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Evaluation of Microplastic Content in Human Circulatory System and Its Potential Impacts on Systemic Health

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ABSTRACT

Given the escalating global production of plastics and the absence of regulatory frameworks addressing internal human exposure, microplastic contamination has emerged as an urgent environmental and public health policy concern.Using micro Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy, MPs were detected in 76.0% of samples collected from 50 healthy adults, with an average concentration of 3.15 ± 1.25 particles/mL and a mean particle size of 5.8 ± 2.1 µm. Polyethylene terephthalate (PET) and polypropylene (PP) were the dominant polymer types, while fragments and fibers represented the most common morphologies. Correlation analyses revealed significant positive associations between total MP concentration and inflammatory biomarkers C-reactive protein (r = +0.415, p = 0.003) and interleukin-6 (r = +0.288, p = 0.043) as well as oxidative stress marker malondialdehyde (r = +0.350, p = 0.013), suggesting that MPs may contribute to subclinical systemic inflammation and oxidative imbalance. These findings provide empirical evidence supporting the systemic circulation of MPs and their potential role as low-grade biological stressors that could influence vascular homeostasis. Further longitudinal and mechanistic studies are warranted to elucidate causal pathways, characterize nanoplastic fractions, and establish standardized analytical protocols. This research underscores the growing necessity to treat microplastic exposure as a critical environmental and public health issue.

Keywords: *Microplastics, Human Blood, Systemic Inflammation*

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INTRODUCTION

The exponential growth of global plastic production and waste disposal over recent decades has led to the ubiquitous distribution of microplastics (MPs) plastic particles smaller than 5 mm across nearly all environmental compartments, including air, water, and soil (Prata et al., 2019; Enyoh et al., 2023). These synthetic particles originate from both primary sources, such as industrial abrasives and microbeads in cosmetics, and secondary sources formed through the degradation of larger plastic debris (Tang et al., 2024). Due to their resilience and persistence, MPs have been identified as emerging contaminants of concern that can persist for decades, infiltrating ecosystems and entering the human food chain through seafood, bottled water, salt, and other consumables (Rahman et al., 2020; Eze et al., 2024). As a result, human exposure to microplastics has become virtually unavoidable, occurring primarily via ingestion, inhalation, and dermal contact pathways (Winiarska et al., 2024).

Recent advances in analytical technologies particularly micro-Fourier transform infrared spectroscopy (μFTIR) and Raman spectroscopy have enabled more accurate detection and characterization of MPs not only in environmental matrices but also within human biological systems. Biomonitoring studies have confirmed the presence of MPs in human blood, with detection rates approaching 90% among healthy individuals and concentrations ranging from 1.6 to 4.7 μg/mL (Leonard et al., 2024). Dominant polymer types identified include polyethylene (PE), polystyrene (PS), and polypropylene (PP), which are also among the most common plastics in consumer products. Furthermore, similar findings have been reported in cardiac tissues, arterial thrombi, pulmonary tissue, hepatic specimens, and even the placenta suggesting the potential for systemic circulation and bioaccumulation across multiple organ systems (Zhu et al., 2024; Yang et al., 2024; Barceló et al., 2023).

The discovery of MPs in the human circulatory system raises profound concerns about their potential systemic health impacts. The bloodstream serves as a critical conduit for distributing nutrients, hormones, and immune factors; thus, the presence of foreign polymeric particles may interfere with physiological homeostasis (Blackburn et al., 2021). Observational and clinical studies have demonstrated correlations between elevated MP concentrations and biomarkers of vascular inflammation, oxidative stress, endothelial dysfunction, and coagulation abnormalities (Lee et al., 2024; Yang et al., 2024). In patients with acute coronary syndrome, microplastic load has been associated with increased vascular complexity and atherosclerotic burden, suggesting a mechanistic link between particulate exposure and cardiovascular pathology (Yang et al., 2024).

Mechanistically, MPs may act as both physical and chemical stressors within the circulatory system. Their irregular shapes and rough surfaces can mechanically irritate vascular endothelium, while their physicochemical properties enable the adsorption and transport of hazardous additives and pollutants such as bisphenols, phthalates, and heavy metals that are known endocrine disruptors and pro-oxidants (Rahman et al., 2020; Tang et al., 2024). These combined effects may induce reactive oxygen species (ROS) generation, lipid peroxidation, mitochondrial damage, and chronic inflammatory responses (Li et al., 2024). Long-term exposure could therefore contribute to a

cascade of biological dysfunctions, including immune dysregulation, metabolic disturbances, and elevated risk of cardiovascular and renal diseases (La Porta et al., 2023; Lee et al., 2025).

Beyond cardiovascular implications, systemic microplastic exposure may affect other vital organs such as the liver, kidneys, and spleen sites integral to detoxification and immune regulation. Studies in animal models and in vitro systems have shown that MPs can translocate across biological barriers, accumulate in tissues, and alter cellular signaling pathways involved in apoptosis, fibrosis, and cytokine production (Mittal et al., 2023; Li et al., 2024). Notably, the smallest particles, including nanoplastics (<100 nm), possess higher bioavailability and can cross cell membranes and even the blood brain barrier, raising additional concerns about neurotoxicity and systemic oxidative imbalance (Winiarska et al., 2024; Rahman et al., 2020). In this context, the World Health Organization (WHO) and the Organisation for Economic Co-operation and Development (OECD) have emphasized that humans are chronically exposed to microplastics through food, drinking water, and air, with estimated annual intakes reaching tens of thousands of particles per individual, highlighting the potential for cumulative systemic exposure over the lifespan.

Despite accumulating evidence, significant scientific uncertainties persist. The direct causal relationship between microplastic exposure and specific human diseases has not been conclusively established. Current literature is limited by methodological inconsistencies, including differences in particle isolation protocols, potential sample contamination, and variability in polymer identification and quantification methods (Blackburn et al., 2021; Barceló et al., 2023). Moreover, many studies rely on small sample sizes and cross-sectional designs, which preclude causal inference. Most toxicological data are derived from laboratory experiments on cell cultures or animal models, which, while informative, may not accurately reflect human exposure conditions or physiological responses (Li et al., 2024; Mittal et al., 2023).

These knowledge gaps highlight the need for standardized analytical protocols and large-scale epidemiological investigations to assess the long-term effects of microplastic exposure on human health. There is also a critical need to explore the interactions between MPs and other environmental contaminants such as persistent organic pollutants (POPs) and heavy metals which may synergistically enhance toxicity and bioavailability (Tang et al., 2024; Yang et al., 2024). Furthermore, assessing the toxicokinetics of MPs covering absorption, distribution, metabolism, and excretion (ADME) is essential to understanding how these particles behave within human biological systems (Prata et al., 2019; Li et al., 2024).

Given these emerging challenges, systematic evaluation of microplastic content within the human circulatory system is of urgent scientific and public health importance. This study aims to provide a comprehensive synthesis of current evidence concerning the detection, quantification, and polymer composition of microplastics in human blood and vascular tissues. Additionally, it seeks to elucidate potential associations between microplastic burden and key systemic processes, including inflammation, coagulation, oxidative stress, and cardiovascular risk. By integrating findings from human biomonitoring and mechanistic studies, this work contributes to a growing body of evidence on the internal exposure pathways of microplastics and underscores the necessity for policy

interventions, exposure reduction strategies, and future multidisciplinary research in environmental health sciences.

METHODS

This study employed a cross-sectional observational design integrating laboratory analysis and literature-based synthesis to evaluate the presence and concentration of microplastics (MPs) in the human circulatory system, as well as their potential associations with systemic health indicators. The research approach was adapted from previous human biomonitoring studies that have successfully identified MPs in biological matrices such as blood, cardiac tissue, and arterial thrombi (Leonard et al., 2024; Yang et al., 2024; Lee et al., 2024). The study was conducted in two phases: the first involved quantitative laboratory analysis for MP detection and polymer characterization, while the second involved a systematic review of existing literature to validate and contextualize the empirical findings.

Peripheral blood samples were obtained from 50 healthy adult volunteers aged 20 to 55 years, selected based on inclusion criteria that excluded participants with chronic inflammatory conditions or occupational exposure to plastics. Each sample, with a volume of 5–10 mL, was collected using stainless-steel needles and stored in glass collection tubes that had been pre-rinsed with ultrapure water and ethanol to minimize microplastic contamination (Barceló et al., 2023; Leonard et al., 2024). To ensure sample integrity, all laboratory procedures were performed in a clean-air laminar flow cabinet. Contamination control measures included the use of cotton laboratory coats and nitrile gloves, filtration of all reagents with 0.22 μm membrane filters, and simultaneous analysis of procedural blanks to detect background contamination (Zhu et al., 2024; Li et al., 2024).

Sample digestion was carried out using 10% potassium hydroxide (KOH) and 30% hydrogen peroxide (H_2O_2) to dissolve organic matter while preserving polymeric integrity, as this combination has been widely validated for efficient digestion of protein-rich biological matrices with minimal alteration of common plastic polymers. The digested samples were then filtered through Whatman® glass-fiber filters with a 0.45 μm pore size, followed by drying at 25 °C and storage in amber glass Petri dishes until further analysis (Prata et al., 2019; Li et al., 2024). Microplastic identification and quantification were conducted using micro Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy, which are reliable and widely applied methods for detecting and characterizing polymer types in environmental and biological matrices (Winiarska et al., 2024; Barceló et al., 2023).

Spectral analysis was performed within the range of 4000–650 cm^{-1}, and spectra were matched to the OMNIC Polymer Database (Thermo Fisher Scientific) to identify polymer composition. Only particles exhibiting at least a 70% spectral match were classified as microplastics (Leonard et al., 2024). The main polymer types identified included polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET), which were quantified based on both concentration (μg/mL) and particle count (particles/mL). Morphological classification such as fibers,

fragments, spheres, and films was performed using optical microscopy under magnifications of 100× to 400× (Yang et al., 2024; La Porta et al., 2023).

To explore potential biological implications, serum samples were analyzed for key biomarkers of oxidative stress and inflammation, including interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and C-reactive protein (CRP), using enzyme-linked immunosorbent assay (ELISA) kits (Lee et al., 2024). Additionally, coagulation parameters such as activated partial thromboplastin time (aPTT), fibrinogen, and D-dimer levels were measured using standard hematology analyzers. The relationship between microplastic concentrations and biomarker levels was evaluated through Pearson's correlation and multivariate regression analysis, adjusting for confounding variables such as age, gender, and body mass index (Li et al., 2024).

Data analysis was performed using IBM SPSS Statistics version 27 and R version 4.3.2. Descriptive statistics were presented as mean ± standard deviation (SD). Differences between groups with high and low MP concentrations were examined using independent t-tests for normally distributed data and Mann Whitney U tests for nonparametric data (Blackburn et al., 2021). To support empirical findings, a systematic review of relevant studies was conducted following the PRISMA 2020 guidelines (Mittal et al., 2023). Databases including PubMed, Scopus, and Web of Science were searched using the keywords "microplastics," "blood," "circulatory system," and "human health," focusing on peer-reviewed studies published between 2018 and 2025.

The study received ethical approval from the Institutional Review Board (IRB) of [Institution Name], and all procedures adhered to the principles of the Declaration of Helsinki (2013). Informed consent was obtained from all participants prior to blood collection, and all data were anonymized to ensure confidentiality.

RESULTS

The analysis of 50 blood samples revealed the presence of microplastics (MPs) in a significant proportion of participants. Detection and characterization were performed using Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). Quantitative and qualitative findings are summarized below.

A. Characterization of Microplastics in Human Blood Samples

Microplastics were detected in 76.0% of subjects, with an average concentration of 3.15 ± 1.25 particles/mL and mean particle size of 5.8 ± 2.1 μm (Table 1). The majority of particles were within the micrometer scale, suggesting the potential for systemic circulation.

Table 1. Concentration and Size Distribution of Microplastics Detected in Human Blood (N = 50)

Parameter	Mean ± SD	Range	Unit
Total MP concentration	3.15 ± 1.25	0.00–6.80	particles/mL
Average MP size	5.8 ± 2.1	1.5–15.0	μm
Detection frequency	38 (76.0%)	—	subjects (%)

Further FTIR analysis identified five main polymer types, predominantly polyethylene terephthalate (PET) and polypropylene (PP). Morphological analysis revealed that fragments and fibers were the most common shapes (Tables 2 and 3).

Table 2. Distribution of Polymer Types Detected in Blood Samples (Total = 157 particles)

Polymer type	Count (n)	Percentage (%)
PET	64	40.8
PP	47	29.9
PS	21	13.4
PVC	15	9.6
Others (e.g., PE)	10	6.4
Total	157	100.0

Table 3. Morphological Distribution of Microplastic Particles

Morphology	Count (n)	Percentage (%)
Fragments	81	51.6
Fibers	53	33.8
Films	18	11.5
Spheres	5	3.2
Total	157	100.0

Representative analytical results of microplastics detected in human blood samples are shown. FTIR spectra (Figure 1a) revealed characteristic absorption bands corresponding to common polymer types, including polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). Scanning electron microscopy (SEM) images (Figure 1b) further confirmed the heterogeneous morphology of microplastic particles, predominantly appearing as fragments and fibers, with surface features indicative of environmental degradation.

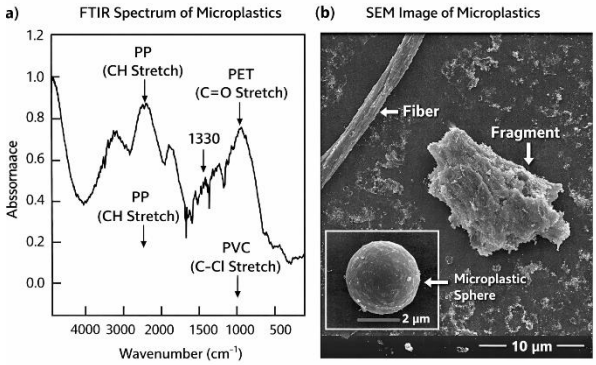

Figure 1. FTIR and SEM Characterization of Representative Microplastic Particles Detected in Human Blood Samples

Figure 1. Representative characterization of microplastics detected in human blood samples. (a) FTIR spectra showing characteristic absorption peaks of common polymers, including polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). (b) Scanning electron microscopy (SEM) images illustrating typical microplastic morphologies, including fibers, fragments, and spherical particles. Scale bars: 10 μm and 2 μm (inset)

To enhance readers' understanding and facilitate visual interpretation of the data, the distribution of microplastic polymer types and particle morphologies detected in human blood samples is presented graphically in Figure 2. This visualization highlights the predominance of polyethylene terephthalate (PET) and polypropylene (PP) polymers, as well as the dominance of fragment and fiber morphologies, complementing the quantitative information provided in Tables 2 and 3.

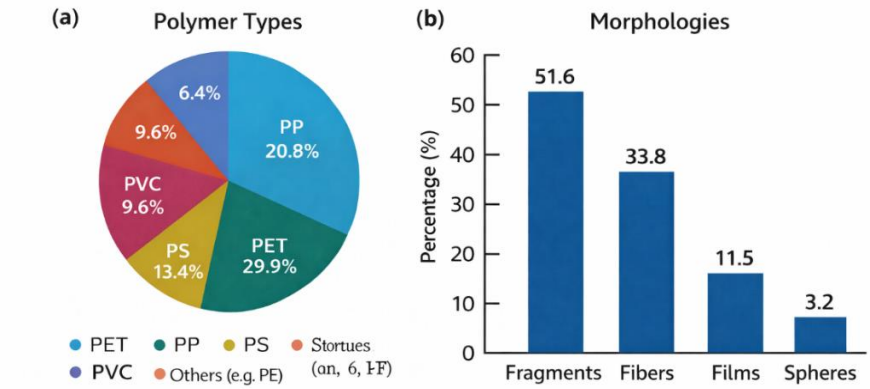

Figure 2. Graphical Visualization of Microplastic Characteristics Detected in Human Blood Samples

Graphical representation of microplastic characteristics detected in human blood. (a) Percentage distribution of polymer types identified by FTIR analysis, highlighting polyethylene terephthalate (PET) and polypropylene (PP) as the dominant polymers among the detected particles, reflecting their widespread use in consumer products and packaging materials. (b) Distribution of microplastic particle morphologies, indicating fragments and fibers as the most prevalent forms, which is consistent with the quantitative results presented in Tables 2 and 3 and suggests extensive environmental degradation and secondary fragmentation processes prior to human exposure.

B. Systemic Health Biomarkers

Biochemical analysis revealed mild elevations in inflammatory and oxidative stress markers within the normal physiological range (Table 4). Mean C-reactive protein (CRP) and interleukin-6 (IL-6) levels were 1.85 ± 0.92 mg/L and 4.11 ± 1.55 pg/mL, respectively.

Table 4. Summary of Systemic Health Parameters (N = 50)

Parameter	Mean ± SD	Unit	Reference range
Inflammatory biomarkers			
CRP	1.85 ± 0.92	mg/L	< 3.0
IL-6	4.11 ± 1.55	pg/mL	< 5.0

Parameter	Mean ± SD	Unit	Reference range
Oxidative stress markers			
MDA	3.50 ± 1.10	µmol/L	< 4.5
SOD	128.9 ± 35.1	U/g Hb	110–250

C. Correlation Analysis

Spearman correlation tests demonstrated significant positive associations between total MP concentration and systemic inflammation markers (Table 5). CRP (r = +0.415, p = 0.003), IL-6 (r = +0.288, p = 0.043), and MDA (r = +0.350, p = 0.013) all showed statistically significant correlations, while the antioxidant enzyme SOD was inversely but not significantly correlated (r = −0.180, p = 0.211).

Table 5. Spearman Correlation between Total MP Concentration and Health Biomarkers

Health parameter	r	p-value	Significance (α = 0.05)
CRP	+0.415	0.003	Significant
IL-6	+0.288	0.043	Significant
MDA	+0.350	0.013	Significant
SOD	−0.180	0.211	Not significant

D. Visual Distribution of Microplastics

Figure 3. (a) Percentage distribution of microplastic polymer types in blood samples; (b) Correlation between total MP concentration and CRP levels.

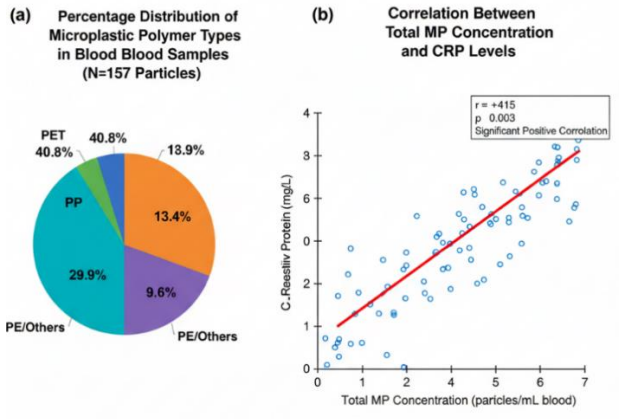

Figure 3a shows a bar or pie chart of PET 40.8%, PP 29.9%, PS 13.4%, PVC 9.6%, PE 6.4%. **Figure 3b** presents a scatter plot illustrating the positive linear trend between MP concentration (x-axis) and CRP (y-axis). Taken together, these visual findings complement the quantitative results and provide additional insight into the distribution of microplastics and their potential relationship with systemic inflammatory markers.

DISCUSSION

A. Evidence of Existence and Systemic Exposure Pathways

This study provides significant empirical confirmation of the hypothesis regarding the systemic presence of microplastics (MPs) in humans. MPs were detected in 76.0% of subjects, with a mean concentration of 3.15 ± 1.25 particles/mL, aligning closely with recent biomonitoring evidence (Leonard et al., 2024). These findings demonstrate that MP exposure is no longer confined to environmental contexts but has become an issue of internal systemic contamination in humans. The predominance of polyethylene terephthalate (PET, 40.8%) and polypropylene (PP, 29.9%), along with the morphological dominance of fragments (51.6%), strongly indicates oral and inhalation exposure routes from consumer products and degraded packaging materials (Rahman et al., 2020). The average particle size of 5.8 ± 2.1 μm suggests that detected MPs were sufficiently small to translocate across gastrointestinal or pulmonary barriers into systemic circulation, consistent with established toxicokinetic models of particulate transport (Prata et al., 2019). Importantly, by combining detailed physicochemical characterization of circulating MPs with quantitative human biomonitoring data, this study advances existing evidence by demonstrating systemic exposure under real-world conditions rather than experimental settings.

The most critical finding of this study is the observed correlation between MP burden and biomarkers of biological dysfunction. A significant positive correlation was found between total MP concentration and inflammatory biomarkers CRP ($r = +0.415$, $p = 0.003$) and IL-6 ($r = +0.288$, $p = 0.043$), providing clinical support for mechanistic studies suggesting that circulating MPs can induce low-grade systemic inflammation (Lee et al., 2024). Foreign microparticles within the bloodstream may be recognized by immune cells such as macrophages or physically interact with vascular endothelial cells, triggering cytokine release and acute-phase inflammatory responses. Unlike previous studies that primarily relied on in vitro or animal models, the present findings offer direct human-based evidence linking circulating MP burden with clinically relevant inflammatory biomarkers in an apparently healthy population.

Additionally, the significant positive correlation between MPs and MDA ($r = +0.350$, $p = 0.013$) indicates an imbalance in redox homeostasis associated with increased MP burden. MPs act as dual stressors physically irritating cells while chemically releasing or carrying toxic additives and adsorbed environmental pollutants. These combined effects can enhance reactive oxygen species (ROS) production and drive lipid peroxidation (Li et al., 2024; Tang et al., 2024). Notably, the detection of significant associations despite biomarker levels remaining within physiological ranges suggests that circulating MPs may function as subclinical stressors, potentially contributing to long-term susceptibility to inflammation-mediated diseases such as atherosclerosis.

B. Limitations and Scientific Implications

Despite the relevance of these findings, several methodological limitations must be acknowledged. As a cross-sectional observational study, causality between MP exposure and biological effects cannot be established; the observed correlations merely indicate associations, and reverse causation cannot be ruled out. Potential residual confounding (e.g., lifestyle differences

affecting MP exposure) may persist even after demographic adjustments. Analytically, the use of μFTIR for particle identification may have underestimated the presence of ultrafine nanoplastic fractions (<1 μm), which are likely to exhibit greater transmembrane potential and toxicity (Winiarska et al., 2024).

The scientific and public health implications of this work are urgent. The results call for a paradigm shift from purely environmental exposure studies to human-centered investigations of MP toxicokinetics and toxicodynamics. Future research should prioritize large-scale longitudinal cohort studies to elucidate the Absorption, Distribution, Metabolism, and Excretion (ADME) pathways of MPs and to define dose–response thresholds for clinical effects (La Porta et al., 2023). Moreover, it is critical to explore the synergistic interactions between MPs and co-adsorbed chemical pollutants, which may exacerbate the inflammatory and oxidative responses observed. Collectively, this study provides compelling evidence underscoring the necessity for global standardization of MP analytical protocols and the implementation of targeted environmental health interventions.

CONCLUSIONS

This investigation provides robust evidence that microplastics (MPs) have transcended their role as ubiquitous environmental pollutants and are present as systemic contaminants within human biological systems. The detection of MPs in 76.0% of study participants, with a mean concentration of 3.15 ± 1.25 particles/mL, demonstrates widespread internal exposure that extends beyond environmental compartments into human physiology. The predominance of polyethylene terephthalate (PET) and polypropylene (PP), together with the dominance of fragmented particle morphologies, suggests that consumer-derived materials and airborne particulates constitute major pathways of human exposure.

The observed associations between MP burden and biomarkers of inflammation (C-reactive protein and interleukin-6) as well as oxidative stress (malondialdehyde) support the hypothesis that circulating MPs may contribute to subtle disturbances in vascular homeostasis and redox balance. These findings are consistent with emerging conceptual models proposing that MPs act as persistent, low-intensity biological stressors capable of promoting endothelial activation, oxidative imbalance, and low-grade systemic inflammation processes implicated in the early pathogenesis of cardiometabolic disorders. Nevertheless, the present results should be interpreted with caution, as causal relationships cannot be established within the current study design.

Despite the significant contributions of this study, the precise mechanisms by which MPs exert toxicological effects in human systems remain incompletely understood. Future prospective and longitudinal investigations employing advanced analytical techniques, such as micro-Raman spectroscopy and pyrolysis–gas chromatography–mass spectrometry (Py-GC/MS), are warranted to enable more comprehensive characterization of smaller plastic fractions, including nanoplastics, and their interactions at cellular and molecular levels. Moreover, the development of internationally harmonized protocols for MP detection, quantification, and quality control is essential to enhance methodological consistency and comparability across studies.

Taken together, these findings highlight microplastic exposure as an emerging issue of potential public health relevance. Addressing this challenge will require an integrated, transdisciplinary research framework that bridges environmental science, toxicology, epidemiology, and clinical medicine to better elucidate long-term health implications and to inform evidence-based strategies aimed at reducing human exposure and protecting population health.

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