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Clinical infusion bypasses physiological barriers to directly deliver microplastics into human circulation

Xin Zhao, Yutong Duan, Liyan Deng, Huaidong Du, Sheng Chen, Yueping Wang, Chunli Wan, Yudong Song, Xiaowei Wang & Changyong Wu

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Intravenous infusion bypasses physiological barriers, directly introducing microplastics (MPs) into the bloodstream. Cleanroom simulations revealed MPs concentrations of 211 ± 34 (0.9% NaCl) and 179 ± 28 MPs/L (5% glucose), mostly < 20 μm in size, plus with 4–5 μg/L nanoplastics. Predominantly polyamide and polyvinyl alcohol, matching infusion materials. A 5-day infusion delivers > 1000 particles - equivalent to months of inhalation/ingestion exposure. This overlooked medical route necessitates safer materials and regulation.

Intravenous infusion systems constitute one of the most widespread applications of synthetic polymers in modern medicine. Globally, billions of infusion bags, tubing sets, and connectors are used annually, primarily composed of polymeric materials such as polyethylene (PE) and polypropylene (PP)[1,2]. Although medical-grade plastics are selected for their chemical stability and biocompatibility. They are continuously subjected during clinical use to fluid shear stress, pump induced compression, puncturing at connection interfaces, and fluctuations in temperature and pressure[3]. These punctures and mechanical stresses can induce microstructural fatigue within the polymers, leading to the physical detachment of solid plastic particles from material surfaces[4].

To date, research on human exposure to microplastic (MPs) has primarily focused on environmental pathways, particularly inhalation and ingestion[5,6]. Particles from these sources must traverse tightly regulated epithelial barriers (e.g., gastrointestinal mucosa or alveolar epithelium) to enter systemic circulation, resulting in a typically low bioavailability of < 1%[7]. In contrast, intravenous infusion represents a direct exposure route that bypasses physiological filtration barriers and may facilitate the systemic distribution of particles via the bloodstream. Despite the extensive global use of intravenous infusion, the potential contribution of infusion solutions to systemic exposure to microplastics and nanoplastics (MNPs) has not been systematically evaluated. Given that critically ill and chronically treated patients often undergo repeated or high volume infusions[8,9], even low particle release per unit volume may result in substantial cumulative exposure. To address this gap, the present study systematically characterizes particle release from commercially available 0.9% sodium chloride and 5% glucose solutions under clinically simulated conditions and quantifies the associated cumulative exposure risk over a typical treatment course.

MNPs release during infusion

Under rigorously simulated clinical infusion conditions with environmental background contamination excluded, we demonstrate that MNPs can be directly introduced into systemic circulation via intravenous infusion (Fig. 1a). This infusion derived direct exposure may represent a potential concern for microcirculatory safety. Once in the bloodstream, MNPs can accumulate in organs such as the lung, brain, liver, and kidney[5,10]. In particular, particles with sizes approaching or exceeding capillary diameters (5–10 μm) may interfere with blood flow in the capillaries (Fig. 1b). Although standard clinical infusion systems are typically equipped with inline filters rated at 15 μm, substantial numbers of MPs were still detected downstream (Fig. 1c and Figs. S1, S2). Size distribution analysis revealed that most detected particles were < 50 μm (Fig. 1d). In sodium chloride samples, particles <20 μm accounted for 67.8% (143 particles L^{-1}). These small and irregularly shaped plastic particles may bypass filtration barriers[11,12]. Polymer characterization based on spectral library matching identified polyvinyl alcohol (PVA) and polyamide (PA) as the dominant components (Fig. 1e). Notably, PA particles were more abundant in sodium chloride solutions than in glucose solutions. This may be due to the higher ionic strength of sodium chloride, which disrupts hydrogen bonding on PA surfaces and facilitates particle detachment[13,14].

Beyond micronscale risks, Pyrolysis Gas Chromatography-Mass Spectrometer (Py-GC/MS) quantification further confirmed the presence of nanoplastics (NPs). The mass concentrations of NPs reached 5.28 μg L^{-1} in sodium chloride and 4.13 μg L^{-1} in glucose solutions (Fig. 1f and Table S1). Owing to their nanoscale sizes, these particles may more readily evade mechanical filtration and interact with biological systems[15,16]. NPs have been reported to undergo cellular uptake and systemic transport through processes such as transendothelial translocation or phagocytosis by immune cells[17–19], with potential associations with oxidative stress responses[20,21]. The strong correspondence between the detected MNPs and the polymer compositions of infusion bags, tubing, and connectors indicates that these particles originate from physical shedding under puncture damage and mechanical stress. Collectively, these findings demonstrate that clinically used infusion solutions contain measurable levels of MNPs and support the consideration of intravenous infusion as a potential pathway for direct plastic particle exposure.

Cumulative MPs exposure

Based on single infusion measurements, we further developed a predictive model to estimate the cumulative systemic burden arising from multi-day

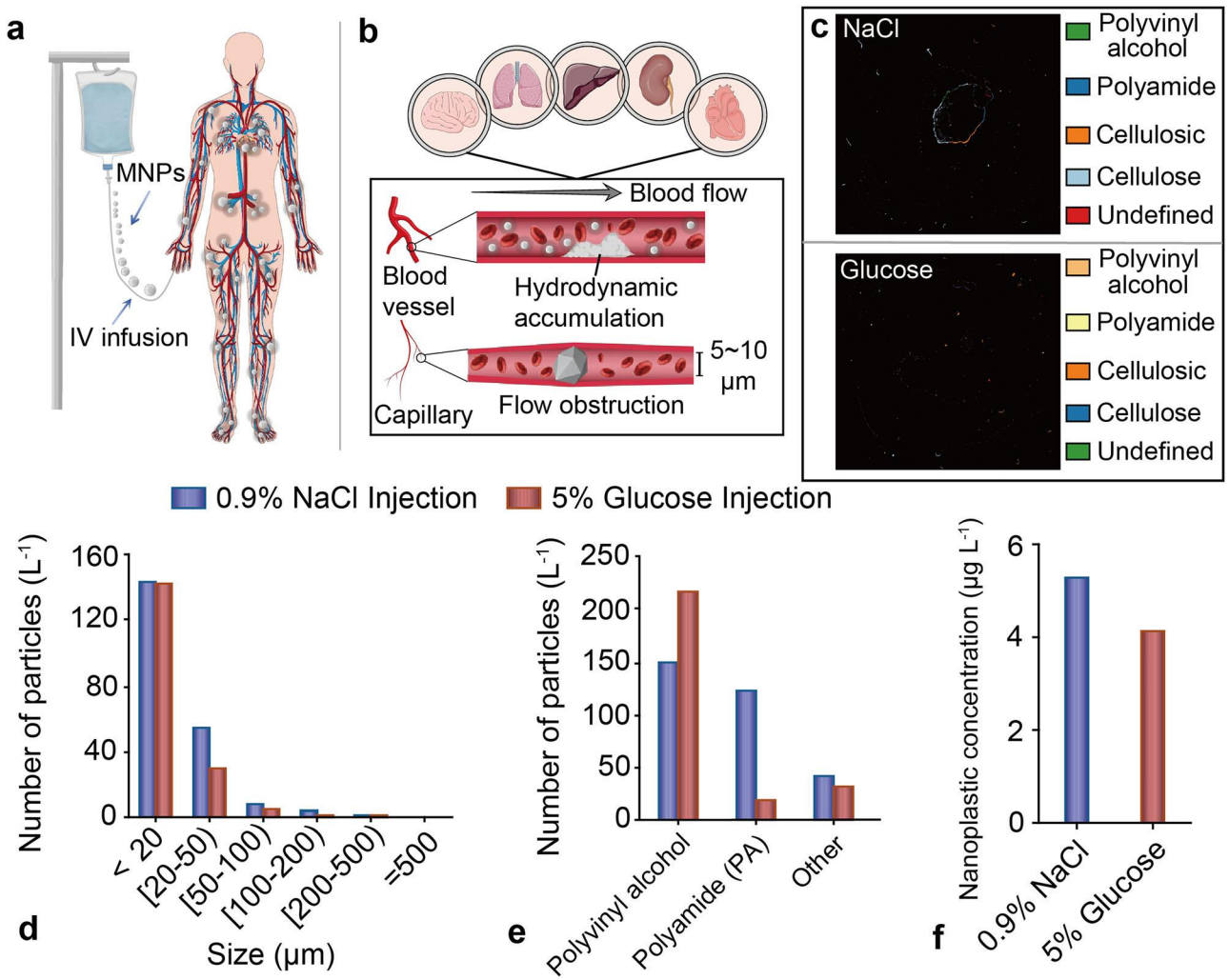

Fig. 1 | MNPs released from infusion systems and their potential exposure pathways in the bloodstream. a Schematic illustration of the potential introduction of MNPs released from medical devices during intravenous infusion. **b** Conceptual model illustrating the distribution and retention of MNPs within blood vessels and major organs (e.g., brain, lung, liver, kidney, and heart). Particles may aggregate under blood flow, and particles with sizes approaching or exceeding capillary diameters (~5–10 μm) may interfere with blood flow in the capillaries. **c** Representative spectral imaging of microplastic particles detected by LDIR in 0.9% sodium chloride (top) and 5% glucose (bottom) injection solutions. **d** Size distribution of detected microplastics in both solutions, expressed as particle number per litre across different size ranges. **e** PVA and PA particles identified in the two solutions. **f** Concentrations of nanoplastics detected in both infusion solutions, expressed in μg L^{-1}.

clinical infusion regimens (Fig. 2a). Over a typical 5 d treatment course, the circulatory system is exposed to an estimated ~1000 MPs (Fig. 2b). This cumulative particle profile is dominated by smaller, higher risk fractions. The particles < 20 μm account for more than 700 particles, while those in the 20–50 μm and 50–100 μm ranges contribute approximately 300 and 50 particles, respectively. Such progressive accumulation over time increasesthe potential for microvascular interference and inflammatory responses[22,23]. To contextualize the relative risk of medical exposure, we compared the infusion pathway with conventional environmental exposure via inhalation and diet (Fig. 2c). Although daily intake of microplastics from environmental sources (~202–331 particles per day)[23,24] exceeds the number released per litre of infusion (~211 particles), their biological fate differs fundamentally. Environmental particles are largely restricted by physiological barriers (e.g., intestinal epithelium and vascular endothelium), resulting in very low systemic uptake (< 1%)[7]. In contrast, particles introduced via intravenous infusion enter directly into the bloodstream, yielding complete systemic exposure (~100%). Consequently, a single day of 1 L intravenous infusion may result in a circulatory exposure burden equivalent to the cumulative intake from months to years of daily environmental exposure. This quantitative comparison underscores the dominant contribution of medical infusion systems to systemic plastic burden and highlights their substantially higher clinical health risk relative to environmental pathways.

Potential risks of clinical exposure

This study demonstrates that clinical intravenous infusion may serve as a direct route for MNPs to enter systemic circulation, identifying a previously overlooked pathway for internal plastic particle exposure. Given that

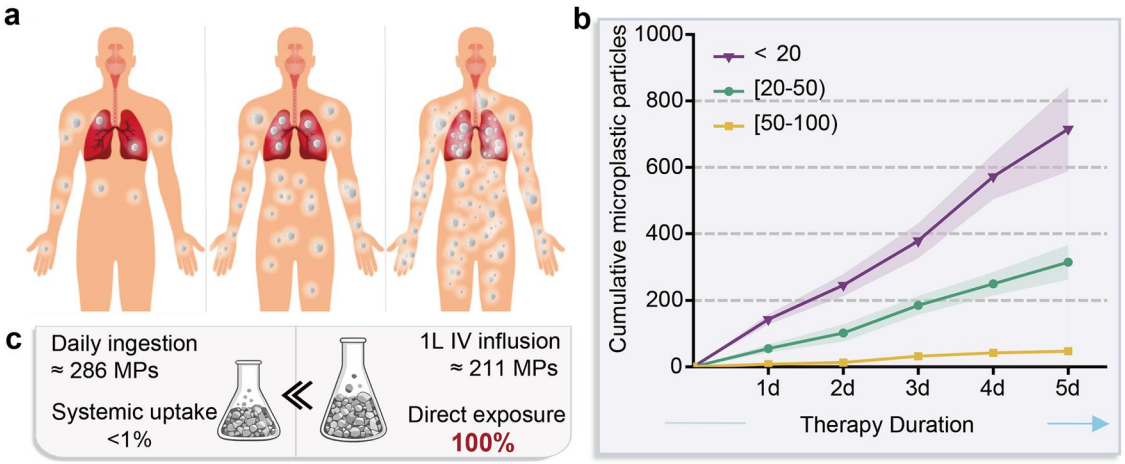

Fig. 2 | Predicted cumulative exposure of MPs during multi-day intravenous infusion. a Schematic illustration of the progressive entry and accumulation of infusion derived MPs during a 5 d continuous intravenous treatment course. **b** Predicted cumulative number of MPs particles entering circulation over the 5 d period, stratified by size ranges (< 20 μm, 20–50 μm, and 50–100 μm). **c** Conceptual comparison between intravenous inhalation and ingestion exposure to microplastics. Although daily dietary intake may involve comparable particle numbers, gastrointestinal barriers markedly limit systemic uptake (< 1%), whereas intravenous infusion may contribute more directly to systemic exposure.

intravenous administration bypasses the physiological filtration barriers. This find highlight a potential systemic exposure concern that further evaluation of possible health implications.

From a physiological perspective, the human body is equipped with highly specialized physical barriers, such as the intestinal mucosa, alveolar epithelium, and skin to intercept exogenous particles from the environment. However, while intravenous infusion provides essential medical treatment, it also creates a route that bypasses these evolved filtration mechanisms. When inline filters within infusion systems cannot completely retain polymer particles, MNPs may still be introduced during infusion and contribute to systemic exposure. This shift from indirect environmental exposure to direct intravascular input transforms MNPs contamination into a clinically relevant exposure concern.

From a metabolic perspective, MPs are generally too large to be efficiently cleared via glomerular filtration and are therefore not readily eliminated once present in systemic circulation. Their removal mainly depends on slow processing by macrophages and organs such as the liver and spleen[10,22,25]. Owing to the high chemical stability and relative biological persistence of many polymer materials, repeated or continuous exposure could potentially contribute to particle accumulation over time. In contrast, NPs possess smaller particle sizes and larger specific surface areas, which may facilitate interactions with cells and biological interfaces. Previous studies have reported that NPs can undergo cellular internalization and may be associated with reactive oxygen species generation, oxidative stress, and inflammation-related signaling responses[21,23]. Persistent particle retention within tissues or immune cells has therefore been proposed as a potential factor contributing to sustained cellular stress and immune perturbation. However, the biological and clinical implications of infusion-derived MNP exposure remain insufficiently understood and require further investigation through in vivo and clinical studies.

The estimated 5 d cumulative exposure in this study represents only a fraction of the potential plastic input during clinical treatment. For patients requiring long-term infusion support or those in intensive care units, the total burden of MNPs may further increase with prolonged and repeated infusions. However, current clinical quality control frameworks for infusion systems primarily focus on chemical purity, sterility, and toxicity levels. Given the widespread use of infusion systems, the potential presence of MNPs in infusion procedures may support further consideration in future safety evaluation frameworks. In addition, the development of medical materials with reduced particle shedding characteristics may help improve the long-term safety of infusion systems. Although this study was conducted under simulated clinical infusion conditions, the presence of MNPs in commonly used infusion solutions highlights a previously underrecognized exposure pathway. Future studies integrating in health assessment and clinical monitoring will be important for clarifying the biological fate and potential health implications of infusion-derived MNPs exposure.

Methods

Clinical simulation and sample collection. To ensure clinical relevance, this study strictly adhered to standardized clinical infusion procedures. Commercially available 250 mL 0.9% sodium chloride and 5% glucose solutions were selected and administered through a standard infusion system, including infusion bags, tubing, and connectors. All effluent infusion samples were collected for subsequent analysis.

To minimize potential interference from environmental MNPs, all infusion experiments were conducted within a Class laminar flow clean bench. Operators wore plastic-free personal protective equipment, and all collection containers were thoroughly rinsed with ultrapure water prior to use and verified to be free of particulate contamination. The infusion system was operated at a constant flow rate (20 drops min^{-1}) to simulate hemodynamic shear forces and mechanical stresses encountered during clinical administration. Only effluent passing through the complete infusion system was collected. For both microplastic and nanoplastic analyses, 1.5 L of effluent infusion samples were obtained for subsequent multiscale particle characterization, ensuring that the measured results accurately reflect the systemic exposure levels experienced by patients during actual infusion procedures.

Microplastics and nanoplastics analysis. MPs (10–500 μm) were quantitatively analyzed and polymer types identified using laser direct infrared (LDIR) chemical imaging (Agilent 8700 LDIR system)[26]. Collected infusion samples were first vacuum filtered through gold-coated polycarbonate membranes (0.8 μm pore size). The entire membrane surface was subsequently scanned automatically in Particle Analysis mode. The LDIR system employs a tunable quantum cascade laser to acquire infrared reflection spectra of individual particles, which are then matched against a polymer spectral library (Agilent + WP-8.29) for material identification. To ensure data reliability, only particles with a spectral match similarity greater than 0.65 were included in the analysis.

Nanoplastics were detected and their mass concentrations (μg L^{-1}) quantified using Pyrolysis Gas Chromatography-Mass Spectrometer[27]. This method enables highly sensitive detection of solid polymer particles by analyzing characteristic pyrolysis products generated at elevated temperatures. Infusion samples were first concentrated and then subjected to pyrolysis; the resulting products were separated by gas chromatography and identified by mass spectrometry based on characteristic ions. Quantification was performed using an external calibration approach, with calibration curves established from polymer standards of known concentrations.

Data availability

No datasets were generated or analysed during the current study.

Xin Zhao[1], Yutong Duan[2], Liyan Deng[2], Huaidong Du[3], Sheng Chen[2], Yueping Wang[1], Chunli Wan[1] ✉, Yudong Song[2], Xiaowei Wang[4] & Changyong Wu[3] ✉

[1]Department of Environmental Science and Engineering, Fudan University, Shanghai, China. [2]State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environment Sciences, Beijing, China. [3]ENT Institute and Department of Otorhinolaryngology, Eye & ENT Hospital, Fudan University, Shanghai, China. [4]Department of Microbiology and Immunology, University of Maryland, Baltimore, MD, USA. ✉e-mail: wan@fudan.edu.cn; wu.changyong@craes.org.cn

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Author contributions

C.L.W., and C.Y.W., designed research; X.Z., Y.T.D., L.Y.D., S.C., and Y.P.W., performed research; H.D.D., Y.D.S., and X.W.W., contributed new reagents/analytic tools; X.Z., C.L.W., and C.Y.W., analyzed data; and X.Z., Y.T.D., L.Y.D., C.L.W., and C.Y.W., wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Chunli Wan or Changyong Wu.

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