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Mercury Toxicity in Public Health

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Abstract

Mercury was the name of the Roman messenger of god who can move really fast. It is also called as quicksilver due to its fast movement and silvery tinge. Liquid metal state mercury (Hg) has little to no solubility and is not poisonous. But the liquid mercury can vaporize, and gaseous mercury becomes poisonous due to its nature of being absorbed into the blood. Mercury in +2 state is more poisonous due to high solubility. Mercury is the only metal that exists in liquid state at normal temperature and pressure. Mercury poisoning occurs by exposure to mercury, i.e., acute and chronic exposures. Symptoms of mercury poisoning depend on the type, dose, method, and duration of exposure. Mercury poisoning effects on the human body are not limited to reddishness of hands and feet; renal failures; cardiovascular, liver, brain, and hormonal issues; and intestinal ulceration. The present chapter describes the mercury sources, types of exposures, types of poisoning, treatments, and preventive measures of mercury poisoning.

Keywords: mercury, heavy metal toxicity, sources, exposure of mercury, mercury poisoning, toxicity of mercury, prevention mercury toxicity

1. Introduction

Heavy metal contamination is a serious problem to the environment, because they are not only biodegradable but also toxic to living organisms. The metals such as cadmium, mercury, and lead are owing much more interest to environmental scientists due to their accumulation in vital organs of the living beings. Once these metals are absorbed into the human body, they can be a threat with more health issues [1]. The absorbed mercury in humans becomes more toxic due to its prolonged half-life and lack of decomposition, and its interaction is not limited with various enzymes and proteins. Mercury has a great affinity with thiol group in proteins and causes many diseases.

Mercury is the only metal that exists in liquid state among the total periodic table elements. It is very important to measure the concentration of mercury in the environment due to its bioaccumulative property in its elemental and organic forms (i.e., methylmercury) and toxic nature. Mercury (Hg) is a naturally occurring element that is toxic in nature. According to the US Environmental Protection Agency, the safe limit of mercury ion in drinking water is 10 nM to avoid the serious health problems to humans [2]. Mercury is a pollutant of global concern. The Minamata Convention on Mercury entered into force from 2017, regarding the protection of human and environmental health. A recent review reported about the worldwide

and regional time trends in total mercury levels in the human blood and breast milk and their associations with health effects [3].

Mercury is a metal that appears as silver balls, and its liquid form is called elemental mercury. Mercury in the environment can exist in different forms, such as mercurous ion (Hg^{+1}), mercuric ion (Hg^{+2}), methylmercury (CH_3Hg^+), ethylmercury ($\text{C}_2\text{H}_5\text{Hg}^+$), and phenylmercury ($\text{C}_6\text{H}_5\text{Hg}^+$). The chemical forms of mercury in the environment are broadly divided into three, i.e., (1) elemental mercury, (2) inorganic salts, and (3) organic compounds.

Elemental mercury: The atmosphere consists of mercury in elemental form, and at room temperature it is present in liquid form. It is used in thermometers and fluorescent bulbs.

Inorganic mercury: It occurs in several forms: metallic (Hg), mercurous (Hg^{1+}), or mercuric form (Hg^{2+}). This is present in crystal form, and it is used in pesticides and antiseptics.

Organic mercury: It is in the forms of aryl and alkyl. Methylmercury is the best example; it mixes with the food chain.

Nagpal et al. [4] reviewed the mercury exposure and health effects of dental personnel. Bernhoft [5] reviewed about the mercury toxicity and its treatments. Driscoll et al. [6] reviewed the sources, pathways, and effects of mercury in global environment. O'Connor et al. [7] reviewed about the mercury speciation, transformation, and transportation in soils, atmospheric flux, and implications for risk management. Taber et al. [8] studied the mercury exposure and effects across the life span. Antoszczyszyn and Michalska [9] reported the potential risk of environmental contamination by mercury contained in Polish coal mining waste. The toxic effects of mercury on human beings depend on several factors, such as chemical form of mercury, age, health condition of person exposed, and type of exposure. A study [10] regarding mercury toxicity reported that yearly around 60,000 babies were born with neurological problems due to their mothers poisoned with mercury.

The present chapter describes the mercury sources, types of exposures, types of poisoning, and preventions to avoid mercury poisoning.

2. Sources of mercury

The sources of mercury in the environment are classified into two types, i.e., natural and anthropogenic. The natural and anthropogenic sources of mercury in the environment are presented in Table 1.

Sources of mercury	
Natural	Anthropogenic
1. Volcanoes	1. Hydroelectric
2. Forest fires	2. Mining
3. Cinnabar (ore)	3. Pulp industry
4. Fossil fuel (coal and petroleum)	4. Paper industry
	5. Medical waste
	6. Municipal waste
	7. Coal using power plant

Table 1.
Sources of mercury.

3. Natural sources

A number of studies worldwide reported the determination of mercury in naturally available sources, such as volcanic eruptions, forest fires, cinnabar, and fossil fuels.

Regarding volcanic eruptions, a research study reported the determination of mercury at Masaya caldera complex, Santiago, Nicaragua. This study found the concentration of mercury at 232 selected points at the research area. They found higher concentrations of Hg(0) at their sampling sites [11]. Speciation of mercury in volcanic eruptions at Mount Etna, Sicily, Italy, was reported by Baganto et al. [12]. This study represents a systematic characterization of mercury partitioning between gaseous mercury and particulate forms in the volcanic eruptions.

Another study reported the determination of mercury in the volcanic eruptions at Kilauea volcano, Hawaii. This study found the low concentrations of mercury at soils with more sulfur content [13]. In Western Wyoming, Hg accumulation was examined between burned and unburned sampling sites with the total tree species composition. Results show that Hg emitted from forest fires depends on the forest fire intensity and Hg formation before the firing [14]. Atmospheric mercury species emitted due to forest fires were studied in three rural sites (southern Quebec, Canada, and northern New York). MODIS satellite reports show forest fires transmitted from Quebec, Canada to northern New York. Accumulation of Hg species in the atmosphere after the forest fire incidents is higher than the normal environmental conditions [15]. In Europe and North African countries, mercury emissions from forest fires are studied based on ground data and phytomass [16].

Mercury is a volatile metal due to its nature; it easily gets away from its deposits and enters into the atmosphere. Globally it was reported that 2000 to 8000 metric tons of Hg emissions takes place during the years 1550–1880. In Florida and the USA, speciation of mercury emissions was studied. Globally more Hg emissions are happening in industrialized areas [17]. At present years, industrial areas are the interesting research zones due to its huge Hg emissions; transport modeling is the tool used for calculating Hg emissions, and this is used for the analysis of Hg emissions in industrial zones [18].

Cinnabar is a toxic mercury sulfide (HgS), and it is the main ore of mercury. It is chemically inert and has low toxic potential when taken orally. Isonzo river (Gulf of Trieste) is the area in which high cinnabar is accumulated and Hg is bounded to it as fine particles [19]. Liu et al. [20] reported that Hg is a toxic metal. Cinnabar is used in Chinese medicines. Heating the ore leads to production of vapors, which are dangerous if inhaled and enter the stomach where it is not absorbed and finally deposits on the kidneys. Prolonged use of cinnabar inhalation leads to kidney damage.

There are two fish species, namely, piscivorous (northern pike and walleye) and non-piscivorous (lake white fish and longnose sucker). Hg concentration depends on fish species and type of reservoirs. After 5 years of rapid filling of reservoirs with water, the Hg level increases, and later in 10 years, Hg concentration will decrease [21]. Hydroelectric reservoirs are increasing rapidly due to the need of electricity. The present studies reported the Hg accumulation in water before and after flooding. The conversion of Hg to MeHg in the environment leads to an increase in the toxicity in water. In order to decline the toxicity, intensive fishing is the best remedy. Adding selenium to water is another best method to decrease the Hg content in water. MeHg is deposited in fishes, and eating such type of fishes leads to severe health risks [22]. Bodaly et al. [23] conducted a study on fish in the boreal reservoir of Northern Manitoba, Canada. In lake white fish, the Hg concentration after floods as post-impoundment is $0.2\text{--}0.4\ \mu\text{g g}^{-1}$ and pre-impoundment is $0.06\text{--}0.14\ \mu\text{g g}^{-1}$. Hg concentration in northern spike and walleye after flooding as below post-impoundment is $0.7\text{--}2.6\ \mu\text{g g}^{-1}$ and pre-impoundment is $0.19\text{--}0.047\ \mu\text{g g}^{-1}$.

Insect larvae are another source of storage of Hg and MeHg in hydroelectric reservoir. The storage of mercury in hydroelectric reservoir is higher than natural lakes. The flooded soil is one of major sources for insect larvae which is studied by Tremblay and Lucotte [24]. Mining is the major anthropogenic source for the release of tones of mercury into the environment. In global consideration Brazil is the topmost country in gold production; nearly 2000 tons of mercury was released into the environment. In some areas there is a lot of Hg accumulation taking place without gold mining; it is due to man-made mistakes (sediments, human hair, and urine) [25].

Appleton et al. [26] reported that Naboc River water is highly contaminated with Hg. Rice paddy fields are present in the Naboc area and were irrigated with Naboc River water, so the soil was highly contaminated with mercury. In contrast the corn and banana crops that are not irrigated with Naboc river water produced mercury-free crops.

Amalgamation is the process of using the mercury in mining gold and silver. Patio process is used in Spanish colonial America, Australia, Southeast Asia, and England. From 1550 to 1930, 260,000 tons of mercury was released into the atmosphere. South America (Amazon), China, Southeast Asia, and African countries have been using widely mercury amalgamation. Mining is the major anthropogenic source; 10% of mercury emissions is involved due to this. About 300 tons of mercury is released into the environment through gold and silver mining since the last 500 years [27].

Malm et al. [28] performed research studies on the sediments of Madeira River basin. The sediment particles are amalgamated with mercury; 30% of mercury was released into the river water, whereas 20% of mercury was released into the atmosphere.

4. Types of exposure

Mercury exposure to the humans can take place in three ways, through dermal contact from soil, through drinking water, and through inhalation of the atmosphere and intake by food. The mercury in the atmosphere can be dissolved into water and can change into a more toxic form of methylmercury by micro-organisms. Methylmercury is more toxic than elemental mercury. The historical incident of Minamata, Japan, was an evidence of the bioaccumulation of methylmercury in fishes in which it can enter into the food web and finally to the humans. The levels of methylmercury in fish depend on what they eat, how long they live, and how high they are in food chain.

There are two types of exposures that we can observe in human populations with mercury, i.e., acute exposure and chronic exposure. Acute exposure to inorganic mercury or mercuric salts is mostly like through oral route. Chronic exposure is usually related to prolonged exposure during occupational incidents.

The exposure of mercury has been historically reported since a few hundreds of years. Inorganic mercury compounds were used in skin ointments which were used to treat some skin diseases in ancient Egypt. In Korea, occupational mercury exposure to humans was observed in fluorescent lamp manufacturing and silver refining plants. In normal populations, mercury exposure is through inhalation by burning charms [29].

Based on the literature, it is concluded that there are no significant toxicological effects observed by the ingestion of elemental mercury by a healthy person because of its poor absorbance into the gastrointestinal tract. The chronic exposure to the mercury vapor mostly affects the central nervous system and the kidneys. The major exposure by the human population to the mercury vapor is through

inhalation route, because 80% of the mercury can reach the lungs and be dissolved in the blood reaching the different organs [30].

5. Types of poisoning

Mercury is a toxic metal, and it occurs naturally and exists in elemental (or metallic), inorganic (mercuric chloride), and organic (methyl- and ethylmercury) forms. Thiomer-sal (sodium ethylmercury thiosalicylate) contains 49.6% ethylmercury. It is used as a preservative in children vaccines. According to American Academy of Pediatrics (AAP) the vaccinated children are prone to Autism due to Hg present in Thiomer-sal [31].

Clarkson et al. [32] reported that the Hg poisoning results in psychiatric disturbances due to CNS dysfunction and it also affects listening and speaking abnormalities. Intention tremor is the abnormality created in speech and mouth disorders [33].

Sensory motor problems and defects (touch, excessive mouthing) are caused by mercury toxicity. According to a study [34], ADHD and ASD are the few abnormalities related to mental retardation, and abnormal behavior is exhibited by the affected people. Some of the abnormal behaviors [35] are seen due to mercury toxic nature, i.e., there is no controlled-on mind activities in babies. Mercury poisoning also affects the memory and involuntary actions.

Mercury toxicology effects on the visions of children and adults include poor visibility, blurriness, and no fixed visuality. Mercury toxic nature not only affects mental health, but also it creates several physical disturbances, such as hyper-/hypotonia [36]. Muscle weakness, shivering in arm, and few disturbances will occur in some patients, and in few cases, the complete chance of paralysis is also studied [37].

Poor blood circulation led to a change in color of feet and hands to red and blue color which is one of the toxic effects of mercury poisoning [38]. Sweating-related problems, i.e., excessive sweating (acrodynia) and fast heartbeat, are seen in few adults [39].

The toxic nature of mercury mostly affects gastrointestinal systems of humans. The inhalation of mercury led to several discomforts in the abdominal region such as gut-related problems, lesions in colon, and severe abdominal pain [40].

The historical incident happened regarding mercury compound poisoning in Minamata Bay, Japan, in 1956. The important features of Minamata diseases are discussed here under.

6. Minamata disease

It is a chronic disease due to methylmercury coming from industrial wastes, and such wastes deposit in water sources as sediments. The deposited methylmercury enters the fishes available in the water sources and enters the food chain and finally reaches the humans. In New Mexico, USA, research was performed on seed grain treated with methylmercury and reported that those grains are exposed to Minamata disease (<https://www.medicinenet.com/script/main/art.asp?article-key=14084>). Akagi et al. [41] reported the methylmercury dose based on umbilical cord concentrations of the patients suffering from Minamata disease.

Matsumoto et al. [42] had reported the clinical survey regarding Minamata disease in children and found symptoms such as cerebral palsy. Ekino et al. [43] studied methylmercury poisoning effects and reviewed the history of its toxicity (1950–1968) for about 20 years and found that methylmercury spread from Minamata Bay to Shiranui Sea.

The consumption of fish or shellfish with mercury by pregnant women affects the fetus brain (Harada 1978). Another study [44] reported at Minamata disease affected people in Kumamoto and found the damage of cerebral cortex.

In addition to the Minamata disease, the other major disease caused due to the mercury poisoning through teething powder is pink disease, in which the foot and hand turn into pink color. The pink disease-affected children were found to have high mercury content in their urine samples [45]. Other than the teething powder, the reasons for the pink disease in young children were viral infections and nutrition deficiency [46].

7. Renal and bone-related effects due to mercury poisoning

Gottelli et al. [47] have studied the effect of mercury on renal function. Phenylmercury enters in the renal tubes through the contaminated diapers, with the excretion of gamma glutamyl transpeptidase in renal cells leading to increase urinary volume and toxicity. Osteoporosis and osteopenia diseases in Korean men due to mercury were studied by Kim et al. [48]. The analysis was performed on Korean men's blood samples, and high mercury range in younger people was found. The analysis was performed on different categories people like alcoholic and in fish consumers, the content of mercury range was found in them due to their intakes. Parejo et al. [49] have studied some cases related to low bone density which is due to the contaminated food and water sources. The intake of Hg was calculated in women in Spain, and studies were related on bone disorder reasons. Garcia et al. [50] reveal that bone disorders, like osteoporosis, are due to heavy toxic metals like mercury, etc. and due to dietary mercury intake which is the reason of accumulation of mercury in the bones. In a study of 158 women, 25.29 µg/day of dietary heavy metal intake leads to several osteoporosis cases and fracturing. Dainowski et al. [51] studied the total mercury (THg) concentration on muscle, kidney, and liver of red foxes in Western Alaska. It was seen that total mercury concentration in hair is correlated with muscle, kidney, and liver. The major reason of mercury content is due to industrialization in Arctic areas. Accumulation of mercury in human tissues and severe knee-related problems were studied by Bogacka et al. [52]. In northwestern Poland, the total mercury percentage in women cartilage was high compared to selenium, and moreover knee joint-related problems in patients are also due to selenium to total mercury ratio.

8. Hormonal effects of mercury poisoning

Adipogenesis is the process of cell differentiation and study on adipocytes (lipocytes, fat cells). Adiposeness is the process of study modules of cell differentiation. Telapolu et al. [53] studied on MD-1, it is a polyherbal used in management of Diabetes mellitus. α -Glycosidase and α -amylase are the two carbohydrate digestive enzymes, HAEF is the extract, and its effect on digestive enzymes was studied. The effect of MD-1 on adipogenesis was studied, and the effect of HAEF on mRNA expression of peroxisome proliferator-activated receptor gamma (PPAR γ) and glucose transporter 4 (GLUT4) in 3T3L1 adipocytes was investigated.

9. Liver-related effects due to mercury poisoning

Hussain et al. [54] studied about the effects of mercurous chloride on the liver, brain, and kidney which are due to enzymes like superoxide dismutase (SOD),

glutathione peroxidase (GPx), and glutathione reductase. The increase in the mercury levels is correlated with enzyme activities, and generation of reactive oxygen species (ROS) is the cause of mercury accumulation. Fish is the major source of mercury; consuming such mercury stored in fish leads to exposure of human tissues to high mercury levels. Pelletier et al. [55] examined by checking mercury levels in rodents as they are exposed frequently with *Rhododendron tomentosum* extract and their blood is with higher mercury levels. Williams et al. [56] reported flurbiprofen (anti-inflammatory drug) is the cause of bone resorption disease. Cyclooxygenase inhibitor is the cause of periodontal disease in beagles.

Crespo et al. [57] studied *Lactobacillus casei* effect on mercury, and results show the decreased methylmercury bioavailability in acutely exposed mice. Mercury accumulation in the liver and kidney was not affected by *Lactobacillus* supplementation. Adult male rats are exposed to Labrador tea and antibiotic cocktail in which methylmercury is present in it. It was observed that when the rats were treated with antibiotics, increased Hg levels in blood levels were observed. El- Demerdash [58] studies reported on oxidative stress of Hg and selenium. Rats were given Hg (0.5 µmol/ml), for 5 days, and several biochemical assays were done on them, and it was observed that after the Hg treatment, the protein content in the brain and liver was decreased.

10. Prevention measures of mercury poisoning

Consuming of fish two servings per a week leads to good cordial health, but the presence of mercury, especially in oil fish like salmon and sardines, leads to an increased risk of cardiovascular health. Avoiding such sort of fish is one of the best prevention measures. Davis (http://www.emedicinehealth.com/mercury_poisoning/article_em.htm) reported on the prevention measures of mercury at various areas. In home broken thermometers and fluorescent light tubes are the major sources; awareness and preventive measures should be taken into account in disposing them far away. Dental amalgam fillings should be avoided by mercury, and any other alternative material should be used. The mothers feeding the infants should be most aware of taking fishes because the mercury content present may affect the infant brain and spine; this is one of the good preventive measures. Thiomersal is the preservative used in flu vaccines; usage of such vaccines may affect the child, so clear precautions are needed for preventing mercury entry into children through the vaccine.

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