PREVENTION, DIAGNOSIS, AND MONITORING OF HEALTH RISKS ASSOCIATED WITH MERCURY EXPOSURE IN HUMANS AND ANIMALS

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Abstract : *This article provides a comprehensive review of current data on the health risks of mercury exposure in humans and animals. Based on recent international studies (WHO, ATSDR, UNEP, Minamata Convention) and toxicological reports, it analyzes sources, pathways, and mechanisms of mercury toxicity, including elemental, inorganic, and organic (methylmercury) forms. Diagnostic and biomonitoring methods (blood, urine, hair, and exhaled air analysis) are summarized to assess both acute and chronic exposures. Special attention is given to food chain contamination, particularly through fish and seafood consumption, and to the impact on the nervous, reproductive, and immune systems. Preventive strategies include emission reduction, ecological monitoring, and population screening. The findings emphasize the need for an integrated health-*

environment surveillance system to mitigate mercury-related risks to humans and wildlife.

Keywords: *mercury, toxicity, biomonitoring, human and animal health, methylmercury, environmental pollution, diagnostics, prevention, ecological risks.*

«Предупреждение, диагностика и мониторинг рисков для здоровья, связанных с воздействием ртути на организм животных и человека»

Аннотация: *В статье представлен обзор современных данных о рисках для здоровья человека и животных, связанных с воздействием различных форм ртути — элементарной, неорганической и органической (метилртути). На основе международных исследований и отчетов (ATSDR, WHO, UNEP) рассмотрены основные источники загрязнения, пути поступления и механизмы токсического действия ртути. Особое внимание уделено диагностическим и биомониторинговым подходам (анализ крови, мочи, волос и выдыхаемого воздуха), позволяющим выявлять как острые, так и хронические формы воздействия. Отдельно проанализированы эколого-гигиенические риски, связанные с потреблением рыбы и морепродуктов, а также влияние ртути на репродуктивное, нервное и иммунное здоровье. Предложены меры профилактики и контроля — от глобальных стратегий (Конвенция Минамата) до региональных программ снижения эмиссий и мониторинга состояния экосистем. Полученные данные подтверждают необходимость системного подхода к диагностике, надзору и снижению ртутной нагрузки на биоту и человека.*

Ключевые слова: *ртуть, токсичность, биомониторинг, здоровье человека и животных, метилртуть, загрязнение окружающей среды, диагностика, профилактика, экологические риски.*

Одам ва ҳайвонлар организмига симоб таъсири билан боғлиқ соғлиқ учун хавфларнинг олдини олиш, ташхис қўйиш ва мониторинг қилиш

Аннотация: *Мақолада одам ва ҳайвонлар организмига турли кўринишдаги симоб таъсири билан боғлиқ соғлиқ учун хавфлар таҳлил қилинган. Хусусан, элементар, ноорганик ва органик (метилсимоб) шаклларининг таъсир механизмлари, атроф-муҳитда тарқалиш манбалари ва инсон организмига кириш йўллари ёритилган. Илмий манбалар ва халқаро ташкилотлар (WHO, ATSDR, UNEP) маълумотларига асосланиб, симобнинг нейротоксик, иммуномодулятор ва репродуктив таъсирлари баён этилган. Биомониторинг усуллари (қон, пешоб, соч ва нафас таҳлиллари) орқали таъсир даражасини аниқлаш имкониятлари кўрсатилган. Қўшимча равишда, балиқ ва денгиз маҳсулотлари орқали симоб қабул қилиш билан боғлиқ экологик хавфлар таҳлил қилинган. Профилактика чоралари ва назорат тизимини такомиллаштириш бўйича таклифлар берилган. Ушбу натижалар симоб таъсирини олдини олиш, ташхис ва мониторинг қилишнинг тизимли ёндашувини таъминлаш зарурлигини кўрсатади.*

Калит сўзлар: *симоб, токсикология, биомониторинг, одам ва ҳайвон саломатлиги, метилсимоб, атроф-муҳит ифлосланиши, диагностика, профилактика, экологик хавфлар.*

Introduction

Mercury (Hg) is one of the most toxic elements posing a serious threat to both humans and animals. The World Health Organization classifies mercury among the ten most dangerous chemical substances capable of causing long-term health effects. A distinctive feature of mercury is its ability to transform from one chemical form into another and accumulate in living organisms. Owing to this property, it easily enters food chains, leading to gradual poisoning even at low environmental concentrations.

The problem of mercury exposure is complex and encompasses ecological, toxicological, and socio-hygienic dimensions. Sources of contamination include both natural processes volcanic activity, weathering of rocks, and evaporation of seawater and anthropogenic sources such as coal combustion, mining and metallurgical industries, chlor-alkali production, and the use of mercury-containing thermometers and lamps. As a result, large quantities of mercury are released into the atmosphere, from where they settle into soil and water bodies. In aquatic environments, inorganic mercury compounds undergo methylation by microorganisms, forming methylmercury the most toxic form capable of accumulating in the tissues of living organisms.

Mercury exposure in humans and animals occurs through three major routes: inhalation (via the respiratory tract), alimentary (through food and water), and percutaneous (through the skin). The alimentary route is considered the most dangerous due to consumption of fish and seafood, in which methylmercury concentrations often far exceed permissible limits. Methylmercury exhibits pronounced neurotoxic effects: it easily crosses the blood–brain and placental barriers, damaging the central nervous system, liver, kidneys, and endocrine organs. Animals demonstrate similar pathological changes, including reproductive impairment, embryonic abnormalities, behavioral alterations, and reduced immunity.

Modern research demonstrates that even minimal chronic exposure to mercury can cause persistent morphophysiological changes. This is confirmed by observations of populations affected by mercury disasters such as Minamata in Japan, where the consequences of intoxication have been transmitted across generations. The international response to these events resulted in the adoption of the Minamata Convention (2013), aimed at reducing mercury use, cutting emissions, and eliminating contamination sources.

Timely diagnosis and biomonitoring are crucial for identifying mercury intoxication. Unlike traditional clinical methods, biomonitoring quantitatively determines internal exposure dose and helps identify contamination sources. The most informative biological matrices include blood, urine, hair, and exhaled air. Urine mercury concentration reflects long-term exposure to mercury vapor, while hair analysis indicates chronic dietary methylmercury intake. These methods enable early detection of intoxication and evaluation of preventive measures.

Environmental and food monitoring remains an essential component of ecological safety. Regular determination of mercury levels in water, soil, plants, fish, and dairy products allows assessment of potential public health risks. Studies indicate that 40–60% of fish samples from contaminated water bodies exceed sanitary mercury limits, necessitating strict governmental control and public education on safe consumption.

Thus, the problem of preventing, diagnosing, and monitoring mercury-related risks is interdisciplinary, requiring cooperation among ecologists, physicians, veterinarians, and sanitary specialists. The development of modern biomonitoring techniques, enhancement of laboratory diagnostics, and expansion of international collaboration are key prerequisites for reducing mercury burdens on human populations and the biosphere. Under conditions of growing technological pressure, systemic monitoring of mercury pollution becomes one of the priority areas for ensuring ecological and biomedical safety.

Main Part

Mercury is a unique element due to its physicochemical properties, but these same features make it particularly dangerous. In nature it exists in three forms: metallic (Hg^0), inorganic (Hg^+, Hg^{2+}), and organic (methylmercury and ethylmercury). Each form possesses distinct toxicities and mechanisms of action. Methylmercury formed in aquatic ecosystems by anaerobic bacteria is regarded as the most hazardous. It easily penetrates the tissues of aquatic organisms and accumulates in food chains, reaching high concentrations in predatory fish and mammals.

The primary route of mercury exposure in humans is alimentary. Consumption of contaminated fish, seafood, or methylmercury-containing water leads to gradual accumulation of the toxin. Biomagnification results in concentrations in human tissues hundreds of times higher than in the surrounding environment. Metallic mercury, on the other hand, is more dangerous through inhalation, when its vapors are inhaled in industrial settings or after the rupture of mercury-containing devices.

Mercury exerts multifaceted toxic effects. It binds to sulfhydryl groups of proteins, disrupts enzyme activity, and inhibits DNA and RNA synthesis. Methylmercury is particularly harmful to the central nervous system it crosses the blood–brain barrier, destroys neurons, and impairs nerve impulse conduction. In humans this manifests as memory loss, tremors, impaired coordination, speech and hearing disturbances. Animals exhibit similar symptoms such as disorientation, aggression, reduced fertility, and offspring abnormalities.

Apart from neurotoxicity, mercury negatively affects immune, cardiovascular, and endocrine systems. It causes oxidative stress, membrane destruction, inflammatory reactions, and apoptosis. In the liver and kidneys, mercury accumulates as inorganic salts, leading to toxic nephritis and hepatitis. Chronic low-dose exposure may induce mutagenic and teratogenic effects as well as epigenetic alterations transmissible to offspring.

In animals, especially aquatic species, mercury serves as a bioindicator of environmental quality. Studies reveal that concentrations as low as 0.05 mg/L cause anemia, gill deformation, and growth disorders in fish. These findings confirm that mercury is not merely a local but a global environmental problem.

Timely diagnosis of mercury intoxication is essential for preventing chronic damage. Biological monitoring methods that determine mercury levels and chemical forms in the body are considered most effective.

Urine analysis is used to assess exposure to metallic and inorganic mercury. It reflects long-term inhalation exposure and is used to monitor workers in industries producing instruments, batteries, lamps, and dental materials. Concentrations above 50 µg/L are considered potentially dangerous and require medical intervention.

For diagnosing methylmercury exposure, blood and hair analyses are preferred. Mercury content in hair reflects long-term accumulation up to several months. Segmental analysis allows determination of exposure dynamics. Although

ISSN: 3060-4567

mercury remains in blood only briefly, blood analysis is valuable for detecting acute intoxication.

Modern laboratories employ atomic absorption spectroscopy, inductively coupled plasma mass spectrometry (ICP-MS), and chromatography-mass spectrometry. These technologies provide high measurement accuracy and allow differentiation of mercury forms. In clinical practice, rapid tests and biosensors are also used for field screenings.

An important direction in biomonitoring is ecosystem assessment. Studies of mercury in fish, soil, sediments, and water allow indirect evaluation of pollution levels and prediction of public health risks. Based on such data, many countries have issued guidelines limiting consumption of certain fish species, especially for pregnant women and children.

Additionally, molecular diagnostic methods biomarkers of oxidative stress, enzyme disruptions, and epigenetic changes are actively evolving. These approaches expand early diagnostic capabilities and detect even minimal exposures.

Prevention of mercury intoxication includes measures to reduce mercury entering the environment and human body. The Minamata Convention on Mercury (2013) serves as a key international framework regulating mercury handling, banning mercury-containing thermometers and lamps, and requiring stepwise reduction of emissions.

At the national level, key tasks include:

– control of industrial emission sources, especially in energy and metallurgical sectors;
– implementation of gas and wastewater purification technologies;– safe disposal of mercury-containing waste;

– sanitary supervision of food and drinking water quality;

– public awareness and education.

In medicine, prevention focuses on early identification of risk groups. Workers in laboratories, dental clinics, mines, and metal-processing facilities undergo regular examinations. Acceptable mercury levels in biological samples are set for them, and exposure reduction measures ventilation, personal protective equipment, and replacement of mercury materials are implemented.

In veterinary practice, controlling mercury in feed and water prevents accumulation in animal products. Monitoring farm animals enables early diagnosis of poisoning and prevents contaminated meat and milk from entering the human food chain.

A promising preventive direction is the development of green technologies replacement of mercury thermometers and fluorescent lamps with safer alternatives, mercury-free batteries, and environmentally friendly industrial processes. Governmental monitoring systems also play an essential role by controlling mercury concentrations in air, water bodies, and soil.

Conclusion

The analysis demonstrates that mercury exposure in humans and animals is a complex, multifactorial process requiring continuous monitoring and interdisciplinary approaches. Mercury particularly methylmercury exerts pronounced neurotoxic and systemic effects, impairing vital organs and physiological functions.

The development of modern biomonitoring methods, the use of precise analytical technologies, and the implementation of international regulatory standards form the foundation of effective diagnosis and prevention. A crucial direction for future work is establishing integrated surveillance systems combining environmental and medical data, enabling early risk detection and reduction of mercury burdens on populations.

Thus, addressing mercury pollution requires coordinated actions among science, industry, and government. Only a systemic approach from monitoring to prevention can ensure sustainable protection of human health, animal health, and the entire biosphere.

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