Understanding the Mercury Reduction Issue: The Impact of Mercury on the Environment and Human Health

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ABSTRACT

Mercury has been used in both medicine and dentistry for centuries. Recent media attention regarding the increased levels of mercury in dietary fish, high levels of mercury in air emissions, and conjecture that certain diseases may be caused by mercury exposure has increased public awareness of the potential adverse health effects of high doses of mercury. Dentistry has been criticized for its continued use of mercury in dental amalgam for both public health and environmental reasons. To address these concerns, dental professionals should understand the impact of the various levels and types of mercury on the environment and human health.

Mercury is unique in its ability to form amalgams with other metals. Dental amalgam — consisting of silver, copper, tin, and mercury — has been used as a safe, stable, and cost-effective restorative material for more than 150 years. As a result of this use, the dental profession has been confronted by the public on two separate health issues concerning the mercury content in amalgam. The first issue is whether the mercury amalgamated with the various metals to create dental restorations poses a health issue for patients. The second is whether the scraps associated with amalgam placement and the removal of amalgam restorations poses environmental hazards which may eventually have an impact on human health. Despite the lack of scientific evidence for such hazards, there is growing pressure for the dental profession to address these health issues.

In this article, the toxicology of mercury will be reviewed and the impact of amalgam on health and the environment will be examined.

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Several reviews of the toxicology of mercury have appeared recently.[1-3] Liquid mercury (quicksilver) has largely been eliminated from homes and work environments. However, rare incidents of poisoning are still reported due to cultural and religious uses of mercury. Human exposure to mercury is from three major sources: dental amalgams, fish consumption, and vaccines. Dental amalgams emit mercury vapor that can be potentially inhaled and absorbed into the bloodstream. However, this amalgam-associated mercury vapor poses a very limited risk to dentists and those with amalgam restorations. The major toxicology concerns about mercury are related to its two organic forms, methylmercury (CH_3Hg^+) and ethylmercury ($CH_3CH_2Hg^+$). Fish consumption is the main source of methylmercury intake in humans. Exposure to ethylmercury is mainly through thimerosal, a preservative used in vaccines.

Each form of mercury has its own characteristic, distinctive toxicologic profile, and clinical symptoms. **Table 1** summarizes the clinical toxicologic features of the various forms of mercury.

Mercury Vapor from Dental Amalgams

An ambient atmospheric level of mercury is negligible. Health risks can occur with occupational exposure to high concentration of mercury vapor. Mercury vapor is a monatomic gas that evaporates from liquid metallic mercury. Historically, occupational exposures were associated with cinnabar mining, extraction of gold and silver with quicksilver, mirror-making, hat-making, and accidental mercury spills from, for example, blood pressure cuffs. Mercury has been used in manufacturing paints, pesticides, and batteries, but is no longer used for these products. Mercury continues to be used in the manufacture of chlorine and fluorescent lamps. Non-occupational exposures to mercury vapor have occurred in the past due to mercury's use in science classes and easy public access to the product. Recreational gold miners are known to use elemental mercury today. Exposures can also occur when devices containing mercury, such as thermostats and thermometers, break. Today, given modern occupational standards and safety precautions and greater awareness of mercury vapor toxicity, human exposure to high concentrations of mercury vapor are rare in the U.S.

Amalgam fillings are the chief source of exposure to low levels of mercury vapor for the general population.[4] How much vapor is absorbed by the body or is breathed out is not known. Brain, blood, and urinary concentration of mercury are proportional with the number of amalgam restorations present. Estimates indicate that 10 amalgam surfaces would raise urinary concentration by 1 µg of mercury per liter, which is twice the normal environmental background concentration.[5] Heavy mastication and prolonged chewing will elevate urinary concentration close to the recommended health limits.[6] A temporary elevation in mercury vapor can be observed with amalgam removal. [7]

Historically, reports of high concentration of mercury vapor inhalation have been characterized by tremor, gingivitis, and erethism (bizarre behavior such as excessive shyness and/or aggression).[8] In today's occupational environment, the risks are low and reversible. With a short half-life of 60 days, mercury is usually cleared from the body with no significant health effects. In extreme cases, reversible kidney changes, mild cognitive changes, and memory loss may occur.

Occupational exposure associated with working with dental amalgam can result in a 10- to 25-fold elevation in urinary output of mercury.[7] Though this is well below recommended health limits, some have speculated that long-term exposure to low concentrations of mercury vapor may cause or contribute

Table 1

Toxicological Features of Mercury*

Variables	Mercury Vapor	Methylmercury	Ethymercury
Route of exposure	Inhalation	Oral ingestion (primarily from fish consumption)	Parenteral (through vaccines)
Target organ	Central and peripheral nervous system; kidney	Central nervous system	Central nervous system; Kidney
Local clinical signs			
Lungs	Bronchial irritation; pneumonitis		
GI	Stomatitis; gingivitis; metallic taste; increase salivation		
Skin			
Systemic clinical signs			
Kidney	Proteinuria (>500 μg/m_3 of air)		Tubular necrosis
Peripheral nervous system	Peripheral neuropathy (>500 μg/m_3 of air)		Acrodynia
Central nervous system	Erethism; tremor (>500 μg/m_3 of air)	Paresthesia, ataxia, visual and hearing loss (>200 μg/l of blood)	Paresthesia; ataxia; vision and hearing loss
Approximate half-life	60 days	70 days	20 days in adult 7 days in infants
Treatment	Meso-2,3-dimercaptosuccinate	Chelators not effective	Chelators not effective

*Data was adapted from Clarkson.[1]

to the development of degenerative diseases such as amyotrophic lateral sclerosis, Alzheimer's disease, multiple sclerosis, and Parkinson's disease. Most of the speculation has been associated with Alzheimer's disease, but epidemiologic studies have failed to correlate this association.[9-11]

With increased public awareness of "anti-amalgamist" claims, some patients have questioned whether they should have all amalgams removed. These patients should be reminded there is no evidence supporting amalgam removal for supposed health benefits. Additionally, patients should be cautioned that removal of amalgams prior to the need for replacement will result in increased exposure to mercury vapor and a transient increase in blood mercury concentration.

Methylmercury from Fish Consumption

The main source of human exposure to methylmercury is the consumption of fish. Mercury vapor (Hg^0) is a stable monatomic gas that evaporates from soil and water and is emitted by volcanoes. The major anthropogenic sources of mercury vapor emissions are coal-burning power stations and municipal incinerators. Eventually, mercury vapor converts to a soluble form (Hg^{2+}) and returns to the earth surface with rainwater. This soluble form may attach itself to aquatic sediments and be microbially converted into methylmercury (MeHg). Methylmercury then enters into the aquatic food chain. Methylmercury becomes concentrated at the top of the aquatic food chain, with the highest concentrations found in long-lived predatory fish such as tuna, swordfish, shark, and bass. The classic case of aquatic contamination is the excessive industrial release of methylmercury into Minamata Bay and the Agano River in Japan, which resulted in two large epidemics of mercury poisoning related to fish consumption.[12]

The brain is the primary target tissue of mercury poisoning, with regional destruction of neurons in the visual cortex and cerebellar granule cells. This is clinically manifested by a latent period with paresthesias of the limbs followed by visual field constriction and ataxia. Some have suggested that MeHg contributes to cardiovascular disease, but epidemiologic evidence does not support this.[13-16] Additionally, it is not clear how this may contribute to this multi-factorial disease.

The main concern about methylmercury is prenatal exposure. The fetal brain is more susceptible to mercury-induced damage. Methylmercury inhibits neuronal cell division and migration, which disrupts brain development. Due to this concern and epidemiologic data,[17-19] the Environmental Protection Agency reduced the allowable intake of MeHg from 0.5 to 0.1 µg of mercury per kilogram per day.[20] This translates into a weekly consumption of one 7-ounce can of tuna for an adult. For pregnant women, nursing mothers, and young children, the Food and Drug Administration is more stringent in recommending these populations avoid eating fish with a high mercury content [>1 parts per billion (ppb)], such as those levels found frequently in shark, swordfish, tilefish, and king mackerels. California Department of Fish and Game regulation guidelines include public health advisories on consumption of sport fish from various water bodies including San Francisco Bay and the Delta region. Due to elevated levels of mercury, PCBs, and other chemicals in these areas, consumers are advised against eating more than two meals per month of certain fish, eating any striped bass or sharks more than 24 inches to 35 inches long, and eating any fish from certain water bodies.

Ethylmercury from Thimerosal in Vaccines

Thimerosal has been used as a vaccine preservative since 1930.[2,21] It contains ethylmercury, which kills microorganisms and fungi. The presence of ethylmercury in vaccines became a concern as a result of a study suggesting infants undergoing the recommended U.S. program of vaccinations from birth to six months of age would be exposed to more than 0.1 µg of mercury per kilogram per day.[2] Utilizing MeHg epidemiologic data on prenatal exposure, the EPA ordered post-natal exposure to ethylmercury to be lowered. This resulted in a rapid change in the U.S. vaccination program whereby thimerosal was completely eliminated from use by switching to vaccines in single dose vials without any preservative.

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The toxicology pattern of ethylmercury has some similarities to methylmercury. They have similar tissue-organ distribution and damage patterns; however, ethylmercury is metabolized more rapidly than MeHg.[22] Whereas the typical half-life of MeHg is 70 days, it is only seven days to 10 days in children receiving thimerosal-containing vaccines. Due to this rapid turnover, there is minimal if any risk for accumulation. It has been postulated that EPA extrapolation of the MeHg data in developing regulatory policies for the U.S. vaccination program is not scientifically sound. Echoing this sentiment, the World Health Organization (WHO) advisory committee recently concluded it is safe to continue to use thimerosal in vaccines.[23]

Amalgam and Human Health

As for the safety of dental amalgam in individuals with fillings, amalgam has a long track record of safety and durability. The U.S. Food and Drug Administration, Public Health Service, National Institutes of Health, WHO, ADA, and Academy of General Dentistry have all stated that no valid scientific evidence shows that the mercury in amalgam has any negative health effect. In the oral environment, the mercury is amalgamated with the various metals and is rendered inert. With chewing, it is possible to have mercury vapor released, but the amount is thousands times lower than the amount considered safe by various scientific studies and the National Institutes of Health. Some experts have calculated that one would need to have approximately 500 fillings to face any toxic effect from this mercury vapor.[4] Despite the preponderance of information that supports the use of amalgam, many have advocated its replacement with alternative restorative materials. This approach may pose greater health risks due to the temporal elevation of mercury, the endodontic risk associated with premature restorative procedures, and the unclear longevity of service for certain categories of restorative materials.

Amalgam and Wastewater

The recent focus of regulatory agencies has not been on the safety of amalgam but rather on amalgam waste. The concern is that the mercury within the amalgam may contribute to the environmental load of mercury, resulting in higher concentration of mercury deposited into our food chain. Whether this is true has been a source of controversy. Nevertheless, regulatory agencies dictate regulations and policies based upon certain assumptions. Since these regulations will have a significant impact on restorative dentists, it is important to understand the issues involved.

With the passage of the Federal Clean Water Act, agencies have imposed regulations in an attempt to protect the nation's water bodies by limiting the concentration and loading of chemicals discharged from various sources including, but not limited to, dental offices, industrial facilities, and sewage treatment plants. Mercury is of particular interest to these regulatory agencies because it is a persistent bioaccumulative toxic chemical.

Environmental regulations and policies on mercury are based on a series of assumptions that are overestimated and not based on scientific evidence. Despite empirical uncertainties, this preventive regulatory approach has been taken to protect human health and the environment. The EPA and other regulatory agencies have made the assumption that all mercury (whether bound or unbound) from dental offices will be converted into methylmercury once released into the environment. Though there is no scientific evidence to support this conversion, this is the fundamental basis for this regulatory scheme. Environmental regulations for mercury do not take into consideration the different forms of mercury. Therefore, as a result of these assumptions, regulations have been imposed to minimize the concentration of total mercury levels in water bodies. In the Great Lakes region, for example, the EPA has dictated a maximum concentration of mercury allowed in the surface water of 0.0013 micrograms of mercury per liter [0.0013µg/l or ppb] as a result of all discharges along this water body.

The EPA, many states, and several municipalities have specifically identified dental offices as a major source of mercury discharge into sewer systems. However, the dental industry is not a major source of mercury release into the environment. The most significant sources to the environment are from air emissions from electric power and chloralkali industries. Mercury has been detected in sewage sludge at concentrations that range between 0.38 mg/kg and 3.0 mg/kg. This mercury is the result of the cumulative impact of all mercury entering the sewage system, including human waste and industrial sources. In addition, the leakage of mercury from silver mining and other industries no longer functioning may continue to contribute to the mercury discharge. Though a large percentage of mercury in dental amalgam is bound, it is not known if any of this mercury is readily bioconverted into methylmercury. Nevertheless, dental amalgam discharge into sewer systems is highly scrutinized by regulatory agencies.

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While dentists' offices are an identifiable source of amalgam waste discharge, there is no evidence that these discharges are converted to methylmercury in the sewer system or during the waste treatment process. There are few reliable quantitative data about the environmental impact of amalgam in wastewater. A study based on dental wastewater discharge suggested that dentists discharge an average of 35 milligrams of mercury in the amalgamated form into the sewer per day.[24] Studies conducted by POTWs in San Francisco and Seattle estimated that dental office wastewater constitutes between 8 percent and 14 percent of the total mercury load.[25,26] However, these findings are based on waste accumulation sampling, and not on how much amalgam or how much free mercury dental offices actually discharge. It is clear that the amount of amalgam discharged can be minimized by 40 percent to 80 percent with the use of chairside and vacuum pump traps.[27-29] This can be further improved to 96 percent to 99 percent with the use of amalgam separators.[30] Nevertheless, research has not determined what effect, if any, dental discharges have on mercury loading at a given POTW.

In one ADA-commissioned study, a simulated treatment model was used to determine whether amalgam would degrade to its individual components with wastewater treatment. Using an assay method that could detect 1 ppb, no soluble mercury was detected when amalgam particulate was subjected to wastewater treatment procedures.[31]

Although regulatory assumptions resulting in higher calculated water quality impacts for amalgam discharges may not be scientifically sound, it is unlikely that regulations will be modified by the EPA or the states. The inherent toxicity of methylmercury is such that the National Academy of Sciences reviewed the EPA's daily limit on exposure to methylmercury (0.1 µg/kg of body weight per day) and concluded it was scientifically justified.[32] The issue is not only concern for water quality, but also for the amount of methylmercury that bioaccumulates in fish, a part of our food chain. The maximum amount of methylmercury allowed in fish tissue by the EPA is 0.3 ppm. The FDA limit is 1 ppm. Both the EPA and the FDA have issued advisories recommending that pregnant women, nursing mothers, and young children, not to eat shark, swordfish, king mackerel, canned tuna, or tile fish. The California Department of Fish and Game, California EPA, and Office of Environmental Health have various advisory warnings recommending limited fish consumption for fish caught in San Francisco Bay, Clear Lake, and other water bodies in California. Many of these concerns are due to the high level of methylmercury in the fish.

Conclusion

Mercury toxicity is not a significant issue when one examines the mercury vapor levels associated with dental occupational exposure and dental amalgams in patients. Health concerns about mercury exposure increase significantly when one examines the levels of mercury associated with fish consumption. Does dental amalgam contribute to this problem? It is not clear. Despite the lack of scientific evidence to support that the mercury associated with dental amalgam readily converts into methylmercury, regulatory agencies act on the assumption that it is completely converted and that it contaminates the food chain. As federal and state regulatory goals to lower the maximum level of mercury allowable in water bodies become more pronounced, it is likely that regulations will become more stringent. Though the regulations may appear unduly harsh and non-scientific, it is unlikely the EPA nor Congress will make any fundamental policy changes. Likewise, an attempt by the dental profession to refute the EPA regulatory assumptions would be both complex and costly, and a heavy burden of proof will be required. CDA

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