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REVIEW ON NANO PLASTICS IN NEURODEGENERATIVE DISORDERS

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Keywords: Nanoplastics (NPs), Blood-brain barrier (BBB), Microplastics, Neurodegenerative disorders, Alzheimers disease, Parkinsonism disease.

Abstract:
Nanoplastics (NPs), defined as plastic particles less than 1 µm in size, are emerging environmental contaminants that pose significant health risks. Due to their small size and ability to cross biolog- ical barriers, including the blood-brain barrier (BBB), recent research has linked nanoplastics to the pathogenesis of neurodegenerative disorders such as Alzheimer's disease (AD) and Parkinson's disease (PD).

Introduction:
Plastic pollution has become ubiquitous in terrestrial and aquatic ecosystems.
With continuous degradation, larger plastics break down into microplastics and eventually nanoplastics. These NPs have enhanced sur- face reactivity and bioavailability, raising concerns about their potential neuro toxic ef- fects in humans and wildlife.

Neurotoxicity of Nanoplastics:
Experimental studies have demonstrated that nanoplastics can induce neurotoxicity through several mechanisms:
Oxidative stress: Exposure to NPs increases reactive oxygen species (ROS), leading to oxidative damage in neuronal cells.
Neuroinflammation: NPs activate microglial cells, resulting in chronic inflammation that contributes to neurodegeneration. Disruption of BBB: NPs can cross the BBB either by en- docytosis or by compromising endothelial in- tegrity.

Implications for Neurodegenerative Dis- eases:
Accumulating evidence suggests a link be- tween chronic exposure to nanoplastics and the progression of neurodegenerative dis- eases:
In Alzheimer's disease models, NPs have been shown to increase amyloid-beta (Aβ) accumulation and tau phosphorylation.

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In Parkinson's disease, exposure to polystyrene nanoplastics alters dopamine levels and induces α-synuclein aggregation.

1. Environmental Presence and Human Exposure

Ubiquitous plastic pollution leads to fragmentation of macro- and microplastics into NPs, found in air, water, soil, food chains, and circulating human tissues Autopsy analyses using advanced techniques (e.g., pyrolysis-GC/MS, electron microscopy) confirm NP accumulation in human brain, kidney, and liver—predominantly polyethylene, with concentrations increasing from 2016 to 2024 .Crucially, brains of dementia patients show 3–5× higher NP prevalence and 7–30× greater concentration than other organs.

2. Blood–Brain Barrier Penetration and Brain Distribution

NPs cross the BBB via endocytosis and by disrupting tight junction proteins such as occludin, increasing endothelial permeability .In vivo studies in mice demonstrate 50 nm polystyrene NPs accumulating in brain tissue, localizing in microglia, and triggering activation and neuronal injury. Analysis of human cerebrospinal fluid (CSF) suggests selective NP presence (PS, PE, PP, PVC), especially following BBB compromise, although causal links to inflammation require further validation.

3. Cellular and Molecular Neurotoxicity Mechanisms

1. Oxidative Stress & Inflammation
NPs induce reactive oxygen species (ROS) production, activate NF-κB signaling, pro- mote pro-inflammatory cytokines (e.g., TNF-α), and trigger necroptosis in BBB en- dothelial models. In microglial cells, NP ex- posure leads to activation and release of neu- rotoxic factors harming adjacent neurons.

2. Protein Aggregation – Alzheimer's Dis- ease (AD)
Enhancing nucleation even at low concentrations, fostering oligomer formation Polystyrene NPs accelerate aggregation of amyloid β peptides (Aβ40/42) by that exhibits neuron toxicity. Such NP-Aβ interactions amplify hydrophobic domain interactions, increasing neurotoxicity risk.

3. Protein Aggregation – Parkinson's Disease (PD)
fibrillation and inhibiting lysosomal degradation of aggregates-Co-administration In vitro and murine models reveal polystyrene NPs bind α synuclein, promoting inclusions- in dopamine-rich brain regions (SNpc) of NPs and α synuclein fibrils intensifies spread of phosphorylated α syn.

4. Cellular Dysfunction & Autophagy
NPs deregulate autophagy, induce iron-overload and ferroptosis in BBB endothelial cells, exacerbating barrier breakdown. Disruption in cellular debris clearance and organelle homeostasis compounds neurotoxicity cas- cades.

5. In Vivo & Behavioural Consequences
Animal studies report NP accumulation in the brain correlating with cognitive deficits,

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anxiety-like behaviours, and memory impairment. Endothelial and neuronal damage observed in rodent models following NP exposure mirrors early neurodegenerative pathology.

6. Human Evidence & Epidemiological Observations
Observational studies identify elevated NP levels in dementia patients, yet causality remains undetermined. Correlations between NP accumulation and strokes, cardiovascular disease raise concern, though further investigation is required.

7. Research Gaps & Future Directions
Standardization: Need for harmonized measurement of NPs in tissues to compare across studies. Exposure Dynamics: Current lab studies often use unrealistically high NP doses or durations; chronic low-dose exposure models are necessary hort Studies**:
Large-scale longitudinal studies to determine NP exposure, tissue accumulation, and neuro

Biological Use of Nanoplastics:
While nanoplastics (NPs) are primarily known for their negative impact on health and the environment, they are also being explored for certain biological and biomedical applications due to their unique physicochemical properties (e.g., small size, surface modifiability, and bio-interactivity). Here's an overview of their potential biological uses — and the complications that arise:

Potential Beneficial Biological Uses

1. Drug Delivery Systems
Functionalized nanoplastics (e.g., polysty- rene or polyethylene-based) can be engi- neered to carry therapeutic agents and target specific tissues.
Advantages of nano particles
It has high surface area for drug loading.It has the ability to cross biological barriers (e.g., BBB), which is otherwise difficult for conventional drugs.
Research Example: Fluorescent-labeled polystyrene nanoparticles are used as model carriers in drug delivery studies to evaluate cellular uptake and trafficking.

2. Biomarker Detection & Imaging
Nanoplastics conjugated with fluorescent dyes or antibodies are used in biosensing platforms to detect pathogens or biomarkers. Application in in vitro diagnostics: e.g., plas- tic-based beads are used in flow cytometry and ELISA (Enzyme-Linked Immuno- sorbent Assay).

3. Vaccine Development (Adjuvants)
Nanoplastics are studied as adjuvant plat- forms to enhance immune responses by stim- ulating antigen-presenting cells. Their high surface-to-volume ratio enables binding of antigens for slow and controlled release.

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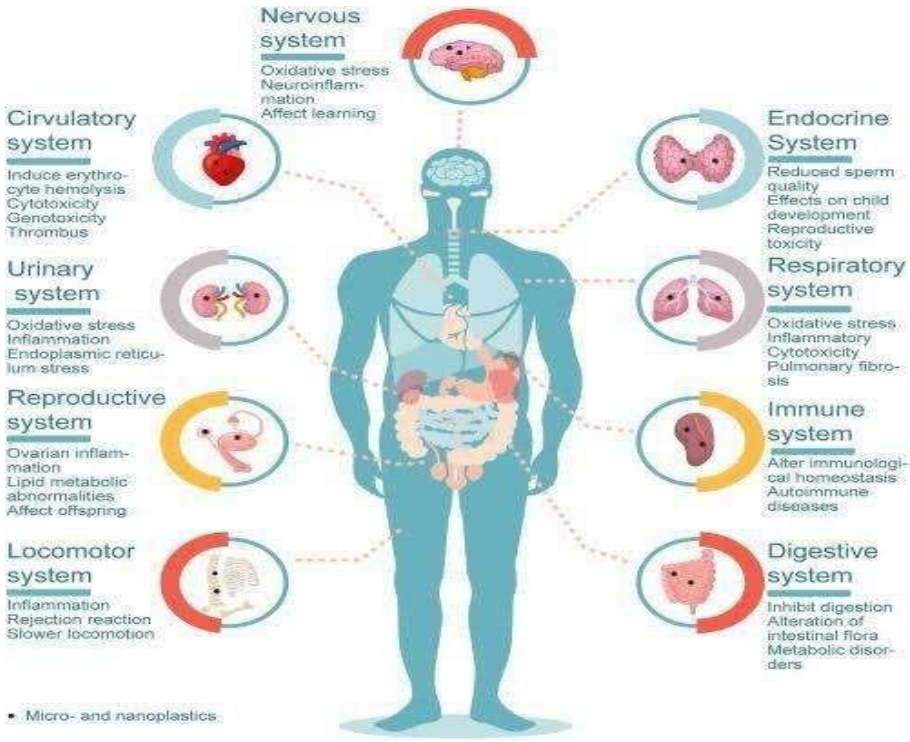
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Concerns in Biological Systems:



Despite these potential uses, non-functionalized or environmental nanoplastics have toxicological concerns. It induce oxidative stress, inflammation, and cell membrane damage.It may impair mitochondrial function and cause genotoxicity. It easily taken up by cells via endocytosis, but not always biodegradable, leading to bioaccumulation.

Conclusion

While environmental nanoplastics are a growing concern in neurodegeneration and other health domains, engineered nanoplastics hold promise in biomedical applications such as drug delivery, diagnostics, and immunotherapy — provided their design is carefully controlled for safety and efficacy.

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