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The Toxicological Profile of Active Pharmaceutical Ingredients—Containing Nanoparticles: Classification, Mechanistic Pathways, and Health Implications

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Abstract

Nanotechnology is the manipulation of matter on an atomic and molecular scale, producing a lot of new substances with properties that are not necessarily easily expected based on present knowledge. Nanotechnology produces substances with unique properties that can be beneficial or harmful depending on their biocompatibility and distribution. Understanding nanomaterial toxicity is essential to ensure their safe application in biological and environmental applications. This review

aims to provide a comprehensive overview of nanoparticle toxicity, focusing on their physicochemical properties, mechanisms of cellular uptake, and potential health risks. Key factors influencing toxicity include particle size, shape, concentration, aspect ratio, crystallinity, surface charge, dissolution, and agglomeration. Nanoparticles can induce oxidative stress and inflammation, contributing to adverse effects when inhaled, ingested, or applied to the skin. However, their toxicity may not be limited to just these pathways, as they can also exhibit other toxic properties, such as activation of the apoptotic pathway and mitochondrial damage. By summarizing the current knowledge on these aspects, this article intends to support the development of nanoparticles in a safer way for future applications. © 2025 by the authors.

Author keywords

inflammation; nanoparticles; oxidative stress; physicochemical properties; toxicity

Indexed keywords

EMTREE drug terms

nanomaterial; nanoparticle

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apoptosis; biocompatibility; classification; dissolution; drug toxicity; electric potential; health hazard; human; inflammation; nanotechnology; nonhuman; oxidative stress; particle size; pharmaceuticals; physical chemistry; review; surface charge; toxicology

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