## Microplastics and Human Health: A Review of Exposure, Biodistribution, and Toxicological Outcomes

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**Abstract**

The pervasive environmental contamination by microplastics (MPs) has precipitated inevitable human exposure across the globe. This review synthesizes the current scientific evidence on the pathways of human exposure to MPs, their biodistribution after entry, and the resulting toxicological effects. Humans are primarily exposed through the ingestion of contaminated food and water, inhalation of airborne particles, and, to a lesser extent, dermal contact. A growing body of literature has confirmed the internalization of MPs in human tissues and fluids, including blood, placenta, and lungs, indicating systemic distribution. In vitro and in vivo studies demonstrate that MPs can induce a range of adverse health effects, including oxidative stress, inflammation, cellular damage, metabolic disruption, and neurotoxicity. These effects are mediated by physical damage, leaching of inherent additives, and the adsorption and transport of exogenous toxicants. While direct epidemiological evidence linking MPs to specific human diseases remains limited, the consistent toxicological data and the confirmed presence of MPs within humans raise significant public health concerns. This review underscores the urgent need for further research, particularly large-scale epidemiological studies and advanced analytical methods for nanoplastics, to fully quantify human health risks and inform effective regulatory policies.

**1. Introduction**

Plastic pollution is a defining environmental issue of the 21st century. A critical and insidious aspect of this pollution is the generation and accumulation of microplastics (MPs), commonly defined as synthetic polymer particles smaller than 5 mm in diameter (1). MPs are categorized as either primary MPs (intentionally manufactured at micro-size, e.g., microbeads in personal care products, industrial scrubbers, and plastic pellets) or secondary MPs (resulting from the environmental degradation and fragmentation of larger plastic debris through photolytic, mechanical, and biological processes) (2).

Their small size, low density, and high persistence have facilitated their widespread dispersion, contaminating every environmental compartment from the deepest marine trenches to remote alpine regions (3,4). This ubiquity has created a scenario of perpetual and unavoidable human exposure through multiple pathways. The confirmation of MPs in human consumables, air, and drinking water has transitioned the issue from an ecological concern to a potential public health crisis (5,6). This review aims to consolidate and critically evaluate the current state of knowledge regarding human exposure to MPs, their fate within the human body, and the mechanistic pathways through which they may exert adverse health effects.

**2. Pathways of Human Exposure**

Human exposure to MPs is a multi-route process, with the relative contribution of each pathway still being actively researched.

2.1. Ingestion

Ingestion is considered the dominant exposure route for the general population (7).

* Food: Seafood, particularly filter-feeding organisms like mussels and oysters, is a well-documented source (8). MPs have also been detected in table salt (sea, rock, and lake), honey, sugar, beer, and various agricultural products due to contamination from soil, water, and air (9,10).
* Water: Drinking water, both tap and bottled, is a significant vector. Bottled water has been shown to contain higher concentrations, likely from the packaging material and the bottling process itself (11,12).
* Food Packaging: The abrasion of plastic packaging materials and the release of particles from plastic containers, especially during microwave heating, can contribute to dietary intake (13).

2.2. Inhalation

Airborne MPs, generated from the wear of synthetic textiles, car tires, and urban dust, are suspended in the air and inhaled (14).

* Indoor Environments: Indoor spaces are a major source, with concentrations often higher than outdoors due to the shedding from furniture, carpets, and clothing (15).
* Fiber-Shaped MPs: Fiber-shaped MPs are the most prevalent type found in indoor air and have been confirmed in human lung samples (16).

2.3. Dermal Contact

While the stratum corneum of the skin acts as an effective barrier against larger MPs, dermal exposure occurs through the use of cosmetics containing microbeads (17). The potential for transdermal absorption of smaller nanoplastics (<100 nm) through hair follicles or sweat glands remains a subject of ongoing investigation (18).

**Table 1: Pathways of Human Exposure to Microplastics**



|  |  |  |
| --- | --- | --- |
| **Exposure Pathway** | **Description and Key Sources** | **Examples** |
| **Ingestion** | Considered the **dominant exposure route** for humans. Involves consuming contaminated food and water. | • **Food**: Seafood (mussels, oysters), sea salt, honey, sugar, beer, and agricultural products.  • **Water**: Both tap and bottled water, with bottled water often showing higher concentrations from packaging and bottling.  • **Food Packaging**: Abrasion of plastic containers, especially during heating. |
| **Inhalation** | Involves breathing in airborne microplastic particles, which are often concentrated in **indoor environments**. | • **Sources**: Wear from synthetic textiles (clothing, carpets, furniture), car tires, and urban dust.  • **Particle Type**: Fiber-shaped microplastics are most found in indoor air and human lung tissue. |
| **Dermal Contact** | Considered a lesser pathway, as the skin's outer layer provides a barrier against larger particles. | • **Sources**: Cosmetics and personal care products containing microbeads.  • **Potential Risk**: Smaller nanoplastics (<100 nm) may have the potential for transdermal absorption through hair follicles or sweat glands, though this is still under investigation. |

**3. Biodistribution and Internalization in Humans**

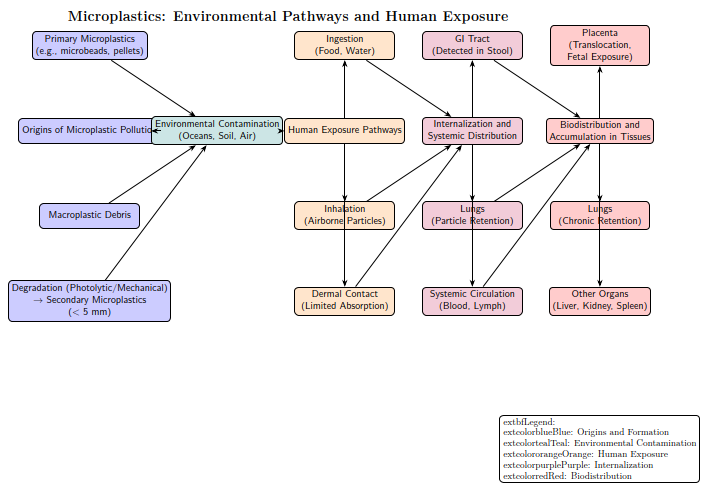
Evidence of human internalization has moved from hypothetical to empirically confirmed, with MPs being identified in various human tissues and biofluids.

* Gastrointestinal Tract: The presence of various MPs in human stool samples from diverse global populations confirms their ingestion and passage through the GI tract (19,20).
* Systemic Circulation: A landmark study detected and quantified MPs in the blood of 77% of tested healthy volunteers, demonstrating that particles can be absorbed and transported throughout the body (21).
* Lungs: MPs, particularly fibers, have been repeatedly identified deep within human lung tissue, indicating inhalation and retention in the respiratory system (16,22).
* Placenta: The detection of MPs in human placental tissue proves their ability to cross biological barriers and raises serious concerns about direct exposure of the developing fetus to these contaminants (23).
* Other Tissues: Further evidence of systemic accumulation comes from the identification of MPs in the human liver, kidney, and spleen, suggesting a potential for accumulation in various organs (24).

Figure 1: Mind map of microplastic presence, human entry and health effects

A screenshot of a computer screen

AI-generated content may be incorrect.



**4. Mechanisms of Toxicity and Observed Health Effects**

The toxicity of MPs is a complex interplay of their physical and chemical properties.

4.1. Physical Effects

The particulate nature of MPs can cause direct physical harm.

* Cellular Damage: Internalized particles can cause physical stress, leading to membrane damage, inflammation, cellular necrosis, and fibrosis, similar to reactions caused by other airborne particulates (25,26).
* Translocation and Accumulation: Smaller particles, particularly nanoplastics, can cross the gut-lung barrier, the blood-brain barrier, and placental tissue, leading to accumulation and potential chronic effects in sensitive organs (27,28).

4.2. Chemical Effects

Plastics are complex materials containing unreacted monomers, additives, and adsorbed pollutants.

* Leaching of Additives: Harmful additives such as phthalates and bisphenol A (BPA) can leach from the plastic matrix inside the body. Many of these are known endocrine-disrupting chemicals (EDCs) linked to reproductive, developmental, and metabolic disorders (29,30).
* Vector Effect: MPs act as vectors for environmental pollutants (e.g., persistent organic pollutants, pesticides, heavy metals) and pathogens, concentrating them and facilitating their entry into tissues (31,32).

4.3. Biological Effects (Evidence from Models)

* Oxidative Stress and Inflammation: This is the most universally reported mechanism of MP toxicity. The particles induce the production of reactive oxygen species (ROS), causing oxidative damage to lipids, proteins, and DNA, which in turn triggers inflammatory responses (33,34).
* Metabolic Disruption: Animal studies show that MP exposure can lead to gut microbiota dysbiosis, altered lipid metabolism, and insulin resistance (35,36).
* Immunotoxicity: MPs can alter immune cell function, potentially leading to immunosuppression or heightened autoimmune responses (37).
* Reproductive and Developmental Toxicity: Studies in model organisms report reduced fertility, decreased sperm quality, and developmental abnormalities in offspring following parental exposure to MPs (38,39).
* Neurotoxicity: Emerging evidence suggests that MPs can cross the blood-brain barrier and induce neuroinflammation, oxidative stress in neural tissues, and disrupt neurotransmitter levels, potentially contributing to behavioral changes and neurodegeneration (40,41).

5. Knowledge Gaps and Future Perspectives

Substantial challenges must be overcome to accurately assess human health risks from MP exposure. Key knowledge gaps include:

1. Analytical Challenges: There is a critical lack of standardized, validated methods for sampling, extracting, and identifying MPs—especially nanoplastics—in complex biological matrices, which hinders accurate quantification (42).
2. Epidemiological Data: There is a severe scarcity of large-scale epidemiological studies that can link internal MP body burdens to specific health outcomes in human populations.
3. Toxicokinetics: The absorption, distribution, metabolism, and excretion (ADME) profiles for different types, sizes, and shapes of MPs in humans are poorly characterized.
4. Dose-Response Relationships: Establishing the threshold levels at which MPs cause observable adverse effects in humans is crucial for realistic risk assessment.

**Table 2: Key Knowledge Gaps and Future Research Directions**

|  |  |  |
| --- | --- | --- |
| **Knowledge Gap** | **Description & Implication** | **Required Future Research** |
| **Analytical Challenges** | There is a critical lack of standardized and validated methods for sampling, extracting, and identifying microplastics—especially **nanoplastics**—in human tissues. This prevents accurate risk assessment. | Prioritize the harmonization of analytical methodologies to ensure data can be compared across studies. |
| **Lack of Epidemiological Data** | There is a severe of large-scale epidemiological studies that can connect the internal load of microplastics in humans to specific diseases or health outcomes. |  |
| **Unknown Toxicokinetics** | The processes of Absorption, Distribution, Metabolism, and Excretion (ADME) for different types, sizes, and shapes of microplastics in the human body are poorly understood. | Advance research on the toxicokinetics of MPs, with a focus on nanoplastics. |
| **Unclear Dose-Response Relationships** | The threshold at which microplastic exposure causes adverse effects is unknown. It is difficult to relate findings from high-dose animal studies to the current levels of human exposure. | Conduct studies to establish clear dose-response relationships for realistic risk assessment. |

6. Conclusion

The infiltration of microplastics into the human body is no longer speculative but a confirmed scientific reality. Compelling toxicological evidence from experimental models provides consistent data that exposure to MPs can elicit a range of adverse biological effects, primarily through oxidative stress and inflammation. While translating these findings directly to human health outcomes requires caution, the precautionary principle dictates that the existing evidence is sufficient to warrant serious concern. Addressing this global challenge requires a concerted effort on multiple fronts: (1) robust scientific research to close critical knowledge gaps; (2) effective policy and regulatory actions to reduce plastic production and improve waste management; and (3) public awareness campaigns to drive behavioral change.

References

1. Thompson, R. C., Swan, S. H., Moore, C. J., & vom Saal, F. S. (2009). Our plastic age. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1526), 1973-1976.
2. Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin, 62*(8), 1596-1605.
3. Bergmann, M., Mützel, S., Primpke, S., Tekman, M. B., Trachsel, J., & Gerdts, G. (2019). White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. *Science Advances, 5*(8), eaax1157.
4. Jamieson, A. J., Brooks, L. S., Reid, W. D., Piertney, S. B., Narayanaswamy, B. E., & Linley, T. D. (2019). Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. *Royal Society Open Science, 6*(2), 180667.
5. Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human consumption of microplastics. *Environmental Science & Technology, 53*(12), 7068-7074.
6. Zhang, Q., Xu, E. G., Li, J., Chen, Q., Ma, L., Zeng, E. Y., & Shi, H. (2020). A review of microplastics in table salt, drinking water, and air: direct human exposure. *Environmental Science & Technology, 54*(7), 3740-3751.
7. Senathirajah, K., Attwood, S., Bhagwat, G., Carbery, M., Wilson, S., & Palanisami, T. (2021). Estimation of the mass of microplastics ingested – A pivotal first step towards human health risk assessment. *Journal of Hazardous Materials, 404*, 124004.
8. Van Cauwenberghe, L., & Janssen, C. R. (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution, 193*, 65-70.
9. Karami, A., Golieskardi, A., Keong Choo, C., Larat, V., Galloway, T. S., & Salamatinia, B. (2017). The presence of microplastics in commercial salts from different countries. *Scientific Reports, 7*(1), 46173.
10. Conti, G. O., Ferrante, M., Banni, M., Favara, C., Nicolosi, I., Cristaldi, A., ... & Zuccarello, P. (2020). Micro-and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. *Environmental Research, 187*, 109677.
11. Kosuth, M., Mason, S. A., & Wattenberg, E. V. (2018). Anthropogenic contamination of tap water, beer, and sea salt. *PloS one, 13*(4), e0194970.
12. Oßmann, B. E., Sarau, G., Holtmannspötter, H., Pischetsrieder, M., Christiansen, S. H., & Dicke, W. (2018). Small-sized microplastics and pigmented particles in bottled mineral water. *Water Research, 141*, 307-316.
13. Du, F., Cai, H., Zhang, Q., Chen, Q., & Shi, H. (2020). Microplastics in take-out food containers. *Journal of Hazardous Materials, 399*, 122969.
14. Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., & Tassin, B. (2017). A first overview of textile fibers, including microplastics, in indoor and outdoor environments. *Environmental Pollution, 221*, 453-458.
15. Vianello, A., Jensen, R. L., Liu, L., & Vollertsen, J. (2019). Simulating human exposure to indoor airborne microplastics using a Breathing Thermal Manikin. *Scientific Reports, 9*(1), 8670.
16. Amato-Lourenço, L. F., Carvalho-Oliveira, R., Júnior, G. R., dos Santos Galvão, L., Ando, R. A., & Mauad, T. (2021). Presence of airborne microplastics in human lung tissue. *Journal of Hazardous Materials, 416*, 126124.
17. Lei, K., Qiao, F., Liu, Q., Wei, Z., Qi, H., Cui, S., ... & An, L. (2017). Microplastics releasing from personal care and cosmetic products in China. *Marine Pollution Bulletin, 123*(1-2), 122-126.
18. Schneider, M., Stracke, F., Hansen, S., & Schaefer, U. F. (2009). Nanoparticles and their interactions with the dermal barrier. *Dermato-endocrinology, 1*(4), 197-206.
19. Schwabl, P., Köppel, S., Königshofer, P., Bucsics, T., Trauner, M., Reiberger, T., & Liebmann, B. (2019). Detection of various microplastics in human stool: a prospective case series. *Annals of Internal Medicine, 171*(7), 453-457.
20. Zhang, J., Wang, L., Trasande, L., & Kannan, K. (2021). Occurrence of polyethylene terephthalate and polycarbonate microplastics in infant and adult feces. *Environmental Science & Technology Letters, 8*(11), 989-994.
21. Leslie, H. A., van Velzen, M. J., Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J., & Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International, 163*, 107199.
22. Jenner, L. C., Rotchell, J. M., Bennett, R. T., Cowen, M., Tentzeris, V., & Sadofsky, L. R. (2022). Detection of microplastics in human lung tissue using μFTIR spectroscopy. *Science of The Total Environment, 831*, 154907.
23. Ragusa, A., Svelato, A., Santacroce, C., Catalano, P., Notarstefano, V., Carnevali, O., ... & Giorgini, E. (2021). Plasticenta: First evidence of microplastics in human placenta. *Environment International, 146*, 106274.
24. Horvatits, T., Tamminga, M., Liu, B., Sebode, M., Carambia, A., Fischer, L., ... & Püschel, K. (2022). Microplastics detected in human liver and lung tissue. *Pneumologie, 76*(S 01), S45.
25. Hwang, J., Choi, D., Han, S., Choi, J., & Hong, J. (2019). An assessment of the toxicity of polypropylene microplastics in human derived cells. *Science of The Total Environment, 684*, 657-669.
26. Dong, C. D., Chen, C. W., Chen, Y. C., Chen, H. H., Lee, J. S., & Lin, C. H. (2020). Polystyrene microplastic particles: In vitro pulmonary toxicity assessment. *Journal of Hazardous Materials, 385*, 121575.
27. Stock, V., Böhmert, L., Lisicki, E., Block, R., Cara-Carmona, J., Pack, L. K., ... & Lichtenstein, D. (2019). Uptake and effects of orally ingested polystyrene microplastic particles in vitro and in vivo. *Archives of Toxicology, 93*(7), 1817-1833.
28. Fournier, E., Etienne-Mesmin, L., Grootaert, C., Jelsbak, L., Syberg, K., Blanquet-Diot, S., & Mercier-Bonin, M. (2021). Microplastics in the human digestive environment: A focus on the potential and challenges facing in vitro gut model development. *Journal of Hazardous Materials, 415*, 125632.
29. Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials, 344*, 179-199.
30. Rochester, J. R. (2013). Bisphenol A and human health: a review of the literature. *Reproductive Toxicology, 42*, 132-155.
31. Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., & Kaminuma, T. (2001). Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environmental Science & Technology, 35*(2), 318-324.
32. Wu, X., Pan, J., Li, M., Li, Y., Bartlam, M., & Wang, Y. (2019). Selective enrichment of bacterial pathogens by microplastic biofilm. *Water Research, 165*, 114979.
33. Lu, L., Wan, Z., Luo, T., Fu, Z., & Jin, Y. (2018). Polystyrene microplastics induce gut microbiota dysbiosis and hepatic lipid metabolism disorder in mice. *Science of The Total Environment, 631*, 449-458.
34. Rubio, L., Marcos, R., & Hernández, A. (2020). Potential adverse health effects of ingested micro-and nanoplastics on humans. Lessons learned from in vivo and in vitro mammalian models. *Journal of Toxicology and Environmental Health, Part B, 23*(2), 51-68.
35. Jin, Y., Lu, L., Tu, W., Luo, T., & Fu, Z. (2019). Impacts of polystyrene microplastic on the gut barrier, microbiota and metabolism of mice. *Science of The Total Environment, 649*, 308-317.
36. Li, B., Ding, Y., Cheng, X., Sheng, D., Xu, Z., Rong, Q., ... & Zhang, Y. (2020). Polyethylene microplastics affect the distribution of gut microbiota and inflammation development in mice. *Chemosphere, 244*, 125492.
37. Jin, H., Ma, T., Sha, X., Liu, Z., Zhou, Y., Meng, X., ... & Xu, J. (2021). Polystyrene microplastics induced male reproductive toxicity in mice. *Journal of Hazardous Materials, 401*, 123430.
38. Park, E. J., Han, J. S., Park, E. J., Seong, E., Lee, G. H., Kim, D. W., ... & Son, H. Y. (2020). Repeated-oral dose toxicity of polyethylene microplastics and the possible implications on reproduction and development of the next generation. *Toxicology Letters, 324*, 75-85.
39. Hou, B., Wang, F., Liu, T., & Wang, Z. (2021). Reproductive toxicity of polystyrene microplastics: In vivo experimental study on testicular toxicity in mice. *Journal of Hazardous Materials, 405*, 124028.
40. Wang, S., Han, Q., Wei, Z., Wang, Y., Xie, J., & Chen, M. (2022). Polystyrene microplastics induce microglial activation and cognitive decline in mice. *Science of The Total Environment, 813*, 152486.
41. Prüst, M., Meijer, J., & Westerink, R. H. (2020). The plastic brain: neurotoxicity of micro- and nanoplastics. *Particle and Fibre Toxicology, 17*(1), 1-16.
42. Koelmans, A. A., Mohamed Nor, N. H., Hermsen, E., Kooi, M., Mintenig, S. M., & De France, J. (2019). Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Research, 155*, 410-422.

**Flowchart: The Journey of Microplastics into the Human Body**

This flowchart illustrates the lifecycle of microplastics, from their origin as pollution to their internalization and distribution within human tissues.

**1. Origins of Microplastic Pollution**

* **Primary Microplastics** (manufactured as small particles, e.g., microbeads)
* **Large Plastic Debris** -> Degrades via environmental processes (photolytic, mechanical) -> **Secondary Microplastics** (fragments < 5 mm)

**2. Environmental Contamination**

* Widespread dispersal into every environmental compartment, including oceans, soil, and air.

**3. Human Exposure Pathways**

* **Ingestion** -> Enters Gastrointestinal (GI) Tract
* **Inhalation** -> Enters Respiratory System
* **Dermal Contact** -> Limited absorption through skin

**4. Internalization and Systemic Distribution**

* Particles are found in the **GI Tract** (confirmed via stool samples).
* Fibers are retained in the **Lungs** (confirmed via lung tissue samples).
* Small enough particles can be absorbed into **Systemic Circulation (Blood)**.

**5. Biodistribution and Accumulation in Tissues**

* Blood circulation transports particles throughout the body, leading to accumulation in various sites:
  + **Placenta**: Demonstrates the ability to cross biological barriers and leads to fetal exposure.
  + **Lungs**: Retention of inhaled particles.
  + **Other Organs**: Detected in the liver, kidney, and spleen.

**Infographic Concept: Mechanisms of Microplastic Toxicity**

This concept outlines the three primary ways microplastics can cause harm once they are inside the body.

**Central Element: Internalized Microplastic Particle**

* **Branch 1: PHYSICAL EFFECTS** (Harm from the particle itself)
  + **Cellular Damage**: Causes physical stress, membrane damage, and cell death (necrosis).
  + **Tissue Inflammation**: Can induce chronic inflammation, granulomas, and fibrosis, particularly in the lungs.
  + **Barrier Crossing**: Nanoplastics can cross the blood-brain and placental barriers, accumulating in sensitive organs.
* **Branch 2: CHEMICAL EFFECTS** (Harm from associated chemicals)
  + **Leaching of Additives**: Releases inherent chemicals like **BPA and phthalates**, which are known endocrine disruptors linked to metabolic and reproductive disorders.
  + **Vector for Pollutants**: Acts like a sponge, adsorbing and concentrating external toxins (pesticides, heavy metals, POPs) from the environment and transporting them into the body.
* **Branch 3: BIOLOGICAL EFFECTS** (Resulting bodily responses observed in models)
  + **Oxidative Stress & Inflammation**: The **most universally reported mechanism**. Triggers the production of reactive oxygen species (ROS), which damages DNA, proteins, and lipids.
  + **Metabolic Disruption**: Can alter gut microbiota, disrupt lipid metabolism, and lead to insulin resistance.
  + **Neurotoxicity**: Induces inflammation in neural tissues and disrupts neurotransmitters, potentially affecting behavior and cognitive function.
  + **Reproductive Toxicity**: Studies show links to reduced fertility, lower sperm quality, and developmental abnormalities in offspring.