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Review

# Microplastics and Breast Cancer: Investigating the Environmental and Biological Intersections

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## Abstract

Through contaminated food, water, and air, microplastics (MPs) have become a ubiquitous environmental hazard invading ecosystems and the human body. Increasing amounts of studies have linked MPs to detrimental health effects, including their participation in endocrine disturbance, inflammatory reactions, and immunological control. Their effects on metabolic and reproductive health are well-known; less is known about how they might support the growth of breast cancer. Endocrine-disrupting chemicals (EDCs); Phthalates and bisphenol A (BPA), have the ability to be transported by MPs through two crucial pathways (hormonal regulation and estrogen receptor (ER) signaling) result in the pathophysiology of breast cancer. Moreover, MPs induce oxidative stress and persistent inflammation, that can change the tumor microenvironment and speed up the spread of cancer and metastases. This review clarifies the present knowledge of MPs' biological interactions with breast tissue, explores the molecular mechanisms behind their putative function in tumor formation, and points up areas of research still lacking. We also discuss new methods for detection, the need of epidemiological research, and viable therapy strategies to reduce MP-induced harm in breast cancer patients. Understanding the links between environmental pollution and oncology will help us to open the path for more investigation on MPs as a new risk factor for the beginning and spread of breast cancer.

**Keywords:** microplastics; breast cancer; PBA; polystyrene; pollution; inflammation

## 1. Introduction

Environmentally present microplastics, which are microscopic plastic particles, have sparked worries about their possible link to diseases including breast cancer. Researchers are looking at the possible role that exposure to these contaminants may have in the cellular alterations associated with the development of cancer. Addressing the dangers of plastic pollution and its effects on human health requires an understanding of this link.

### 1.1. Breast Cancer

Though it mostly affects women, men can still get breast cancer; one of the most common cancers in the world; results from the cells of the breast tissue growing out of control, usually starting in the lobules or milk ducts [1]. Estimating around 2.3 million new cases annually, the World Health Organisation (WHO) notes that over 12% of all new cancer diagnosis worldwide [3,4] and has been on increase globally over the past several decades. However, the low- and middle-income nations frequently deal with issues like late-stage diagnoses, restricted access to treatment, and insufficient awareness campaigns, high-income regions typically have better screening and early detection programs, which improve survival rates [6]. Breast cancer risk is influenced by a number of factors,

including hormone changes, lifestyle choices, genetics, and environmental factors. As a result, research into prevention, treatment innovations, and individualized therapeutic approaches is continuously needed [8]. Thus, in order to lessen the burden of breast cancer worldwide, efforts to improve healthcare infrastructure, increase early detection, and create tailored medicines are still essential [10].

### *1.2. Microplastics as Environmental Pollutants*

From 5 Mt a-1 to 359 Mt from 1950 s to 2018, plastic output grew; by 2025 the total will reach 34,000 Mt. Though just 10% of plastic penetrated the sea surface, has been regarded as one of the most major environmental challenges in the world; 20–42% of plastic garbage remained and long-termly escaped in the soils [11]. Microplastic (MP) and nanoplastics (NP) particles are produced from the breakdown of plastic trash and the basis of this separation is the size of the plastic fragments or particles; MPs have a diameter less than 5 mm and NPs have a diameter between 1 and 100 or 1000 nm [12]. MPs contaminate air, soil, and water bodies over decades since they are not biodegradable in environments. Microplastics, or microscopic plastic particles that have found their way into practically every element of the environment, come from the breakdown of bigger plastics, industrial processes, and consumer goods including textiles and cosmetics [13]. Documented in marine life, drinking water, even human organs, their presence raises questions regarding their possible health risks. MPs keep accumulating despite worldwide attempts to control plastic trash, which causes great environmental problems [14]. Strength and toughness define several types of microplastics, including polylactic acid (PLA), polypropylene (PP), polyvinylchloride (PVC), polyethylene terephthalate (PET), and polythene (PE). Two types of microplastics exist: main and secondary ones. Raw components used in toiletries like shampoo and cosmetics are primary microplastics. Primary microplastics break down via physical, chemical, and biological processes to become secondary microplastics. Recent research imply that MPs could be transporters of endocrine disruptors, pesticides, heavy metals, and hazardous substances, so confounding their biological effect [15].

#### *Routes of Human Exposure*

Microplastics find their way into humans via several routes, mostly cutaneous absorption, inhalation, and swallowing [16].

1. One gets ingesting contaminated food and drinking water as bottled water, shellfish, vegetables, and processed foods have all been reported to contain MPs, possibly accumulating over time in the digestive tract. Furthermore, adding to this exposure are plastic utensils and food packaging since MPs can leak into consumables [17].
2. Another important pathway is breathing since MPs are prevalent in airborne pollutants from household dust, textiles, and industrial emissions. Airborne MPs might endanger public well-being more than those in water, food, or soil, researchers discovered. This is so because both inhalation and ingestion allow airborne MPs to penetrate the human body [18]. Deeply ingrained in the respiratory system, fine airborne microplastics could induce inflammation and respiratory illness.
3. When the skin comes into touch with MPs in synthetic clothes, cosmetics, and contaminated surroundings, a process known as dermal absorption results. Although the skin acts as a barrier, some nano plastics may pass through deeper layers, which begs questions regarding systemic effects and long-term skin contact [19].

### *1.3. Microplastics and Breast Cancer*

Particularly in hormone-sensitive malignancies like breast cancer [20], microplastics are under growing research for their possible contribution in cancer formation. Endocrine-disruption-causing substances (EDCs) including polystyrene-derived microplastics (PS-MPs), bisphenol A (BPA),

phthalates, and persistent organic pollutants (POPs) [21] can be carried by MPs and these drugs upset hormonal balance, particularly in relation to estrogen signaling, which is so important for the etiology of breast cancer [22]. Factors that cause tumor development and progression are; oxidative stress, chronic inflammation, and DNA damage which may also be contributed by MPs [23]. Research shows that some MPs might gather in breast tissue, changing cellular behaviour and raising the chance of metastases. Although exact correlation between MPs and breast cancer is yet unknown, new studies point to long-term exposure perhaps greatly increasing cancer risk.

#### 1.4. *The Need for Comprehensive Studies, Evaluating MPs' Interactions in Breast Cancer Pathophysiology*

Research on microplastics and breast cancer is still lacking despite mounting worries; hence thorough studies are absolutely necessary to evaluate their biological relationships. One of the most significant environmental issues facing modern society and linked to several chronic diseases are polystyrene-derived microplastics (PS-MP). Previous research indicates that PS-MP causes estrogenic effects on aquatic life, which through estrogenic endocrine disturbance could function as a possible risk factor for breast cancer. More research is needed on the processes by which MPs interact with breast tissues, upset cellular homeostasis, and change the tumor microenvironment [24]. Furthermore, looking at possible biodegradable plastic substitutes and detoxifying techniques can open the path for better environmental policies and the oncological and environmental health research depends on a knowledge of their long-term effects on cancer growth and treatment resistance as MPs keep invading human physiology.

## 2. Microplastic Exposure and Accumulation in Human Tissue

Apprehending the great possibilities of nanomaterials for biomedical uses would need a comprehensive knowledge of their interactions with organs, tissues, and cells. Based on their physicochemical characteristics and ensuing interactions, there is evidence that nanomaterials are definitely absorbed by cells; microplastics can enter cells, disturb biological processes, and maybe create carcinogenic settings [25]. Their small size and tenacious character enable them to enter the body via several channels, which causes long-term accumulation in tissues including breast tissue [26]. Recent research indicates that MPs might bioaccumulate in organs, therefore affecting cellular functions and maybe contributing to the pathogenesis of diseases including cancer formation. Advanced imaging technologies, which are constantly developing to increase detection accuracy as the risk of human exposure to micro- and nanoplastics (MNPs) has garnered growing attention in recent years [27], are required in the identification and monitoring of MPs in biological tissues. Particularly through drinking water, airborne contaminants, and personal care products, microplastic contamination has grown to be a rising issue in many spheres of daily life. Research on packed water have established the presence of microplastics (MPs), mostly resulting from the breakdown of plastic containers over time causing small particles to leak into the liquid [18]. Likewise, ageing pipelines, poor filtration systems, and contaminated water sources make tap water prone to MPs and help to contribute to microplastic buildup in municipal water supplies [28]. While MPs from shampoos, lotions, and hygiene products may either be absorbed through the skin or washed into water systems,

MPs are also purposefully included in cosmetic and personal care products with microbeads found in exfoliating scrubs, toothpaste, and skincare items, so further contributing to environmental pollution. The total exposure from consumption, inhalation, and cutaneous absorption emphasises the immediate need of more stringent rules, modern filtration techniques, and sustainable substitutes to lower microplastics contamination and their possible health hazards.

#### 2.1. *Bioaccumulation in Organs, Including Breast Tissue*

Particularly prone to buildup in fat-rich tissues including the breast, liver, and gastrointestinal tract, microplastics (MPs) contain lipophilic characteristics that is, great affinity for fat molecules. MPs' capacity to interact with lipids enables them to remain in biological tissues, therefore enhancing

their bioavailability and possible toxicity and generating questions regarding their involvement in metabolic diseases and cancer formation [29]. Because of their lipid-binding character, MPs may gather in breast tissue and provide a route for interaction with endocrine-disrupting compounds (EDCs) like phthalates and bisphenol A (BPA). These substances disrupt hormonal signaling, especially estrogen control, which is very imperative for the development of breast cancer [30,31]. Particularly those classified as hormone receptor- positive, breast cancer cells are very susceptible to estrogen fluctuations and MPs may act as carriers enhancing the effects of EDCs, hence fostering carcinogenesis and metastatic potential [32]. Likewise, gut microbiome disturbance resulting from MPs entering the liver via bloodstream absorption from the gastrointestinal system has been linked to chronic inflammation, metabolic imbalances, and increased immune responses, which can help to explain liver disease and systemic health complications [33]. Deep into lung tissue, MPs absorbed by respiratory exposure can cause oxidative stress, immunological dysregulation, and inflammation, processes that can be involved in respiratory illnesses and chronic pulmonary disorders [34]. Workers in industrial settings with significant airborne pollutants run more danger of MP inhalation, which might have long-term health effects [35]. These results not only inspire debates on policy rules, safer packaging alternatives, and environmental management to reduce human exposure to MPs but also underline the critical need of more research on MPs' biological effects and their part in disease pathogenesis, including cancer progression.

## 2.2. Detection Methods

Given that their fast-screening character or even complete a full study of plastic particles in some situations, microscopic techniques are regarded as perfect tools to critically help other analytical techniques [36]. Finding microplastics (MPs) in biological samples calls for advanced imaging methods with exact identification at structural and molecular levels. By means of microscopy methods including Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM), researchers can view MPs at the nanoscale level, therefore offering thorough morphological insights [37]. Fluorescence microscopy improves detection by means of staining methods that raise contrast for enhanced visualization in biological tissues [38]. Mass Spectrometry (MS) allows molecular-level identification of MPs within biological matrices; spectroscopic analysis, (including Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy) helps ascertain the polymer composition and chemical characteristics of MPs [39,40]. Histopathological staining techniques show their presence in biological structures when investigating MPs buried in tissues; Confocal Microscopy offers further understanding of their interactions with cellular components, especially malignant tissues [41]. By analysing vast biopsy datasets, enhancing pattern identification, and forecasting MPs' possible contribution in disease progression, machine learning and artificial intelligence-assisted imaging approaches have lately transformed MP detection. These cutting-edge techniques used together improve tracking of MP bioaccumulation and analysis of their health effects, so supporting more investigation on environmental pollution and its biological effects.

## 3. Endocrine Disruption and Breast Cancer Risk

Microplastics (MPs) have attracted interest for their capacity to transport endocrine-disrupting chemicals (EDCs), including bisphenol A (BPA), phthalates, and persistent organic pollutants (POPs), so interfering with hormonal signaling pathways [42]. Widely present in plastics and food packaging, BPA mimics estrogen and might cause aberrant estrogen receptor (ER) activation, a major factor in hormone-sensitive breast cancers [43]. Comparably, phthalates, widely used as plasticizers in consumer goods like cosmetics, PVC, deodorants etc., are known to interfere with progesterone receptor (PR) functions, hence influencing breast cell proliferation. Over time, POPs including dioxins and polychlorinated biphenyls (PCBs) build up in the body and cause oxidative stress and chronic inflammation, two processes that might drive carcinogenesis [44]. Through these EDCs, MPs apparently alter important pathways in breast cancer including ER, PR, and HER2 signaling, so accelerating tumor development. Although their endocrine-disruption characteristics make hormone

receptor-positive breast tumors more susceptible to MPs, new research suggests that MPs might potentially be involved in the development of estrogen-independent breast cancer. For triple-negative breast cancer (TNBC), for instance, which lacks ER, PR, and HER2 expression, MPs may affect it via means of inflammatory cytokine activation and immune evasion strategies. MPs may also induce oxidative DNA damage, which causes genomic instability promoting aggressive breast cancer characteristics [45]. Given the ubiquitous prevalence of MPs in food, air, and water, their possible connection to hormone dysregulation and cancer initiation emphasises the critical need of more study, legislative laws, and mitigating strategies to lower human exposure.

#### 4. Microplastics-Induced Oxidative Stress and DNA Damage

Particularly by means of the formation of reactive oxygen species (ROS), which causes oxidative stress and genomic instability, microplastics (MPs) have been increasingly acknowledged as capable of inducing cellular stress. Chemically reactive molecules called ROS can overwhelm the body's antioxidant defences when overproduced by environmental toxins such as MPs, therefore causing DNA damage, protein oxidation, and lipid peroxidation. This oxidative stress not only disturbs normal cellular activity but also accelerates mutagenesis processes, which by causing mutations in tumor suppressor genes and oncogenes could support carcinogenesis. It also triggers a plethora of signaling cascades, such as the p53 signaling pathway, Mitogen-activated protein kinases (MAPKs) signaling pathway including the c-Jun N-terminal kinases (JNK), p38 kinase, and extracellular signal related kinases (ERK1/2) signaling cascades, Nuclear factor erythroid 2-related factor 2 (Nrf2)-pathway, Phosphatidylinositol-3-kinases (PI3Ks)/Akt signaling pathway, and Transforming growth factor-beta (TGF- $\beta$ ) pathways, to name a few. Different kinds of organ damage are seen in living species, including humans, such as pulmonary toxicity, cardiotoxicity, neurotoxicity, nephrotoxicity, immunotoxicity, hepatotoxicity, etc., as a result of oxidative stress generated by the MPs/NPs [46]. Moreover, MPs have been shown to affect epigenetic changes, therefore modulating the expression of important genes linked to cancer development. Epigenetic alterations include DNA methylation, histone modification, and non-coding RNA control can either silence tumor suppressor genes or activate oncogenic pathways, hence raising cancer risk. MPs may also meddle with DNA repair systems, therefore compromising the effectiveness of cellular mechanisms that fix mutations and generating genomic instability and unregulated cellular proliferation [47]. Beyond their contribution to DNA damage, MPs profoundly affect the tumor microenvironment, where they may control extracellular matrix remodeling, immune cell activity, and inflammatory cytokines, therefore promoting a pro- metastatic environment. This disturbance can improve lymphatic dissemination, angiogenesis, and cancer cell invasion, therefore affecting metastatic capability. MPs help to create a tumor- supportive niche by changing immune responses and boosting chronic inflammation, therefore enabling cancer cells to escape immune surveillance and expand more rapidly [48]. Particularly in breast cancer and other hormone-sensitive malignancies, the combined impacts of oxidative stress, epigenetic instability, and tumor microenvironment remodeling underline the urgent need of more study on the function of MPs in cancer progression.

#### 5. Chronic Inflammation and Immune System Modulation

Consistent with oxidative stress, immunological dysregulation, and cellular damage, microplastics (MPs) have been progressively linked to chronic inflammatory responses, thereby fostering an environment that might promote tumors [49]. All of which are linked with cancer growth, MPs entering the body can activate pro-inflammatory signaling pathways, hence releasing cytokines like interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF- $\alpha$ ), and nuclear factor kappa B (NF- $\kappa$ B). By boosting angiogenesis, accelerating cancer cell proliferation, and hence affecting normal death processes, this continuous inflammatory state promotes tumor growth [50]. Moreover, immune surveillance, which is in charge of identifying and destroying aberrant cells and may be hampered by MP-induced immune suppression, therefore enabling breast cancer cells to elude immunological defences and spread uncontrolled. MPs might meddle with macrophage polarization, thus distorting

the immune system towards an immunosuppressive state, and cause T-cell depletion, so compromising the body's capacity for a strong anti-tumor response. For metastatic lobular breast cancer, where MPs may be involved in lymphatic drainage obstruction, so preventing the effective clearance of immune cells and fluids, resulting in lymphatic congestion, increased metastatic spread, and compromised treatment response, this disturbance can be especially worrying [51]. MPs may further improve the invasive properties of metastatic lobular breast cancer by sustaining inflammation-driven extracellular matrix remodeling and encouraging cancer-associated fibroblast activation, so aggravating disease progression given the diffuse invasion of surrounding tissues of this disease. Further studies are vital to grasp the degree of MPs' impact in breast cancer pathophysiology and create plans to minimize their effects given their great consequences in inducing inflammation, lowering immunological defenses, and enabling cancer metastases.

## 6. Microplastics and Treatment Resistance in Breast Cancer

Microplastics (MPs) have especially caused concerns in oncology especially in conditions like breast cancer since they might affect the absorption and efficacy of chemotherapy drugs. Studies show that MPs could be drug carriers or barriers, attaching to drug molecules to reduce their bioavailability and affect their distribution across the body, therefore changing the pharmacokinetics of chemotherapy [20]. Moreover, thought to be controlling cancer stem cell behaviour is a fundamental element influencing therapy resistance: Cancer stem cells (CSCs) are a small population of tumor cells with self-renewal and multi-drug resistance characteristics that can cause tumor recurrence even after rigorous treatment. MPs might increase the lifespan of CSCs and allow tumors persist even in spite of treatment by triggering inflammatory responses, promoting oxidative stress, and changing death pathways [52]. The fact that MPs still exist in biological systems highlights how urgently research on biodegradable alternatives for medical application is required. Development of biodegradable polymers for drug delivery systems, medical implants, and pharmaceutical packaging could help to lower unintended patient exposure to MPs even while maintaining therapeutic effectiveness. Sustainable materials could provide safer medical interventions by means of biodegradable drug carriers or biopolymer-based nanoparticles, therefore reducing the negative impact of MPs on cancer treatment outcomes [53]. More study on the molecular interactions between MPs and drug delivery methods is essential to address these issues and increase the efficacy of chemotherapy in resistant tumors.

## 7. Current Research Gaps and Future Directions

Though microplastic (MP) contamination and its possible health hazards cause increasing worries, there is a notable dearth of epidemiological studies specifically connecting MP exposure to breast cancer incidence [54]. Most current studies concentrate on cellular and molecular aspects, therefore leaving a knowledge vacuum about how long-term MP exposure affects actual cancer risk. Longitudinal studies evaluating MP accumulation in breast tissue are absolutely crucial if one wants a clear link. These studies could track people over long periods, looking at biomarkers, MP retention rates, and health outcomes, therefore offering vital information on exposure levels and susceptibility variables [55]. Reducing plastic-related toxicity could also depend critically on investigating the function of biodegradable polymers and detoxifying techniques in lowering MP-induced carcinogenesis. Developing biopolymer-based materials that break down safely without releasing toxic chemicals may reduce human exposure [53]. Moreover, detoxification techniques including focused antioxidant treatments could help reduce oxidative stress generated by MPs. The possibility for probiotic and gut microbiota modification as protective treatments presents still another interesting field of study. Certain probiotics may help to neutralise MP toxicity, thereby preserving immunological homeostasis, and lowering systemic inflammation that can support the development of cancer by MPs upsetting the balance of gut microbiome and causing inflammation and metabolic abnormalities [56]. Together, improving epidemiological data, creating sustainable substitutes, and

using microbiome science could open the path for fresh approaches to counteract the biological effect of MPs on the course of breast cancer.

## 8. Conclusion

Because microplastics (MPs) interfere with hormonal control, oxidative stress, immunological function, and treatment resistance, they are a newly discovered environmental risk factor for breast cancer. Endocrine-disrupting compounds (EDCs) such phthalates and bisphenol A (BPA) can upset estrogen and progesterone signaling, therefore raising the risk of breast cancer. Their capacity to create reactive oxygen species (ROS) causes DNA damage and genomic instability, thereby maybe driving tumor growth. MPs also produce a tumor-supportive milieu, compromise immune surveillance, and cause persistent inflammation. Studies also point to MPs possibly lowering the efficacy of chemotherapy, therefore affecting drug absorption and raising resistance. Understanding and lessening MPs' influence in oncology depends on strengthening legislative rules, waste management, and expanding scientific research. Future research has to concentrate on detoxifying techniques, biodegradable substitutes, and epidemiological studies to lower human contact and enhance cancer results.

**Conflicts of Interest:** The authors claim no competing interests.

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