Mechanism of Nanoparticle Toxicity

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Abstract

Nanoparticles (NPs), materials less than 100 nm in size, are being utilised in diverse biomedical, commercial, and industrial applications due to their unique physicochemical properties. However, the same properties that make nanoparticles so appealing for novel uses also raise concerns regarding their potential health and environmental impacts. A significant body of *in vitro* and *in vivo* research over the past two decades has aimed to elucidate the mechanisms by which nanoparticles induce adverse effects. Nanoparticle toxicity is mediated through a multifaceted process encompassing their interactions with biological components at the molecular, cellular, and tissue levels. Oxidative stress, inflammation, physical disruption of cell membranes, and alteration of cell signalling pathways have been identified as key events induced by nanoparticles in organisms. Nanoparticles can penetrate into cells and stimulate excessive reactive oxygen species formation which damages lipids, proteins, and DNA. They trigger inflammatory responses through activation of signalling cascades and molecular mediators. Cationic nanoparticles can directly interact with and damage cell membranes. Biodistribution and accumulation of nanoparticles in organs over time can lead to chronic inflammation. Soluble nanoparticle components like metal ions also drive toxicity through oxidative damage, protein binding, enzyme inhibition, and other mechanisms. Other factors influencing nanoparticle toxicity include surface adsorption of proteins, dissolution, aggregation state, and ability to cross tissue barriers. A comprehensive understanding of the mechanisms of nanoparticle toxicity is critical for appropriate safety assessment and design of nanomaterials.

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