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Penetration of heavy metals into breast milk and their impact on infant health - research analysis and literature review

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Abstract

Introduction and Purpose:

Breast milk is considered the best food for infants due to its nutritional and protective properties. However, in the era of increasing environmental pollution, there is a problem of heavy metals penetrating breast milk, which may pose a threat to infants' health. The aim of the study was to review studies on the presence of heavy metals in mothers' milk, their sources, mechanisms of penetration, and the impact on infants' health.

Materials and Methods:

The work is based on a review of the scientific literature on the content of heavy metals in human milk and their impact on infant development. Publications from peer-reviewed scientific journals, reports from public health institutions and guidelines from organizations such as WHO, EFSA and FDA were used. Data on the levels of lead, mercury, cadmium and arsenic in human milk from different regions of the world were analyzed, taking into account environmental, dietary and lifestyle factors.

Results:

Research results clearly indicate a significant impact of environmental factors and lifestyle on the content of heavy metals in breast milk, which emphasizes the need for preventive measures and educating women on how to minimize exposure to these substances.

Conclusion:

The presence of heavy metals in breast milk poses a serious threat to the health of infants. Therefore, it is necessary to implement preventive measures, such as educating mothers about their diet and limiting their exposure to toxic substances. It is also important to conduct biomonitoring and develop effective strategies to reduce environmental pollution. The work emphasizes the importance of further research on the mechanisms of heavy metal transfer to breast milk and their long-term effects on infant health.

Keywords:
toxicology; heavy metals; breastfeeding; effects of exposure to heavy elements; transfer of substances into milk; lactation; exposure of infants to heavy metals.

Introduction

Breastfeeding is one of the most important elements of proper development of infants and is crucial for their health. Breast milk is considered the optimal food for newborns and infants, adapted to their nutritional and immunological needs.[1] According to the World Health Organization (WHO), exclusive breastfeeding is recommended for the first six months of life, and then continued along with expanding the diet until at least the child's second year of life.[2] Numerous studies confirm that breastfed children have a better developed immune system,

a lower risk of allergic diseases, obesity, type 2 diabetes and respiratory and digestive system infections.[3] Breast milk is a dynamic and unique biological fluid, the composition of which adapts to the changing needs of the child. It contains proteins, fats, carbohydrates, vitamins and micro- and macroelements, necessary for the proper growth and development of the infant.[4] In addition, mother's milk provides numerous bioactive factors, such as enzymes, hormones, antibodies and immune cells, which strengthen the child's immune system and protect it against infections.[5] The composition of milk in terms of unsaturated fatty acids, which support the development of the child's brain and cognitive functions, is also important.

Despite the numerous benefits of breastfeeding, breast milk can be contaminated with toxic substances, including heavy metals. The modern natural environment is increasingly contaminated with heavy metals, such as lead (Pb), mercury (Hg), cadmium (Cd) and arsenic (As). Their sources include industry, transport, the use of artificial fertilizers and the combustion of fossil fuels. Heavy metals enter the human body mainly through ingestion, inhalation and skin contact, and can then be passed on to infants through breast milk.[6] Long-term exposure to heavy metals can lead to serious health consequences, such as damage to the nervous system, impaired cognitive functions, metabolic disorders and weakened immunity.[7]

For this reason, the analysis of the content of heavy metals in breast milk and their potential impact on the health of infants is an important issue for both scientists and clinical practice. This work aims to review the literature on the mechanisms of heavy metals passing into breast milk, their concentrations and possible effects on the health of breastfed children.

Purpose and scope of the work

The aim of this review is to analyze studies on the passage of heavy metals into breast milk and assess their impact on the health of infants. This work aims to present the current state of knowledge on the mechanisms of heavy metals passing into breast milk, factors influencing their concentration and health effects resulting from infants' exposure to these substances.

The scope of the work includes a review of scientific literature on: types of heavy metals found in breast milk, potential sources of mothers' exposure to heavy metals, mechanisms

of these substances passing into breast milk, health effects of infants' exposure to heavy metals, possibilities of minimizing the risk associated with the presence of these substances in breast milk. Thanks to the comprehensive analysis of available scientific data, this work can provide a basis for further research and support for doctors and dieticians in the field of protecting the health of breastfeeding mothers and their children.

Characteristic of heavy metals

Definition and classification of heavy metals

Heavy metals are chemical elements with high density and atomic mass that can have toxic effects on living organisms. Their negative impact on health results from their tendency to accumulate in tissues and disrupt metabolic processes.[8]

Lead (Pb) – a neurotoxic metal that affects cognitive functions and the development of the nervous system. It can cause kidney damage and hematological disorders.

Mercury (Hg) – occurs in inorganic and organic forms (methylmercury). It penetrates the blood-brain barrier and can lead to neurological damage.

Cadmium (Cd) – a highly toxic element that accumulates in the kidneys and bones. It can cause osteoporosis and kidney failure.

Arsenic (As) – a carcinogenic element found in water and soil. It can cause skin cancer and damage to the cardiovascular system.

Infants and newborns are primarily exposed to Pb and Cd due to their immature central renal system, which is why they have a very narrow tolerance for these elements. Based on the opinion of the Scientific Committee on Food, the first step is to limit the presence of heavy metals such as Pb and Cd in food as much as possible.[9]

Sources of heavy metal emissions into the environment

Industry – steel mills, coal-fired power plants and waste incinerators emit large amounts of heavy metals into the atmosphere.

Water and soil pollution – industrial sewage, artificial fertilizers and pesticides cause the accumulation of heavy metals in ecosystems.[10]

Food products and dietary supplements – fish, vegetables and fruits may contain heavy metals as a result of environmental contamination.[11]

Pathways of exposure for infants and nursing mothers:

Diet – consumption of contaminated food products and drinking water leads to the absorption of heavy metals in the body.

Polluted air and water – inhalation of heavy metals in the form of aerosols and contact with water containing toxic elements can lead to accumulation in the body.

Dermal contact – penetration of heavy metals through the skin is possible in the case of long-term exposure to contaminated surfaces, e.g. in workplaces.

All these factors contribute to the increased accumulation of heavy metals in the human body, which can lead to serious health consequences, including their penetration into breast milk and exposure of infants to their toxic effects.

Mechanisms of the penetration of heavy metals into breast milk

Physiology of lactation and transfer of substances from blood to milk.

The process of lactation allows the transfer of nutrients and exogenous substances from the mother's blood to breast milk.[12] These substances can pass through the barrier of the mammary gland epithelium by various membrane transport mechanisms[13]:

Passive diffusion – occurs for metals in ionic form or complexes with a low molecular weight. Highly lipophilic metals, such as methylmercury, can easily pass through the lipid membranes of mammary epithelial cells.

Active transport – some metals, such as cadmium, can use ion transporters or calcium channels to move across cell membranes.

Endocytosis and exocytosis – metals can be transported in membrane vesicles and secreted into milk bound to transport proteins, such as lactoferrin.

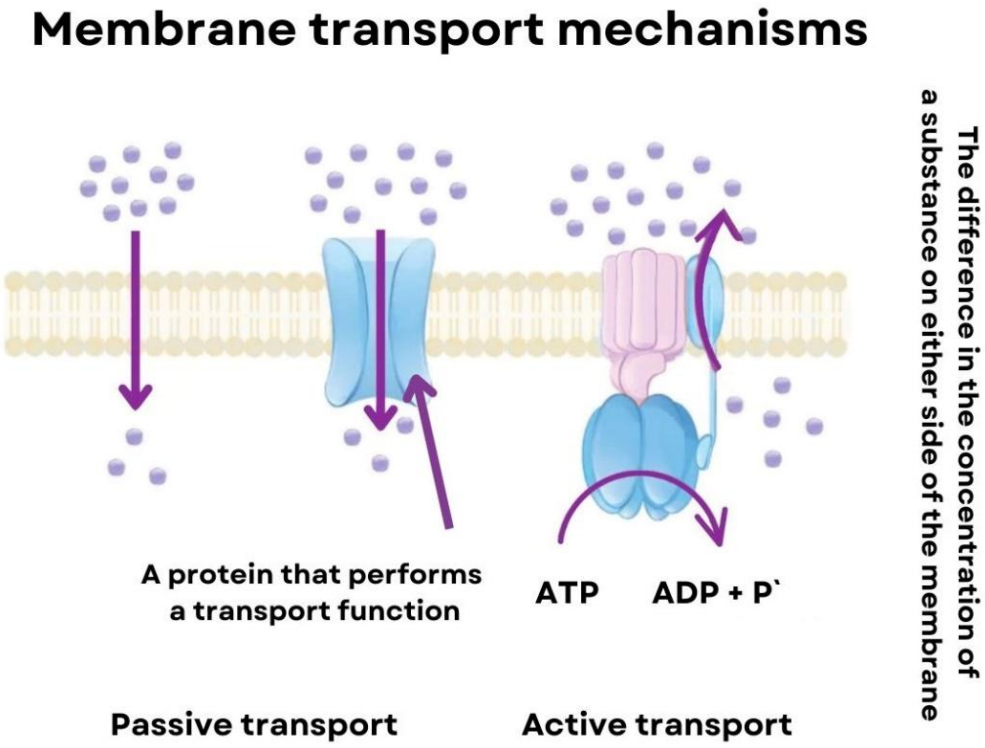

Figure 1. Membrane transport mechanisms

Factors influencing heavy metal transfer:

Nutritional status and diet of the mother – deficiencies in minerals such as calcium or zinc can increase the absorption of heavy metals and their transfer into milk.

Maternal age and duration of lactation – older mothers may have higher levels of heavy metals accumulated in their bodies, which increases the risk of their transfer into milk.

Occupational and environmental exposure – long-term exposure to heavy metals in the workplace or in the environment increases their plasma levels, increasing the risk of transfer to milk.

Detoxification mechanisms in lactating women The mother's body has several detoxification mechanisms that can limit the accumulation of heavy metals in milk:

Chelation – binding of heavy metals to proteins such as metallothioneins and lactoferrin, which reduce their bioavailability to the infant.

Renal filtration and excretion – elimination of metals by the kidneys and in the feces limits their availability to the blood and milk.

Competitive mineral absorption – adequate intake of calcium, magnesium and zinc can reduce the absorption of heavy metals in the intestines, reducing their transport into milk.
Understanding these mechanisms is crucial to developing strategies to reduce infant exposure to toxic metals and prevent their negative health effects.
Review of studies on heavy metals in human milk.

In recent years, numerous studies have been conducted on the presence of heavy metals in the milk of breastfeeding women in different parts of the world. Studies have shown varying levels of lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) depending on the geographic region, level of industrialization, diet, and environmental exposure of the mothers.[14]

In highly industrialized countries such as the United States, Germany, and Japan, higher levels of mercury and lead have been shown, mainly due to greater environmental pollution and consumption of fish rich in methylmercury. In developing countries such as India and Bangladesh, studies indicate elevated concentrations of arsenic, which is the result of groundwater contamination with this element.[15]

Comparison of heavy metal concentrations in human milk

Urban areas vs. rural – Studies show that women living in urban areas have higher levels of lead and cadmium in their milk, which is associated with greater exposure to car exhaust fumes, industrial emissions and air pollution.

Smokers vs. non-smokers – Smoking is one of the important factors that increases the levels of cadmium and lead in the body, which translates into higher concentrations of these metals in the milk of mothers who smoke.

Women occupationally exposed to heavy metals – Higher levels of heavy metals have been observed in women working in the metallurgical, chemical or agricultural industries, where pesticides containing heavy metals are used.

The impact of environmental factors and dietary habits on heavy metal levels.

Diet plays a key role in maternal exposure to heavy metals. Consuming contaminated fish, seafood or vegetables grown in contaminated soil increases the level of heavy metals in milk. In addition, women who consume insufficient amounts of calcium, iron and zinc are more susceptible to the accumulation of heavy metals in the body, because deficiencies in these elements promote increased absorption of toxic metals.

In summary, the research results clearly indicate a significant impact of environmental factors and lifestyle on the content of heavy metals in breast milk, which emphasizes the need for preventive measures and educating women on minimizing exposure to these substances.

The impact of heavy metals present in breast milk on infant health. Toxicity of individual heavy metals.

Lead is a strong neurotoxin that affects the development of the nervous system of infants. Its exposure can lead to reduced intelligence, cognitive impairment, and problems with concentration and memory. There are also studies indicating an increased risk of ADHD in children exposed to elevated levels of lead in early childhood. Lead absorption in the neonatal period depends primarily on the bioavailability of this element from the milk diet. Pb, as a heavy element, is absorbed, and the amount that is not excreted becomes inactive through storage in the body. Lead can be partially available (e.g. Pb in bones) or mostly unavailable in chemical structures such as metallothioneins in the kidneys and in the liver.[16]

The toxicity of Pb to the central nervous system in the initial stages of life is also well-known. This metal can also cause subtle effects on the children's renal and dopaminergic systems - in particular, renal hyperfiltration appears in an early response to lead.[17] Feeding an infant with breast milk can be a source of lead poisoning and result in later neurocognitive disorders. However, the transfer of Pb from plasma to breast milk is limited and according to some studies is about 3%, according to others it reaches 20%.[18] Mercury, especially in the form of methylmercury, can cause serious neurological damage. Infants exposed to mercury through breast milk may show delays in motor development, sensory disorders and difficulties in processing sensory stimuli.[19]

Mercury occurs in metallic, organic and inorganic forms. The form of this element plays a decisive role in its fate in the body and determines the course, effects and symptoms of poisoning. Metallic mercury is oxidized to organic (divalent) mercury when it gets into rainwater. Through metabolic reactions of microorganisms and chemical reactions occurring in the aquatic environment, alkylated derivatives of mercury are created, including methylmercury (CH3Hg) or dimethylmercury (CH3)2Hg. Metallic mercury is absorbed mainly through the respiratory tract. The degree of absorption of mercury vapors in the lungs is about 80%. The metallic form of mercury also enters the body through the skin, but, what is worth emphasizing, it is practically not absorbed through the digestive system (the degree of absorption is less than 0.01% of the dose taken).

Metallic mercury absorbed through the lungs in the form of vapors is transported around the body with the participation of erythrocytes. It is partially oxidized by erythrocyte catalase to organic mercury and in this form is excreted to a small extent in urine and feces. Metallic mercury vapors can also penetrate the blood-brain barrier and the placenta.[20] Mercury accumulates in the CNS, which in turn is caused by its oxidation to an organic form, which is difficult to eliminate from the body after crossing the barrier of the choroid plexuses of the brain. This phenomenon is referred to as a "brain trap", and as a result, the central cerebral system is a critical organ in poisoning with metallic mercury. Cadmium has a nephrotoxic effect, which means that it can lead to kidney damage in infants. Long-term exposure can also negatively affect calcium metabolism, which can result in weakened bones and an increased risk of osteoporosis in later life. The main sources of this element are diet, quality and lifestyle, smoking, and the type of profession performed. Arsenic is associated with the risk of cancer and immunological disorders. As accumulates in vegetables and the meat of some fish.

This element is one of the strongest poisons. It has primarily carcinogenic properties and disrupts the course of metabolic processes in the cells of organisms. Exposure to As during pregnancy is associated with increased fetal mortality and reduced birth weight in infants, and also contributes to impaired cognitive function. High levels of As lead to chronically weakened immune systems in newborns and infants, increasing susceptibility to autoimmune diseases and infections.

Short-term and long-term health effects.

Impaired brain and nervous system development.

The effects of heavy metals on the nervous system can result in delayed cognitive development, speech problems, and learning disabilities.[21]

Reduced immunity and increased susceptibility to infections. Some heavy metals, such as arsenic and cadmium, weaken the immune function of the infant, increasing the risk of bacterial and viral infections.

Metabolic and hormonal problems. Exposure to heavy metals can lead to metabolic disorders, including problems with blood sugar regulation and an increased risk of type 2 diabetes later in life.

In summary, heavy metals present in breast milk can significantly affect the health of infants, causing both short-term effects and long-term health problems. Therefore, it is important to monitor the levels of these substances and take action to reduce them in the environment and in the bodies of breastfeeding women.

WHO, EFSA, FDA standards and guidelines.

The World Health Organization (WHO)[22], the European Food Safety Authority (EFSA) and the US Food and Drug Administration (FDA) set standards for maximum levels of heavy metals in food, including breast milk and infant products. WHO indicates that all levels of heavy metals should be as low as possible to minimize the risk of their toxic effects on infants' health. EFSA and FDA have developed detailed limits for individual heavy metals, taking into account their impact on the body of a developing child.

Permissible levels of heavy metals in breast milk and infant formula

Currently adopted standards indicate the following maximum levels for infant formula:[23]

Lead (Pb): less than 0.01 mg/kg in infant formula,

Mercury (Hg): less than 0.004 mg/kg in dairy formula,

Cadmium (Cd): less than 0.002 mg/kg in infant formula,

Arsenic (As): less than 0.01 mg/kg in food formula.

Although the levels of heavy metals in breast milk are not precisely regulated, it is recommended that they be monitored as part of food safety assessment programs.

Methods for monitoring and assessing contamination of human milk

A variety of analytical techniques are used to effectively assess the presence of heavy metals in human milk, including:

Atomic absorption spectrometry (AAS), which allows for precise analysis of the concentration of individual metals in milk,

Inductively coupled plasma mass spectrometry (ICP-MS), which provides highly accurate results for heavy metal analysis.

High-performance liquid chromatography (HPLC), which is used to study organic compounds of metals,

Electrochemical methods, which allow for the detection of low levels of toxic elements.

Monitoring the levels of heavy metals in human milk is crucial for protecting the health of infants. Regular testing allows for early detection of threats and implementation of strategies to reduce the exposure of nursing mothers to these substances.

Dietary recommendations for breastfeeding mothers

One of the key ways to reduce exposure to heavy metals is to eat a proper diet for breastfeeding mothers. Eating foods rich in antioxidants, such as vitamins C and E, beta-carotene, selenium, and polyphenols, can support the body's natural detoxification mechanisms and reduce oxidative stress. Examples of beneficial foods include[24]:

• leafy greens (spinach, kale),
• citrus fruits and berries,
• nuts and seeds,
• whole grains.

Avoiding contaminated foods

It is crucial to avoid foods that may be a source of heavy metals. It is particularly important to limit your consumption of:

• predatory fish (tuna, swordfish, shark), which may contain high levels of mercury,
• vegetables and fruits grown in contaminated soils,
• drinking water from unreliable sources, especially in regions with high levels of arsenic.

Education of mothers on reducing exposure to heavy metals

Raising awareness about sources of heavy metals and ways to avoid them is a key element of the prevention strategy. Educational programs should include information on sources of contamination, alternative food products and methods of minimizing exposure in everyday life.

The role of preventive examinations and biomonitoring

Regular testing of heavy metal levels in the body of breastfeeding women can help to quickly detect potential threats and take appropriate actions. Biomonitoring involves the analysis of blood, urine and breast milk samples to determine the level of exposure to toxic substances.[25] Such activities allow for the implementation of effective preventive measures and the development of dietary and environmental recommendations tailored to the individual needs of lactating women.

Summary and conclusions

In summary, the presence of heavy metals in breast milk is a significant health problem that can have long-term consequences for the health of infants.

Heavy metals such as lead, mercury, cadmium and arsenic can pass into breast milk through various biological mechanisms and have a negative impact on the development of the nervous system, cognitive functions and immunity of the child. The paper presents the mechanisms of heavy metals transfer into human milk, their potential sources and factors influencing their concentration.

The health effects resulting from infants' exposure to these toxic elements, both in the short and long term, are also discussed. The review of studies indicates the need to monitor the level of heavy metals in human milk and implement strategies to limit the exposure of breastfeeding women to these substances. In order to minimize the risk of breast milk contamination, it is recommended to follow the principles of a healthy diet, rich in antioxidants and microelements that limit the absorption of heavy metals, avoid food and water contaminated with heavy metals, regular preventive examinations or biomonitoring, and educate mothers about the sources of exposure and methods of avoiding it. Finally, further research on the mechanisms of detoxification and the health effects of heavy metals in human milk is necessary to develop effective strategies to protect the health of infants and breastfeeding mothers. Taking action to reduce environmental contamination with heavy metals and promoting a healthy lifestyle among breastfeeding women can contribute to improving the quality of health of future generations.

Disclosures

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