Critical Appraisal

SAFETY OF DENTAL AMALGAM

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This Critical Appraisal is a departure from our usual format. Usually, contributors review several articles about a specific topic. Instead, we have asked Dr. Osborne to review several topics related to a specific issue, the safety of dental amalgam. Despite the increasing use of tooth-colored restorative materials, amalgam remains a widely used and important part of the dentist's armamentarium. This article provides the practicing dentist with essential information regarding the safety of amalgam. We hope that you will find this helpful as you discuss safety issues with concerned patients.

Dental amalgam has been a controversial restorative material since it was first introduced. Nevertheless, amalgam materials have been the most widely used direct restoratives in dentistry. One of the biggest issues surrounding dental amalgam has been its mercury content and potential toxicity. In the past 20 years, significant research has been conducted on the health effects of amalgam. The science is very good, but highly charged emotional and political views have clouded the toxicologic evidence.

The safety of dental amalgam is best put into context with an understanding of mercury and its toxic properties. The purpose of this article is to examine mercury, its abundance, its many forms and their toxicity, and the studies relating to the safety of dental amalgam.

MERCURY

Mercury, the 80th element in the periodic table (atomic weight 200.6, symbol Hg), is a silvery white metal that has a mirror-like surface as a liquid.[1–3] It has a specific gravity of 13.55, and is the only metal that is liquid at room temperature. The temperature range of the liquid phase is about 550°F. Mercury is a poor conductor of heat and a fair conductor of electricity.[1–3] The liquid phase has a low viscosity and a high surface tension that allows it to run freely and ball up. Mercury forms alloys, a process called amalgamation, with most metals other than iron.[1,2] Mercury vapor is odorless and colorless and has a high vapor pressure that doubles with every 10°C temperature increase.[1,4–6] It is most commonly found in nature as cinnabar (HgS) and only rarely as an unreacted metal.[1,3] An exception to this is found in the California gold fields, where liquid mercury was extensively used in mining in the 1850s. Because of this practice, it can be panned readily in area streams today.

Abundance

Mercury is a ubiquitous environmental toxin. The sources and abundance of this element are almost staggering. According to geologists, sources of mercury in the environment include volcanic activity, degassing of the earth's crust,

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and evaporation from the oceans at 30,000 to 150,000 ton/yr.[7–10] The earth's crust contains 0.5 mg Hg/kg, and soil-forming rocks contain 10 to 300 mg Hg/kg.[11,12] Because of mercury's high vapor pressure, atmospheric mercury levels are highest in the summer and at midday and lowest in the winter and at midnight.[13] The average atmospheric mercury level is 1.5 $\mu g/m^3$, but in industrial areas the mercury level can exceed 50 $\mu g/m^3$.[9,14]

The United States Environmental Protection Agency (EPA) states that the greatest source of man-made mercury contamination is from the United States.[15] The EPA cites sources such as the burning of fossil fuels (which adds 20,000 ton/yr),[15–18] agriculture (3,000 ton/yr),[9] smelting and mining operations (10,000 ton/yr),[19] and sewage (15,000 ton/yr).[9] In addition, waste incineration, particularly from hospitals, contributes another 3,000 tons of mercury annually.[20] Mercury is not degradable, and the major pathway for the global transport of mercury is via the atmosphere.[9] Because it is ubiquitous, the daily personal consumption of mercury from air, food, and water is 10 to 20 μg, even if one consumes a diet low in fish.[21,22]

Forms and Their Toxicity

As with all toxins, "the dose makes the poison,"[23] but the different forms of mercury, each with its own unique toxicity profile, and the wide range of the effects of mercury must be carefully examined. For the purposes of this article, the forms are categorized as liquid mercury, inorganic mercury, organic mercury, and mercury vapor.

Liquid Mercury. Minimal absorption (< 0.1%) occurs with dermal contact to liquid mercury.[24,25] Liquid mercury has no toxic effect when swallowed.[25–27] Prior to the turn of the twentieth century, physicians recommended drinking mercury to alleviate constipation. Members of the Lewis and Clark expedition took "Blue Mass," a pill containing licorice, honey, and mercury, on a daily basis.[28] One medical report showed that liquid mercury was cleared from the gut with no adverse effects in 10 days when 3.2 kg of mercury (about 284 mL) was ingested.[29]

Some bizarre forms of liquid mercury intake occur when it is injected subcutaneously, intramuscularly, and/or intravenously.[30–33] These are the result of suicide attempts, self-administered experiments, or mistaken efforts to build muscle mass. Boxers in Latin American countries, for instance, have injected mercury into their hands.[34] Individuals have injected liquid mercury into their arms, legs, and abdomen, and in most cases these people do not see a doctor for years.[35] Serious mercury toxicity does not occur in these individuals. However, aspiration of liquid mercury causes necrotizing bronchitis and progressive pulmonary fibrosis.[36–38]

Inorganic Mercury. Inorganic mercury compounds (salts) are highly toxic, and poisoning is usually the result of accidental or intentional ingestion.[7,39–42] Mercuric chloride ($HgCl_2$) is a "violent poison,"[1] and when ingested, the caustic nature of this compound dissolves the lining of the gastrointestinal tract.[43,44] Patients experience severe pain, nausea, vomiting, and diarrhea, and cardiovascular collapse.[34,44] Patients do not die from mercury toxicity but from renal failure owing to the severe loss of fluids and proteins. Death occurs in 6 to 23 days.[34,44]

Preparations of mercurous chloride, Hg_2CL_2 (calomel), are known to cause a toxic reaction in patients.[45–47] Mercurous chloride is irritating to the skin, and exposure in this manner causes urticaria and vesication.[46,47] It has been used as a skin-lightening cream,[45–47] teething powder,[34] and laxative,[48] and it is commonly found in Chinese herbal medicines.[49]

Absorption of mercury oxide, a compound found in many batteries, can cause elevated blood and urine levels.[50,51] Children have swallowed small button batteries, and the contents have spilled into the gut. Another inorganic compound is

mercuric sulfide, Chinese vermilion, which is commonly used as the red color in tattooing. In addition, mercury salts and liquid mercury are sprinkled in religious ceremonies in some Latin and Caribbean cultures.[52] The hazard to children is great because they can crawl around in it or eat it.

Organic Mercury. The organic mercury compounds are very toxic, with a 90% absorption rate in the gut and a biologic half-life of 70 to 90 days.[34,53,54] Of alkyl organic compounds, methyl mercury is most common.[12,55] Methylation of mercury by microorganisms is well documented but has never been found in the human body.[56,57] This form of organic mercury enters the food chain, is concentrated as it moves up the chain, and finally is consumed by humans.[57] Episodic methyl mercury poisoning has occurred in places where fish and/or shellfish are the major part of the diet.[58] The classic example is the Bay of Minamata in the 1950s. Industrial discharge of mercury in the waterway was converted into methyl mercury, and chronic consumption of seafood caused degenerative neurologic disorders and other systemic malformations.[6,58–60]

Thimerosal, 49% mercury by weight, is an ethyl mercury organic compound widely used as an antimicrobial in pharmaceuticals.[52] A wide spectrum of antibacterial activity with thimerosal can be obtained at concentrations of 0.003 to 0.1%. It is used in ophthalmic solutions, nasal sprays, soaps, and hypoallergenic cosmetics and flu, rabies, diphtheria, gamma globulin, and various other injections.[34,52] However, it has been reduced or eliminated from many applications. The American Association of Pediatrics has recommended discontinuation of thimerosal in vaccines because of the potential excessive exposure during vaccinations of young children.[52] Single-dose units are no longer preserved with thimerosal.

The fungicidal properties of aryl organic mercury compounds have been used for generations to prevent seed rot.[61] However, the consumption of grains treated with aryl mercury compounds has caused serious environmental disasters. The treated seed is ground into flour or fed to livestock instead of being planted.[6,34] When the bread or the meat is ingested, the aryl organic mercury is converted into the mercuric ion and symptoms of the mercury poisoning occur within 2 months of exposure.[34] The patients exhibit visual, cerebellar, and sensory dysfunction and may exhibit renal and gut toxicity.[56] The classic example of this type of poisoning occurred in Iraq in 1972.[62,63]

Mercury Vapor. Mercury vapor accounts for most occupational and accidental exposures in mercury intoxication episodes.[64–68] Eighty percent of mercury vapor inspired is absorbed in the lungs,[67] and the toxic exposure is generally cumulative.[34] Acute toxicity can occur but is rare. When it does occur, the large dose of mercury vapor can cause acute pneumonitis, renal failure, seizures, and neurologic dysfunction.[34,69] The classic cases of mercury intoxication occur when mercury is spilled in a house or other enclosed area.[70–73] Typically, an aerosol of mercury vapor is created when vacuum cleaners are used to clean up the spill.[72–76] Another scenario occurs when mercury compounds are heated, such as in the smelting of lead and or gold, typically in South America, or during paint removal.[77–80] These intoxication profiles are far more common than one might expect.

There is a wide range of sources for chronic exposure to mercury vapor (Table 1).[14,81] Exposures can be from broken items such as fluorescent light bulbs,[82] thermometers,[66] sphygmomanometers,[83,84] mercury-containing clock pendulums, and antique barometers. Chronic mercury toxicity commonly occurs in poorly ventilated areas where mercury is used in manufacturing.[6,69] Items such as electric relay switches, pesticides, furniture polish, bleaches, and vinyl chloride materials are potential sources for mercury contamination. Dental offices have the potential for chronic

TABLE 1. POTENTIAL OCCUPATIONAL EXPOSURES TO MERCURY.

Elemental
- Amalgam makers
- Barometer makers
- Battery makers
- Boiler makers
- Bronzers
- Calibration instrument makers
- Carbon brush makers
- Caustic soda makers
- Ceramic workers
- Chemistry teachers
- Chlorine makers
- Vinyl chloride makers
- Dental amalgam manufacturers
- Dentists and their operating staff
- Diffusion pumps makers
- Direct current meter workers
- Electric apparatus makers
- Electroplaters
- Fingerprint detectors
- Gold extractors
- Jewelers
- Lamp makers, fluorescent and mercury arc
- Lighthouse keepers
- Manometer makers
- Mercury workers, miners, refiners
- Neon light makers
- Paint makers
- Paper pulp workers
- Photographers
- Pressure gauge makers
- Silver extractors
- Thermometer makers
- Operators of large liquid mirror telescopes

Salts
- Disinfectant makers
- Dye makers
- Explosives makers
- Fireworks makers
- Fur processors
- Ink makers
- Percussion cap makers and loaders
- Tannery workers
- Taxidermists

Organic
- Bactericide makers
- Drug makers
- Embalmers
- Farmers
- Fungicide makers
- Histology technicians
- Insecticide makers
- Pesticide workers
- Seed handlers
- Wood preservative workers

Continued

TABLE 1 (continued)

Adapted from Goldfrank LR et al.[88]

mercury vapor exposure. The European Union has passed new laws that will eliminate many clinical medical instruments that use mercury because of the potential exposure hazard.[83]

Chronic exposure to mercury vapor manifests as mild to moderate central nervous system dysfunction with irritability, memory loss, insomnia, renal failure, anorexia, and tremor.[85,86] There is considerable overlap among concentrations of mercury found in the normal population, asymptomatic exposed individuals, and patients with clinical signs of mercury toxicity, making diagnosis difficult.[34,85] Most patients exhibited only two symptoms rather than several.[34] And there are many conditions that can mimic mercury toxicity, including alcoholism, lead and arsenic poisoning, Parkinson's disease, cerebellar lesions, senile dementia, and vascular degenerative diseases.[76] Because of the variety of symptoms and the various conflicting conditions, toxicology textbooks specify that only a 24-hour urine test for mercury levels can be used make a final diagnosis of mercury intoxication.[34,87,88] A urine level of 10 μg mercury/L is normal, 100 μg/L indicates a significant exposure, and 300 μg mercury/L is typically seen in patients with symptoms.[34,87,88]

Mercury Compounds. The *Merck Index* lists at least 75 compounds that contain mercury.[1] Medical compounds comprise 75% of the list and include antibacterial, antisyphilitic, topical antiseptic, immunosuppressant, antiinfective, fungicide, diuretic, cathartic, and preservative agents.

Over 3,000 industrial processes use mercury or its compounds in manufacturing; the Web site < www.chemicalfinder.com > lists over 250 mercury-containing compounds.[2,89] Poison Control Centers received over 4,000 mercury-related calls in 2001.[90] Of these, 51 were moderate cases, 6 were severe, and 1 was fatal.

Biologic Activity

The body contains 70 known trace elements, and 35 are known to have some biologic activity. Mercury has no biologic benefits.[91] Mercury passes the blood-brain barrier readily and, in sufficient quantity, causes neurologic dysfunction.[92] The pervasive disruption of normal cell physiology by mercury can be from binding to sulfur, which replaces the sulfhydryl groups, and reactions with phosphoryl, carboxyl, and amine groups. These reactions with mercury disrupt enzyme and transport mechanisms and membrane and structural proteins.[34,53] Kidney and liver functions can be particularly disrupted by the latter reactions.[53]

Research on the carcinogenicity of mercury and its compounds has indicated no positive results in humans[93,94]; however, mercury compounds have been widely observed to be teratogenic.[59,60,95] The developing fetus is thought to be disproportionately affected by mercury exposure toxicity, and the mercury affects multiple organ systems in the child.[52]

Levels that Produce Mercury Toxicity

The National Academy of Sciences recommends that blood-mercury levels be < 5 μg/L.[96] Most individuals have levels far below this and test at about 1 μg Hg/L, with children having levels three to four times less.[97] Certainly workplace exposure to mercury (see Table 1) and a diet of fish can elevate that blood-mercury level.[98]

So what is safe? Recent studies in the Seychelles and Faroe Islands have provided some answers.[99–103] These islands have isolated populations and their inhabitants eat different amounts and types of fish. In the Seychelles, fish is eaten at an average of 12 meals per week and women have a blood-mercury level that is 6 to 10 times higher than that found in the US population.[102] In the Faroe Islands, cod is eaten one to three times per week, but these people also have feasts with a main course of pilot whale.[99] Pilot whales contain 200 times more methyl mercury than tuna. The average Faroe Islander has about the same level of blood mercury as that in the people of Seychelles.[99,102] Methyl mercury consumption was different yet produced the same higher-than-average levels in vivo at both research sites. Results from the Seychelles show that children up to 6 years old showed no adverse effects on development or intelligence quotient.[101,102] However, in the Faroe Islands, many children up to 7 years old showed subtle but significant adverse effects on memory, attention, and language.[99,100] These latter children even show problems at 14 years of age.[101] The confounding results might suggest that the mercury spike caused by the mother feasting on whale meat may be more critical for a fetus than a high but steady level of methyl mercury exposure in the mother.

DENTAL AMALGAM

The dental industry uses about 75 tons of mercury to place approximately a half-billion amalgam restorations per year. These dental amalgams are a source of mercury vapor. In 1985 Vimy and Lorscheider reported that 27 μg Hg per 12 amalgams per day are released.[104] It was quickly shown, however, that their calculations overestimated exposure by about 16 times.[105,106] A variety of difficulties in determining the amalgam-derived mercury had complicated the results. These were overcome, and by 1990 Berglund's carefully monitored and controlled human study provided an estimate that the release is 1.7 μg Hg per 12 amalgams per day.[107] Other data have substantiated this assessment.[108] Interestingly, if one corrects the Vimy and Lorscheider data by the factor of 16 as others have recommended,[105,106] the amount is the same as that reported by Berglund.[107] According to these data, it would take 10,000 years for all the mercury to be lost from an amalgam restoration.

Clinical studies have also shown that tissue fluid mercury levels attributable to amalgam restorations are very low.[108–114] In the largest study to date (involving over 1,100 men), Kingman and colleagues reported that 10 amalgam

surfaces will increase the urine mercury level by about 0.9 μg/L.[115]

There have been multiple studies on the release of mercury vapor during the removal of amalgams.[116–119] Engle and colleagues reported that mercury vapor levels generated during amalgam removal for a Class I restoration using an air-water spray are 15 to 20 μg.[116] However, using high-volume evacuation and extending the suction for 30 seconds reduced the mercury vapor levels by 90%. This reduction would apply to larger restorations as well. As this study and others point out, the total amount of mercury vapor released was far below the maximum level established as permissible for occupational exposure.[116–119] These dental time exposures are dramatically shorter than occupational exposure times calculated for 8-hour days, 5 d/wk.[9]

Several studies have examined patients who had all their amalgams removed in one dental session.[120–122] In one study 12 patients were examined who had an average of 18 amalgam surfaces removed at one session.[121] The patients' tissue fluids were monitored before removal of their amalgams and up to 115 days after the procedure. Removal of the amalgam fillings resulted in a transient increase of mercury in both blood and plasma but no increase in urinary mercury excretion.

Molin and colleagues evaluated 10 patients who had all amalgams removed in one session and 10 matched controls who did not have amalgams removed.[120] They examined 22 supplementary biochemical analyses for the 20 patients and concluded that mercury vapor generated during amalgam removal did contribute to a slight increase in blood and urine mercury levels. However, the biochemical analyses showed no influence on organ functions.

Allergic Reactions

Allergic reactions to dental amalgams have been reported.[123,124] This condition is rare, and the allergen-antibody response could be to metals other than mercury in the amalgam, such as copper, tin, or zinc. Interestingly, gold causes allergic reaction intraorally at a higher rate than does amalgam. A recent study on pathologic changes around gingival restorations indicates that amalgams change the local bacterial environment very little when compared with composites.[125]

Dentists

Dentistry is regarded as one of the safest professions.[126] Many other professions and even recreational sports are far more hazardous. But dental operatory personnel experience multiple episodic exposures to mercury vapor, and dentists have more mercury exposure than does the general population. Generally, their blood-mercury level is two to four times higher.[127] Health and morbidity studies indicate that dentists have no unusual diseases and, in fact, live longer than their physician colleagues, who generally are not exposed to mercury in the workplace.[128–132] Dentists are the canaries; if there were serious medical issues associated with the elevated blood-mercury levels seen in dentists, why do dentists not show up in the epidemiologic studies? Consideration of how much more exposure dentists have to mercury and their lack of related adverse effects serves to demonstrate how much greater the level of safety is for patients.[133]

Metallurgic Aspects of Dental Amalgam

Dental amalgam contains 50% mercury, and restorations weigh 1.5 to 2.0 g.[134] We often hear these figures from special interest groups and those opposed to the use of amalgam. The implication is that grams of mercury are readily available, but this is misrepresentation. Dental amalgam is a metallomatrix composite in which the matrix phase is a silver-mercury intermetallic compound.[135] In such a compound, the bonds exhibit characteristics that are sometimes typical of metallic bonding and at other times more typical of covalent bonding. The silver-mercury compound forms when mercury dissolves silver from the alloy powder. When the mercury becomes supersaturated with silver, the silver-mercury compound precipitates out of mercury.

During trituration this precipitation consumes all of the liquid mercury. This dissolution of silver into mercury and the resulting formation of the silver-mercury compound are accelerated by trituration.

The bonds that make up intermetallic compounds are very stable, and a great deal of energy is needed to break these bonds.[136] It has been proposed that when masticatory forces are applied to a single point and approach 30,000 psi, these high stresses cause tiny amounts of mercury to be released from the surfaces of amalgam (Richard J. Mitchell, personal communication, March 2004). Surface atoms are more prone to release because, unlike atoms within the bulk of the silver-mercury compound, they are not bound to other atoms on all sides. Interestingly, amalgams, including dental amalgam, have been used as electrodes.[128–142] The main reason given for the choice of amalgam as an electrode material is the great stability of amalgam compounds.

Psychological Aspects of Amalgam Illness

Noting the highly remote possibility of mercury intoxication from dental amalgams, one must pose serious questions regarding individuals who claim they have been poisoned by their amalgams. *Amalgam illness* is a term used to identify the maladies of these patients.[143,144] Reports on dental, medical, and psychological aspects of amalgam illness provide profiles of patients presenting with this illness that often include psychogenic problems such as psychosomatic disorders, anxiety, and depression, panic disorder, and the inability to perceive and understand threatening situations.[110,113,143–155] The frequency of these patterns across available studies is noteworthy.[133]

Stenman and Grans reported that patients seeking treatment for suspected amalgam illness often have been encouraged to seek bogus care because of the hyperattention given to this issue by the media.[145] Many of these patients actually suffer from diagnosable medical conditions. Individuals with neurologic symptoms may be especially vulnerable. Their symptoms can be quite frightening, and the thought that they are experiencing "amalgam illness" might seem preferable to facing the unknown consequences of some serious health problem. Without the correct diagnosis, however, these patients can be placed in a dangerous situation.

A well-controlled study presented in a Scandinavian psychiatric journal compared 67 patients diagnosed with possible amalgam illness with 64 matched controls.[146] A battery of psychological tests was used within the context of a semistructured interview, along with dental and medical examinations. Eighty-nine percent of the patients with alleged amalgam illness met the criteria for psychiatric diagnoses of the somatoform-anxiety-affective types, whereas only 6% of the control group exhibited psychiatric problems. Affective disorders were common among the amalgam illness group, which also reported more psychological services and use of psychotropic drugs. Patients with alleged amalgam illness also received higher scores on tests of somatic anxiety, muscular tension, psychasthenia, and low socialization.

Two studies examined 100 Swedish patients, including a group presenting with amalgam illness and a control group matched for age, gender, and residence.[147,148] They examined mercury levels in blood, urine, and hair. The patients were given oral, stomatognathic, psychiatric, and biochemical assays, and they completed a checklist of medical symptoms. Mercury levels in both groups were similar and far below levels that cause negative health effects. Patients in the amalgam illness group reported more medical symptoms and had more temporomandibular disorders. Psychiatric diagnoses were established in 70% of patients in the amalgam illness group compared with 14% in the control group. Anxiety and mood disorders were the most frequent psychiatric diagnoses, and psychological tests confirmed related symptoms such as illness behaviors, disruptive life events, and emotional disturbance.

Another Swedish study evaluated 20 patients with self-diagnosed amalgam illness and 37 controls using a projective technique, the Defense Mechanism Test.[149] This test is comparable to looking at a picture of a child by a pond with a monster behind her. The most characteristic traits of people with alleged amalgam illness appeared to be difficulty in perception of threats and inappropriate emotional response to such threats, probably reflecting denial as a primary coping mechanism. The members of the control group always could see the threat. The authors suggested that people with alleged amalgam illness might have major psychological difficulties with threatening situations.

These studies have found that patients with alleged amalgam illness did not have elevated mercury levels.[110,113,143–155] In fact, many had lower mercury levels than did controls. The data suggest further that these patients have difficulty in dealing with threats and in expressing emotions and might therefore lack coping skills for dealing with life's difficulties.

DISCLOSURE

The author does not have any financial interest in the companies whose materials are discussed in this article.

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Editor's Note: We welcome readers' suggestions for topics and contributors to Critical Appraisal. Please address your suggestions to the section editor:

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THE BOTTOM LINE

The following are truths regarding mercury/amalgam:

- Mercury is a part of our everyday lives.
- Everyone is exposed to it 24 h/d.
- The chances that dental amalgam causes any disease are highly remote.
- Several European countries have dramatically reduced or restricted the use of amalgam. As yet, there is no evidence that health in these countries has improved.
- Dental amalgam is a very stable compound, even in the oral environment.