

# Chapter 15

## Toxicity of Metal and Metal Oxide Nanoparticles: Impact of Physical State, Mechanisms of Action, and Strategies for Remediation in Biomedical Applications

**Elkhatim Hassan Abdelgadir**

*Naif Arab University of Security Sciences, Saudi Arabia*


**Fauzia Ashfaq**

*College of Nursing and Health Sciences, Saudi Arabia*


**Sakshi Gupta**

*Amity Institute of Forensic Sciences, India*


**Nimish Dhakad**

 <https://orcid.org/0009-0004-6987-0335>  
*Amity Institute of Forensic Sciences, India*

**Sachil Kumar**

 <https://orcid.org/0000-0002-2681-3937>  
*Amity University, Greater Noida, India*

**Shipra Rohatgi**

 <https://orcid.org/0000-0003-0532-9908>  
*Amity University, India*

### ABSTRACT

*Metal and metal oxide nanoparticles (NPs) show great promise in biomedical applications, but their toxicity varies. Metallic NPs are stable, while metal oxide and alloy NPs dissolve in biological conditions, releasing metal ions that generate reactive oxygen species (ROS), causing oxidative stress and cellular damage. Their rapid distribution and accumulation in tissues raise toxicity concerns. This chapter reviews their toxicological effects, mechanisms, and strategies for risk mitigation, including surface modifications and remediation.*

### 1. INTRODUCTION

With major contributions to biological and pharmaceutical applications, nanotechnology has emerged as a crucial element of many cutting-edge scientific and technical fields. Because of their special physicochemical qualities, such as chemical reactivity, optical traits, and structural plasticity, metal and metal oxide nanoparticles (NPs) have become potential instruments for applications such as drug administration,

DOI: 10.4018/979-8-3373-0055-9.ch015

diagnostics, and sensor technologies. NPs such as copper oxide, iron oxide, zinc oxide, titanium dioxide, gold, and silver are frequently employed. In therapeutic contexts, these nanoparticles offer improved imaging capabilities and new pathways for targeted medication delivery.

Despite their potential, nanoparticles' small size, wide surface area, and special surface characteristics frequently cause them to interact significantly with biological systems, which raises questions regarding their toxicity. For example, oxidative stress, reactive oxygen species (ROS), and consequent cellular damage might result from the dissolution and ion release of metal oxide nanoparticles. Additionally, nanoparticles have the ability to infiltrate the bloodstream, build up in tissues, and disrupt biological functions, all of which may have a negative impact on health. These materials' size, shape, charge, crystallinity, and stability in biological contexts all have a significant impact on their toxicity profiles (Manuja et al., 2021). Understanding how these nanomaterials interact with biological systems and resolving the related toxicity issues are crucial given their growing production and use. The objective of this research is to present a thorough analysis of the physicochemical characteristics that affect the toxicity of nanoparticles, clarify the underlying molecular pathways, and suggest methods for reducing negative effects.

### **1.1. Overview of Metal and Metal Oxide Nanoparticles**

The remarkable chemical, optical, magnetic, and structural characteristics of metal and metal oxide nanoparticles set them apart from their bulk counterparts. Gold (Au), silver (Ag), iron oxide ( $\text{FeO}_4$ ), zinc oxide (ZnO), and titanium dioxide ( $\text{TiO}_2$ ) nanoparticles are a few examples. To accomplish particular functionality, these materials can be synthesised in a variety of shapes, including sheets, rods, and spheres, with customised surface chemistries. Notwithstanding their adaptability, the way nanoparticles behave in biological settings—including how they dissolve, release ions, and aggregate—has a big impact on how reactive and stable they are. Potential cytotoxicity and genotoxicity are raised by the oxidative stress and reactive oxygen species (ROS) that can arise from these interactions (Sengul & Asmatulu, 2020).

### **1.2. Biomedical Applications of Metal Nanoparticles**

The potential of metal nanoparticles to improve therapeutic efficacy and diagnostic accuracy has led to a significant increase in their application in biomedicine. Applications include enhanced imaging methods like magnetic resonance imaging (MRI) and fluorescence imaging, which use nanoparticles as contrast agents, and targeted drug delivery, in which they act as carriers for medicinal medicines (Attarilar et al., 2020). Furthermore, by integrating detection and treatment onto a single platform, metal nanoparticles have shown potential in cancer theranostics. For instance, silver nanoparticles have potent antibacterial qualities, while gold nanoparticles are frequently employed in photothermal therapy. Despite these developments, any toxicity concerns must be addressed before they can be safely incorporated into clinical practice.

### **1.3. Importance of Understanding Toxicity Profiles**

Knowing the toxicity characteristics of nanoparticles is essential as they are used in more biomedical applications. The size, shape, surface charge, and solubility of nanoparticles all affect how they interact with cells and tissues, which frequently results in toxic effects. The degree of systemic exposure and

20 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:

[www.igi-global.com/chapter/toxicity-of-metal-and-metal-oxide-nanoparticles/391109](http://www.igi-global.com/chapter/toxicity-of-metal-and-metal-oxide-nanoparticles/391109)

## Related Content

---

### An Overview of Telemedicine Technologies for Healthcare Applications

P. S. Pandian (2016). *International Journal of Biomedical and Clinical Engineering* (pp. 29-52).

[www.irma-international.org/article/an-overview-of-telemedicine-technologies-for-healthcare-applications/170460](http://www.irma-international.org/article/an-overview-of-telemedicine-technologies-for-healthcare-applications/170460)

### Study of Fetal Anatomy using Ultrasound Images: A Systematic Conceptual Review

Sandeep Kumar E. and N. Siraam (2014). *International Journal of Biomedical and Clinical Engineering* (pp. 1-13).

[www.irma-international.org/article/study-of-fetal-anatomy-using-ultrasound-images/127395](http://www.irma-international.org/article/study-of-fetal-anatomy-using-ultrasound-images/127395)

### Spatial Multi-Omics in Drug Discovery

Kazi Asraf Ali, Dipika Mandal, Sourav Dutta, Syed Nazimul Haque and Basudev Sahana (2026). *Spatially Resolved Single-Cell and Multiple Omics in Human Diseases* (pp. 71-106).

[www.irma-international.org/chapter/spatial-multi-omics-in-drug-discovery/399334](http://www.irma-international.org/chapter/spatial-multi-omics-in-drug-discovery/399334)

### Developing Trust Practices for E-Health

Elizabeth Sillence, Pamela Briggs, Peter Harris and Lesley Fishwick (2009). *Medical Informatics: Concepts, Methodologies, Tools, and Applications* (pp. 1976-1996).

[www.irma-international.org/chapter/developing-trust-practices-health/26351](http://www.irma-international.org/chapter/developing-trust-practices-health/26351)

### Data Integration for Regulatory Gene Module Discovery

Alok Mishra (2009). *Handbook of Research on Systems Biology Applications in Medicine* (pp. 516-529).

[www.irma-international.org/chapter/data-integration-regulatory-gene-module/21552](http://www.irma-international.org/chapter/data-integration-regulatory-gene-module/21552)