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Review

Linking particulate matter exposure and neurological disorders: Evidence from epidemiology, biomarkers and mechanistic studies

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ABSTRACT

Exposure to particulate matter (PM) including fine ($PM_{2.5}$), coarse (PM_{10}), and ultrafine particles (UFPM) has emerged as a critical environmental determinant of neurological disorders, including Alzheimer's and Parkinson's diseases, neurodevelopmental impairments, and cognitive decline. This review integrates evidence from 129 research articles (2002–2025) to elucidate the mechanistic, biomarker-based, and public health dimensions of PM-induced neurotoxicity. Mechanistic pathways include oxidative stress, neuroinflammation, mitochondrial dysfunction, and blood–brain barrier disruption, with documented structural and functional damage in brain regions such as the hippocampus and prefrontal cortex. $PM_{2.5}$ serves as a carrier of neurotoxic metals (e.g., lead, cadmium, vanadium) and understudied organic toxicants (e.g., PAHs, pesticides), amplifying its pathogenic potential. Exposure occurs through the olfactory route, systemic circulation, and gut–brain axis, highlighting multiple entry points into the central nervous system. Biomarkers such as $A\beta_{42}$, phosphorylated tau (p-tau), and α-synuclein are elevated in experimental models, but require greater validation in human PM-exposed populations. Children and older adults represent the most vulnerable groups due to developmental sensitivity and cumulative neuroinflammatory burden, yet remain underrepresented in cohort studies. Geographic disparities further limit generalizability, with low- and middle-income countries underrepresented despite experiencing the highest PM burdens. Future research must advance longitudinal, cohort and life-course studies, multi-omics biomarker discovery, and real-world mixture toxicology to identify intervention targets. These findings call

Abbreviations: AD, Alzheimer's Disease; APoE, Apolipoprotein E; ASD, Autism Spectrum Disorder; Aβ, Amyloid-beta; BACE, Beta-Site APP Cleaving Enzyme; BBB, Blood-Brain Barrier; BDNF, Brain-Derived Neurotrophic Factor; Cd, Cadmium; CNS, Central Nervous System; COX-2, Cyclooxygenase-2; Cr, Chromium; CSF, Cerebrospinal Fluid; CXCL13, C-X-C Motif Chemokine Ligand 13; DMT1, Divalent Metal Transporter 1; EPA, Environmental Protection Agency; GFAP, Glial Fibrillary Acidic Protein; GHS, Globally Harmonized System; GPx4, Glutathione Peroxidase 4; GSH, Glutathione; GSK3, Glycogen Synthase Kinase-3; Hg, Mercury; HRTEM, High-Resolution Transmission Electron Microscopy; IL, Interleukin; IL-1β, Interleukin 1 beta; IL-6, Interleukin 6; MCI, Mild Cognitive Impairment; MDA, Malondialdehyde; MMP-9, Matrix Metalloproteinase-9; NfL, Neurofilament Light Chain; NF-κB, Nuclear Factor Kappa B; Ni, Nickel; NLRP3, NOD-like Receptor Protein 3; NSE, Neuron-Specific Enolase; P38 MAPK, p38 Mitogen-Activated Protein Kinase; Pb, Lead; PD, Parkinson's Disease; PI3K/Akt/mTOR, Phosphoinositide 3-Kinase/Protein Kinase B/Mammalian Target of Rapamycin; PM, Particulate Matter; $PM_{2.5}$, Particulate Matter with a diameter of less than $_{2.5}$ micrometres; PP1, Protein Phosphatase 1; P-tau, Phosphorylated tau; PTGEs, Prostaglandins; ROS, Reactive Oxygen Species; S100β, S100 Calcium Binding Protein B; TBI, Traumatic Brain Injury; TLR, Toll-Like Receptor; TNF-α, Tumor Necrosis Factor-alpha; T-tau, Total tau; UFPM, Ultrafine Particulate Matter; V, Vanadium.

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