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Metal Toxicity or Metal Poisoning in Certain Forms and Doses of Life

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ABSTRACT: Metal toxicity or metal poisoning is the toxic effect of certain metals in certain forms and doses on life. Some metals are toxic when they form poisonous soluble compounds. Certain metals have no biological role, i.e. are not essential minerals, or are toxic when in a certain form.^[1] In the case of lead, any measurable amount may have negative health effects.^[2] It is often thought that only heavy metals can be toxic, but lighter metals such as beryllium and lithium may also be in certain circumstances. Not all heavy metals are particularly toxic, and some are essential, such as iron. The definition may also include trace elements when abnormally high doses may be toxic. An option for treatment of metal poisoning may be chelation therapy, a technique involving the administration of chelation agents to remove metals from the body.

Toxic metals sometimes imitate the action of an essential element in the body, interfering with the metabolic process resulting in illness. Many metals, particularly heavy metals are toxic, but some heavy metals are essential, and some, such as bismuth, have a low toxicity. Most often the definition of toxic metals includes at least thallium, cadmium, manganese, lead, mercury and the radioactive metals.^[3] Metalloids (arsenic, polonium) may be included in the definition. Radioactive metals have both radiological toxicity and chemical toxicity. Metals in an oxidation state abnormal to the body may also become toxic: chromium(III) is an essential trace element, but chromium(VI) is a carcinogen.

KEYWORDS: metal toxicity, heavy metals, trace elements, chelation, metalloids radioactive, carcinogens

I. INTRODUCTION

Toxicity is a function of solubility. Insoluble compounds as well as the metallic forms often exhibit negligible toxicity. The toxicity of any metal depends on its ligands. In some cases, organometallic forms, such as methylmercury and tetraethyl lead, can be extremely toxic. In other cases, organometallic derivatives are less toxic such as the cobaltocenium cation.

Decontamination for toxic metals is different from organic toxins: because toxic metals are elements, they cannot be destroyed. Toxic metals may be made insoluble or collected, possibly by the aid of chelating agents, or through bioremediation. Alternatively, they can be diluted into a sufficiently large reservoir, such as the sea, because immediate toxicity is a function of concentration rather than amount. Another method of decontamination of heavy metals in the soil is using a method called phytoremediation.^[4] This method uses plants to extract and lower the concentration of toxic heavy metals in the soil.^[4]

Toxic metals can bioaccumulate in the body and in the food chain.^[5] Therefore, a common characteristic of toxic metals is the chronic nature of their toxicity. This is particularly notable with radioactive heavy metals such as radium, which imitates calcium to the point of being incorporated into human bone, although similar health implications are found in lead or mercury poisoning.

People are continually exposed to metals in the environment.^[6] Medical tests can detect metals often, but this is to be expected and alone is not evidence that a person is poisoned.^[6] Metal screening tests should not be used unless there is reason to believe that a person has had excessive exposure to metals.^[6] People should seek medical testing for poisoning only if they are concerned for a particular reason, and physicians should consider a patient's history and physical examination before conducting tests to detect metals.^[7]

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Chelation therapy is a medical procedure that involves the administration of chelating agents to remove heavy metals from the body. Chelating agents are molecules that have multiple electron-donating groups, which can form stable coordination complexes with metal ions. Complexation prevents the metal ions from reacting with molecules in the body, and enable them to be dissolved in blood and eliminated in urine. It should only be used in people who have a diagnosis of metal intoxication.^[8] That diagnosis should be validated with tests done in appropriate biological samples.^[9]

Chelation therapy is administered under very careful medical supervision due to various inherent risks.^[10] Even when the therapy is administered properly, the chelation drugs can have significant side effects.^[9] Chelation administered inappropriately can cause neurodevelopmental toxicity, increase risk of developing cancer, and cause death;^[9] chelation also removes essential metal elements and requires measures to prevent their loss

Aluminium has no known biological role and its classification into toxic metals is controversial.

Acute aluminium phosphide poisoning (AAIPP) is a large, though under-reported, problem in the Indian subcontinent. Aluminium phosphide (ALP), which is readily available as a fumigant for stored cereal grains, sold under various brand names such as QuickPhos and Celphos, is highly toxic, especially when consumed from a freshly opened container.^{[11][12]} Death results from profound shock, myocarditis and multi-organ failure.^[13] Aluminium phosphide has a fatal dose of between 0.15 and 0.5 grams (0.0053 and 0.0176 oz).^[14] It has been reported to be the most common cause of suicidal death in North India.^[15] The very high toxicity of aluminium phosphide is attributed to the phosphine content and is not related to aluminium. Calcium phosphide and zinc phosphide are similar poisons. Arsenic poisoning is a medical condition caused by elevated levels of arsenic in the body. The dominant basis of arsenic poisoning is from ground water that naturally contains high concentrations of arsenic. A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning from drinking water.^[16] Beryllium poisoning is illness resulting from the toxic effect of beryllium in its elemental form or in various chemical compounds. The toxicity of beryllium depends upon the duration, intensity and frequency of exposure (features of dose), as well as the form of beryllium and the route of exposure (i.e. inhalation, dermal, ingestion). According to the International Agency for Research on Cancer (IARC), beryllium and beryllium compounds are Category 1 carcinogens; they are carcinogenic to both animals and humans.^[17] Cadmium is an extremely toxic metal commonly found in industrial workplaces. Due to its low permissible exposure limit, overexposures may occur even in situations where trace quantities of cadmium are found. Cadmium is used extensively in electroplating, although the nature of the operation does not generally lead to overexposures. Cadmium is also found in some industrial paints and may represent a hazard when sprayed. Operations involving removal of cadmium paints by scraping or blasting may pose a significant hazard. Cadmium is also present in the manufacturing of some types of batteries. Exposures to cadmium are addressed in specific standards for the general industry, shipyard employment, construction industry, and the agricultural industry.^[18]

II.DISCUSSION

Copper toxicity, also called copperiedus, refers to the consequences of an excess of copper in the body. Copperiedus can occur from eating acid foods cooked in uncoated copper cookware, or from exposure to excess copper in drinking water, as a side-effect of estrogen birth control pills, or other environmental sources. It can also result from the genetic condition Wilson's disease. Iron poisoning is an iron overload caused by a large excess of iron intake and usually refers to an acute overload rather than a gradual one. The term has been primarily associated with young children who consumed large quantities of iron supplement pills, which resemble sweets and are widely used, including by pregnant women—see overnutrition (approximately 3 grams is lethal for a 2 year old).^[19] Targeted packaging restrictions in the US for supplement containers with over 250 mg elemental iron have existed since 1978, and recommendations for unit packaging have reduced the several iron poisoning fatalities per year to almost nil since 1998.^{[20][21]} No known cases of iron poisoning have been identified that are associated with iron mining. Lead poisoning, also called Plumbism is a medical condition in humans and other vertebrates caused by increased levels of the heavy metal lead in the body. Lead interferes with a variety of body processes and is toxic to many organs and tissues including the heart, bones, intestines, kidneys, and reproductive and nervous systems. It interferes with the development of the nervous system and is therefore particularly toxic to children, causing potentially permanent learning and behavior disorders. Symptoms include abdominal cramping, constipation, tremors, mood changes, infertility, anemia, and toxic

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psychosis. Lithium is used in some medications, specifically to treat bipolar disorder. The level of "sufficient" medication is thought by many physicians to be close to toxic tolerance for kidney function. Therefore, the patient is often monitored for this purpose. Manganism or manganese poisoning is a toxic condition resulting from chronic exposure to manganese and first identified in 1837 by James Couper. Mercury poisoning is a disease caused by exposure to mercury or its compounds. Mercury (chemical symbol Hg) is a heavy metal occurring in several forms, all of which can produce toxic effects in high enough doses. Its zero oxidation state Hg^0 exists as vapor or as liquid metal, its mercurous state Hg_2^{2+} exists as inorganic salts, and its mercuric state Hg^{2+} may form either inorganic salts or organomercury compounds; the three groups vary in effects. Toxic effects include damage to the brain, kidney, and lungs. Mercury poisoning can result in several diseases, including acrodynia (pink disease), Hunter-Russell syndrome, and Minamata disease. Symptoms typically include sensory impairment (vision, hearing, speech), disturbed sensation and a lack of coordination. The type and degree of symptoms exhibited depend upon the individual toxin, the dose, and the method and duration of exposure. Argyria or argyrosis is a condition caused by inappropriate exposure to chemical compounds of the element silver, or to silver dust.^[27] The most dramatic symptom of argyria is that the skin turns blue or bluish-grey. It may take the form of generalized argyria or local argyria. Generalized argyria affects large areas over much of the visible surface of the body. Local argyria shows in limited regions of the body, such as patches of skin, parts of the mucous membrane or the conjunctiva.^[28] Thallium and its compounds are often highly toxic.^[29] Contact with skin is dangerous, and adequate ventilation should be provided when melting this metal.^[30] Many thallium(I) compounds are highly soluble in water and are readily absorbed through the skin. Exposure to them should not exceed 0.1 mg per m² of skin in an 8-hour time-weighted average (40-hour work week). Thallium is a suspected human carcinogen.^[30] Tin poisoning refers to the toxic effects of tin and its compounds. Cases of poisoning from tin metal, its oxides, and its salts are "almost unknown"; on the other hand certain organotin compounds are almost as toxic as cyanide.^[31] Even though zinc is an essential requirement for a healthy body, excess zinc can be harmful, and cause zinc toxicity. Such toxicity levels have been seen to occur at ingestion of greater than 225 mg of zinc.^[32] Excessive absorption of zinc can suppress copper and iron absorption. The free zinc ion in solution is highly toxic to bacteria, plants, invertebrates, and even vertebrate fish.^{[33][34][35]} It is difficult to differentiate the effects of low level metal poisoning from the environment with other kinds of environmental harms, including nonmetal pollution.^[36] Generally, increased exposure to heavy metals in the environment increases risk of developing cancer.^[37]

Without a diagnosis of metal toxicity and outside of evidence-based medicine, but perhaps because of worry about metal toxicity, some people seek chelation therapy to treat autism, cardiovascular disease, Alzheimer's disease, or any sort of neurodegeneration.^[9] Chelation therapy does not improve outcomes for those diseases.^[9]

III.RESULTS

An example of poisoning in the workplace can be seen from the phrase "mad as a hatter" (18th and 19th century England). Mercury was used in stiffening the felt used to make hats involved. This forms organic species such as methylmercury, which is lipid-soluble (fat-soluble), and tends to accumulate in the brain, resulting in mercury poisoning. Other lipid-soluble poisons include tetraethyllead compounds (the lead in leaded petrol), and DDT. These compounds are stored in the body fat, and when the fatty tissues are used for energy, the compounds are released and cause acute poisoning.

Strontium-90, part of the fallout from atomic bombs, is chemically similar enough to calcium that it is taken up in forming bones, where its radiation can cause damage for a long time.

Some animal species use bioaccumulation as a mode of defense: by consuming toxic plants or animal prey, an animal may accumulate the toxin, which then presents a deterrent to a potential predator. One example is the tobacco hornworm, which concentrates nicotine to a toxic level in its body as it consumes tobacco plants. Poisoning of small consumers can be passed along the food chain to affect the consumers later in the chain.

Other compounds that are not normally considered toxic can be accumulated to toxic levels in organisms. The classic example is vitamin A, which becomes concentrated in livers of carnivores, e.g. polar bears: as a pure carnivore that feeds on other carnivores (seals), they accumulate extremely large amounts of vitamin A in their livers. It was known by the native peoples of the Arctic that the livers of carnivores should not be eaten, but Arctic explorers have suffered hypervitaminosis A from eating the livers of bears; and there has been at least one example of similar

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poisoning of Antarctic explorers eating husky dog livers. One notable example of this is the expedition of Sir Douglas Mawson, whose exploration companion died from eating the liver of one of their dogs.

Two common groups that are known to biomagnify are chlorinated hydrocarbons, also known as organochlorines, and inorganic compounds like methylmercury or heavy metals.^[4] Both are lipophilic and not easily degraded. Novel organic substances like organochlorines are not easily degraded because organisms lack previous exposure and have thus not evolved specific detoxification and excretion mechanisms, as there has been no selection pressure from them. These substances are consequently known as "persistent organic pollutants" or POPs.^[11]

Metals are not degradable because they are chemical elements. Organisms, particularly those subject to naturally high levels of exposure to metals, have mechanisms to sequester and excrete metals. Problems arise when organisms are exposed to higher concentrations than usual, which they cannot excrete rapidly enough to prevent damage. Persistent heavy metals, such as lead, cadmium, mercury, and arsenic, can have a wide variety of adverse health effects across species.^[12]

The presence of mercury in fish is a health concern for people who eat them, especially for women who are or may become pregnant, nursing mothers, and young children. Fish and shellfish concentrate mercury in their bodies, often in the form of methylmercury, a highly toxic organomercury compound. This element is known to bioaccumulate in humans, so bioaccumulation in seafood carries over into human populations, where it can result in mercury poisoning. Mercury is dangerous to both natural ecosystems and humans because it is a metal known to be highly toxic, especially due to its neurotoxic ability to damage the central nervous system.^{[1][2]}

In human-controlled ecosystems of fish, usually done for market production of wanted seafood species, mercury clearly rises through the food chain via fish consuming small plankton, as well as through non-food sources such as underwater sediment.^[3]

Fish products have been shown to contain varying amounts of heavy metals, particularly mercury and fat-soluble pollutants from water pollution. Species of fish that are long-lived and high on the food chain, such as marlin, tuna, shark, swordfish, king mackerel and tilefish contain higher concentrations of mercury than others.^[4] Cetaceans (whales and dolphins) also bioaccumulate mercury and other pollutants, so populations that eat whale meat, such as the Japanese, Icelanders, Norwegians and the Faroese, are also vulnerable to mercury ingestion.

The consumption of fish is by far the most significant source of ingestion-related mercury exposure in humans and animals.^[5] Mercury and methyl mercury are present in only very small concentrations in seawater. However, they are absorbed, usually as methyl mercury, by algae at the start of the food chain. This algae is then eaten by fish and other organisms higher in the food chain. Fish efficiently absorb methyl mercury, but excrete it very slowly.^[6] Methyl mercury is not soluble and therefore not excreted. Instead, it accumulates, primarily in the viscera, although also in the muscle tissue.^[7] This results in the bioaccumulation of mercury, in a buildup in the adipose tissue of successive trophic levels: zooplankton, small nekton, larger fish, and so on.^[8] The older that such fish become, the more mercury they may have absorbed. Anything that eats these fish within the food chain also consumes the higher level of mercury that the fish have accumulated, including humans.^[8] This process explains why predatory fish such as swordfish and sharks or birds like osprey and eagles have higher concentrations of mercury in their tissue than could be accounted for by direct exposure alone. Species on the food chain can amass body concentrations of mercury up to ten times higher than the species they consume. This process is called biomagnification. For example, herring contains mercury levels at about 0.1 parts per million, while shark contains mercury levels greater than 1 part per million.^[9]

IV. CONCLUSIONS

Terrestrial mercury pollution

There are three types of mercury emission: anthropogenic, re-emission, and natural, including volcanoes and geothermal vents. Anthropogenic sources are responsible for 30% of all emissions, while natural sources are responsible for 10%, and re-emission accounts for the other 60%. While re-emission accounts for the largest proportion of emissions, it is likely that the mercury emitted from these sources originally came from anthropogenic sources.^[10]

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Anthropogenic sources include coal burning, cement production, oil refining, artisan and small-scale gold mining, wastes from consumer products, dental amalgam, the chlor-alkali industry, production of vinyl chloride, and the mining, smelting, and production of iron and other metals.^[10] The total amount of mercury released by mankind in 2010 was estimated to be 1,960 metric tons. The majority of this comes from coal burning and gold mining, accounting for 24% and 37% of total anthropogenic output respectively.^[10]

Re-emission, the largest emitter, occurs in a variety of ways. It is possible for mercury that has been deposited in soil to be re-emitted into the mercury cycle via floods. A second example of re-emission is a forest fire; mercury that has been absorbed into plant life is re-released into the atmosphere. While it is difficult to estimate the exact extent of mercury re-emission, it is an important field of study. Knowing how easily and how often previously emitted mercury can be released helps us learn how long it will take for a reduction in anthropogenic sources to be reflected in the environment. Mercury that has been released can find its way into the oceans. A 2008 model estimated the total amount of deposition into the oceans that year to be 3,700 metric tons. It is estimated that rivers carry as much as 2,420 metric tons.^[10] Much of the mercury deposited in the oceans is re-emitted, however; as much as 300 metric tons is converted into methyl mercury. While only 13% of this finds its way into the food chain, that is still 40 metric tons a year.^[10]

Much (an estimated 40%) of the mercury that eventually finds its way into fish originates with coal-burning power plants and chlorine production plants.^[11] The largest source of mercury contamination in the United States is coal-fueled power plant emissions.^[12] Chlorine chemical plants use mercury to extract chlorine from salt, which in many parts of the world is discharged as mercury compounds in waste water, though this process has been largely replaced by the more economically viable membrane cell process, which does not use mercury. Coal contains mercury as a natural contaminant. When it is fired for electricity generation, the mercury is released as smoke into the atmosphere. Most of this mercury pollution can be eliminated if pollution-control devices are installed.^[11]

Mercury in the United States frequently comes from power plants, which release about 50% of the nation's mercury emissions.^[13] In other countries, such as Ghana, gold mining often uses mercury compounds, leading to workers receiving significant quantities of mercury while performing their jobs. Such mercury from gold mines is specifically known to contribute to biomagnification in aquatic food chains.^[14]

Elemental mercury often comes from coal power plants, and oxidized mercury often comes from incinerators. Oil-fired power plants also contribute mercury to the environment.^[1] The energy industry therefore is a key player in the introduction of mercury into the environment. When addressing the issue of reducing seafood mercury bioaccumulation on a global scale, it is important to pinpoint major energy producers and consumers whose exchange of energy may be the root of the problem.

Aquatic mercury pollution

The farming of aquatic organisms, known as aquaculture, often involves fish feed that contains mercury. A study by Jardine has found no reliable connection between mercury in fish food affecting aquaculture organisms or aquatic organisms in the wild.^[15] Even so, mercury from other sources may affect organisms grown through aquaculture. In China, farmed fish species, such as bighead carp, mud carp, and *Siniperca chuatsi*, carried 90% of total mercury content in all of the measured fish in a study by Cheng. This study also concluded that mercury bioaccumulates through food chains even in controlled aquaculture environments. Both total mercury and methyl mercury absorption was found to be derived from sediments containing mercury, not mainly from fish feed.^[3]

The Hawaii Institute of Marine Biology has noted that fish feed used in aquaculture often contains heavy metals such as mercury, lead, and arsenic, and has dispatched these concerns to organizations such as the Food and Agriculture Organization of the United Nations.

Mercury can get into freshwater systems by point sources and extended flooding.^[8] In Canada, mercury poisoning in Grassy Narrows was likely caused by a spill at a paper mill, which is a point source. Non-point sources include floods that create hospitable habitats for bacteria that can convert mercury to methylmercury, which is the toxic form that bioaccumulates through aquatic food webs. The effects of these different sources of mercury have been studied at the Experimental Lakes Area in Ontario, Canada, using research procedures including whole-lake ecosystem experiments and non-lethal fish muscle biopsies.^[8]

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