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Microplastics in Breastmilk – An Overview

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ABSTRACT

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have become pervasive environmental contaminants and are now recognized as emerging threats to human health. Their persistence and widespread distribution have led to exposure through food, water, air, and consumer products. Recent biomonitoring studies have confirmed the presence of Micro plastics in human breastmilk, raising concern about maternal and neonatal exposure during a critical developmental stage. This review summarizes current evidence on the occurrence, pathways, and health implications of Microplastics in breastmilk. Dietary ingestion and inhalation represent major exposure routes, while physicochemical characteristics such as particle size, charge, and hydrophobicity influence systemic absorption and transfer into mammary tissue. Common polymers identified include polypropylene, polyethylene, and polystyrene. Analytical methods such as Fourier-transform infrared (FTIR) and Raman microspectroscopy have facilitated detection, though methodological inconsistencies and contamination risks limit data comparability. Experimental studies indicate that Microplastics and their additives may trigger oxidative stress, inflammation, endocrine disruption, and immunotoxicity, with infants being particularly vulnerable. Preventive strategies emphasize reducing plastic use in food packaging, promoting sustainable alternatives, and implementing regulatory frameworks to control environmental plastic pollution. Significant research gaps remain in standardizing analytical protocols, conducting longitudinal human studies, and improving detection technologies for nano-sized particles. Understanding the mechanisms and health implications of microplastic transfer through breastmilk is crucial for developing evidence-based guidelines to safeguard maternal and infant health.

KEYWORDS: Microplastics, Breastmilk, Environmental toxicology, Public health.

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INTRODUCTION

Plastic production and waste have increased exponentially over the past decades, leading to the pervasive distribution of plastic particles in the environment. Among these, microplastics (commonly defined as plastic particles < 5 mm in size) have emerged as a significant contaminant of concern in ecosystems worldwide (1). These particles persist through degradation of larger plastics, industrial processes, and can be found in terrestrial, aquatic, and atmospheric systems. As highlighted by the World Health Organization, the study of human exposure to microplastics is still in its infancy, yet the ubiquity of these particles raises questions about potential risks to health (2).

Human exposure to microplastics occurs via multiple pathways ingestion of contaminated food and water, inhalation of airborne particles, and dermal contact in certain contexts (3). Once inside the body, microplastics may traverse biological barriers, accumulate in tissues, or act as carriers for chemical additives and sorbed pollutants. Toxicological studies and human-biomonitoring efforts indicate potential adverse responses such as oxidative stress, inflammation, reproductive dysfunction, and immune modulation, although definitive causal links in humans remain limited (4, 5). The relevance of these findings is particularly acute for maternal and infant health, given physiological vulnerability during pregnancy and lactation, and the possibility of trans-maternal transfer of contaminants.

Thus the investigation of microplastics in human breastmilk becomes especially pertinent. Breastmilk represents the primary nutritional source for infants in the early months of life and can serve as a direct exposure medium to infants during a critical developmental window. Reports have now documented detection of microplastics in human breastmilk samples, with studies identifying particles in a significant proportion of samples and polymers such as polypropylene, polyethylene, polystyrene and PVC (7). As the unique sensitivity of this exposure route, both for the mother and the nursing infant the rationale for a comprehensive overview is highly needed. This paper therefore aims to synthesise current evidence on the occurrence of microplastics in breastmilk, pathways of exposure, methodological challenges, health implications, and research gaps for future investigation.

SOURCES AND PATHWAYS OF MICROPLASTIC EXPOSURE

Microplastics (MPs) can enter the human body through various environmental and biological routes. Among these, dietary intake, inhalation, and dermal absorption constitute the main exposure pathways. In pregnant and lactating women, these routes contribute to systemic accumulation and possible transfer of particles into the placenta and breastmilk.

Environmental and Dietary Exposure Routes

Dietary ingestion is considered the predominant source of micro plastics exposure in humans. Micro plasticshave been identified in seafood, table salt, honey, bottled water, milk, and various packaged foods (8). Consumption of seafood such as shellfish and small fish plays a major role, since these organisms ingest plastic particles present in aquatic systems, allowing bioaccumulation and trophic transfer (9). Drinking water, both bottled and tap, has also been shown to contain microplastics, with estimates suggesting that an average adult may ingest between 39,000 and 52,000 MP particles per year (10). In addition, food processing and storage using plastic containers, as well as heating food in plastic packaging, can release micro plasticsthat migrate into food items (11).

Inhalation and Dermal Contact Pathways

Inhalation of airborne microplastics, especially fibers from synthetic textiles, indoor dust, and urban particulate matter, represents another major pathway (12). Indoor environments generally contain higher micro plasticsconcentrations than outdoor air, attributed to household sources such as carpets, clothing, and upholstery. Once inhaled, smaller micro plastics (< 10 µm) can penetrate the alveoli and translocate into the bloodstream, potentially distributing systemically (13). Dermal exposure, though less significant, may occur through the use of cosmetics, personal care products containing microbeads, or contact with contaminated air and water. Studies show limited but possible dermal uptake, especially through compromised or inflamed skin (14).

Maternal Ingestion and Absorption Mechanisms

During pregnancy and lactation, maternal ingestion and systemic absorption of micro plastics may occur via gastrointestinal uptake. Particles below 10 µm in diameter can pass through intestinal epithelium by endocytosis or paracellular transport, entering circulation and reaching various organs including adipose and mammary tissue. Micro plasticsmay also adsorb or release toxic chemicals such as phthalates, bisphenols, and flame retardants, which can further influence maternal endocrine and immune functions.

Placental Transfer and Lactational Exposure Routes

Recent evidences have demonstrated the presence of microplastics in human placenta, suggesting their ability to cross placental barriers and potentially reach fetal tissues (16). The mechanism may involve cellular internalization or passive diffusion of nano-sized particles. During lactation, micro plasticsthat have accumulated in maternal tissues or bloodstream can migrate into breastmilk, possibly via transcellular transport or secretion from mammary epithelial cells (17). Detection of micro plastics in breastmilk samples supports the concept of lactational transfer, highlighting a direct and sensitive exposure route for newborns. Understanding these exposure pathways is crucial for evaluating maternal and neonatal risks, informing preventive strategies, and guiding future research into the toxicological consequences of early-life microplastic exposure.

OCCURRENCE OF MICROPLASTICS IN BREASTMILK

Microplastics have now been reported in human breastmilk across multiple studies and geographic regions, though prevalence, particle counts and analytical approaches vary considerably between investigations.

Global evidence and reported findings

The first peer-reviewed evidence of micro plasticsin human breastmilk was reported by Ragusa et al., who analysed 34 milk samples with Raman microspectroscopy and detected micro plastics in 26 samples (76.5% positive) (18). Subsequent studies have confirmed the presence of micro plasticsin breastmilk in larger cohorts and different countries; for example, Saraluck et al. found micro plasticsin 38.98% (23/59) of samples and explored associations with milk microbiota composition (19). Smaller pilot studies from other regions have likewise documented detectable micro plasticsin a notable proportion of tested samples, supporting the reproducibility of the finding across laboratories and populations (20,21). Systematic and scoping reviews of microplastics in human foods and tissues also cite breastmilk among matrices where micro plasticshave been identified, reinforcing that lactational exposure is plausible and has been observed in multiple studies.

Concentration levels and polymer types identified

Reported concentration metrics differ by study because of heterogeneity in sampling, contamination control, sizing thresholds and analytical platforms (e.g., Raman vs. µ-FTIR). Many investigations report presence/absence and particle counts per sample rather than standardized particles-per-volume units, making direct comparison difficult (18,19). Across studies that report polymer identity, common polymer types recovered from breastmilk include polypropylene (PP), polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC). Ragusa et al. and Saraluck et al. both list PP and PE among the most frequently identified polymers (18,19).

Temporal and geographical variations

Temporal and spatial variability in breastmilk micro plasticsfindings likely reflect a combination of true exposure differences and methodological variability. Geographic factors such as local plastic production/use, dietary patterns (notably seafood consumption), water source (bottled vs. tap), and waste management practices influence environmental micro plasticsloads and

thus maternal exposure (20). Temporal trends are harder to establish because most studies are cross-sectional; however, recent reviews of human tissues and foodstuffs suggest an overall increase in environmental plastic contamination over recent decades, which may translate into higher human body burdens over time if exposures are not reduced.

MECHANISMS OF TRANSFER TO BREAST TISSUE AND MILK

Physicochemical properties influencing transfer

Microplasticbehavior in biological systems depends largely on intrinsic physicochemical parameters such as particle size, surface charge, shape, and hydrophobicity. These factors determine cellular uptake efficiency, systemic translocation potential, and tissue distribution. Smaller micro plastics and nanoplastics (< 10 µm) are more likely to traverse epithelial barriers due to enhanced diffusion and endocytotic uptake, while irregular shapes and higher surface area increase interactions with cell membranes (25). Surface functionalization and charge polarity further influence the affinity of micro plasticstoward biological membranes and plasma proteins, potentially facilitating their adsorption and subsequent translocation across tissues.

Role of particle size, charge, and hydrophobicity

Particle size is considered the most critical determinant of biological penetration. Experimental data show that polystyrene particles of 20–100 nm can cross intestinal and placental barriers, whereas larger particles (> 10 µm) generally remain confined to the gut lumen (27). Surface charge also modulates cellular interactions; positively charged micro plastics exhibit greater internalization in epithelial cells through electrostatic attraction, while neutral or negatively charged particles demonstrate slower uptake (25,27). The hydrophobicity of common polymers such as polyethylene (PE) and polypropylene (PP) enables affinity to lipid-rich tissues including mammary glands thereby promoting accumulation and possible secretion into breastmilk (18). Moreover, hydrophobic micro plastics may act as vectors for lipophilic contaminants, enhancing co-transport of adsorbed additives and persistent organic pollutants (18).

Possible biological transport mechanisms

Proposed biological mechanisms for micro plastics transfer into breastmilk include endocytosis, passive diffusion, and paracellular transport. Studies using placental and mammary epithelial models have demonstrated vesicle-mediated uptake of nano-sized plastic particles, suggesting similar pathways may occur in mammary cells (27,29). Once internalized, micro plastics could translocate through intracellular vesicles to the basolateral membrane, releasing into the milk matrix through exocytosis. The high lipid content of breastmilk may further facilitate partitioning of hydrophobic MPs and promote their stability in the milk fat globule fraction (18).Although the exact rate and extent of MP transfer to milk remain uncertain, the detection of particles in breastmilk provides evidence that these mechanisms are biologically plausible. Continued research combining human biomonitoring with mechanistic cellular studies is needed to elucidate kinetic behavior, dose-response relationships, and factors modulating maternal–infant transfer efficiency.

DETECTION AND QUANTIFICATION METHODS

Sampling and Sample Preparation Techniques

Accurate microplastic analysis begins with contamination-free sampling. Breastmilk samples must be collected using non-plastic equipment, preferably glass containers pre-rinsed with filtered ultrapure water, to prevent introduction of extraneous particles (30). Laboratory personnel should wear cotton clothing, and procedural blanks should be included to monitor airborne contamination. Sample digestion is typically employed to remove organic matter while preserving plastic integrity. Common digestion agents include hydrogen peroxide (H_2O_2), potassium hydroxide (KOH), and enzymatic mixtures, optimized to minimize polymer degradation (31). Following digestion, samples are filtered through membranes (0.45–10 µm pore size) made of inert materials such as polycarbonate or glass fiber, allowing isolation of residual micro plastics for spectroscopic analysis (32).

Analytical Tools

Characterization and identification of microplastics rely on advanced analytical instruments. Fourier-transform infrared spectroscopy (FTIR) and Raman microspectroscopy are the two most frequently applied methods for polymer identification in breastmilk and other biological fluids (18). FTIR provides chemical fingerprinting based on molecular vibrations, suitable for particles > 20 µm, while Raman spectroscopy offers higher spatial resolution, enabling detection of particles as small as 1 µm (18). Pyrolysis–gas chromatography/mass spectrometry (Py-GC/MS) allows thermal degradation of polymers into characteristic fragments for quantitative polymer-specific analysis, although it sacrifices information on particle morphology (34). Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) can further assess morphology and elemental composition, complementing spectroscopic methods (35).

Challenges and Limitations in Detection

Major analytical challenges include background contamination, lack of standardized protocols, and limitations in detecting nanoplastics (< 1 µm) (32,35). Sample heterogeneity and the small sample volumes typical of breastmilk studies also restrict detection sensitivity. Cross-contamination from laboratory air and equipment is a persistent issue, emphasizing the need for rigorous blank controls and clean-room procedures (31). Additionally, differentiating synthetic polymers from natural fibers or degraded bioplastics can be complex, particularly when particles have undergone environmental aging or chemical modification (34).

Advances in Microplastic Identification

Recent advances aim to improve detection accuracy and quantification reliability. Coupling spectroscopic techniques with automated image analysis and machine-learning algorithms has enhanced throughput and reduced operator bias (36). Nano-FTIR,

thermal desorption–proton transfer–mass spectrometry (TD-PT-MS), and fluorescence tagging methods have been proposed to extend the detection limit to the nanoscale (35,36). Development of standardized reference materials and harmonized protocols by international agencies such as ISO and UNEP is expected to improve data comparability across studies. These technological innovations, combined with strict contamination control, are critical to advancing the field of microplastic biomonitoring in human milk and other biological specimens.

TOXICOLOGICAL AND HEALTH IMPLICATIONS

The presence of microplastics (MPs) in human breastmilk has raised serious concerns regarding maternal and infant health. Although direct evidence in humans is limited, extrapolations from animal studies and cellular models suggest that micro plasticscan exert adverse biological effects, including inflammation, oxidative stress, endocrine disruption, and altered immune responses.

Potential Effects on Maternal Health

Maternal exposure to micro plasticscan result in bioaccumulation within tissues, potentially triggering inflammatory or oxidative stress pathways. In vivo and in vitro studies have demonstrated that micro plasticscan activate macrophages and promote cytokine release, leading to local tissue damage and systemic immune responses (37). Some polymers and additives, such as bisphenol A (BPA), phthalates, and brominated flame retardants, are known to interfere with hormonal homeostasis and reproductive health (1). Chronic exposure may also influence metabolic and immune regulation in mothers, contributing to oxidative damage and increased susceptibility to infections or metabolic disorders (39). However, comprehensive human epidemiological data remain limited.

Impact on Infant Development and Immune Function

Infants are particularly vulnerable to toxicant exposure due to immature detoxification systems and higher metabolic rates. MPs ingested via breastmilk could potentially cross the gut barrier and interact with immune cells in the intestinal mucosa (40). Animal studies have shown that nanosized plastic particles can induce intestinal dysbiosis, compromise gut barrier integrity, and alter cytokine signaling (25). These effects may impair immune development and increase the risk of allergic or autoimmune conditions in early life. Additionally, chemical additives associated with micro plastics, such as plasticizers and stabilizers, may exert neurodevelopmental toxicity, affecting learning, memory, and behavioral outcomes (42).

Endocrine Disruption and Long-Term Risks

Many polymers and additives found in MPs act as endocrine-disrupting chemicals (EDCs), mimicking or antagonizing natural hormones. Long-term exposure may disrupt estrogenic, androgenic, and thyroid signaling pathways, leading to reproductive and developmental abnormalities (39,42). Prenatal and lactational exposure to EDCs has been linked to low birth weight, altered pubertal timing, and impaired fertility in offspring (1). Additionally, bioaccumulatedmicro plasticsmay serve as carriers for other environmental contaminants such as persistent organic pollutants (POPs) and heavy metals, further compounding toxicity (40). The cumulative exposure over time may contribute to chronic health outcomes including metabolic disorders, carcinogenesis, and reproductive dysfunction (43).

MITIGATION AND PREVENTIVE STRATEGIES

Reducing Exposure in Daily Life

Individuals can substantially reduce their exposure to microplastics through mindful choices in food consumption and product use. Studies indicate that dietary ingestion is a primary route of exposure, particularly from seafood, packaged foods, and bottled water (6). Switching to glass or stainless-steel containers, avoiding microwaving food in plastic containers, and preferring fresh or unpackaged produce can significantly lower ingestion levels (15). Using tap water filtered through reverse osmosis or activated carbon systems can further reduce plastic particle intake (22). In addition, promoting sustainable consumer practices such as reducing single-use plastics, supporting biodegradable packaging, and choosing textile materials with lower synthetic fiber content can help limit environmental and personal contamination sources (24).

Policy and Regulatory Frameworks

Mitigating microplastic exposure also requires strong policy interventions and global cooperation. Regulatory measures must address the entire plastic lifecyclefrom design and manufacturing to disposal and recycling. The European Union's Single-Use Plastics Directive (2019/904) and the United Nations Environment Programme's (UNEP) Global Plastic Treaty (2022) are landmark initiatives aimed at reducing plastic pollution at its source (22). National agencies, including India's Central Pollution Control Board (CPCB) and the U.S. Environmental Protection Agency (EPA), have also begun implementing microplastic monitoring and risk assessment frameworks. However, many developing nations still lack enforceable standards for microplastic content in consumer products and food packaging (24). Encouraging extended producer responsibility (EPR) policies, plastic taxes, and incentives for eco-design could promote industry-level compliance and innovation toward sustainable alternatives (26).

Need for Sustainable Alternatives to Plastics

Transitioning to sustainable materials is a long-term solution to reducing microplastic contamination. Research into biodegradable polymers (such as polylactic acid and polyhydroxyalkanoates) and natural-fiber composites shows promise, though scalability and cost remain barriers (15). Circular economy approaches emphasizing recycling, reuse, and reduction are essential for curbing virgin plastic demand. Moreover, advancements in green chemistry can facilitate the design of safer polymers that minimize fragmentation and toxic leachate formation (24,26). At the consumer level, awareness campaigns and environmental education can empower individuals to adopt low-plastic lifestyles. Collectively, these integrated strategies represent the most effective path

toward reducing human and ecological exposure to microplastics and protecting maternal–infant health in the long term.

RESEARCH GAPS AND FUTURE DIRECTIONS

Although research on microplastics (MPs) in human biological systems has advanced rapidly in recent years, substantial gaps remain in understanding their full health implications, especially in the context of maternal and infant exposure through breastmilk. Addressing these gaps requires standardized methodologies, robust long-term studies, and adoption of emerging monitoring technologies to ensure reproducibility and comparability of data across studies.

Standardization of Sampling and Analytical Protocols

One of the foremost challenges in microplastic research is the lack of universally accepted protocols for sampling, extraction, and analysis. Current methods vary significantly in terms of sample digestion agents, filtration membranes, and spectroscopic identification criteria, making it difficult to compare results across studies (28). Establishing harmonized standards for microplastic sampling particularly for complex biological matrices like breastmilk would enable better inter-laboratory validation and global data integration. Organizations such as the International Organization for Standardization (ISO) and the World Health Organization (WHO) have recently emphasized the need for unified protocols to enhance reliability and minimize contamination risks (33). Additionally, development of certified reference materials for calibration and quality control could further strengthen analytical consistency in micro plasticsresearch.

Longitudinal Human Studies and Risk Assessment

Most existing data on microplastics and their health effects are derived from short-term or cross-sectional studies, often with small sample sizes. There is a critical need for longitudinal human cohort studies that monitor microplastic exposure across different life stages pregnancy, lactation, and infancy to establish causal relationships with health outcomes (38). These studies should integrate exposure biomarkers with clinical parameters to assess dose–response effects. Moreover, comprehensive human health risk assessments considering additive chemicals, co-contaminants, and cumulative exposure are lacking (41). Modeling approaches integrating toxicokinetic data and exposure estimations could help refine safety thresholds and guide regulatory decisions. Collaborative efforts between environmental scientists, clinicians, and public health policymakers will be essential for translating laboratory findings into effective preventive policies.

Emerging Technologies for Microplastic Monitoring

Advances in analytical science are paving the way for more precise and high-throughput microplastic detection. Emerging technologies such as nano-FTIR spectroscopy, thermal desorption–proton transfer–mass spectrometry (TD-PT-MS), and microfluidic-based sensors offer enhanced sensitivity for detecting micro- and nanoplastics in biological fluids (33,44). In addition, machine learning and automated image recognition are being integrated into microscopy workflows to improve classification accuracy and reduce manual errors. Future innovations may also include biosensor-based detection systems and lab-on-a-chip devices capable of real-time micro plasticsquantification in biological samples. Developing open-access databases for spectral signatures and morphology profiles will further facilitate rapid polymer identification and global data sharing. Ultimately, technological innovations, coupled with harmonized methodologies and robust epidemiological evidence, are vital for closing the current knowledge gaps and informing health-protective policies.

CONCLUSION

Microplastics have emerged as a global environmental and public health concern, with growing evidence of their presence in human biological systems, including breastmilk. Current research underscores that maternal exposure through diet, air, and consumer products can lead to microplastic transfer to infants during lactation. Although the concentrations detected are generally low, the potential implications for infant health and development remain uncertain.The existing body of evidence highlights a pressing need for comprehensive risk evaluation and standardized research approaches. From a public health standpoint, the detection of microplastics in breastmilk signifies more than an environmental issue it represents a human health challenge that intersects with nutrition, maternal well-being, and early-life exposure. Government and health authorities must prioritize preventive strategies, promote the reduction of plastic use in food contact materials, and strengthen global frameworks to regulate microplastic contamination.Ultimately, continued interdisciplinary research, combined with public awareness and sustainable consumption practices, will be critical in addressing the long-term impacts of microplastics. Protecting maternal and infant health requires a collective effort bridging scientific discovery, policy implementation, and behavioral change to ensure a safer and healthier future for the next generation.

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