transformation, and Environmental Fate of Dental Effluent

Dental evacuation systems play an essential role in controlling infection within clinical settings and reducing environmental impact. These systems capture bulk oral fluids, aerosols, and

particulates generated during dental procedures, including entrained microorganisms and dissolved or suspended contaminants. The aspirated effluent is a chemically and biologically complex suspension composed of saliva, blood, plaque, tooth structure, oral microbes, lipids, proteins, and biofilm residues from intraoral surfaces [6].

Embedded within this mixture are metallic ions and microplastic particles originating from both intraoral sources and the evacuation system itself. Within the mouth, mechanical abrasion and chemical processes release fine particles from restorative materials such as amalgam, composites, and plastic devices. These may include metals such as silver, chromium, zirconium, and mercury, as well as polymeric fragments from resin-based fillings.

Once aspirated from the oral cavity, this mixture of oral fluids, cooling water, and generated contaminants is transported through an intricate network of vacuum lines, pipes, and bends that connect multiple operatories to a central collection point at the suction device [4,7]. Along its path, the effluent interacts with and mobilizes accumulated debris, microbial biofilms, and materials that have leached from the interior surfaces of the plumbing system.

Each operatory may introduce distinct contaminants depending on the clinical procedures performed, ranging from metallic filings and composite dust to disinfectant residues and prophylactic paste. Within the vacuum tubing, physical turbulence, temperature shifts, and the presence of microorganisms promote a series of chemical and biological reactions that can transform metals such as mercury into soluble or reactive forms. Simultaneously, microplastic fragments and organic residues may adsorb ions or microbes, forming composite particles that complicate downstream treatment.

Before final discharge, the combined effluent typically passes through an amalgam separator designed to remove larger particulate mercury and amalgam fragments. However, dissolved mercury species, colloidal microplastics, and microbial byproducts may remain in suspension where it is discharged either to a

municipal wastewater treatment facility or to an on-site septic system. In municipal systems, contaminants may accumulate in biosolids and sludge, whereas in septic systems they may percolate through soil, potentially entering groundwater. These distinct pathways highlight the environmental importance of proper dental wastewater management and underscore the need for ongoing improvements in contaminant capture and treatment technologies.

### Microbial Mercury Transformation Within the Dental Evacuation Systems

Within the dental evacuation network, microbial biofilms colonize surfaces where moisture, nutrients, and trace metals accumulate. Aspirated oral bacteria within or adhered to the biofilms and play an active biochemical role in the transformation of mercury from dental amalgam debris. In vitro, studies have shown that common oral bacteria can transform inorganic mercury into methylmercury, a potent neurotoxin [8]. Salivary pH and enzymes promote the release of ionic and colloidal mercury providing promotion of bacterial methylation [9].

Anaerobic microenvironments found within the evacuation system foster the proliferation of mercury-transforming bacteria that harbor genes mediating mercury methylation [10,11]. Facultative bacteria such as *Streptococcus* and *Pseudomonas* species also exhibit methylating potential, expanding the known ecological range of mercury-transforming organisms. Biofilms trap metal ions and particulates, forming dense matrices that concentrate ionic mercury and organic substrates. This enables in-situ conversion of inorganic or particulate-bound mercury into methylmercury and other soluble organomercury compounds.

Microplastics as Contaminant Carriers and Microbial Substrates  
Microplastics are tiny particles, usually less than 5 millimeters in size, which are formed through wear, abrasion, or the ablation of larger components. These particles are a major health and environmental concern because they disperse easily through water, air, and soil [12].

Primarily insoluble, in aquatic ecosystems, fish and other marine animals often mistake microplastics for food, leading to digestive problems or poisoning from absorbed toxins. On land, microplastics can accumulate in soil, affecting plant growth by blocking water and nutrient absorption. Over time, these pollutants move through food chains, threatening not only wildlife but also human health and the overall balance of ecosystems.

Microplastics enter the dental evacuation system when plastic-based materials inside the mouth are subjected to abrasion, polishing, drilling, or cutting and then aspirated. Composite filling materials, used for restorations and temporary crowns, are important sources of microplastics. They typically contain polymeric resins and plastics like methacrylate or urethane, strengthened with silica, glass, or ceramic particles bonded by coupling agents such as silanes. When material is removed by shaping or polishing, tiny particles are released. These particles mix with cooling water and saliva and are then aspirated through high-volume evacuation lines. They add microplastic pollution to the environment [13].

Within the evacuation system, polymers can bind metals from amalgam residues. Adhesion and interaction with bacterial biofilms enhance their persistence and toxicity [14,15]. Biofilm-coated microplastics absorb and transport heavy metals far more effectively than clean polymers [16]. The biofilm's negatively charged groups and extracellular polymers attract cations like

$\text{Cu}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Cd}^{2+}$ , and  $\text{Hg}^{2+}$ , transforming microplastics into active pollutant carriers [17]. Aged or biofilm-coated microplastics absorb far more metals than pristine ones, and these can release metals under environmental changes, leading to secondary contamination. Microplastics thus function as dynamic vectors for concentrating and transporting toxic elements through ecosystems, including aquatic systems and food webs.

### Microbial Detoxification, Learning from Nature

When harmful substances are released by industry, nature often reduces their impact, particularly through microbes. These microbes have evolved to neutralize toxic metals like mercury and break down persistent plastics, converting them into less dangerous forms for natural cycles. Effluents from dental systems entering wastewater or septic tanks may be addressed either by industrial treatment or natural remediation.

Soluble mercury ions ( $\text{Hg}^{2+}$ ) bind tightly to thiol ( $-\text{SH}$ ) and selenol ( $-\text{SeH}$ ) groups within enzymes such as proteases, distorting their active sites and inhibiting catalytic activity [18,19]. Naturally, when protease is used for organic degradation such as in evacuation and wastewater systems this hinders its functionality. This inhibition disrupts microbial proteolysis and organic degradation interfering with the digestive capacity of microbes. Fortunately, certain bacteria possess genetic systems that reverse mercury's toxicity. The mer operon, a gene cluster found in many soil and aquatic microbes, encodes enzymes that detoxify mercury through a two-step biochemical reduction. MerB first cleaves the carbon-mercury bond in methylmercury, converting it into ionic mercury ( $\text{Hg}^{2+}$ ), and MerA then reduces this ionic form to elemental mercury ( $\text{Hg}^0$ ), a volatile, far less bioavailable species that dissipates from water and soil (Barkay et al., 2003; Boyd & Barkay, 2012) [20,21].

This natural detoxification occurs across diverse ecosystems—from wetlands and estuaries to deep-sea sediments and Arctic waters [22,23]. Field studies confirm microbial mercury reduction in wetland sediments [24], the Tagus Estuary in Portugal, and even in cold Arctic environments where active merA genes persist [25,26]. Long-term monitoring of Tennessee's East Fork Poplar Creek demonstrates that native soil bacteria continuously convert soluble mercury into inert vapor, mitigating environmental spread [27].

Just as microbes detoxify mercury, others are beginning to tackle one of the planet's most persistent pollutants, plastics. Synthetic polymers like polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polyurethane (PU) resist natural degradation due to their high molecular weight and hydrophobic carbon backbones. Yet certain bacteria such as *Pseudomonas putida* and *Bacillus subtilis* can generate enzymes capable of breaking down these materials, in nutrient-limited or polluted environments where plastics become available carbon sources [28, 29].

While complete mineralization is slow, these microbial pathways represent a promising foundation for bio-upcycling—converting waste plastics into valuable intermediates such as biodegradable polymers, biosurfactants, or biofuels. Combined microbial consortia and enzymatic cocktails are now being explored to accelerate degradation rates and broaden polymer compatibility [30-34].

### Extending Nature's Strategy to the Dental Evacuation System

These natural processes are now being translated into engineered solutions. Solmetex has developed dental wastewater systems

that capture particles released from dental amalgam removals before environmental discharge, while the Mereduce™ microbial consortium in their line cleaner Power Scrub employs naturally occurring mercury-transformative bacteria to convert dissolved mercury into inert for capture. By integrating biological detoxification, these systems kickstart nature's own mercury-cleaning strategy to industrial and healthcare applications.

Nature's microbial networks demonstrate that the same biochemical versatility that detoxifies mercury can also dismantle synthetic pollutants like plastics. In both cases, microbes transform environmental liabilities into biologically manageable forms. Technologies such as Solmetex and Mereduce™ are examples of how these natural strategies can be harnessed and optimized for real-world environmental remediation—combining physical capture, biological transformation, and sustainable pollution control.

Together, microbial mercury detoxification and plastic biodegradation highlight a powerful principle: by understanding and replicating microbial processes, we can restore balance to systems impacted by industrial waste, ensuring cleaner water, healthier ecosystems, and a more sustainable future.

#### Author's note

Solmetex is recognized for its leadership in dental cooling, wastewater management, and amalgam separation technologies, delivering solutions that ensure compliance with EPA 40 CFR Part 441 while advancing responsible environmental stewardship.

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