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THE IMPACT OF MICROPLASTICS AND NANOPLASTICS ON HUMAN DIGESTIVE, RESPIRATORY AND CARDIOVASCULAR SYSTEMS

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Abstract: *The proliferation of plastic production in recent years has precipitated a global surge in environmental pollution, with microplastics and nanoplastics (M-NPLs) emerging as omnipresent contaminants across ecosystems. Despite growing awareness of plastic pollution, the systematic toxicity and effects of M-NPLs on human health are often neglected. This paper provides a comprehensive overview of the formation, routes of exposure, and potential health impacts of M-NPLs on the human digestive, respiratory, and cardiovascular systems. Mechanisms of M-NPL formation, including mechanical breakdown, chemical degradation, and biological degradation, are examined, alongside the primary routes of human exposure through ingestion, inhalation, and dermal contact. The potential effects of M-NPLs exposure include disruption to intestinal homeostasis, inflammatory responses in the respiratory systems and cardiovascular complications. The findings emphasize the importance of conducting comprehensive investigations to fully grasp the enduring impacts of M-NPLs on human health and the environment, addressing this significant challenge to environmental and public health.*

Keywords: human health, microplastics, nanoplastics, exposure routes

1. Introduction

In the last decades there has been a significant surge in the demand for plastic. Plastic products offer numerous advantages to both individuals and communities, playing an increasingly vital role in various industries, particularly in the food sector, where they provide a sustainable and secure option. Over the past half-century, the production of plastics has experienced a remarkable escalation. It is estimated that from the 1950s to 2015, approx. 6.3 billion tons of plastic waste were produced globally. If this trajectory persists, projections suggest that by 2050, this figure could soar to 26 billion tons. In the year 2022 alone, the production of plastic reached a staggering 390.7 million tons, with only 32.5 million tons originating from post-consumer recycled plastics [1,2]. Due to the chemical stability inherent in conventional plastics, the accumulation of plastic waste in the environment is on the rise, presenting significant threats to various animal species. These threats include physical entanglement and entrapment, acting as barriers to food supply, and causing congestion in digestive tracts [3]. When disposed of, plastic waste undergoes physical, chemical, and microbial degradation processes, transforming into micro and nanoscale-sized plastics of diverse structures and chemical compositions [4]. The accepted classification of plastic waste is based on its origin (primary and secondary) and size categories, which include macroplastics (>1 cm), mesoplastics (1–10 mm),

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microplastics (1–1000 μm; MPs), and nanoplastics (1–1000 nm; NPs) [5].

The aim of this paper is to provide an overview of the current understanding of the health implications associated with M-NPLs. Although the visible impacts of plastic waste on marine ecosystems and land habitats have received considerable attention, the threat of M-NPLs to organisms across all ecosystems, including humans, remains inadequately researched and understood [4].

2. Formation of M-NPLs

M-NPLs are formed through several processes, including:

2.1. Mechanical Breakdown: larger plastic items, such as bottles, bags, and packaging, gradually break down into smaller pieces through physical processes like abrasion from waves, sunlight, and friction against surfaces. This fragmentation results in microplastics.

2.2. Chemical Degradation: Exposure to environmental factors such as sunlight (UV radiation), heat, and certain chemicals can lead to the degradation of plastics. This process, known as photodegradation or chemical weathering, breaks down the molecular bonds of plastic polymers, resulting in the formation of smaller plastic fragments, including M-NPLs.

2.3. Biological Degradation: Microorganisms in the environment, such as bacteria and fungi, can also play a role in breaking down plastics through biodegradation. While this process is typically slower than mechanical or chemical degradation, it can still contribute to the formation of M-NPLs over time.

2.4. Primary M-NPLs: Some plastics are purposely manufactured at small sizes, such as microbeads in personal care products or microfibers from textiles. These primary M-NPLs are directly released into the environment and contribute to plastic pollution.

3. Routes of Human Exposure to M-NPLs

Understanding the pathways of human exposure to M-NPLs is vital for assessing potential health risks and implementing strategies to mitigate plastic pollution and protect human health. Humans and other organisms encounter M-NPLs primarily through ingestion, inhalation, and dermal contact. Exposure can happen through consuming contaminated food and water, inhalation of airborne particles, or dermal encountering M-NPLs (Figure 1).

3.1. Oral Intake:

Microplastics are found in numerous everyday items, including bottled beverages and water, salt, sugar, tea bags, and various foods. Europeans consume about 11,000 microplastic particles per person per year through shellfish, with total intake estimates ranging from 39,000 to 52,000 particles/person per year based on food consumption. They are also widespread in soil, where they can enter plants' water transport systems and contaminate crops. Take-out food boxes made of common polymer materials contribute to microplastic exposure, with individuals consuming take-out food potentially ingesting 12–203 microplastic pieces per week [6].

3.2. Inhalation of M-NPLs:

Inhalation is a significant human exposure route to M-NPLs. Studies have detected fibrous M-NPLs in the atmosphere, originating from sources like synthetic clothing, building materials, waste incineration, and landfill sites. These particles can end up in human lungs and sputum samples, with researchers finding varying quantities and sizes of M-NPLs in pulmonary tissue and respiratory samples. Upon inhalation, M-NPLs may undergo different fates, including systemic circulation, cellular internalization, and eventual removal from the body [4].

3.3. Dermal Exposure

Humans and other organisms can also absorb M-NPLs through direct contact with topical products such as cosmetics, body washes, pharmaceuticals, and medical devices. M-NPLs have been detected in products like hand and face washes, facemasks, sunscreens, and toothpaste, often in the form of beads that can be absorbed by the skin and potentially cause injury. Furthermore, M-NPLs are commonly used in prosthetic equipment, surgical instruments, and pharmaceutical agents. Although they do not typically penetrate the subcutaneous barrier under normal conditions, they can accumulate in hair follicles, and certain types have been observed to be absorbed by Langerhans cells. Additionally, damaged or injured skin, which is more permeable than intact skin, may provide a pathway for unintentional entry of microplastics [4].

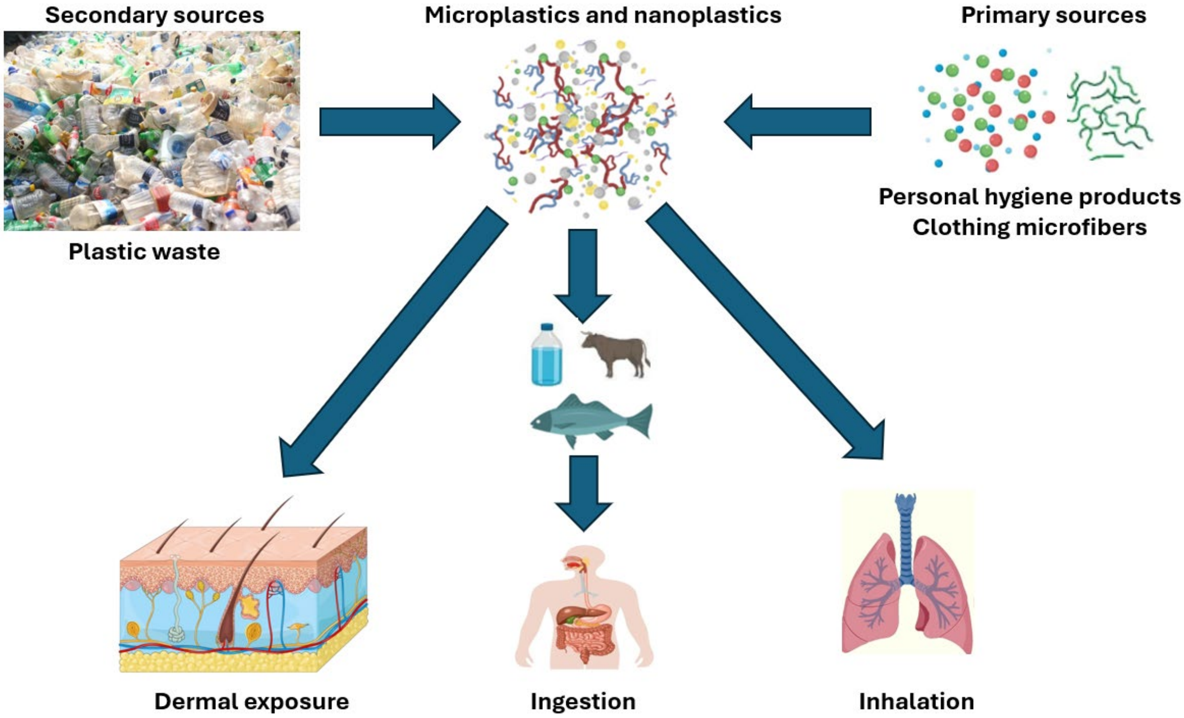

Figure 1: Flowchart showing pathways of human microplastic and nanoplastic exposure.

4. Impact of M-NPLs on Human Health

The primary route of exposure to M-NPLs is through ingestion of contaminated food or water, leading to potential intestinal homeostasis disruptions. Once ingested, M-NPLs interact with the intestinal environment, with larger particles remaining attached to the intestinal mucus layer and smaller particles potentially crossing into tissues through various mechanisms such as transcytosis and endocytosis. While most particles are excreted through feces, a small portion can persist in the intestine, causing damage and inflammation and potentially translocating into other tissues.

4.1. Toxicity of M-NPLs in the Digestive System

The effects of M-NPLs on the digestive system of humans are an area of active research and still not fully understood. However, several potential effects have been identified based on studies conducted on animals and some preliminary research in humans:

- **Alteration of Gut Microbiota**: Ingestion of M-NPLs has been linked to changes in the composition of the gut microbiota. These particles can affect the balance between beneficial and harmful bacteria in the gut, potentially leading to dysbiosis (microbial imbalance).

- **Inflammation**: Some studies suggest that exposure to M-NPLs may trigger an inflammatory response in the gastrointestinal tract. This inflammation can disrupt the normal functioning of the digestive system and may contribute to the development of gastrointestinal disorders [7].
- **Intestinal Barrier Dysfunction**: M-NPLs have been shown to interfere with the integrity of the intestinal barrier, which normally prevents harmful substances from entering the bloodstream. Disruption of this barrier can lead to increased intestinal permeability, allowing toxins and pathogens to enter the circulation and potentially cause systemic health problems [8].
- **Interaction with Nutrient Absorption**: There is some evidence to suggest that M-NPLs may interfere with nutrient absorption in the gut. By binding to nutrients or blocking absorption sites in the intestines, these particles may impair the body's ability to obtain essential nutrients from food [9].
- **Potential for Chemical Transfer:** M-NPLs have the capacity to absorb and concentrate harmful chemicals from the environment, such as persistent organic pollutants and heavy metals. Upon ingestion, these particles may release these chemicals in the digestive tract, potentially exposing the body to additional toxicants [10].

4.2. Toxicity of M-NPLs on the Respiratory System

M-NPLs can potentially have several effects on the respiratory system of humans:

- **Tissue Irritation and Inflammation:** Inhalation of M-NPLs can lead to tissue irritation and inflammation in the respiratory system. These particles may cause irritation of the nasal passages and throat, leading to symptoms such as coughing, sneezing, and throat irritation. In the lungs, M-NPLs may induce inflammation, which can contribute to respiratory diseases such as asthma and chronic obstructive pulmonary disease.
- **Pulmonary Toxicity:** Some studies suggest that exposure to M-NPLs through inhalation may lead to pulmonary toxicity, including damage to lung tissue and impairment of lung function. These particles can trigger oxidative stress and inflammation in the lungs, which may exacerbate respiratory diseases and increase the risk of respiratory infections.
- **Transport of Contaminants:** M-NPLs can act as carriers for other contaminants, including toxic chemicals and pathogens. When inhaled, these particles can transport these contaminants deep into the respiratory system, where they may exert harmful effects on lung health.
- **Potential Systemic Effects:** There is emerging evidence suggesting that MPs and NPs may have systemic effects beyond the respiratory system. Once deposited in the lungs, these particles may enter the bloodstream and circulate throughout the body, potentially affecting other organs and systems [11].

4.3. Toxicity of M-NPLs on the Cardiovascular System

While the understanding of the direct effects of M-NPLs on the cardiovascular system in humans is still evolving, several potential mechanisms and indirect effects have been proposed:

- **Inflammation and Oxidative Stress:** M-NPLs have been linked with the induction of inflammation and oxidative stress, both of which are involved in the development of cardiovascular diseases. Inhaled or ingested MPs and NPs may interact with immune cells and vascular endothelial cells, triggering inflammatory responses and the generation of reactive oxygen species in the cardiovascular system.

- **Endothelial Dysfunction,** characterized by impaired vasodilation, pro-inflammatory state, and increased permeability of blood vessels, is a key early event in the pathogenesis of cardiovascular diseases. M-NPLs could potentially disrupt endothelial function through direct contact with endothelial cells or through systemic effects mediated by inflammation and oxidative stress.
- **Thrombosis and Blood Coagulation:** it is thought that M-NPLs can promote thrombosis (blood clot formation) and affect blood coagulation pathways. In vitro studies have shown that certain types of M-NPLs can interact with platelets and other blood components, leading to platelet activation, aggregation, and thrombus formation. These effects may increase the risk of cardiovascular events such as heart attacks and strokes.
- **Cardiac Remodelling and Fibrosis:** Chronic exposure to M-NPLs may contribute to cardiac remodelling and fibrosis, which are hallmarks of various cardiovascular diseases, including heart failure. Animal studies have shown that exposure to M-NPLs can induce myocardial fibrosis, inflammation, and structural changes in the heart, which could potentially impair cardiac function over time [3].
- **Systemic Effects on Lipid Metabolism and Lipoprotein Profiles**: M-NPLs may interact with lipids and lipoproteins in the bloodstream, potentially altering lipid metabolism and circulating lipid profiles. Disruption of lipid homeostasis and dyslipidaemia are major risk factors for atherosclerosis and cardiovascular diseases. Although direct evidence in humans is limited, studies in animal models have suggested that M-NPLs can influence lipid absorption, metabolism, and distribution in the body [12].
- **Impact on Blood Pressure Regulation:** M-NPLs could potentially affect blood pressure regulation through various mechanisms, including endothelial dysfunction, inflammation, and oxidative stress. Chronic exposure to M-NPLs may disrupt the balance between vasoconstriction and vasodilation, leading to alterations in blood pressure and increased cardiovascular risk [3].

Probably the most noteworthy results were published in a 2024 paper in the New England Journal of Medicine, titled "Microplastics and nanoplastics in atheromas and cardiovascular events" [13], which showed that patients with carotid artery plaque in which M-NPLs were detected had a higher risk of experiencing a myocardial infarction, stroke, or death from any cause during the 34-month follow-up period compared with those in whom M-NPLs were not detected.

The current body of research on M-NPLs predominantly focuses on acute and short-term toxicity effects. However, there is a noticeable gap in long-term and systematic toxicity studies, necessitating urgent attention and future research endeavours.

Comprehensive investigations into the enduring impacts of M-NPLs on human digestive, respiratory, and cardiovascular systems are imperative to fully understand the potential health risks posed by these pervasive pollutants.

5. Conclusions and Perspectives

The surging use of plastic products has led to a drastic increase in plastic production, resulting in widespread environmental pollution. The accumulation of plastic waste, coupled with its degradation into (M-NPLs, presents a significant threat to ecosystems and human health. This paper has provided an overview of the formation of M-NPLs, routes of human exposure, and potential health impacts on the digestive, respiratory, and cardiovascular systems. Key findings suggest that M-NPLs may disrupt intestinal homeostasis, trigger inflammation, and interfere with nutrient absorption in the digestive system. In the respiratory system, inhalation of M-NPLs can lead to tissue irritation, inflammation, and potential pulmonary toxicity. Furthermore, M-NPLs may induce inflammation, oxidative stress, endothelial dysfunction, and thrombosis in the cardiovascular system, contributing to the development and progression of cardiovascular diseases. The lack of comprehensive long-term and systematic toxicity studies poses a significant challenge in fully assessing the health risks associated with M-NPL exposure. Immediate attention and future research initiatives are necessary to address this gap of knowledge and elucidate the enduring impacts of M-NPLs on human health.

Moving forward, interdisciplinary collaborations involving researchers, policymakers, and industry stakeholders are essential to facilitate robust risk assessments, develop effective mitigation strategies, and promote sustainable alternatives to mitigate plastic pollution and safeguard human health.

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