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The Effects of Microplastics and Nanoplastics on Human Health and the Environment

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ABSTRACT

Background and Objective: Microplastic and nanoplastic particles, because of their small size, readily penetrate water, soil, and air and, through the adsorption of hazardous pollutants, represent a serious threat to ecosystems and human health. The aim of the present study is to review and categorize the toxic effects of these particles on the environment and humans.

Methods: In the present narrative review study, articles published between 2000 and 2025 addressing the toxicity effects of micro-nanoplastic particles on the body's cells were examined. These articles were retrieved through searches using English keywords, including "Microplastics", "Nanoplastics", "Health effect", "Human", "Cell", "Tissues" and "Environment" in the PubMed, Scopus, ScienceDirect, and Google Scholar databases, as well as Persian keywords in the SID, Magiran, and Irandoc databases.

Findings: A total of 112 articles were selected from scientific databases in accordance with the research topic, and 84 articles were excluded from the study owing to a lack of relevance among the main keywords. According to the available data, the articles were categorized based on the effects of micro-nanoplastics on the liver, kidney, placenta, lung, neural cells, digestive system, blood, and immune system.

Conclusion: According to the results of this study, the toxicity of micro-nanoplastics depends on several factors, including particle size, the level and duration of exposure, and the type of target cell. Owing to their ability to penetrate various tissues and organs, particularly nanoplastics, which can reach the brain, these particles pose considerable risks to human health and the balance of ecosystems. Consequently, a more precise understanding of the mechanisms of toxicity and a reduction in exposure to these particles are essential for protecting human health and the environment.

Keywords: *Microplastic, Nanoplastic, Human Health, Environmental Pollution, Cell Toxicity*.

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Introduction

The presence of microplastics (MPs) as an emerging environmental pollutant is a major global concern owing to their harmful environmental effects (1, 2). MPs are plastic particles with a diameter of less than 5 mm, while nanoplastics (NPs) are typically 100–1000 nm (3). These particles can adsorb organic and inorganic pollutants because of their hydrophobic surface (4, 5) and can introduce chemicals derived from plastic additives, such as plasticizers and pigments, into the environment (6). The ubiquitous presence of plastic particles and nanoparticles in the environment and consumer products leads to human exposure through three main routes: inhalation, ingestion, and skin contact (7, 8). Furthermore, over the past decade, the development of nanotechnology has promoted a new set of materials for various industrial and consumer products. With their continuous commercialization, human exposure to nanoparticles has increased dramatically, and the assessment of their potential toxicity is essential (9), because nanoparticles—generally owing to their different physical and chemical characteristics compared with larger particles, such as their small size, high surface area, and strong biological penetration—may penetrate various organs, including the placenta and brain, and affect certain biological functions (7).

Furthermore, over time, plastics degrade into NPs and enter the food chain, contaminating food sources for human consumption more than previously expected. MPs and NPs are transferred to humans through various routes, such as tap water, bottled water, seafood, beverages, milk, fish, salts, fruits, and vegetables (1, 10-12). They are also present in personal care products, such as skin care products and cleansers, which are absorbed through the skin (13, 14). Research has shown that these particles have been detected in human stool samples, which confirms the exposure of the human body to these plastic particles (3, 15). In addition, these particles can cause oxidative stress, cytotoxicity, altered metabolism, immune system dysfunction, neurotoxicity, and cancer (16).

Zhou et al. reported that kidney organoids exhibited reduced size and abnormal tubular structure after MP exposure, underscoring the negative effects of these particles on kidney development (2). In the study conducted by Nacka-Aleksić et al., it was demonstrated that 40-nanometer polystyrene particles disrupt the mesenchymal phenotype of trophoblasts (17). Furthermore, the investigation of polystyrene nanoplastics in the study by Kim et al. revealed that these particles reduce proliferation and induce apoptosis in endometrial stromal cells (18). To date, a substantial body of research has been conducted to investigate the health risks of plastic particles and nanoparticles in animals; however, owing to interspecies differences, ethical limitations, strict biosecurity measures required for examining human samples, and limited laboratory techniques, investigations into the effects of plastic particles and nanoparticles on human health have been restricted (19-21). Given that no comprehensive study has been conducted in Iran concerning the effects of microplastic and nanoplastic particles on human body cells, the aim of this review study is to provide a categorization of the current knowledge regarding the factors influencing the entry of these particles into the body, their toxicity to human health and the environment, and potential clinical pathways, in order to establish a foundation for further research.

Methods

The present review study was approved by the Ethics Committee of Mazandaran University of Medical Sciences (approval code: IR.MAZUMS.REC.1402.296). In this study, articles published between 2000 and 2025 concerning the toxicity effects of nano- and microplastic particles (NMPs) on the human body were reviewed. These articles were retrieved using keywords such as "Microplastics", "Nanoplastics", "Health effect", "Human", "Cell", "Environment" and "Tissues" from the PubMed, Scopus, ScienceDirect, and

Google Scholar databases, and using the Persian keywords on SID, Magiran, and Irandoc databases. A total of 4 articles from domestic scientific databases and 108 articles from international scientific databases were obtained according to the research topic.

Results

After searching with the keywords mentioned, a total of 112 articles were found on the toxicity of microplastics and nanoplastics to human health. After removing duplicates, irrelevant articles, and articles whose full texts were not available (84 articles), 28 articles with full texts were made available. The articles were classified based on the effects of micro- and nanoplastics on the liver (3 articles), kidney (3 articles), placenta (3 articles), lung (2 articles), nervous system (4 articles), digestive system (6 articles), blood (4 articles), and immune system (3 articles), demonstrating that micro-nanoplastics can enter and affect various body cells.

Discussion

In this study, the factors influencing the entry of microplastic and nanoplastic particles into the human body through ingestion, inhalation, and skin absorption were examined, as well as the toxic effects of these particles on human health and the environment, including the risks arising from the adsorption of pollutants such as phthalates, heavy metals, and persistent organic pollutants. Potential clinical exposure pathways and the consequences associated with neurological and inflammatory diseases were also analyzed in this section.

Factors influencing the entry of plastic particles and nanoparticles into the body: Cellular uptake pathways and the intracellular fate of microplastics and nanoplastics play an important role in determining the function and biological response of these particles, and their toxicity is related to the number of particles that enter (22). Particles of different sizes can enter blood vessels and be transported to various tissues and organs via the bloodstream. Biological membranes serve as the primary barrier against the entry of these particles, and polyethylene (PE) nanoparticles can penetrate lipid membranes, causing membrane damage and thickening (23, 24). Uptake pathways are influenced by size, surface characteristics, and cell type; for example, particles larger than 50 micrometers have been observed more frequently in certain body fluids, such as cardiac and uterine effusions. In the study by Guan et al., the size of microparticles among different categories of body fluids exhibited specific characteristics (25). Furthermore, in the study by Li et al. (26), molecular simulations have shown that polystyrene and polyethylene nanoplastics readily enter the membrane, whereas polypropylene and polyvinyl chloride exacerbate membrane disruption. Inhaled nanoparticles, particularly particles smaller than 100 nanometers, can penetrate deep into the respiratory tract and cause pulmonary damage.

Toxic effects of microplastics and nanoparticles on health and the environment: The toxic effects of MPs and nanoparticles on health and the environment can be divided into three categories—physical, biological, and chemical—which are also examined based on clinical exposure pathways (19). Physical effects include the shape, size, and concentration of particles, the ingestion of which can cause physical damage and disorders in the digestive system. In aquatic environments, these particles are mistakenly consumed by marine organisms such as fish and shellfish, accumulating in their livers and becoming toxic (27). In the study by Davidson et al., the level of microplastics in Manila clams was estimated to range from 0.07 to 5.5 particles per gram (28). Microplastics contain two types of chemical substances: first, additives and raw polymeric materials that are added during plastic production to improve physical and mechanical properties and may include carcinogenic monomers such as PVC (1, 19, 29). Second, chemicals adsorbed

from the environment, such as toxins, dyes, and persistent organic pollutants, which can pose serious risks to human health and the environment (6). These chemical compounds can cause hormonal disorders, immune system weakening, inflammation, cardiovascular diseases, and even genetic alterations.

Phthalates: Phthalates (PAEs) are esters of phthalic acid that function as plastic additives and increase the flexibility of industrial polymers. Among the various types of phthalates, diethyl phthalate is classified as hazardous to the environment (30, 31). These substances are endocrine disruptors in animals and humans and cause gene mutation, carcinogenesis, and malformations (6). The processing of food containers and plastic packaging may lead to the contamination of beverages and foods with chemical additives, especially PAEs. Additionally, tea bags, due to their plastic coating, release MPs and phthalates when heated at high temperatures. The mechanism of absorption and transport of PAEs in the intestines of mammals may cause tissue damage, fibrosis, inflammatory and toxic effects on human lung cells, as well as infertility, sexual abnormalities, asthma, nephrotoxicity and hepatotoxicity, hypertension, type 2 diabetes, obesity, neurological disorders, and even cancer (32).

Heavy metals: Among the toxic pollutants that are adsorbed onto microplastic particles, heavy metals are key toxic pollutants in nature that are capable of interacting with nuclear proteins and DNA and causing damage. When they enter the environment through natural or anthropogenic activities, these metals are transported and accumulated via physical, chemical, and biological pathways. These metals also pose a threat to animals and human health through the food chain (33-35).

Persistent organic pollutants: Persistent organic pollutants (POPs) are recognized as harmful agents to humans and ecosystems, and these concerns are heightened when they interact with microparticles (36, 37). Currently, these include compounds that are intentionally produced or used in agriculture and disease control (such as dichlorodiphenyltrichloroethane, which is still used to control mosquitoes and prevent malaria in some parts of the world), or compounds that are unintentionally produced, such as dioxins or polycyclic aromatic hydrocarbons, which result from certain industrial processes and combustion (38). Exposure to these pollutants causes serious health problems, such as hormonal disorders, cancer, cardiovascular diseases, obesity, reproductive and neurological diseases, learning disabilities, and diabetes (36, 39).

Potential clinical exposure pathway: Table 1 presents the effects of micro-nanoplastics on various cell types of the body and demonstrates that microplastics and nanoplastics, after penetrating the stratum corneum and being absorbed by the human body, can interact with numerous target cells. Toxicity assessments of micro- and nanoplastics in humans have primarily focused on gastrointestinal and pulmonary toxicity, which includes oxidative stress, inflammatory responses, and metabolic disorders (19, 40). Referring to Table 1, it can be observed that most of the reported studies have been conducted using polystyrene, as this material is easily synthesized and converted into nanoparticles, whereas the most commonly used commercial plastics are polyolefins (such as polyethylene and polypropylene), polyesters, and polyurethanes (40, 41). Consequently, given the wide diversity in the size, shape, and chemical composition of plastics, the potentially hazardous effects of different types of micro- and nanoplastics on human health remain largely unknown. Therefore, future research should focus on understanding the potential hazards and risks of chronic exposure to diverse micro- and nanoplastics at environmentally relevant concentrations.

The results of this study demonstrated that the cytotoxicity of microplastics and nanoplastics varies depending on the type of cells, such as gastrointestinal cells, lung cells, immune cells, neural cells, hepatic cells, and others. The challenges of investigating the effects of micro-nanoplastics on human body cells include the small dimensions of these particles for detection and measurement, difficulties in the transport and distribution of these particles within the human body due to unintended and sudden effects on cells, the

unknown mechanism of action of these particles on cells and their impact on cellular and molecular activities, as well as their effects on biological processes. Although cellular uptake of plastic particles occurs, awareness of their clearance rate is also important. Therefore, by designing extensive and multifactorial studies using specific cell types under identical experimental conditions, it may be possible to obtain reasonably accurate results regarding the effects of these particles on various body cells.

Table 1. The effect of micro-nanoplastic particles on various cells and tissues of the body

Cell type	Particle type	Article summary and results	Reference
Liver	NPs	At NP concentrations below 0.0125 mg/mL, they can enter cells and cause mitochondrial damage and overproduction of reactive oxygen species, which leads to changes in mitochondrial membrane potential.	(9)
	MPs	When liver organoids were exposed to PS concentrations of 0.25, 2.5, and 25 µg/mL, potential mechanisms of PS-MP-induced hepatotoxicity and lipotoxicity were determined, including ATP production, altered lipid metabolism, ROS production, oxidative stress, and inflammatory response.	(16)
	NPs	The cytotoxicity of polystyrene (PS) nanoplastics operates through a molecular mechanism involving oxidative stress-induced damage to mitochondria and the cell membrane, leading to reduced adenosine triphosphate production and increased membrane permeability.	(26)
Kidney	NPs	When particle size was above 100 nanometers, there was no obvious cell death. As particle size decreased below 100 nanometers, cell mortality increased.	(26)
	MPs	Results showed that the uptake of PS-MPs at various concentrations by human renal proximal tubule cells (HK-2 cell line) led to higher levels of mitochondrial reactive oxygen species (ROS), and exposed cells had higher endoplasmic reticulum stress and inflammation markers.	(42)
	NPs	PS-NPs increased ROS production and caused structural changes in the mitochondrial and endoplasmic reticulum networks.	(43)
Placenta	NPs	Nanoparticles entering the trophoblast cytoplasm led to reduced cell viability, cell cycle arrest, decreased cell invasion ability, increased intracellular reactive oxygen species levels, and production of pro-inflammatory cytokines in a dose-dependent manner.	(9)
		NPs pose significant risks to the placenta through inhibition of its key enzymes.	(15)
		After 24 hours of exposure to PS-NPs at a concentration of 50 µg/mL on the human trophoblast cell line HTR8/SVneo, 40% of cells died and the morphology of the remaining cells changed. These particles also enter cells and affect the formation of the endoplasmic reticulum and mitochondrial networks.	(44)

Lung	MPs	Most particles observed were in the structure of PS, nylon, and polyethylene terephthalate. The presence of these particles in industries involved in the production of plastic products can be a serious risk for workers.	(45)
		PS nanoparticles lead to reduced cell survival, activation of inflammatory gene transcription, changes in the expression of cell cycle-related proteins, and cell death. These particles can cause specific damage and functional disorders in the human respiratory system.	(46)
Neural cells	MPs, NPs	Neurotoxicity caused by MPs mainly causes oxidative stress and acetylcholinesterase inhibition. Also, oxidative stress caused by microplastics in brain tissue may cause DNA damage, mitochondrial dysfunction, and ultimately cell death through free radical attacks on neurons.	(47)
	NPs	They can cause severe toxicity and changes in metabolic activity in various cells of nervous tissue, depending on cell type and concentration. Also, microglial cells and primary brain cell culture showed greater toxicity at the highest concentration of carboxylated PS nanoparticles.	(48)
		NPs enter muscle tissue through the larval epidermis, causing mitochondrial damage in muscle and destroying nerve fibers (atrophy) and inhibiting acetylcholinesterase activity.	(49)
	MPs, NPs	SH-SY5Y neuroblastoma cells were exposed to PS-NPs at different concentrations and sizes. Findings showed that these particles were phagocytosed by cells. The effect of PS-NPs on cell viability depended on their concentration and size, such that increased concentration led to reduced cell viability, with the smallest particle size showing the greatest toxicity.	(50)
Gastrointestinal cells	MPs, NPs	A digestive process aided by simulated digestive fluid was used to test the effects of digestive treatment on the toxicity and function of MPs and NPs at concentrations of 1 and 20 µg/mL. It was reported that digestive treatment reduces cytotoxicity and CaCO2 transport dysfunction.	(20)
	MPs	MPs accumulation causes multiple toxic effects in the intestine, including mucosal damage and increased permeability, inflammation, and metabolic disorders.	(27)
	MPs, NPs	Disruption of intestinal flora balance, as well as loss of secretory glands and increased loss of villi, accompanied by leukocyte infiltration and inflammation.	(47)
	MPs	The effect of repeated 14-day exposure to a dose of 21 µg/day of PE-MPs on human intestinal microbiota and intestinal barrier using an artificial colon mucosa model, along with co-culture of intestinal epithelial and mucus-secreting cells, caused increased abundance of potentially harmful bacteria, Enterobacteriaceae and Desulfovibrio, and decreased beneficial bacteria.	(51)

	MPs, NPs	The association of MPs in human stool with inflammatory bowel disease showed that the mixture of MPs with Helicobacter pylori significantly accelerates H. pylori infection and enhances the inflammatory response of gastric and intestinal tissues.	(52)
		To create epithelial tissue to mimic cellular complexity and natural body tissue function, organoids isolated from patient intestines were used, and it was shown that high concentrations of particles significantly cause secretion of inflammatory cytokines associated with human inflammatory bowel disease.	(53)
Blood cells	PS particles	RBC hemolysis after direct contact with PS particles at different concentrations and sizes showed that smaller particles tended to aggregate more due to their size, and high concentration affected RBC hemolysis.	(54)
	Carboxylated PS nanoparticles	PS nanoparticles can be adsorbed onto RBCs, and especially PS nanoparticles with a size of 27 nanometers can induce changes in cell shape.	(55)
	PS nanoparticles	PS nanoparticles (0.05, 0.2, and 0.5 µg/mL) had negative effects on RBC and endothelial cell function in the vascular system and cause blood disorders.	(56)
	MPs-PS	Direct effects of microplastics on fibrin clot formation under laboratory conditions showed that, depending on surface charge and particle concentration, they had inhibitory effects on fibrin clot formation.	(57)
Immune cells	NPs	A laboratory study on human lung cells showed that PS nanoparticles can activate the immune system through increased autophagic flux.	(19)
		Carboxylated PS nanoparticles in the range of 10–2000 µg/mL affected uptake, cytotoxicity, cytokine release, phagocytosis, oxidative burst, nitric oxide production, and myeloperoxidase production in model test cells.	(58)
	MPs, NPs	Commercial and environmental MNPLs, at a concentration of 1 mg/mL, significantly stimulate inflammatory IL-1β and IL-6 secretion in a time-dependent manner, and PET-rich environmental samples showed a strong dose-dependent response and induced IL-1β secretion at doses as low as 100 ng/mL.	(59)

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