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THE ENVIRONMENTAL HAZARDS OF MICRO- AND NANOPLASTICS

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Abstract. Plastic pollution is a major global environmental issue, with significant impacts on both ecosystems and human health. The widespread use of plastics in everyday life contributes to environmental contamination, with plastics taking hundreds of years to degrade. Primary microplastics, including microbeads and synthetic fibers and secondary microplastics, formed through the degradation of larger plastic materials, are prevalent in ecosystems worldwide. These particles pose serious risks to human health, as they can accumulate in tissues, cross biological barriers and disrupt systems like the digestive, immune and nervous systems. Microplastics can also carry toxic chemicals like bisphenol A (BPA), which cause hormonal imbalances and affect reproductive health. Exposure to microplastics is linked to chronic diseases, including cancer and neurodegenerative disorders, as well as inflammation and immune dysfunction. As plastics continue to contaminate the environment, there is an urgent need for comprehensive research and effective solutions to reduce plastic production, enhance waste management and minimize exposure to microplastics to protect both ecosystems and human health.

Keywords: *Microplastics, nanoplastics, immune system, toxicity, human health.*

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1. Introduction

The ecological situation, which is recognized as one of the global problems of our time and the protection and preservation of the environment have become current issues (Hasanzadeh *et al*., 2017; Kavetskyy *et al*., 2022; Nasibova *et al*., 2023). Environmental pollution and its causes are constantly being studied (Hosainzadegan *et al*., 2020; Khomutov *et al*., 2014; Nasibova *et al*., 2017). Numerous researches are conducted to assess and monitor the ecological state of the environment and solutions to these problems are sought based on modern technologies (Ahmadkhani *et al*., 2017; Nasibova, 2019; Nasibova *et al*., 2021).

In addition to investigating the causes of existing environmental problems, their prevention and elimination are also very important issues (Aliyeva *et al*., 2023; Nasibova *et al*., 2021; Nasibova, 2015).

Plastics are one of the factors causing current environmental problems. Plastics have become an integral part of everyday human activities and their use in various contexts is

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widespread. On the other hand, the widespread distribution of plastic waste in both marine and terrestrial ecosystems has an extremely detrimental impact on the various life forms that inhabit our planet. These materials are present in many commercial products, from cosmetics to construction materials (Jayavel *et al*., 2024).

Global plastic production has almost doubled since the turn of the century, reaching nearly 400 million tons in 2021. Considering that the average lifespan of plastic products is 10 years, it is stated that their degradation can last up to 500 years depending on their composition and waste disposal (Alves, 2024; Park *et al*., 2020).

Plastics are made from natural products that undergo various chemical processes and physical reactions; the main processes used are polycondensation and polymerization, which ultimately synthesize polymer chains (Smith *et al*., 2018).

Not only the production and use of plastic products, but also their post-use phases pose a serious threat to the environment and living organisms.

Primary plastics are small particles, ranging in size from 0.1 μm to 5 mm, designed for commercial purposes and include microbeads found in personal care products, plastic microfibers used in synthetic textiles, etc. (Park *et al*., 2020; Yee *et al*., 2021).

Secondary microplastics result from the degradation of primary microplastics and other large pieces of plastic due to physical, chemical and biological effects (Park *et al*., 2020).

The degradation of plastics results in the formation of micro- and nanoplastics, which occur in two main ways: biodegradation and non-biodegradation. Thermal and physical degradation, photodegradation, thermo-oxidative decomposition and hydrolysis are examples of biodegradation processes (Andrady, 2011). Other methods cause degradation that increases the specific surface area of polymer structures by changing their mechanical properties (Nasibova, 2019).

Nanoplastics are polymer-based particles of 0.01-0.1 μm in size. Microplastics have a specific size and structure and can be used in various products such as medical devices, pharmaceuticals, etc. They can be intentionally synthesized or formed by the degradation of larger plastic products (Park *et al*., 2020).

Microplastics and nanoplastics have been found to be small enough to be transported in water and food and these particles can easily enter the food chain of humans and other living organisms, causing various pathologies (Alimi *et al*., 2018; Okoye *et al*., 2022). Due to the difficulty in analyzing and detecting nanoplastics, their potential effects on human health have not been fully investigated (Yee *et al*., 2021).

2. Effects of micro- and nanoplastics on human health

Microplastics are found in oceans, rivers, sewage, soil, crops and even table salt, in short, everywhere in the world, from Mount Everest to the depths of the ocean (Parata, 2018).

Microplastics accumulate in the body and disrupt the digestive, immune, endocrine, respiratory and nervous systems and can even cause chromosomal abnormalities (Burkard *et al*., 2019).

The size of microplastics is primarily related to the effectiveness of their impact on the human body. For example, microplastics 0.1-10 μm in size easily cross the blood-brain barrier and the placenta, while microplastics smaller than 5 μm can accumulate in lymph nodes, spleen, liver and macrophages (Shrivastava, 2018). In a study, Prof. Dick Vethaak and colleagues found such microplastics in human blood and breast milk.

Microplastics in the human placenta have been shown to have serious adverse effects on embryonic development by disrupting the immune system and growth factor signaling (Ibrahim *et al*., 2021). It has also been found that microplastics can be effectively transported from one organ to another, depending on their size and that the toxicity of microplastics increases with decreasing size (Yee *et al*., 2021).

3. Pathways and risks of human exposure to nano- and microplastics

Microplastics can migrate into food from plastic materials used in food preparation and heating (Lucas, 2008). When exposed to abiotic stress through heat, single-use plastic containers can release 1.07-1.57 million microplastic particles into water, especially when in contact with water at 100°C (Liu *et al*., 2022). The concentration of these particles can be higher than in reusable plastic containers (Yee *et al*., 2021).

Microplastics ingested by humans through mucus or M cells can enter the digestive system after entering the respiratory tract. The anatomy and physiology of the human lung allows small and low concentration microplastics such as polyethylene to enter the respiratory tract. Microplastics can also increase epithelial permeability, which can facilitate their penetration into tissues and cells, causing infections (Jayavel *et al*., 2024).

Microplastics can cause neurotoxicity, immunotoxicity, genotoxicity, cytotoxicity and developmental, reproductive and movement disorders (Yang *et al*., 2022).

4. Impact of microplastics on the human body

Microplastics detected and transported in human tissues can cause serious health problems. Laboratory mice and human cell lines are used as model organisms to assess the toxicity of microplastics. However, the number of studies investigating the effects of micro- and nanoplastics on the human body is extremely limited. Most of the existing studies have been conducted on peripheral blood cells and intestinal epithelial cells.

Studies show that cells exposed to microplastics undergo apoptosis more rapidly than other cells (Kadac-Czapska *et al*., 2024). Continued exposure to microplastics increases oxidative stress, affects mitosis and meiosis and may cause DNA damage, cancer and neurodegenerative diseases (Cheng *et al.*, 2023; Lozano *et al*., 2021).

Microplastics in particular can contain toxic compounds such as bisphenol A (BPA), which can be easily absorbed into the body and cause serious health problems. BPA is a chemical widely used in the plastics industry that interferes with the endocrine system and causes hormone disruption. This compound interacts with estrogen receptors, causing hormonal imbalances and reproductive problems. In addition, BPA weakens the immune system, contributing to the exacerbation of inflammatory processes and the development of metabolic diseases (Deng *et al*., 2017).

According to studies conducted by Cheng and colleagues, the combined effects of polystyrene (PS) microplastics and bisphenol A (BPA) on the liver resulted in synergistic hepatotoxic effects of microplastics. Studies show that microplastics and nanoplastics enter cells through macropinocytosis and phagocytosis, form polystyrene-protein complexes, hide from the immune system and persist in the bloodstream for a long time. As a result, microplastics and the chemicals they carry, such as BPA, can remain in the body for long periods of time and cause systemic toxicity (Cheng *et al*., 2023).

5. Immune system and the toxicity of microplastics

Concerns about the health effects of microplastics have increased after researchers found microplastics even in the placentas of unborn babies. These microplastics are likely to have entered the placenta as a result of the mother's ingestion of microplastics through aerosols or food (Jayavel *et al*., 2024).

Microplastics can weaken the immune system, leading to autoimmune diseases or immunosuppression (Prata, 2020; Prietl *et al*., 2014). Exposure to microplastics impairs the immune system, leading to disruption of molecular processes related to Ca^{2+} signaling and apoptosis. Microplastic immunotoxicity has been shown to be caused by oxidative stress, which leads to the synthesis of reactive oxygen species (ROS) and DAMPs.

ROS are molecules that play an important role in intracellular signaling pathways, but when present at high levels, they cause cell damage and oxidative stress. ROS include superoxide anion (O^{2-}), hydroxyl radical (OH^-) and hydrogen peroxide (H_2O_2). When microplastics enter cells, they increase ROS production through mitochondrial dysfunction and activation of the enzyme NADPH oxidase. High levels of ROS cause lipid peroxidation, DNA damage and protein oxidation, leading to cell apoptosis and the initiation of inflammatory responses (Wright & Kelly, 2017; Yang *et al*., 2022).

Damage Associated Molecular Patterns (DAMPs), also known as danger signaling molecules, are biomolecules secreted by cells as a result of stress or injury. DAMPs stimulate the immune response and cause inflammation. When microplastics cause intracellular damage, DAMPs are released from the cell and activate receptors such as TLR (Toll-like receptor) and NLRP3 inflammasome. This activation amplifies inflammatory processes by increasing cytokine secretion and predisposes to the development of chronic immune disorders (Wright & Kelly, 2017).

6. Microplastics and the cardiovascular system

Plastic particles enter the body through digestion, skin or respiration and are transported through the circulatory system to organs and tissues. Red blood cells are particularly affected by high concentrations of microplastics, which stimulate endothelial cells and cause them to aggregate. Nanoplastics can easily spread through the bloodstream to various tissues and accumulate in organs, contributing to the development of cardiovascular disease. Application of polystyrene nanoplastics to red blood cells can promote aggregate formation and adhesion to endothelial cells, which has been more clearly demonstrated at higher concentrations of nanoplastics, indicating the correlation of these nanoplastics with cardiovascular diseases (Barshtein *et al*., 2016).

7. Effects of microplastics on brain cells

Acetylcholinesterase (AChE) is one of the key enzymes of the nervous system, helping to transmit nerve signals properly by breaking down acetylcholine. Under normal conditions, this enzyme maintains the balance between nerve cells, but certain external factors can affect its activity.

Studies show that exposure to microplastics increases AChE activity in brain tissue, leading to severe changes in neurotransmitter levels (Deng *et al*., 2017). Initially, increased enzyme activity can lead to overstimulation of the nervous system, but over time AChE activity weakens. Meanwhile, acetylcholine accumulates between nerve cells without being broken down, leading to disruption of normal brain function.

This process can lead to behavioral changes, especially in amphibians and mammals. Oxidative stress caused by micro- and nanoplastics can damage neurons, leading to impaired brain function and even degenerative diseases. A study by Schirinzi and colleagues showed that microplastics caused inflammatory responses and oxidative stress in T98G glioma cells, resulting in neuronal damage (Jayavel *et al*., 2024).

Another study found polyethylene and polystyrene particles in the brain tissue of people with Alzheimer's and Parkinson's disease. This finding suggests that micro- and nanoplastics may play a role in the development of neurodegenerative diseases (Campen *et al*., 2024). In other words, the long-term effects of microplastics on the brain are not limited to behavioral changes, but may also lead to serious neurological diseases.

Such findings make it important to further investigate the effects of microplastics on human health, especially on brain function. Future research in this area could help to better understand the neurotoxic mechanisms of microplastics and reduce their potential risks.

8. Microplastics and the respiratory tract

Microplastics are carried into the atmosphere by the wind and mix with the air we breathe. When these particles reach the lungs through inhalation, they can cause problems such as immune system disorders, inflammatory responses, damage to the epithelial layer and breathing difficulties. The accumulation of microplastics is thought to aggravate disease symptoms, particularly in people with asthma or chronic respiratory diseases (Lui *et al*., 2022).

The physicochemical properties of microplastics determine how deeply they can penetrate the lung. For example, while small particles such as polyethylene can easily reach the respiratory tract, polystyrene nanoplastics (PS-NPs) can reach the alveoli. Although the body tries to clear these particles through the mucus layer, phagocytosis or the lymphatic system, it has been observed that nanoplastics in particular can bypass these mechanisms (Barshtein *et al*., 2016).

9. Conclusion

Microplastics are not only changing the environment, they are changing us. They are in our blood, in our cells, even in the bodies of future generations. Over time, they weaken our immune systems, cause genetic disorders and serious diseases. If we don't control this process, in the future there will be more plastic in the water we drink, the food we eat and the air we breathe. This is not just an ecological crisis, it is a test of human existence. If we don't act now, we won't be able to save our future from plastic.

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