World Journal of Pharmacology and Toxicology

Ukase, World J Pharmacol Toxicol 2025, 8:1

Short Communication Open Access

Neuroepigenetics in Toxicology: Impacts of Environmental Pollutants on Brain Health

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Abstract

Neuroepigenetics explores how environmental factors influence gene expression in the brain without altering DNA sequences, playing a crucial role in neurodevelopment and neurodegeneration. Environmental pollutants such as heavy metals, pesticides, air pollutants, and endocrine-disrupting chemicals (EDCs) can induce epigenetic modifications, including DNA methylation, histone modifications, and non-coding RNA alterations, leading to neurotoxic effects. These epigenetic changes contribute to cognitive dysfunction, neuroinflammation, and increased susceptibility to neurodevelopmental disorders such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and neurodegenerative diseases like Alzheimer's and Parkinson's. Understanding the epigenetic mechanisms underlying neurotoxicity is essential for identifying biomarkers of exposure, developing preventive strategies, and guiding regulatory policies. This review highlights recent findings on the epigenetic impact of environmental toxicants on brain health, discusses potential therapeutic interventions, and underscores the need for further research in neuroepigenetic toxicology.

Keywords: Neuroepigenetics; Environmental toxicants; DNA methylation; Histone modifications; Non-coding RNAs; Neurodevelopmental disorders

Introduction

Neuroepigenetics is an emerging field that investigates how environmental exposures influence gene expression in the brain through epigenetic modifications, without altering the DNA sequence. Epigenetic mechanisms such as DNA methylation, histone modifications, and non-coding RNA regulation play a critical role in brain development, synaptic plasticity, and neuroprotection. However, exposure to environmental pollutants—including heavy metals, pesticides, air pollutants, and endocrine-disrupting chemicals (EDCs)—can disrupt these processes, leading to neurotoxicity and increased risk for neurological disorders [1]. The developing brain is particularly vulnerable to environmental toxicants, as epigenetic programming during early life establishes the foundation for cognitive function and mental health. Disruptions in neuroepigenetic regulation have been linked to neurodevelopmental disorders such as autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD), as well as neurodegenerative diseases like Alzheimer's and Parkinson's. Studies have shown that pollutants can induce persistent epigenetic changes, which may contribute to long-term neurological dysfunction and even transgenerational inheritance of disease susceptibility. Despite growing evidence supporting the role of environmental epigenetics in neurotoxicity, the precise mechanisms linking toxicant exposure to neurological disease remain unclear. Identifying epigenetic biomarkers of neurotoxicity may improve early detection of environmental risk factors and facilitate targeted interventions. Additionally, understanding the reversibility of epigenetic modifications could pave the way for novel therapeutic strategies aimed at mitigating the adverse effects of toxicant-induced neuroepigenetic alterations. This review explores the current understanding of neuroepigenetic toxicology, highlighting key mechanisms through which environmental pollutants impact brain health. It also examines recent research findings, discusses potential therapeutic approaches, and underscores the need for further investigation into epigenetic biomarkers and regulatory policies to mitigate neurotoxic risks [2].

Discussion

The impact of environmental pollutants on neuroepigenetics is a growing concern in toxicology, as accumulating evidence suggests that toxicant-induced epigenetic changes contribute to neurological disorders. Epigenetic modifications such as DNA methylation, histone modifications, and non-coding RNA regulation play a fundamental role in brain function, and their disruption can lead to long-term cognitive and behavioral impairments. This section discusses the major epigenetic mechanisms affected by environmental toxicants, the implications for neurological diseases, and potential therapeutic and regulatory approaches [3].

Epigenetic Mechanisms in Neurotoxicity

DNA Methylation: One of the most well-studied epigenetic modifications, DNA methylation, is critical for gene expression regulation in neurons. Exposure to heavy metals like lead and mercury has been shown to alter DNA methylation patterns, leading to the silencing or activation of genes involved in neurodevelopment. For example, prenatal exposure to lead is associated with hypermethylation of genes related to synaptic function, potentially increasing the risk of neurodevelopmental disorders [4].

Histone Modifications: Histone acetylation and methylation regulate chromatin structure and gene expression. Environmental pollutants such as air pollution and pesticides can disrupt histone modification patterns, leading to aberrant gene transcription. Studies have demonstrated that exposure to diesel exhaust particles can reduce histone acetylation in brain cells, impairing neuronal plasticity and

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Received: 01-Jan-2025, Manuscript No: wjpt-25-163626, **Editor Assigned:** 03-Jan-2025, pre QC No: wjpt-25-163626 (PQ), **Reviewed:** 17-Jan-2025, QC No: wjpt-25-163626, **Revised:** 24-Jan-2025, Manuscript No: wjpt-25-163626 (R), **Published:** 30-Jan-2025, DOI: 10.4172/wjpt.1000292

Citation: Ukase N (2025) Neuroepigenetics in Toxicology: Impacts of Environmental Pollutants on Brain Health. World J Pharmacol Toxicol 8: 292.

increasing susceptibility to cognitive dysfunction [5].

Non-Coding RNAs: MicroRNAs (miRNAs) and long non-coding RNAs (lncRNAs) play a crucial role in post-transcriptional gene regulation. Environmental toxicants, including endocrine-disrupting chemicals (EDCs), can alter miRNA expression profiles, affecting pathways involved in neuroinflammation and oxidative stress. For instance, bisphenol A (BPA), a common plastic additive, has been linked to changes in miRNA expression that influence synaptic function and neurobehavioral outcomes [6].

Neuroepigenetics and Disease Susceptibility

Neurodevelopmental Disorders: Epigenetic dysregulation caused by environmental toxicants has been implicated in neurodevelopmental disorders such as autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD). Studies have found that prenatal exposure to air pollution and pesticides correlates with altered DNA methylation patterns in genes associated with neural development, increasing the risk of ASD [7].

Neurodegenerative Diseases: Epigenetic modifications may also contribute to late-onset neurodegenerative diseases such as Alzheimer's and Parkinson's. Heavy metals like cadmium and arsenic have been linked to hypermethylation of genes involved in neuroprotection, potentially accelerating neurodegeneration. Additionally, chronic exposure to fine particulate matter (PM2.5) from air pollution has been associated with increased histone modifications linked to neuroinflammation and amyloid-beta deposition, hallmarks of Alzheimer's disease [8].

Challenges and Future Directions

Despite the growing evidence supporting the role of epigenetics in neurotoxicity, several challenges remain:

Lack of Standardized Biomarkers: Identifying reliable epigenetic biomarkers for neurotoxicity is essential for early diagnosis, yet the variability in individual epigenetic responses complicates biomarker validation [9].

Reversibility of Epigenetic Changes: While some epigenetic modifications are reversible, the extent to which interventions can mitigate toxicant-induced neuroepigenetic alterations remains uncertain.

Transgenerational Effects: Some toxicant-induced epigenetic modifications may be inherited across generations, raising concerns about long-term public health consequences.

Future research should focus on developing standardized protocols for epigenetic biomarker identification, exploring the potential of epigenetic therapies (such as histone deacetylase inhibitors), and integrating neuroepigenetic data into environmental health policies [10].

Conclusion

Neuroepigenetic toxicology is a rapidly evolving field that sheds light on how environmental pollutants influence brain health through epigenetic mechanisms. By understanding these complex interactions, researchers can identify potential biomarkers for early detection, develop targeted therapeutic strategies, and advocate for regulatory measures to minimize toxicant exposure. Continued research and interdisciplinary collaboration will be essential to unravel the full impact of environmental toxicants on neuroepigenetics and human health.

References

1. Mahant S, Sharma AK, Gandhi H, Wadhwa R, Dua K et al. (2022) Emerging trends and potential prospects in vaginal drug delivery. Curr Drug Deliv
2. Cho M, Joo M, Kim K, Wook Y, Lee S, et al. (2018) Biochemical and Biophysical Research Communications the immunotherapeutic effects of recombinant Bacillus rin resistant to antimicrobial peptides on Calmette-Gu e bladder cancer cells. Biochem Biophys Res Commun
3. Palugan L, Cerea M, Cirilli M, Moutaharrik S, Maroni A, et al. (2021) Intravesical drug delivery approaches for improved therapy of urinary bladder diseases. Int J Pharm X 3
4. Verma R, Garg S (2001) Current Status of Drug Delivery Technologies and Future Directions.
5. Keraliya RA, Patel C, Patel P, Keraliya V, Soni TG, et al. (2012) Osmotic drug delivery system as a part of modified release dosage form. ISRN Pharm 2012.
6. Mattos BD, Rojas OJ, Magalh WLE (2017) Biogenic silica nanoparticles loaded with neem bark extract as green. slow-release biocide 142: 4206-4213.
7. Ding C, Li Z (2017) A review of drug release mechanisms from nanocarrier systems. Mater Sci Eng C 76: 1440-1453.
8. Chen K, Chen X (2010) Design and Development of Molecular Imaging Probes. pp. 1227-1236.
9. Faheem AM, Abdelkader DH (2020) Novel Drug Delivery Systems. Elsevier LTD 1.
10. Pathak C, Vaidya FU, Pandey SM (2019) Chapter 3 - Mechanism for Development of Nanobased Drug Delivery System. Elsevier Inc.