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Microscopic Menace: Exploring the Link Between Microplastics and Cancer Pathogenesis

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Table S1: Characteristics of microplastics: The following table summarizes the main categories of microplastic sources and their characteristics. [19-31]

Source Category	Examples	Type	Primary Environmental Compartment
Personal care products	Microbeads in cosmetics, toothpaste	Primary	Aquatic (via wastewater)
Textiles	Synthetic fibers from clothing	Primary	Aquatic, Atmospheric
Industrial production	Pre-production pellets	Primary	Terrestrial, Aquatic
Single-use Plastics	Bags, bottles, packaging	Secondary	Terrestrial, Aquatic
Automotive	Tire wear particles	Secondary	Terrestrial, Aquatic, Atmospheric
Construction	Paint fragments, insulation materials	Secondary	Terrestrial, Atmospheric
Agriculture	Mulch films, irrigation systems	Secondary	Terrestrial
Urban environments	Artificial turf, road markings	Secondary	Terrestrial, Aquatic
Marine activities	Fishing gear, aquaculture equipment	Secondary	Aquatic
Atmospheric deposition	Airborne particles	Primary/Secondary	Ubiquitous

Table S2: Sources of microplastics. [19-31]

Source	Description	Type	Size Range (mm)	Typical Uses
Microbeads	Small plastic spheres in personal care products	Primary	0.1 - 5	Exfoliating scrubs, toothpaste, shower gels
Industrial pellets	Raw materials for plastic manufacturing	Primary	1 - 5	Production of plastic items
Synthetic fibers	Fibers from synthetic textiles	Primary	< 1	Clothing, carpets, upholstery
Degradation of larger plastics	Fragmentation of larger plastic debris	Secondary	< 5	Plastic bottles, bags, containers
Rubber abrasion	Wear and tear of rubber products	Secondary	< 5	Tires, rubber mats
Paints and coatings	Breakdown of paints and coatings	Secondary	< 5	Marine vessels, infrastructure

Table S3: Physical and chemical properties of microplastics

Property	Description	Polymers Type
Size	1 µm to 5 mm	Microbeads (1 µm), Fragments (5 mm)
Shape	Fragments, fibers, films, foams, pellets	Fibers (from textiles), Pellets (nurdles)
Density	Affects buoyancy in water	PE (0.91-0.97 g/cm³), PET (1.38-1.41 g/cm³)
Surface Area	High surface-area-to-volume ratio	Increases adsorption of pollutants
Surface Roughness	Pits and cracks enhance pollutant adsorption	Weathered plastic debris
Polymer Composition	Determines chemical stability and persistence	PE, PP, PVC, PET, PS
Additives	Chemical compounds added to enhance performance	Phthalates, BPA, BFRs
Adsorption Capacity	Ability to adsorb hydrophobic organic pollutants	PCBs, PAHs, heavy metals

Table S4: Properties of different types of microplastics: Key physical and chemical properties of common microplastic types found in the environment

Polymer Type	Density (g/cm³)	Common Shapes	Typical Size Range	Primary Applications	Key Chemical Characteristics
Polyethylene (PE)	0.91-0.97	Fragments, Films	10 µm - 5 mm	Packaging, Bottles	Highly resistant to chemicals, Low water absorption
Polypropylene (PP)	0.89-0.91	Fibers, Fragments	20 µm - 5 mm	Textiles, Ropes	Good chemical resistance, Low moisture absorption
Polystyrene (PS)	1.04-1.09	Spheres, Foams	10 µm - 5 mm	Packaging, Insulation	Brittle, Susceptible to UV degradation
Polyvinyl Chloride (PVC)	1.16-1.58	Fragments, Films	50 µm - 5 mm	Construction, Pipes	High chlorine content, Requires stabilizers
Polyethylene Terephthalate (PET)	1.37-1.45	Fibers, Fragments	10 µm - 5 mm	Textiles, Bottles	High strength, Good chemical resistance

Table S5: Role of microplastics in generating ROS, focusing on their characteristics, mechanisms, biological effects, and outcomes.

Aspect	Description
Microplastic characteristics	- Increased surface area-to-volume ratio. - Contain chemical additives - Adsorb pollutants
ROS generation mechanisms	-Surface interaction -Chemical leaching -Pollutant release
Cellular pathways activated	- NADPH oxidase activation - Mitochondrial dysfunction due to oxidative damage - Pro-inflammatory cytokine release
Biological effects	- Oxidative stress - Lipid peroxidation - Protein and DNA damage
Toxicological outcomes	- Inflammation: - Cellular dysfunction - Disease susceptibility
ROS detection markers	- Malondialdehyde (MDA): Marker for lipid peroxidation - Protein carbonylation: Indicator of oxidative protein damage - Increased ROS levels detected through assays
ROS amplification	- Lipid peroxidation feedback loop - Synergistic effects with co-pollutants and chemicals

Table S6: Role of microplastics in generating inflammation.

Aspect	Description
Microplastic exposure routes	- Ingestion - Inhalation

Aspect	Description
	- Dermal contact
Key immune cells involved	- Macrophages - Neutrophils - Dendritic Cells
Mechanisms of inflammation	Physical interaction Pattern recognition receptor activation Lysosomal stress
Key inflammatory pathways	- Toll-like receptors (TLRs) - NLRP3 inflammasome
Pro-inflammatory cytokines	- Tumor Necrosis Factor-alpha (TNF-α) - Interleukin-1β (IL-1β) - Interleukin-6 (IL-6)
Inflammatory mediators released	- Chemokines - ROS
Tissue effects	- Mechanical damage - Lysosomal damage
Chronic inflammation outcomes	- Lung Inflammation. - Gut Inflammation - Systemic Inflammation

Table S7: Carcinogenic properties of microplastics and the associated chemicals.

Component	Source/Type	Carcinogenic mechanism	Health effects	Key findings
Microplastics	Degraded plastics	Physical damage, oxidative stress, and chronic inflammation	Potential risk of cancers	Animal studies reveal microplastic accumulation in organs, inducing inflammation and oxidative stress.
Polycyclic Aromatic Hydrocarbons (PAHs)	Environmental contaminants adsorbed onto microplastics	DNA adduct formation, oxidative stress, interference with DNA repair mechanisms	Lung, skin, and bladder cancers	Animal models have shown PAH-exposed microplastics lead to increased risk of lung and skin cancers.
Bisphenol A (BPA)	Plastic additive used in polycarbonate plastics	Endocrine disruption, estrogen receptor binding, abnormal cell proliferation	Breast, prostate, and ovarian cancers	BPA is linked to hormone-related cancers, increasing the risk of breast and prostate cancer.
Phthalates	Plasticizers used in flexible plastics	Endocrine disruption, hormone receptor interference, chronic inflammation	Testicular, breast, liver, and reproductive system cancers	Chronic exposure also promotes liver inflammation and fibrosis.
Heavy metals	Adsorbed onto microplastics from the environment	Direct interaction with DNA, oxidative stress, inhibition of DNA repair	Lung, liver, kidney, and bone cancers	Heavy metals, such as cadmium and lead, are classified as carcinogens.
Persistent Organic Pollutants (POPs)	Environmental toxins adsorbed on microplastic surfaces	Hormone disruption, oxidative stress, DNA damage, bioaccumulation in tissues	Breast, liver, thyroid, and reproductive cancers	POPs are known carcinogens.
Endocrine-Disrupting Chemicals (EDCs)	Chemicals like BPA, phthalates, and other plastic additives	Disruption of hormonal balance, abnormal growth signaling pathways, tumorigenesis	Hormone-dependent cancers (breast, ovarian, prostate)	EDCs are known to interfere with the body's hormonal system, leading to a higher incidence of hormone-related cancers.
Flame retardants	Additives in plastics to prevent fire	Endocrine disruption, oxidative stress, potential DNA damage	Breast, thyroid, and liver cancers	Chemicals interfere with thyroid hormone regulation, contributing to thyroid and liver cancers.
Nanoplastics	Smaller fragments of	Increased cellular uptake, oxidative	Potential for gastrointestinal,	Nanoplastics can penetrate deeper into

Component	Source/Type	Carcinogenic mechanism	Health effects	Key findings
	microplastics (<100 nm)	stress, DNA damage, chronic inflammation	lung, liver, and kidney cancers	tissues and cells, potentially leading to long-term carcinogenic effects.
Oxidative stress	ROS generated by microplastic exposure	ROS damage DNA, lipids, and proteins, resulting in mutations and genomic instability	Broad range of cancers depending on site of accumulation	Microplastics induce ROS, leading to DNA damage and tumor initiation in several organs.
Chronic inflammation	Persistent immune response triggered by microplastics	Inflammatory cytokines promote cell proliferation, inhibit apoptosis, and foster a pro-carcinogenic environment	Various cancers, including colon, lung, and liver cancers	Chronic inflammation, as induced by microplastics, can drive cancer progression, particularly in the gastrointestinal tract and respiratory system.

Table S8: Summary of techniques used to detect microplastics in human tissues:

Technique	Principle	Advantages	Limitations	Detection Range	Applications in microplastic detection
Fourier Transform Infrared (FTIR) Spectroscopy	Measures vibrational modes of polymers to identify chemical composition	Non-destructive, widely available, high chemical specificity	Limited spatial resolution, challenging for small particles (<10 µm)	Micrometres to millimeters	Identifies specific polymer types in tissues
Raman Spectroscopy	Detects molecular vibrations providing chemical fingerprints	High spatial resolution, non-destructive, effective for smaller particles	Fluorescence interference, time-consuming for large samples	Sub-micrometers to millimeters	Detection of smaller microplastics and nanoplastics in complex matrices
Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Spectroscopy (EDS)	Provides high-resolution imaging and elemental composition	Detailed morphological data, surface analysis	Cannot directly identify polymers, requires sample preparation	Micrometers to millimeters	Imaging and surface characterization of microplastic particles
Pyrolysis Gas Chromatography-Mass	Thermal degradation of microplastics	High sensitivity, quantitative,	Destructive, no information	Nanometers to millimeters	Identifies polymer types and

Spectrometry (Py-GC-MS)	followed by GC-MS analysis of breakdown products	applicable for complex samples	about particle morphology		quantifies microplastics in biological samples
Nile Red Staining	Fluorescent dye binds to hydrophobic particles like microplastics	Rapid screening, low-cost	Non-specific binding to other hydrophobic materials	Micrometers to millimeters	Quick screening of microplastics under fluorescence microscopy
Thermogravimetric Analysis (TGA)	Measures weight loss as a function of temperature to differentiate between organics and polymers	Quantifies plastic content, useful for complex matrices	Destructive, cannot identify specific polymer types	Bulk analysis	Estimation of microplastic content based on thermal profiles
Laser Direct Infrared (LDIR) Imaging	Automated IR imaging that maps microplastics in samples	High-throughput, fast-scanning	Limited to surface analysis, costly equipment	Micrometers to millimeters	Rapid detection and mapping of microplastics in tissue sections
Liquid Chromatography-Mass Spectrometry (LC-MS)	Separates and identifies dissolved components by mass	High sensitivity, potential for nanoscale detection	Requires sample dissolution, early-stage application	Nanometers to micrometers	Detection of small microplastics or nanoplastics in tissues
Field Flow Fractionation (FFF)	Separates particles based on size in a fluid flow	Highly sensitive, can separate small particles	Expensive, time-consuming, requires specialized equipment	Nanometers to micrometers	Separating and detecting nanoplastics in biological samples