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Assessment of mercury exposure and its impacts on human health

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ABSTRACT

Introduction: Mercury, found both naturally and as a man-made contaminant, affects diverse populations globally, mainly through dietary consumption of seafood and occupational exposure. Mercury poses a significant threat to human, with well-documented adverse effects observed globally, especially among vulnerable communities. The aim of this study was to review the literature on mercury exposure and its effects on human health.

Material and methods of research: A literature review was performed using databases like PubMed and Google Scholar focused on keywords related to the topic.

Brief description of the state of knowledge: Dietary intake, notably from seafood containing methylmercury, constitutes a significant pathway for human mercury exposure. Additionally, occupational exposure, such as in artisanal and small-scale gold mining operations, poses significant risks, particularly in communities residing near these operations. Mercury exposure poses significant health risks across multiple bodily systems, including the nervous, cardiovascular, endocrine, reproductive, gastrointestinal, pulmonary, urinary, and immune system, potentially leading to a wide range of adverse effects. The intricacies of mercury's impact have been extensively discussed in research, delving into its specific mechanisms of harm within each bodily system.

Summary: Although a plethora of studies demonstrate the toxicity of mercury and its detrimental effects on human health, further research exploring this topic is essential, particularly on a pathophysiological level, to comprehensively understand the complex interactions between mercury exposure and its diverse effects on human health across various populations and exposure scenarios.

Keywords: mercury, mercury exposure, heavy metals, health

INTRODUCTION

Mercury exists both naturally and as a man-made contaminant. According to The Global Mercury Assessment from 2018 [1], mercury exposure impacts diverse populations worldwide, with dietary intake from fish, shellfish, marine mammals, and other foods being a primary source of methylmercury for many global communities. Furthermore, exposure to elemental and inorganic mercury also occurs in occupational settings, such as artisanal and small-scale gold mining, as well as through contact with mercury-containing products. Mercury is known to exert a wide array of significant and well-documented adverse impacts on both human health and the environment, with its deleterious effects being observed and documented across various regions worldwide [2]. This raises significant concerns, particularly for vulnerable communities like certain indigenous groups and those with elevated mercury exposure due to their diets or occupations, necessitating ongoing attention and protective measures.

OBJECTIVE

The objective of this study was to conduct a literature review to evaluate the primary routes of mercury exposure and its implications for human health, aiming to enhance comprehension and facilitate risk management strategies.

MATERIALS AND METHODS

A search of online medical databases PubMed and Google Scholar was undertaken, focusing on original and review articles. The search included different combinations of specific keywords: 'mercury,' 'mercury exposure,' and 'health.' Only studies relevant to the topic of assessing mercury exposure and its impacts on human health were included in the review. Inclusion criteria involved manual searches in databases, along with an evaluation of the quality and reliability of the sources. Although the literature review included works published after 2017, the selection was based on the latest sources available to assess the proper quality of the manuscript. Additional studies were identified through manual searches of reference lists of relevant articles. The analysis included data from 42 scientific references deemed the most current and relevant to the study, published in English between 2017 and 2024.

RESULTS

Dietary exposure - seafood

Human exposure to mercury primarily occurs through the consumption of fish and seafood containing methylmercury (MeHg), constituting a significant pathway for mercury exposure. Mercury (Hg) is recognized as a harmful substance, entering marine ecosystems through natural and human-induced means [3].

A study on the effects of seafood consumption on mercury exposure in Norwegian pregnant women established how consuming more Atlantic cod, a fish species with comparatively low levels of methylmercury contamination, affect the overall concentration of mercury in human hair. The results showed that the intervention with 400 g of cod per week slightly increased total hair mercury (THHg) concentration, but it did not lead to an increase in number of subjects exceeding the US EPA reference dose, which is a dose level at which no adverse effects are expected to occur over a period of lifetime exposure [4]. Consistent conclusions were drawn by researchers Dix-Cooper L et al. who showed that the blood mercury levels were 2.5 (7.3) µg/L among East Asians, notably higher than the 0.20 (0.83) μg/L recorded among South Asians. The researchers link this discovery to seafood intake and dental amalgams as the main predictors of blood Hg [5].

Moreover, in a trial conducted by Kvestad I et al. [6], Norwegian preschool children were served fatty fish for lunch three times a week over a span of 16 weeks. Interestingly, they experienced a notable rise in THHg levels compared to those who were served meat. However, comparably, the THHg levels remained below the thresholds established by EFSA, WHO/FAO, and US-EPA for risk assessment. The results were confirmed in a different trial [7], where children, aged 4 to 6 y, were provided with lunch consisting of either fatty fish (herring or mackerel) or meat (chicken, lamb or beef) three times per week for a duration of 16 weeks. Hair mercury concentration increase was one of the strongest effects of fatty fish intake.

On the contrary, findings from a study conducted by Hustad KS et al. in 2022 [8] diverged from those observed previously. This investigation revealed contrasting results, indicating that there was no significant change in whole blood mercury levels over the course of an 8-week intervention period. During this period, 88 adults were subjected to randomization, either receiving a salmon fish protein supplement or a placebo. This discrepancy underscores the complexity and variability inherent in research outcomes, urging further exploration and analysis within the field.

The issue of the exposure to total mercury and methylmercury during prenatal and early postnatal periods due to low maternal fish intake was addressed by Ursinyova M et al. They found that at the minimal exposure levels observed among Slovak population, there was only a slight connection between fish consumption and the concentration of MeHg in cord blood. Furthermore, the link between consuming freshwater fish and lower levels of total mercury in breast milk implies that essential elements found in fish may have a protective effect [9].

It is important to note that in a study assessing the risks to human health from mercury level variations in seafood across various key regions of Rio de Janeiro, Brazil [10], it has been proved that the fish exhibited elevated levels of mercury, whereas cooked mussel samples showed lower mercury levels compared to raw ones. Among *Micropogonias furnieri*, *Sardinella brasiliensis*, and *Callinectes spp*., mercury concentrations were influenced by seasonal variations, while in *Merluccius merluccius*, a disparity between genders was noted, with males showing higher mercury values.

Studies worldwide indicate the complex interplay between seafood consumption and mercury exposure, emphasizing the need for further investigation into the factors influencing mercury levels in human populations.

Healthcare exposure

It is interesting to note that Mercury is a key component found in dental amalgam fillings [11], which makes this group more subject to its harmful effects. In a meta-analysis convoyed by Jonidi Jafari A et al. [12] this point has been proven. They have analyzed 13 studies, with 1499 participants who were Iranian dentists. The average mercury levels in urine, nails, and blood were estimated to be 6.29 (95% CI: 2.61-9.97, I-square: 62.7%, P: 0.006), 3.54 (95% CI: 2.81-4.28, I-square: 0.0%, P: 0.968), and 11.20 (95% CI: 2.28-20.13, I-square: 59.9%, P: 0.082), respectively.

In comparison to the World Health Organization (WHO) standard, the mean mercury level (MML) in the biological samples of Iranian dentists was found to be higher. Based on the latest findings from Czech Republic [13], current dental exposures do not surpass acceptable risk thresholds and remain below the biological limit of mercury in urine established for occupationally exposed individuals (100 μg.g-1 of creatinine). However, the authors advocate the view that amalgam fillings present in the oral cavity serve as a continual source of mercury exposure for the body.

Drawing upon toxicological, clinical, and epidemiological insights, there are a lot of surrounding potential adverse health consequences resulting from occupational exposure to metallic mercury (Hg) within the field of dental practice [14].

Artisanal and small-scale gold mining exposure

Gold, considered one of the most precious materials, is often extracted in conditions posing health risks to artisanal and small-scale gold miners. Harianja AH et al. conducted a study [15] with the objective to assess the impacts of mercury contamination and socioeconomic factors on communities residing near artisanal and small-scale gold mining (ASGM) operations. They have found that individuals living near artisanal and small-scale gold mining (ASGM) operations had elevated levels of mercury content in their hair, with the majority falling into the alert and high categories. Women exhibited higher mercury content than men. Factors influencing the level of mercury content in hair included education level and the distance of mining sites and ball mills from settlements.

These conclusions have been corroborated by other researchers who, during a study conducted in Colombia, evaluated THg levels in blood, urine, and hair, as well as methylmercury MeHg levels in human hair samples collected from 238 individuals with occupational exposure to mercury in the most significant artisanal and small-scale gold mining (ASGM) communities of Colombia. The median concentrations of total mercury in blood (3.70 μg/L), urine (4.00 μg/L), and hair (1.37 mg/kg), as well as methylmercury in hair (1.47 mg/kg), among all participants were found to be below the permissible limits established by the World Health Organization (WHO). However, approximately 40% of the miners exhibited mercury concentrations in their blood, urine, and/or hair that exceeded the WHO thresholds [16].

Nevertheless, as the authors of an article studying mercury-related health effects in ASG miners explicitly indicate, exposure to mercury in the workplace is not confined to artisanal and small-scale gold mining (ASGM), it can also occur in other industrial sectors, such as fluorescent lamp production companies [17, 18].

Ayurvedic traditional medicine exposure

The linkage we observed between blood Hg and Ayurvedic or Chinese traditional remedies is less well established. Hore P et al. [19] tried to deepen the understanding of this connection. Over 10 years, from 2010 to 2019, the New York City Department of Health and Mental Hygiene gathered 584 samples of health remedies during investigations of poisoning incidents and surveys of stores for analysis of lead, mercury, or arsenic content. A key discovery of this study was that rasa shastra Ayurvedic medications were notably more prone than other forms of health remedies to surpass permissible limits for lead, mercury, and arsenic, reaching levels as high as 220,000 times the regulatory thresholds.

Effects on human health

Mercury exists in elemental (Hg°) and inorganic (Hg+, Hg2+) forms, as well as various organic species, such as methylmercury (MeHg (CH3Hg+)). All manifestations of mercury are deemed toxic [20]. Mercury toxicity occurs when individuals are exposed to mercury or its compounds, leading to diverse toxic effects that vary depending on the chemical form and route of exposure [21]. Numerous studies investigating methylmercury toxicity often utilize total mercury measurements in whole blood to gauge MeHg exposure. Nonetheless, whole blood THg encompasses various mercury (Hg) forms, including inorganic Hg, originating from distinct exposure sources and exhibiting differing toxicological effects compared to MeHg [22]. The World Health Organization (WHO) established a permissible level of 0.2 $\mu g/m^3$ for prolonged inhalation exposure to elemental mercury vapor, along with a permissible daily intake of total mercury of 2 µg/kg body weight [23].

Exposure to mercury, whether methylmercury or otherwise, has been firmly linked to a range of neurological issues, supported by research conducted in both live organisms and laboratory settings. These neurological effects are diverse, encompassing visual deficits such as impaired color vision, reduced acuity, and contrast sensitivity, as well as motor problems including dexterity challenges, decreased strength, slower speed, and compromised balance. In children exposed to mercury, there is a notable association with delays in developmental milestones like walking and talking, language difficulties, and lower mental and psychomotor performance scores. Moreover, studies suggest potential additional impacts on motor speech abilities, hearing loss, mood alterations, and a decline in intelligence quotient. [24, 25]. Specifically methylated mercury, which is the most neurotoxic form, is associated with nervous system damage in adults and impaired neurological development in infants and children.

In the cardiovascular realm, long-term exposure to mercury has been linked to a heightened risk of mortality from all causes, as well as incidents of both fatal and nonfatal ischemic heart disease (IHD). The risk of various cardiovascular outcomes begins to rise steadily when the concentration of mercury in hair reaches 2 μg/g [26]. Mercury toxicity has been notably associated with several cardiovascular conditions, including hypertension, coronary heart disease, myocardial infarction, cardiac arrhythmias, carotid artery blockage, cerebrovascular accidents, and generalized atherosclerosis. These health issues have been consistently linked to high levels of mercury exposure, highlighting the significant impact of mercury toxicity on cardiovascular health [27].

Mercury's interference with the endocrine system raises concerns, as it has the potential to induce genotoxicity, provoke autoimmune responses, and cause oxidative damage. This suggests a potential link between mercury exposure and the development of thyroid cancers, autoimmune thyroiditis, and hypothyroidism [28]. High doses of mercury disrupt thyroid function by damaging the thyroid structure and altering the expression of relevant genes. Interestingly, total mercury concentrations positively correlate with thyroxine (T4) levels and inversely correlate with triiodothyronine (T3), consistent with mercury-induced disruption of T4 deiodination [29]. Moreover, over time, mercury accumulates in human pituitary cells, predominantly within the growth hormone-containing somatotrophs. This suggests that mercury toxicity may contribute to the decline in growth hormone levels observed with aging [30]. Furthermore, both prenatal and postnatal exposure to mercury (Hg) show significant associations with testosterone levels and attainment of Tanner stage > 1 in children [29]. There's a notion that mercury could potentially disrupt endocrine function by interfering with hormone-receptor binding or by inhibiting crucial enzymes or processes involved in hormone production.

Reproductive health is compromised by mercury's influence, as it affects reproductive function in both men and women. Exposure to mercury leads to damage in sperm DNA and causes abnormalities in sperm morphology and motility [31]. Men exposed to mercury may experience erectile and ejaculation issues. In women, it disrupts estrogen levels, leading to infertility or subfertility and various reproductive disorders. During pregnancy, mercury crossing the placenta can cause spontaneous abortions, premature births, congenital disabilities, and developmental delays in the fetus [32].

Within the gastrointestinal system, mercury disrupts cell membranes, causing the release of intracellular contents into the bloodstream, a process known as hepatocellular necrosis. It readily binds to enzyme sulfhydryl groups, leading to their inactivation and resulting in hepatotoxicity. Elevated levels of mercury in the blood have been associated with severe liver damage [33, 34]. Both inorganic mercury and methylmercury were discovered to induce disturbances in intestinal microbial balance, aberrant production of metabolites, impairment of tight junctions, and immune reactions within the gastrointestinal tract [35]. Mercury intoxication is also linked with acute symptoms, such as abdominal pain, indigestion, nausea, and decreased appetite [36].

Respiratory complications arise from mercury inhalation, with various pulmonary issues, including pneumothorax, interstitial emphysema, pneumatocele, interstitial fibrosis, and pneumomediastinum. Furthermore, exposure to exceptionally high levels of elemental mercury may result in fatal acute respiratory distress syndrome [37].

Exposure to any form of mercury can result in nephrotoxic effects, with available data suggesting a correlation between mercury exposure and a higher incidence and severity of renal disease. The exposure of elderly individuals to mercuric compounds may exacerbate cell susceptibility to injury due to the combined effects of aging and mercury on cellular function [38]. Metals like mercury are recognized for their ability to trigger apoptosis in renal cells. Additionally, there's a belief that transporters within the kidney play a significant role in the nephrotoxic effects of mercury [39].

Immunologically, mercury triggers inflammatory and autoimmune responses, characterized by proinflammatory cytokine expression, lymphoproliferation, and autoantibody production [40]. Exposure to mercury has been associated with immune disorders, with even minimal levels posing a risk especially to children's immune systems, potentially leading to conditions such as atopic dermatitis [41].

This intricate interplay between mercury exposure and various physiological systems underscores the pervasive threat posed by this toxic metal to human health across multiple organ systems.

CONCLUSIONS

Heavy metals, such as mercury, enter the body through ingestion, inhalation, or skin contact. Once absorbed, they accumulate and cause toxic effects on various tissues and organs, leading to acute or chronic symptoms. They disrupt cellular functions, including growth, repair processes, and apoptosis [42]. The main routes for mercury exposure include dietary intake, particularly through seafood consumption, as well as occupational exposure, such as from dental amalgam fillings and artisanal and small-scale gold mining operations. Mercury toxicity can lead to various symptoms and conditions, including neurological impairments, cardiovascular diseases, reproductive dysfunctions, gastrointestinal issues, respiratory problems, kidney damage, and immune system disorders. Further studies are needed to comprehensively understand the complex interactions between mercury exposure and its diverse effects on human health across various populations and exposure scenarios.

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