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Microplastics And Nanoplastics: Environmental Sources, Human Exposure Pathways, And Potential Health Impacts

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Abstract:
Plastics have a profound impact on daily life, including packaging, medicine, and household items. Their disposal after single use and subsequent breakdown into micro- and nano-plastics raise significant concerns about their effects on ecosystems and human health. Microplastics and nanoplastics have emerged as ubiquitous contaminants in natural and human-made environments, including oceans, freshwater systems, and the atmosphere. These particles have been implicated in sources of human exposure including contaminated seafood, drinking water, and various food items, exacerbated by migration from packaging materials. This systematic review synthesizes current literature on the sources, pathways, and health impacts of these particles, focusing on human exposure and associated risks. Microplastics and nanoplastics can enter the human body primarily through ingestion, inhalation, and dermal contact, posing potential health risks such as oxidative damage, inflammation, and disruption of physiological processes in the gastrointestinal, central nervous system, nephrons and respiratory systems leading towards gastrointestinal disturbances, neurotoxicity, nephropathy, and respiratory diseases. This paper aims to inspire further studies to understand the full extent of microplastic and nanoplastic contamination, their interaction with biological pathways and the implementation of effective regulatory measures to mitigate human health risks associated with these particles.

Introduction

Over the past seven decades, the global production of plastics has surged, leading to its pervasive spread into the environment (Campanale et al., 2020). The studies reported that global plastic production exceeded 368 million tons in 2019 (Garside, 2019). Plastics significantly influence various aspects of daily life, from technology and medicine to household appliances and they are discarded by consumers after just one use and often end up in landfills, oceans, and other waterways, leading to a major environmental issue (Yee et al., 2021). Nowadays Microplastics and nanoplastics are ubiquitous pollutants with sizes ranging from 1 µm to 5 mm and 1 nm up to 1000 nm respectively. These particles result from the degradation of larger plastic materials through photo-oxidation and biodegradation which pose a significant threat to both environmental and human health due to their persistence and potential to interact with biological systems (Amobonye et al., 2021; Ziani et al., 2023; Ali et al., 2023). The contamination by microplastics and nanoplastics, ranging from oceans and rivers to the air we breathe, has emerged as a critical environmental and public health issue (Priya et al., 2022; Laskar, 2019). Their pervasive presence is alarming due to the complex pathways they enter and persist in ecological and human systems (Stapleton, 2023). Given their small size, these particles can easily infiltrate natural ecosystems and, subsequently, the human food chain through the ingestion of contaminated water, seafood, and even airborne particles (Giri et al., 2024). Recent research has illuminated the widespread distribution of microplastics in various environmental matrices, including wastewater, freshwater, and the atmosphere (Talukdar et al., 2024). Once inside, they can accumulate in vital organs, including the lungs, liver, kidneys, and brain potentially causing a spectrum of health issues. These range from gastrointestinal disturbances and respiratory conditions to neurotoxicity and carcinogenic effects. Microplastics ability to carry and release toxic compounds further exacerbates their impact on human health (Campanale et al., 2020). Due to the widespread presence and potential health risks associated with microplastic and nanoplastic contamination, there is an essential need for further research and regulation, emphasizing the critical need to understand the pathways through which these particles enter and persist in ecological and human systems is crucial for developing effective mitigation strategies. This review consolidates the current knowledge on the sources, route of exposure, and health impacts of microplastics.

Literature Search

A systematic search was conducted using scientific databases such as PubMed, Scopus, and Web of Science was conducted up to May 2024 using keywords such as microplastics, human health, toxicity, and biochemical interaction. Studies were selected based on relevance, focusing on peer-reviewed articles.

Sources of Microplastics

Recent studies have documented the pervasive presence of micro and nanoplastics in diverse environmental systems such as wastewater, freshwater, and the atmosphere (Szymanska et al., 2020). Research has identified various sources of microplastic contamination in human consumables, including tea cups and a wide range of packaging materials such as beverages, energy drinks, and cold tea with packaging materials such as plastic food containers and disposable cups implicated (Shruti et al., 2020; Jadhav et al., 2021). Microplastics and nanoplastics have been found in diverse food items, including seafood, drinking water, honey, sugar, milk, fruit, and meat, indicating multiple pathways through which they can enter the human body (Pironti, 2021). Seafood, particularly bivalves, filtering organisms, and small fish, is a notable source of microplastic ingestion (Martínez, 2018). Moreover, Microplastics and nanoplastics have also been detected in vacuum-packed fish, raising concerns about the potential for human exposure through consumption of packaged foods (Nalbone et al., 2021). They have been found in take-out food containers, with the highest abundance in polystyrene (Du et al., 2020). In packaged meat, microplastics from extruded polystyrene trays have been identified (Kedzierski, 2020).
Studies have shown that plastic teabags release substantial amounts of microplastics and nanoplastics into tea during the steeping process (Hernandez et al., 2019). The study conducted by Li et al., 2022 further supports the microplastic and nanoplastic contamination in beer, mineral water, and tea, emphasizing the potential for these particles to enter the food chain (Li et al., 2022). Agricultural farmland contamination with micro- and nanoplastics also highlights their widespread presence and associated (Harms et al., 2021). Consumer plastic food containers, including those used for food delivery, are also a potential source of microplastic exposure (Fadare et al., 2020). Addressing these concerns highlights the need for further research and regulatory measures to mitigate the health risks of microplastic and nanoplastic contamination in the food chain.
Kadac-Czapska (2022) highlights the role of food, particularly fish, shellfish, and other consumables, as a major route of exposure to microplastics. These particles can enter the human body through the consumption of contaminated beverages, potentially posing health risks (Altunışık, 2023). Drinking water has emerged as a significant source of microplastic contamination as it revealed the presence of plastic particles in over 90% of bottled water samples across various countries (Siegel, 2018). Rose et al. (2023) further emphasize the role of soil as a carrier of microplastic contaminants, with potential impacts on the food web and human health. Ali et al., 2023 underscore the prevalence of microplastics in freshwater systems, particularly from wastewater treatment plants, and their potential to cause harmful physical effects and act as carriers of toxins.

Route of Entry

Microplastics and nanoplastics can enter the human body through various routes, such as ingestion, inhalation, and dermal contact (Setala, 2018; Sun et al., 2023). The most common exposure pathways for humans are through food and the respiratory system (Rodrigues et al., 2022). Microplastics are present in the atmosphere, especially in urban areas, and indoor environments, where synthetic textiles with higher concentrations can be inhaled through respiration (Wright et al., 2020). The most common route of human exposure is believed to be through the gastrointestinal tract, with various food types being contaminated with microplastics and nanoplastics (Kadac-Czapska et al., 2024). Studies indicate that microplastics can translocate from the gut and respiratory tract to other organs, including the liver, kidney, and even the brain (Ramsperger et al., 2023). Particle size, shape, and chemical composition influence their biodistribution and persistence within tissues. While the absorption of microplastics across the gastrointestinal tract is relatively low, their potential toxicity, particularly in the form of nanoparticles, is a concern (Paul et al., 2020). However, estimating human exposure to microplastics through food consumption is challenging due to the lack of studies on non-seafood items and the need for optimized analytical methods (Kwon et al., 2020). Direct contact with contaminated water or soil, as well as the use of certain dermal products, can lead to the absorption of microplastics through the skin (Enyoh et al., 2020).

Health Complications

The accumulation of micro and nano plastics in various organs such as the lungs, liver, kidneys, and brain, leads to a range of health issues (Bastyans 2022; Zhang et al., 2024). These include gastrointestinal disturbances, respiratory conditions, neurotoxicity, nephrotoxicity and potential cancers. More research is needed to fully understand the health risks associated with microplastic pollution and to establish risk assessment frameworks (Ma, 2024).

Effect on Intestine

Research has shown that microplastics and nanoplastics have a range of effects on the gastrointestinal tract in humans (Fournier et al., 2021). Studies have shown that microplastics can cause oxidative damage, inflammation, and destruction of the gut epithelium, leading to disturbances in the intestinal microenvironment (Huang et al., 2021). Furthermore, they can alter mucus secretion, the permeability of tight junctions, and the intestinal microbiome, potentially leading to dysbiosis (Fackelmann and Sommer, 2019). Microplastics and nanoplastics can act as vectors for heavy metals such as chromium and lead, which can be released into the body during the digestive process (Godoy et al., 2020). This can further lead to cholestasis and dysregulation of bile acid metabolism through a gut-liver axis (Wen et al., 2024). Despite the

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resistance of microplastics to digestion, they can still be found in the gastrointestinal tract of fish, potentially posing a risk to human health (Stock, 2019; Karuppasamy, 2020).
Djouina et al., 2022, reported that oral exposure to polyethene microplastics has been found to alter gut morphology, immune response, and microbiota composition in mice, indicating potential similar effects in humans. The *In vitro* study conducted by Shi et al., 2022, have also demonstrated that prolonged exposure to microplastics can induce cytotoxicity, lysosomal membrane permeabilization, and oxidative damage in human intestinal cells, leading towards intestinal disorders. These findings collectively suggest that microplastic exposure can be a significant factor in the development of gastrointestinal disturbances in humans.

Effect on Respiration

A series of studies have highlighted the detrimental effects of microplastic exposure on the respiratory system. Inhaled microplastics and nanoplastics with plastic additives, can induce pro-inflammatory or pro-carcinogenic effects on the respiratory system (Lombardi, 2022). Research has shown that microplastics, including nanoplastics, can penetrate human airway tissues and cells, leading to mitochondrial dysfunction and impaired bioenergetics (Winiarska et al., 2024). These particles can translocate to the circulatory and lymphatic systems via the respiratory and gastrointestinal tracts, potentially causing chronic inflammatory responses, neoplasia, and fibrosis (Silva, 2023). Furthermore, microplastics can carry toxic compounds and stimulate a chronic inflammatory response, leading to potential health issues (Caputi et al., 2022).
Microplastics and nanoplastics have been shown to have particularly detrimental effects on bronchial epithelial cells. For example, Jeon et al. (2023) found that polystyrene microplastic particles induced autophagic cell death in these cells, leading to inflammatory responses in the lungs. This finding is corroborated by Lu et al. (2021), who demonstrated that microplastic exposure caused pulmonary inflammatory cell infiltration and increased TNF-α levels. Dong et al. (2019) also highlighted the cytotoxic and inflammatory effects of polystyrene microplastic particles on lung epithelial cells. Furthermore, Van et al. (2021) found that inhalable textile microplastic fibres impaired the growth of airway epithelial cells.
Exposure to microplastics and nanoplastics, particularly originating from polyethene, has been shown to increase airway smooth muscle contractility, mimicking the pathophysiological responses in respiratory diseases (Anuar et al., 2021). The *in vivo* study conducted by Lu et al., 2021 revealed that microplastic exposure has been associated with pulmonary inflammation, increased mucus production, and altered gene expression, indicating a potential risk to respiratory health. Studies have shown that microplastics can have a detrimental effect on the alveoli and lungs. The study conducted by Xu et al. (2019), showed that polystyrene nanoparticles, can significantly affect the viability of human alveolar epithelial cells and trigger a TNF-α-associated apoptosis pathway, which can impair the biophysical function of pulmonary surfactant, leading to proinflammatory responses and lung injury. These effects include increased cell death and mediator production (Hu et al., 2020: Xu et al., 2023).
Lu et al., 2021 studied that, exposure to microplastics led to pulmonary inflammation and altered gene expression, affecting both healthy and asthmatic mice. Anuar et al., 2021 further demonstrated that polyethylene microplastics can increase airway smooth muscle contractility, potentially exacerbating respiratory diseases. Lu et al., 2023 provided evidence of microplastic presence in the lower respiratory tract, particularly in smokers, suggesting a link between smoking and microplastic inhalation. Finally, Dong et al., 2020 showed that polystyrene microplastics can induce cytotoxic and inflammatory effects in lung cells, potentially increasing the risk of lung disease. Collectively, these studies underscore the significant impact of microplastics and nanoplastics on bronchial health and highlight the need for further research and action to mitigate the impact of microplastics on respiratory health.

Effect on the central nervous system

The neurotoxicity of micro and nanoplastics is complex and multifaceted. Research indicates that microplastics can have a significant impact on neural toxicity. Studies have shown that microplastics can cause size-dependent neurotoxicity, oxidative stress, and altered antioxidative system and metabolism (Lei et al., 2018; Prokic et al., 2019). Micro and nano plastics can accumulate in the brain and induce cellular stress, leading to neurodegeneration (Han et al., 2023). The specific mechanisms through which microplastics affect neurotransmission are not yet fully understood, but they can have a significant impact on neuronal plasticity and synaptic function (Rojoni et al., 2024).
Micro and nanoplastics can influence the folding of proteins and potentially trigger the development of amyloidosis (Windheim et al., 2022). Exposure to micro and nano plastics can lead to inhibition of acetylcholinesterase activity, altered neurotransmitter levels, and behavioural changes (Prüst et al., 2020). The interaction between microplastics and other pollutants, such as mercury, can exacerbate these effects, leading to neurotoxicity through oxidative damage, and changes in energy-related enzymes (Barboza et al., 2018). Studies conducted by Savuca et al., 2023 on zebrafish have shown that exposure to plastic nano- and microparticles can lead to oxidative stress, which in turn can cause neurodevelopmental issues and behavioural impairments.

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Effect on kidney

Micro and nanoplastics can accumulate in kidney tissue after ingestion or inhalation can lead to inflammation, oxidative stress, and potentially impaired kidney function (Arpita et al., 2023). A study by Li et al. (2020) demonstrated that polystyrene microplastics could cross biological barriers and accumulate in the kidneys of mice. Upon accumulation, the particles can induce oxidative stress in kidney cells. Research by Deng et al. (2021) showed increased levels of reactive oxygen species and decreased antioxidant enzyme activities in the kidneys of zebrafish exposed to polystyrene microplastics. In addition, these particles can trigger inflammatory responses in kidney tissue. Wang et al. (2022) observed increased expression of pro-inflammatory cytokines in the kidneys of rats exposed to polyethylene microplastics. Furthermore, micro and nanoparticles can cause structural alterations in kidney tissue. A study by Zhang et al. (2023) reported glomerular basement membrane thickening and tubular atrophy in mice chronically exposed to polypropylene nanoplastics. The investigation by Zou et al. (2022) reported that microplastics exacerbate cadmium-induced kidney injury in mice by enhancing oxidative stress, apoptosis, autophagy, and fibrosis. Chen et al. (2022) found altered levels of serum creatinine and blood urea nitrogen in rats exposed to polyethylene terephthalate microplastics, indicating potential renal dysfunction. The chemicals adsorbed onto the surface of microplastics can leach into the body and contribute to additional damage to the kidneys (Arpita et al., 2023). The study conducted by Wang et al., 2023 reported the impact of oxidative stress induced by polystyrene microplastics on kidney function. They found that these microplastics disrupted serum blood urea nitrogen, and creatinine levels as well as pro-inflammatory mediators like IL-1β, IL-6, and TNF-α in the kidney of rats. Additionally, these particles can adsorb harmful chemicals like polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and heavy metals on their surface, further exacerbating the damage to the kidneys (Arpita et al., 2023). While these studies provide initial insights into the potential renal toxicity of MNPs, more research is needed to fully understand the long-term impacts on human kidney health and to establish safe exposure limits.

Conclusion

Microplastics and nanoplastics are ubiquitous environmental pollutants that pose significant risks to human health. These tiny plastic particles are found in a wide range of consumables, including seafood, drinking water, and packaged foods, leading to multiple pathways for human exposure. The most common routes of entry into the human body are ingestion, inhalation, and dermal contact. Upon entering the human system, they tend to accumulate in various organs such as the lungs, liver, kidneys, and brain, leading to a range of health issues. These particles can cause oxidative damage, inflammation, and alterations in cellular metabolic pathways. The gastrointestinal tract, respiratory system, central nervous system, and kidneys are particularly affected, with potential consequences including gastrointestinal disturbances, respiratory conditions, neurotoxicity, nephrotoxicity, and even cancer. It is necessary for further research and development of regulatory measures to mitigate the health risks caused by microplastic and nanoplastic pollution. Also, there is a critical need for analytical methods to measure human exposure through food consumption and to fully understand the long-term effects on human health.

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