REVIEW ARTICLE

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Invisible Threats: Ecophysiological Effects of Microplastics on Human Physiological and Neurological Systems

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Abstract

Microplastics have become ubiquitous environmental pollutants found in soil ecosystems, food systems, water, and air. There is growing evidence that these particles can enter the human body by ingestion, inhalation, and skin contact, which raises questions about possible physiological and neurological effects. The objective of this study is to compile the most recent research on the origins of microplastics, exposure routes, and possible health impacts on humans, with a focus on neurological and eco-physiological processes. Numerous organ systems, including the digestive, respiratory, cardiovascular, and neurological systems, may be impacted by microplastics' potential to cause oxidative stress, inflammation, endocrine disruption, and cellular toxicity. Additionally, new research suggests that microplastic particles may be able to pass through biological barriers like the blood–brain barrier and cause neurotransmitter imbalance and neuroinflammation. This Review talks about Chronic Neurodegeneration: Chronic inflammation that triggers a cycle of neuronal deterioration, including multiple sclerosis, Parkinson's, Alzheimer's, and other neurological illnesses in humans. Additionally, the paper talks about how MPs may facilitate the entry of other toxic substances into fish, which affects humans in the form of bioaccumulation. These toxins can accumulate in fish that consume MPs, endangering both the fish and the humans who consume them. Significant information gaps about long-term human exposure and toxicity thresholds still exist despite expanding research. In order to limit human exposure to microplastics, environmental policies and mitigation measures must take these mechanisms into account.

Major Findings: The major findings suggest that microplastics get into the human body through the contaminated food chain, where microplastics cause neurotoxicity, oxidative stress, and inflammation. Substantial knowledge gaps are present about the long-term effects on human health.

Keywords: Environmental Pollution, Hazardous Pollutant, Microplastics, Neurological Health, Physical Health, Toxicity

1. Introduction

Microplastics (MPs), because of their tenacity, extensive distribution, and capacity to infiltrate the food chain, are defined as minute-size plastic particles of no more than five millimetres (mm) in diameter and have become a significant environmental contaminant[1].

These microscopic particles are either purposefully created for industrial uses, as in textiles, cosmetics, cleaning supplies, and personal items, or they are the outcome of more extensive plastic garbage breaking down. The widespread use of plastic materials in terrestrial, marine, and atmospheric environments due to their global production has sparked worries about

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the possible health dangers connected to their presence in human ecosystems[2]. As studies on MPs' effects on the environment advance, more focus is being placed on how they could affect human health[3]. Studies show that ingestion, inhalation, and skin absorption are some of the ways that humans might be exposed to MPs. However, little is known about how MPs, especially those that are smaller than microns, affect human health.

This study compiles the most recent information on MPs' exposure pathways, toxicological consequences, and possible health hazards. A newspaper article was presented regarding MPs in Indian salt and sugar brands. A Test carried out on salt and sugar that were purchased from online and local markets in India shows the presence of MPs, as Environmental Research Organisation "Toxic Link" asserts that the test, which was carried out on 10 types of salt and 5 types of sugar-containing MPs whose size included the spectrum from 0.1 mm to 5 mm, they were present in various configuration as filaments, pellets, films, etc. According to the report, the highest quantity of MPs was found in iodised salt at 89.15 pieces per kilogram. Emphasising sugar samples, the range of MPs was from 11.85 to 68.25 per kilogram, with non-organic sugar reported the highest levels. The minimum average intake of MPs from sugar stands at 0.47 pieces, while the maximum was 2.73 pieces. For salt, the minimum and maximum microplastic consumption by an average Indian stands in the range of 0.07 to 0.097 pieces. The integration of maximum and minimum values for both salt and sugar concluded that the daily intake of MPs ranged from 0.55 to 3.71 pieces[4]. Nine per cent of plastic waste is recycled; in total, fifteen per cent is collected for recycling, of which sixty per cent is successfully recycled. Twenty-two per cent enters waste management systems that transport it to uncontrolled dumpsites where it burns in open pits or ends up in terrestrial or aquatic habitats in underdeveloped countries, while the remaining nineteen per cent is burnt, and fifty per cent ends up in landfills[5].

The objective of this review is to compile current scientific knowledge on the sources, exposure pathways, and eco-physiological effects of microplastics on human health, with a focus on neurological mechanisms and potential research needs.

2. Literature Review Methodology

This review was carried out using a systematic search of scientific literature from databases such as PubMed, Scopus, Web of Science, and Google Scholar. MPs, human exposure, neurotoxicity, plastic pollution, oxidative stress, microplastic toxicity, and eco-physiological effects were among the keywords utilised. Most of the studies that were taken into consideration were published between 2010 and 2024. The study comprised peer-reviewed articles, experimental investigations, and review papers on the effects of microplastics on biological systems. Articles unrelated to physiological or neurological effects or with insufficient scientific support were eliminated.

3. Routes of Microplastic Exposure in Humans

The three main ways that humans can be exposed to MPs are by ingestion of food items, inhalation of particles in the air, and dermal absorption. Several mechanisms facilitate MPs' build-up in human tissues and organs. As people ingest plastic particles found in tainted food and water, ingestion is considered the most frequent way that people are exposed to microplastics. According to a recent study, depending on food and lifestyle, the average person may consume anywhere from 39,000 to 52,000 MPs annually[6]. MPs are commonly present in bottled water, shellfish and other foods, and MPs contamination in drinking water samples from all across the world, demonstrating that MPs enter the human gastrointestinal tract through drinking water[7]. Various studies have examined the pathways of microplastic exposure and their health implications. Table 1 summarises research findings related to microplastic contamination and its distribution.

3.1 Inhalation and Dermal Absorption

Different methodologies were used to detect and analyse microplastics in various studies. Table 2 presents a comparison of materials, methods and approaches in different studies.

Dermal exposure to microplastics is a possible problem, particularly for people who use personal care products that include microbeads. There are two ways that MPs and NPs can penetrate the skin: one good way is that one can use MPs to deliver drugs and imaging agents directly into the body, known as nanomedicine, and the bad side is that if the MPs penetrate the skin, they carry toxins into the body[12]. The properties of particles define the penetration of plastic particles inside the skin, due to

Table 1. MPs exposure through seafood and implications for human health

Author	Title	Objectives	Materials/ Methods	Findings
Smith *et al.*[6]	MPs in seafood and the implications for human health	To determine the level of microplastic contamination in seafood and the potential effects on human health	Detection of microplastics in seafood products and assessment of human exposure through consumption of fish in the diet.	MPs are present in seafood, with implications for human health through dietary exposure.
Bergmann *et al.*[7]	High Quantities of MPs in Arctic Deep-Sea Sediments from the HAUSGARTEN Observatory	To quantify MPs contamination in Arctic deep-sea sediment	Sediment sample collection and analysis from the Arctic's HAUSGARTEN Observatory	Deep-sea sediments from the Arctic were discovered to contain high levels of MPs.
Choi *et al.*[8]	Evaluation of MPs' toxicity in accordance with different-sized MPs in marine zooplankton	To evaluate the toxicity of different-sized MPs using marine zooplankton	Experimental toxicity study using marine zooplankton exposed to various sizes of microplastics	MPs' toxicity varies according to particle size; significant impacts on marine zooplankton health and marine ecosystems.

The build-up of MPs in marine zooplankton significantly impacts human health and marine ecosystems. The characteristics and main conclusions of the study on MPs' toxicity in marine zooplankton were illustrated in Figure 1.

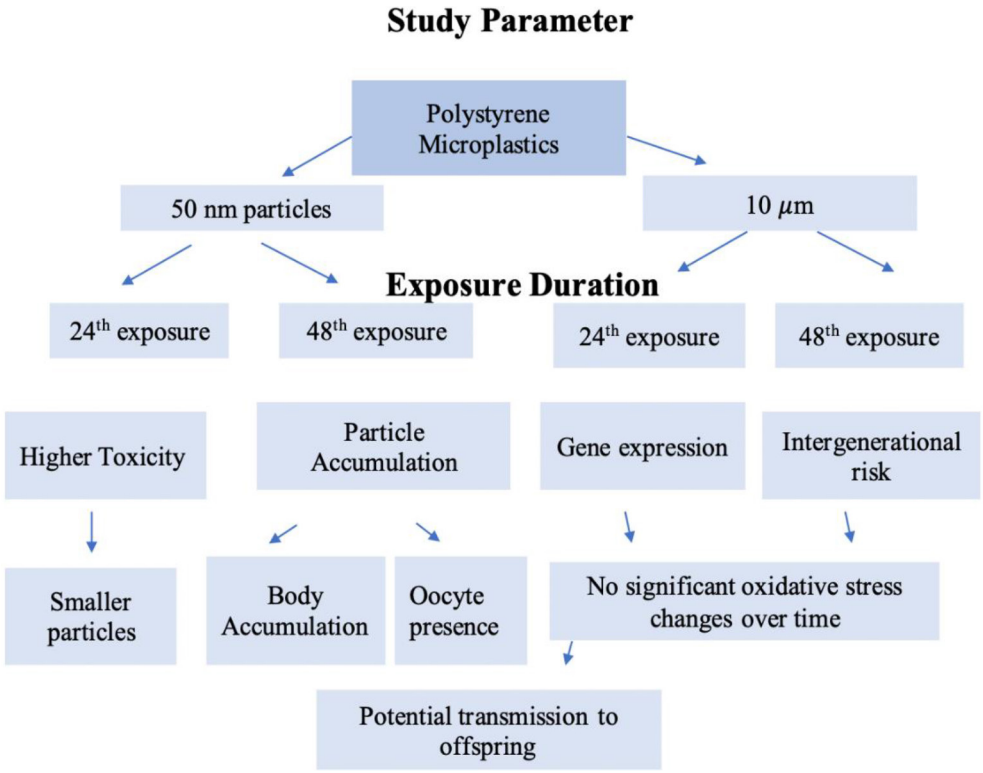


Figure 1. Study parameters and key findings in marine Zooplankton (Choi *et al*)[8].

the density of particles as heavier particles are generally harder to suspend and transport, the chemical reactivity also determines the penetration of plastic particles inside the skin as particles start corroding and dissolving the barrier of the skin, due to the size of MPs diffuse randomly and collide with the barrier through Brownian Motion. MPs are non-spherical in shape; hence, they have a greater chance of being intercepted or impinging on the surface of the skin because they present a larger cross-sectional area in some orientations[13]. MPs are found in the cosmetics

Table 2. Overview of research on airborne microplastics and detection approaches

Author	Title	Objectives	Materials/Methods	Findings
Rednikin, *et al.*[9]	Airborne MPs: Challenges, prospects, and experimental approaches	To review challenges and experimental approaches for studying airborne MPs	Literature review of airborne MPs detection methods and exposure assessment.	Comprehensive review of methodologies and challenges in assessing airborne MPs exposure
Borgatta, M., and Breider, F.[10]	Inhalation of MPs -A toxicological complexity	To review the toxicological complexity of MPs' inhalation	Literature review and analysis of MPs' inhalation exposure and toxicity	Daily accumulation rates of MPs in human lungs can reach up to 130 particles, representing a significant exposure risk.
Revell, *et al.*[11]	Micro (nano) plastics: A threat to human health?	To determine whether human health is at risk from micro and nanoplastics (NPs)	Literature review of toxicological and epidemiological evidence on plastic particle health effects	Research indicates that human health may be at risk from micro and nanoparticles (NPs) through a variety of routes.
Menichetti *et al.*[12]	Penetration of MPs and NPs through the skin: a study of surface chemistry and shape	To study how microplastics and NPs' surface chemistry and shape affect skin penetration.	Experimental analysis of different MP types and their penetration through skin models	The capacity of micro- and NPs to enter skin is greatly influenced by surface chemistry and particle form.
Arísitzabal *et al.*[13]	MPs in dermatology: Potential effects on skin homeostasis	To investigate how MPs could affect the homeostasis and health of the skin	Review of literature and research on dermal absorption and effects of MPs on skin	MPs have potential effects on skin homeostasis and can penetrate skin barriers.
Guerranti *et al.*[14]	MPs in cosmetics: Environmental issues and needs for global bans	To promote international prohibitions and resolve environmental concerns with MPs in cosmetics	Review of MPs' sources in cosmetics and their environmental impact	MPs in cosmetics contribute approximately 229,000 particles to wastewater: need for global regulations.

industry as contaminants and packaging materials, according to a growing body of studies. Cosmetics and personal care items contain up to fifty thousand three hundred ninety-one particles per gram[14]. In domestic sewage, the contribution of MPs is 229000 in the form of tiny beads. The initial contact of these tiny particles occurs through interaction with products like facial/body scrubs and shedding fibres from clothing. Talking about MPs can encourage or speed up the growth and multiplication of cancer cells. As the Key Research techniques used in this study were microscopic analysis, cell proliferation assays and molecular mechanism investigations, the findings in the study show that the extent to which MPs interact with cells depends on Time-Dependent Penetration which tells the longer the cells are exposed to the microplastics, more deeply the microplastics penetrate them, in the same way, there is Dose Dependent Accumulation which state that the more MPs get exposed with cells, the more MPs accumulate inside the cells, which results in enhancing the cancer cells to grow and multiply faster which was confirmed by microscopy and cell cultures method by researchers[15].

4. Toxicological Mechanisms of Microplastics

4.1 Inflammation and Immune Response

One of the main sources of MPs in human diets is fish products. Consuming toxic seafood exposes people to MPs as well, which includes fish, shellfish and other marine animals. 6-7 % of human body weight is made up of blood, which is essential for carrying nutrition, oxygen and potentially dangerous materials like plastic particles[16]. The filtration process in the kidney decides how these plastics get disposed of, whether they are eliminated by bile or become lodged in organs like the liver or spleen.

The particle size, shape, charge and surface characteristics determine the interaction path as illustrated in Figure 2.

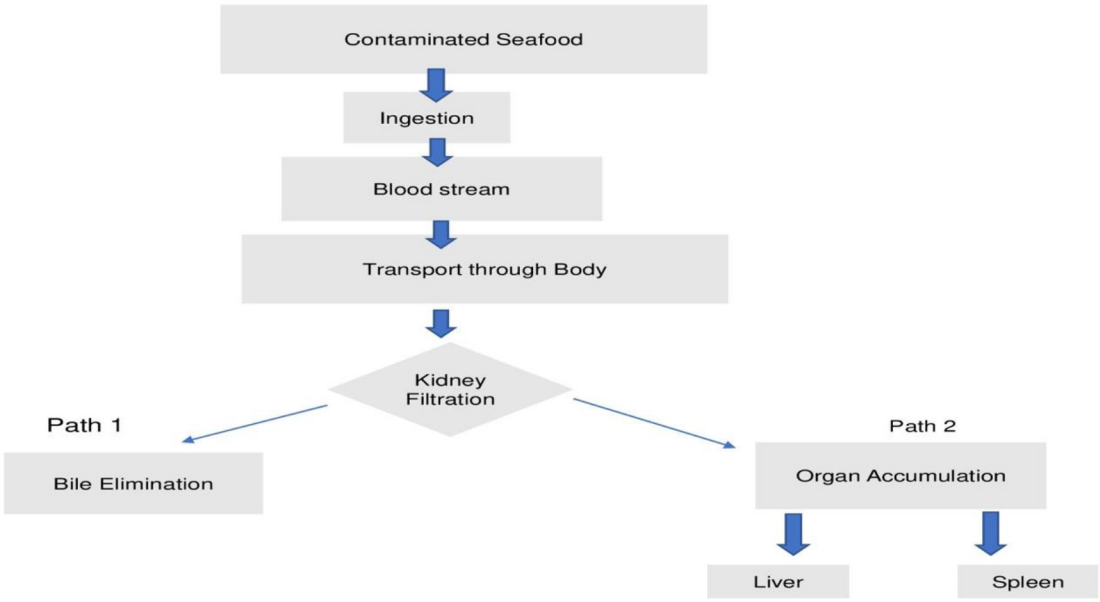


Figure 2. Flow diagram of filtration process (Leonardo Alberghini *et al*)[17].

Table 3. Process and mechanism for damage caused by microplastics (Kornelia Kadac-Czapska[21])

Process	Mechanism	Cellular Impact	Long-Term Consequences
ROS Generation	Surface Chemistry catalyses free radical formation	Increased oxidative environment	Cellular damage and aging
Mitochondrial Disruption	Impair electron transport chain	Reduced energy production	Metabolic dysfunction
DNA Damage	Induce chromosomal aberrations	Genetic mutations	Cancer Risk
Lipid Peroxidation	Interacts with cell membrane	Membrane structural compromise	Cellular vulnerability
Inflammatory Response	Activate pro-inflammatory pathways	Cytokine recruitment	Chronic inflammatory diseases
Molecular Integrity	Compromise cellular repair mechanisms	Systemic cellular stress	Accelerated disease progression

The study talks about how MPs, especially those with sharp edges or irregular shapes, can induce physical irritation and inflammation through ingestion[18]. One of the body's main reactions to foreign substances is inflammatory conditions. According to research, MPs can activate immune cells like neutrophils and macrophages, which causes the production of cytokines that promote inflammation[19]. The study on the aetiology of lung ground glass nodules comes with the emerging role of MPs, as these nodules have become more commonly seen in recent years, in correlation with MPs.

4.2 Oxidative Stress

The research states how microplastics trigger oxidative and inflammatory adverse outcomes, examining how MPs can affect biological organisation at various levels, ranging from molecules to populations[20]. The framework "Adverse Outcome Pathway" was used to link the observed negative effects of MPs or NPs to particular biological alterations. This framework helps to map out the sequence of events leading from initial exposure to a stressor, that is, micro and NPs, to a specific negative outcome. From the ecological perspective, it was found that in the environment, MPs and NPs can lead to oxidative stress, which then causes problems like stunted growth and altered behaviour in organisms due to inflammation and other related processes. From the Public Health Perspective, it was found that micro- and NPs induce stress in humans, potentially leading to health issues. This study carries limitations as there is not enough detailed information to fully map out the "Adverse Outcome Pathway" for human health

effects. Hence, most research is needed, especially studies that use mammalian models and epidemiological studies in humans to get a better understanding and predict the health risks that are posed by microplastics and NPs and develop robust AOPs for public health. The damage caused by MP[21] is summarised in Table 3.

Cellular Damage and Genotoxicity

Research has shown that MPs can induce cellular damage through physical interactions with cell membranes, resulting in membrane disruption, altered cell signalling, and even apoptosis (cell death). Additionally, MPs can be internalised by cells and accumulate in intracellular compartments, where they can potentially disrupt normal cellular function. Human lung cells treated with microplastic particles showed signs of genotoxicity, indicating that MPs may harm DNA and raise the risk of cancer. After entering the human body through ingestion, inhalation, or skin contact, micro- and NPs are taken up by cells through endocytosis or membrane penetration[22]. Within cells, they induce oxidative stress, inflammation, mitochondrial dysfunction, DNA damage, apoptosis, and autophagy. Particle size, surface characteristics, dose, and length of exposure all affect toxicity; smaller, weathered particles cause more cellular damage[23].

4.3 Microplastics as a Vector for Hazardous Pollutants

MPs act as a chemical source, where MPs themselves release harmful chemicals into the environment. MPs act

Table 4. Environmental distribution and human exposure pathways of microplastics

Author	Title	Objectives	Materials and Methods	Findings
Li *et al.*[3]	Potential Health Impact of MPs: A review of environmental distribution, human exposure, and toxic effects	To investigate the environmental distribution, human exposure pathways, and detrimental impacts of MPs	Review of the literature on the dispersion of MPs in the environment and human exposure routes	A thorough analysis of the harmful consequences of MPs on human health, including their distribution patterns
Jin *et al.*[27]	Impacts of polystyrene MPs on the gut barrier, microbiota and metabolism of mice	To examine the impacts of polystyrene MPs on gut health in mice	Experimental study with mice exposed to polystyrene MPs; analysis of gut barrier, microbiota, and metabolic change	Polystyrene microplastics impact gut barrier integrity, alter microbiota composition, and affect metabolism.
Gaylarde *et al.*[28]	Indoor Airborne MPs: Human Health Importance and Effects of Air Filtration and Turbulence	To investigate indoor airborne MPs, their significance for human health, and how turbulence and air filtration affect their dispersion	Review and analysis of indoor airborne MPs sources, concentrations, health implications, and mitigation strategies, including air filtration systems and air turbulence effects	Indoor airborne MPs pose significant health risks; air filtration and turbulence management can affect MPs' distribution and human exposure levels.
Vasse and Melgert[29]	MPs and plastic pollution: impact on respiratory disease and health	To examine how plastic pollution and MPs affect respiratory conditions and health	Literature review of studies examining MPs' exposure effects on the respiratory system and related diseases	The development of respiratory diseases and general respiratory health is significantly impacted by MPs and plastic pollution.
Chartres *et al.*[30]	Effects of MPs exposure on human digestive, reproductive, and respiratory health: A rapid systematic review	To systematically evaluate and gather the information that is currently available about the effects of MPs' exposure on human digestive, reproductive, and respiratory health	The quick and comprehensive analysis of animal research, human epidemiological studies, and mechanistic in vitro studies; structured literature search, study screening, evidence synthesis, and assessment of the strength of evidence across health domains	MPs' exposure is associated with gastrointestinal inflammation and gut barrier disruption; evidence indicates potential reproductive toxicity, including hormonal imbalance and impaired fertility markers.

like sponges that act for transportation and attraction of other heavy metal pollutants or organic chemicals, which pose significant problems or threats to living organisms[24]. To completely comprehend the relationships between MPs and other contaminants and their detrimental effects on public health, there is a requirement for more research in this field. To reduce the total harm caused by MPs and the chemicals with which they interact, proactive measures for the development and use of biodegradable alternatives must be implemented. Therefore, additional research and better alternatives must be developed to alleviate the harm. The study occurred on MPs, which serve as a potential vector for carrying chromium, as MPs absorb heavy metals like chromium from the environment that is present in the food, The methodology used by the researchers was to test the absorbent capacity of chromium metal by five types of microplastics that include Polystyrene, Polypropylene, Polyvinylchloride, Polystyrene and Polylactic Acid, where lab based *in-vitro* model formed to track how much chromium was released and become accessible in each digestive phase. The results showed that PLA, a biodegradable material, adsorbed the least chromium and released the most Cr (VI) in the digestive tract, including the large and small intestines.

This indicates the risk that MPs pose to the human digestive system by serving as vectors. When MPs enter water bodies, they interact with chemical pollutants that become attached to their surfaces, leading to concentrations much higher than in the surrounding environment. These particles are consumed by aquatic organisms, which misinterpret them as food and, consequently, when consumed by humans, pose a health hazard[25].

5. Potential Health Risks

5.1 Digestive Problems and Respiratory Diseases

While the direct health impacts of MPs remain under study, long-term exposure to MPs raises the risk of several illnesses. Table 4 summarises studies that have examined the pathways of exposure to microplastics and their health implications.

Consuming MPs affects digestive processes and causes physical irritation of the gastrointestinal tract, which can result in inflammation and a variety of gastrointestinal symptoms. Bloating, stomach pain, and altered bowel habits are among the gastrointestinal symptoms caused by MPs that alter the gut microbiota and create an imbalance between good and bad bacteria[26]. In addition to their physical effects on the digestive system, MPs may cause chemical toxicity, which is the absorption and accumulation of environmental contaminants such as heavy metals and polycyclic aromatic hydrocarbons. Oral consumption of MPs can allow these dangerous substances to enter the body through the digestive system and cause a variety of gastrointestinal symptoms, such as nausea, vomiting, and abdominal pain. The gastrointestinal system is thought to be the organ that NPs attack[27].

The inhalation of MPs leads to respiratory problems, particularly in individuals with pre-existing lung conditions. It has been demonstrated that MPs induce inflammation, fibrosis, and other lung disorders in animal models; anyone exposed to significant concentrations of airborne plastics is likely to have comparable consequences. Rats exposed to microplastic fibres developed pulmonary inflammation and fibrosis. MPs are thought to be inhalable and tend to lodge in both larger and smaller airways because of their unique aerodynamic characteristics, which range from 2.5 to 100 μm. Research has shown that the levels of micro-nano plastics are generally higher indoors than outdoors, especially in dust. The study stated that people usually spend more than ninety per cent of their time indoors, which is quite concerning. While indoor air can contain concentrations of more than 1500 particles per cubic metre, outdoor MNP levels can vary greatly[28]. Research on occupational exposures showed that exposure to plastic materials, especially from producing, processing, and recycling plastic products, raises the risk of several lung abnormalities, such as interstitial lung disease and cancer. The contribution of gases and debris particles can result in cellular damage and lung tissue alterations. Pneumoconiosis is a specific kind of interstitial lung disease that can be brought on by inhaling particulate matter that is common in the plastics sector[29].

5.2 Gastrointestinal and Liver Toxicity

The build-up of ingested MPs in the gastrointestinal system causes inflammation, gut permeability, and potentially altered microbiota composition. In rat models, MPs damage intestinal integrity and cause hepatic inflammation[30]. Being the primary organ for detoxification, the liver becomes overloaded with harmful substances and MPs that are absorbed from the gut, which

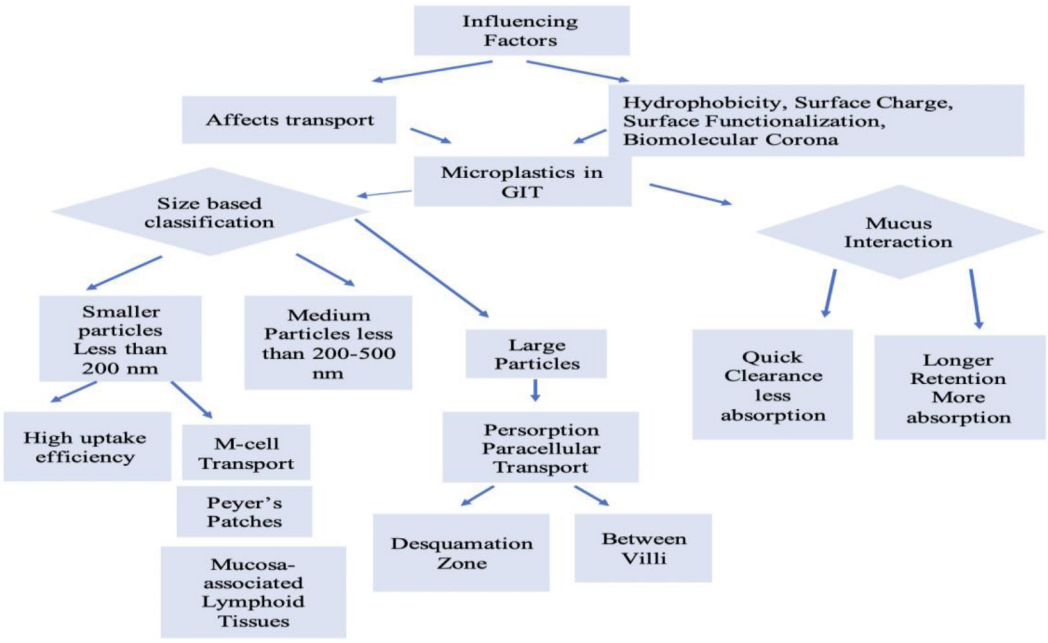


Figure 3. Schematic representation of factors influencing MPs' behaviour and transport in the Gastrointestinal Tract (GIT), Alberghini *et al*[33].

Table 5. Recent studies on the neurological and bioaccumulation effects of MPs

Gecegelen *et al.*[36]	A novel risk factor for dementia: chronic MPs exposure	To analyse existing exposure routes and assess new data regarding the possibility of long-term exposure to MPs.	**Rapid narrative review** of existing human, animal, and mechanistic research; synthesis of published evidence on MPs exposure pathways,	MPs increased oxidative stress, chronic neuroinflammation, transport of adsorbed neurotoxic chemicals (POPs and metals), and acceleration of amyloid-β aggregation; evidence of elevated MPs concentrations in human brain tissue from dementia patients suggests a possible dose-dependent relationship.
Nihart *et al.*[37]	Bioaccumulation of MPs in decedent human brains	To look at the bioaccumulation and existence of MPs in human brain tissue	Analysis of brain tissue samples from deceased individuals using advanced detection methods to identify and quantify MPs particles	Identification and measurement of MPs particles in brain tissue samples from deceased people, utilising cutting-edge detection techniques
Zheng *et al.*[38]	Impact of urinary MPs exposure on cognitive function in primary school children	To look at the connection between primary school-aged children's exposure to urine MPs and their cognitive function.	Urinary MPs concentrations in elementary school students are analysed in this cross-sectional study, and standardised tests are used to evaluate cognitive performance.	Children in elementary school who were exposed to urinary MPs showed reduced cognitive function, suggesting possible neurodevelopmental effects.

could cause liver damage. With an estimated 1.5 billion cases, liver cirrhosis ranks as the ninth most prevalent cause of death globally[31]. MPs have been detected in human liver tissue samples from liver cirrhosis patients[32]. Additionally, the study discovered that cirrhotic hepatic tissue samples had higher levels of microplastics than non-cirrhotic liver samples. The study discovered that a range of polymer-based MPs were present in cirrhotic

liver cells. Other polymers were discovered in addition to the well-known plastic polymers, including polystyrene, polyvinyl chloride, and polypropylene. Significant expression of fibrosis markers was seen in rats exposed to MPs, which changed the proliferation of α-smooth muscle actin, fibronectin, and factor-β. The Wnt/β-catenin signalling system is essential for maintaining proper cellular functions and tissue growth. To sustain appropriate cellular processes and tissue growth, the Wnt/β-catenin signalling pathway is crucial.

It also significantly affects the causes and consequences of liver fibrosis, suggesting that MPs either induce or promote hepatic fibrogenesis. One study found that polystyrene MPs caused oxidative stress and apoptosis, a process of programmed cell death, in the heart of a rat model. Ultimately, they were able to induce cardiac fibrosis. The primary cause of the clinical manifestations of liver cirrhosis, portal hypertension, and intestinal barrier disruption, which allows MPs to enter the liver through the intestinal wall, was postulated in a figure that illustrates how physicochemical properties, including hydrophobicity, surface charge, surface functionalization, and biomolecular corona, govern MPs' interactions within the GIT[33].

5.3 Neurological Effects

MPs have been implicated in neuroinflammation and neurodegenerative diseases in animal models; however, human data are still lacking. The study discusses the effects of MPs on the central nervous system because exposure routes include ingestion and inhalation, which result in biological barriers in the blood-brain and gut-brain axis. It was hypothesised that tiny particles have detrimental effects on the nervous system through a variety of mechanisms of neurotoxicity, including oxidative stress, inflammatory response, neurotransmitter alterations, and impairment of nerve conduction enzymes, all of which can have long-term effects, including neuronal disruption, altered memory, and behavioural changes[34]. The review article provides an overview of the neurotoxicity that chemically inert metal oxide nanoparticles from polymers might cause. These particles are extensively utilised in the manufacturing of food, cosmetics, personal hygiene items, and biological uses like gene therapy and medication administration[35]. According to recent experimental research, micro and NPs particles may be able to pass across the blood-brain barrier and have neurotoxic consequences. These particles may cause oxidative stress and inflammatory reactions once they enter neural tissues, which may interfere with neuronal signalling pathways. Changes in the modulation of neurotransmitters, such as dopamine and acetylcholine signalling, have also been observed in experimental models and may have an impact on behavioural and cognitive processes. Table V highlights the studies based on neurological and bioaccumulation effects of microplastics on human health.

5.4 Research Gaps

Even though our knowledge of the possible health concerns caused by microplastics has advanced significantly, there are still several important gaps. Since most studies to date have focused on animal models or *in vitro* systems, further research is needed to definitively demonstrate a causal relationship between MPs exposure and human disorders[39,40]. For assessing the long-term health impacts of MPs, longitudinal epidemiological studies are essential, particularly in populations with high exposure levels[40,41]. Because of the complex interactions between MPs, chemical contaminants, and the human microbiota, further research is required to fully understand the range of potential health risks[39,42]. A thorough grasp of MPs' awareness, their effects on the environment, and sustainable development routes has been made possible by the review of several studies[43,44]. The study highlights the pervasiveness of MPs in various ecosystems, their detrimental effects on human and animal health, and the pressing need for legislative changes[45,46]. Research emphasises how crucial public education and awareness are to lowering MPs contamination[40,41]. Several studies have examined how consumer behaviour, technological advancements, and regulatory frameworks can all serve to improve the problem. Despite the increase in the number of studies, little is known about the cumulative and long-term consequences of exposure to MPs on human health, particularly related to the effects on development and neurological conditions[47,48]. Furthermore, research and policy development are complicated by discrepancies in the definition of MPs, the measurement of their prevalence in various environments, and the standardisation of mitigation techniques[43,44]. The literature analysis also points out differences in international rules, with some areas implementing stricter laws while others fall behind because of infrastructure and economic constraints. There needs to be an intervention to reduce the negative impact caused by MPs on the health of humans because many

studies talk about the exposure pathways of microplastics, but none of them talks about mitigation strategies. Hence, further studies must include the problems along with the mitigation strategies.

Increasing public knowledge of MPs' pollution through educational programs and community involvement is crucial to promoting behavioural changes[41]. Stricter laws and regulations controlling the production, use, and elimination of the use of plastics, such as the abolition of single-use plastics and improved recycling facilities, are necessary for effective mitigation[45,46]. Standardised detection techniques should be used to improve accuracy in long-term studies on the neurological and reproductive impacts of MPs exposure. Environmental contamination can be considerably decreased by making investments in filtration systems, biodegradable substitutes, and MPs removal technology. Businesses should be urged to embrace circular economy projects, minimise plastic footprints, and use eco-friendly packaging.

6. Findings and Conclusion

A review of recent literature shows the levels of human exposure to MPs through several mechanisms[39,49,41]. The study on the generation of plastic waste in coastal areas, is 275 metric tons, talking about its management system, which is categorised in two ways: one is an adequate system that is properly managed by recycling, landfill and incineration, on the other side it talks about the inadequate system that occurs by littering and inadequate landfills that goes into the ocean and causes 4.8-12.7 million marine plastic debris. In the same way, variable factors that have an impact on human health through plastic characteristics, such as its dose, polymer type, size, surface chemistry and hydrophobicity. The findings show that the contamination source is from manufacturing chemicals and environmental chemicals that lead to MPs pollution, which goes into the marine environment, affecting marine life, and then it gets consumed by human[6]. The research priorities should be talking about physical and chemical toxicity, its epidemiology and then the exposure assessment. According to the study, little is known regarding the existence of MPs in far-flung locations, such as the deep sea and the polar regions[7]. The samples in this study were prepared for spectroscopic examination by the researchers using Fenton's reagent and an MPs sediment separator. Study emphasises the disruption caused by MPs towards marine food chains, which comes with particular concern as the transfer of toxins to humans by consuming contaminated marine organisms[2]. Some studies find that personal care products contain microbeads that serve as efficient conduits for harmful hexavalent chromium into human systems[39,42], increasing the risk of cancer, causing respiratory problems, gastrointestinal problems, liver and kidney damage from chromium exposure, as well as DNA damage and genetic mutations[1]. There are difficulties in detecting MPs because improved technology is required to identify micro- and nano-plastics in living things[48]. Results indicate that although awareness programs have increased people's understanding of MPs, there has been no consistency in behavioural adjustments. The degree of individual and group action is influenced by socioeconomic conditions, cultural beliefs, and the availability of sustainable alternatives. Research has also shown that microplastics impact terrestrial ecosystems, food chains, and even human physiological systems[50], in addition to marine biodiversity. The findings of MPs in drinking water and air raise concerns about long-term health risks[51,41]. In their study, the advantages of MPs as nanoparticles can be used to deliver drug medicine inside the body, but the disadvantages of the toxicity created by microplastics are not stated clearly[12]. To increase local effect, community-led initiatives, including waste segregation programs, plastic-free marketplaces, and rewards for sustainable behaviour, should be put into place. To create consistent worldwide regulations and cooperative initiatives to address plastic pollution on a large scale, international cooperation must be strengthened. Furthermore, the implementation of MPs' free labelling can encourage businesses to provide safer substitutes while assisting customers in making sustainable decisions. By combining these tactics, it will be possible to guarantee that initiatives go beyond raising awareness to take tangible action, protecting the public's health from the negative effects of microplastic pollution and advancing environmental sustainability. This review also highlights the importance of gaining a thorough understanding of the full impact of microplastics.

7. Declaration

The authors acknowledge that this paper makes use of artificial intelligence (AI) technology. The use of AI technology in the creation of this review article demonstrates how crucial it is to improving the productivity, calibre, and depth of our writing.

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Author Contribution

V.M conceived the study, conducted the literature review and drafted the manuscript, and led all aspects of writing and revision. U.V supervised the overall project, provided content expertise in the implementation science and health system and critically reviewed the manuscript.

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