



REVIEW ON MAGNESIUM OXIDE NANOPARTICLES AND THEIR APPLICATIONS IN BIOMEDICAL FIELDS

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ABSTRACT

Magnesium oxide (MgO) nanoparticles have gained considerable attention in recent years due to their unique physicochemical properties and wide-ranging biomedical applications. Typically ranging from 6–130 nm in size, MgO nanoparticles exhibit high surface reactivity, strong catalytic performance, excellent adsorption capacity, and notable antimicrobial, anticancer, and antioxidant activities. These properties make them suitable for diverse applications, including biosensors, medical imaging, cancer detection, tissue engineering, bone repair, and antibacterial materials. In magnesium-based orthopaedic composites, MgO nanoparticles act as effective reinforcements, enhancing mechanical strength, corrosion resistance, and bioactivity through mechanisms such as load transfer, grain refinement, and improved phase interactions. Additionally, MgO nanoparticles promote the formation of protective Mg (OH)₂ and calcium–phosphate layers in simulated body fluid, supporting improved osseointegration. Green synthesis approaches further improve the sustainability and biocompatibility of MgO nanoparticles, offering eco-friendly and cost-effective alternatives to conventional production methods.

Despite their promising therapeutic potential, challenges such as rapid magnesium degradation, possible cytotoxicity, uneven nanoparticle distribution, and limited in vivo and clinical data remain. Comprehensive biological evaluations and standardized studies are essential to ensure safety and optimize clinical performance. Overall, MgO nanoparticles represent highly promising, multifunctional nanomaterials with significant potential for future biomedical and industrial applications.

KEYWORDS: Magnesium Oxide, Nanoparticles, Antibacterial, Dental Implantation, Tissue Engineering

1. INTRODUCTION

Nanotechnology has evolved into a multidisciplinary domain with applications in healthcare, biology, environmental science, and materials engineering. Metal oxide nanoparticles have garnered considerable research attention owing to their substantial surface-to-volume ratio, reactive surfaces, adjustable shape, and distinctive physicochemical characteristics. Their distinctive characteristics have rendered them advantageous in antibacterial uses, catalysis, environmental clean-up,

drug transport, biosensing, and tissue engineering (Gatou *et al.*, 2024).

The MgO NPs have significant potential as metal oxide nanoparticles due to their exceptional chemical and thermal durability, extensive surface area, elevated surface reactivity, and broad band gap. The physicochemical characteristics can be modified by the regulation of particle dimensions, morphology, crystallinity, and synthesis methodology, hence influencing biological and functional efficacy. Consequently, the use of MgO

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nanoparticles has been investigated across several domains such as antibacterial, antioxidant, anti-inflammatory, anticancer, drug delivery, tissue engineering, and environmental applications (Chandrasekaran *et al.*, 2023; Thakur *et al.*, 2022). The engagement of MgO NPs with biological systems and microorganisms is closely linked to the biological efficacy of the nanoparticles. They have demonstrated antibacterial characteristics against Gram-positive and Gram-negative bacteria, fungus, and biofilms. Proposed processes including the production of reactive oxygen species (ROS), oxidative stress, membrane rupture, liberation of Mg^{2+} , and disruption of cellular activities. Furthermore, MgO nanoparticles have anticancer, antioxidant, and anti-inflammatory effects influenced by their size and shape, concentration, surface characteristics, and biological environment (Thakur *et al.*, 2022).

The fabrication of MgO nanoparticles using several physical and chemical techniques, including sol-gel, hydrothermal, precipitation, co-precipitation, combustion, and thermal breakdown, has been documented (Kumar *et al.* 2021). However, several conventional techniques necessitate elevated temperatures, specialized apparatus, and hazardous substances, thus limiting their eco-friendly and biomedical utilization. Consequently, green synthesis (utilizing plant extracts, microbes, algae, etc.) has emerged as a straightforward, cost-effective, and eco-friendly method that is gaining increasing popularity. Magnesium oxide nanoparticles (MgO NPs) are environmentally sustainable and economically feasible. They are crucial in industrial applications owing to their elevated refractive index, superior corrosion resistance, robust thermal conductivity, diminished electrical conductivity, and good biocompatibility. Their distinctive physicochemical features render them important across multiple domains (Thakur *et al.*, 2022). Moreover, they function as efficient catalysts in several chemical processes and are investigated in pharmaceutical research for drug delivery and medicinal purposes. Phytochemicals sourced from plants may have a role in the synthesis and stability of nanoparticles, thereby influencing the surface characteristics and biological efficacy of the resultant MgO nanoparticles (Sharmila *et al.*, 2019; Gatou *et al.*, 2024).

While there is mounting data supporting their biological efficacy, critical obstacles persist related to the repeatability of their synthesis, structure–activity correlations, toxicity, biocompatibility, and the implementation of their discoveries in medicinal applications. Consequently, possessing an in-depth understanding of the synthesis, physicochemical characteristics, biological processes, uses, and safety of MgO nanoparticles is essential. This review seeks to encapsulate the recent advancements in the synthesis and characterisation of MgO nanoparticles, their biological activities, mechanisms of action, biomedical applications, toxicity, existing obstacles, and future outlook.

2. CLASSIFICATION OF NANOPARTICLES BASED ON THEIR DIMENSIONS

There are several dimensions that nanomaterials can have, including zero, one, two, and three dimensions. Most nanoparticles have at least one dimension that is between one and one hundred nanometers. They may take on a variety of shapes, including tubular, spherical, and irregular shapes, and exist in a range of forms, including individual particles, aggregates, and fused structures. Nanofibers, nanotubes, quantum dots, and nanosheets are the most often encountered nanomaterials. Additionally, according to their dimensional characteristics, nanomaterials are divided into four different categories by Siegel's classification system: zero-dimensional, one-dimensional, two-dimensional, and three-dimensional nanostructures (Singh *et.al*, 2020).

2.1 Zero-dimensional Nanoparticles: In the study of nanomaterials, zero-dimensional nanoparticles, or zero D-NPs, are frequently seen. They are all classified as nanoscale particles because of their minuscule size—none of them are larger than 100 nm. These nanoparticles resemble microscopic points in space due to their point-like structure. Several often-seen 0D-NPs include homogeneous and heterogeneous particle arrays, such as hollow spheres, nano lenses, and quantum dots (particles organised uniformly) (Singh *et.al*, 2020).

2.2 One-dimensional Nanoparticles: One-dimensional nanoparticles have two dimensions at the nanoscale and a third dimension that is beyond the nanoscale and has a needle-like shape.

These particular nanostructures have drawn a lot of interest from a variety of academic fields because of their remarkable characteristics when compared to bulk materials and structures. Nanowires, nanorods, and nanotubes are examples of one-dimensional nanomaterials, or 1D-NPs. One-dimensional nanostructures are well known for their extraordinary use in size reduction and in the investigation of electrical, mechanical, and thermal characteristics. Moreover, these one-dimensional nanostructures are essential for the production of electrical, electromechanical, and electrochemical devices because they serve as functional units and linkages (Rafique *et al.*, 2020).

2.3 Two-dimensional Nanoparticles: One-dimensional and two-dimensional structures on the nanoscale are characteristics of two-dimensional nanomaterials. Nails, nanocoatings, and nanolayers are a few examples of two-dimensional NSMs. Plate-like shapes are typical for these nanomaterials. By depositing them as a single layer or as multi-layered structures onto a substrate, they are created. Amorphous or crystalline, metallic or non-metallic, and even polymeric in nature are just a few of the qualities these nanomaterials may display. Because of their distinct surface and electrical characteristics, 2D NSMs have drawn a lot of attention recently from researchers in industries like solar energy (Rafique *et al.*, 2020).

2.4 Three-dimensional nanomaterials: The nanocrystals in the three-dimensional nanoparticles are arranged in discrete layers in each of the three dimensions. The behaviour of nanomaterials has drawn more attention in the last ten years, especially those with three-dimensional structures. These nanomaterials' morphology, size, dimension, and shape all have a significant impact on how well they work and how they are applied in a variety of contexts, including medical research and science. Applications for three-dimensional nanomaterials have proven to be many and include catalysis, batteries, magnetic materials, and reactant and product transportation. Three dimensional nanoparticles with notable characteristics include quantum dots, dendrimers, and fullerenes (Ijaz *et.al.*, 2020)

3. THE SHAPE OF MGO NANOPARTICLES

MgO nanoparticles exhibit several morphologies, such as spherical nano cubes, nanocrystals, nanofibrous nanowires, nanotubes, and nanosheets. The diverse morphologies of MgO nanoparticles have led to several applications that use each form across various domains. The morphological characteristics of MgO nanoparticles were analyzed with several analytical methods. X-ray Diffraction (XRD) is employed to ascertain the crystallinity and dimensions of MgO nanoparticles. Transmission electron microscopy (TEM) is employed to ascertain the dimensions and morphology of particles. The infrared spectrum of the sample was obtained using Fourier transform infrared microscopy, indicating its powdered state. UV-Visible spectroscopy was employed to assess the optical characteristics of the nanoparticles (Fahmy *et al.*, 2022).

4. ROLE OF MGO NPS IN MEDICAL FIELDS

4.1 Antibacterial agents:

In recent times, inorganic antimicrobials are being utilized more frequently for decontamination and the prevention of biodegradation. Magnesium oxide had significant antimicrobial efficacy. Magnesium oxide granules exhibit considerable antibacterial efficacy against both Gram-positive and Gram-negative microorganisms. Magnesium oxide nanoparticles possess antimicrobial characteristics. The qualities are contingent upon its morphology and dimensions. Nanoscale dimensions of MgO enhance antibacterial efficacy against *E. coli* and *S. aureus*. Magnesium oxide nanoparticles exhibit antibacterial activity that is depending on dosage (Saber *et al.*, 2024).

The study by (Schwechheimer *et al.* 2015) demonstrated that the antibacterial efficacy of MgO nanoparticles against aquatic bacteria, specifically *Pseudomonas aeruginosa* and *Staphylococcus aureus*, is more pronounced against gram-positive pathogens than gram-negative ones. This disparity is ascribed to the lack of an outer membrane in the cell wall of gram-positive bacteria, in contrast to the intricate structure of gram-negative bacterial walls. The MgO nanoparticles exhibited significant bactericidal action, creating an extensive inhibitory zone around them, with enhanced efficacy against gram-positive bacteria compared to gram-negative bacteria. The antibacterial efficacy was more correlated with the

surface area than with the resultant nanoparticle size (Vatsha *et al.*, 2013).

The application of MgO NPs damages the cell membrane, leading to the leaking of intracellular contents and, subsequently, bacterial cell death. (Fahmy *et al.*, 2022). MgO nanoparticles exhibit antibacterial properties against foodborne pathogens, such as *E. coli* and *Salmonella enteritidis*, by producing a break in the bacterial cell membrane, ultimately leading to cell death (He *et al.*, 2016).

(Rabi,2025) demonstrates that MgO nanoparticles exhibit potent antibacterial action against Gram-positive bacterial species. The antibacterial assay, along with magnesium nitrate and the aqueous extract of neem leaves utilized for synthesizing MgO nanoparticles, indicates action at elevated concentrations. Hirphaye *et al.* (2023) demonstrate that green produced MgO nanoparticles, utilizing aqueous extract from *Hagenia abyssinica* female flowers, exhibit enhanced antibacterial effectiveness against *S. aureus* and, to a lesser degree, *E. coli*. The bacterial strain *Acidovorax oryzae* is responsible for the disease termed bacterial brown stripe, which proliferates among rice crops and devastates rice agriculture. Consequently, another study documented that the manufacture of MgO nanoparticles using *Matricaria chamomilla* L., which had a significant inhibitory effect on the proliferation of *Acidovorax oryzae* bacteria. A further investigation by a research group indicated that magnesium oxide nanoparticles exhibit a favorable antibacterial response against phytopathogenic bacteria responsible for the lethal wilt disease in *R. solanacearum* (Cai *et al.* 2018).

4.2 MgO Nanoparticles role in cancer therapy:

Cancer is a hereditary disorder resulting from mutations in genes that govern cellular functions, such as growth and division. Nanoparticles measuring less than 100 nm can engage with proteins, nucleic acids, and lipids both intracellularly and extracellularly, hence enhancing cancer diagnostics and treatment (Saber *et al.*, 2024). Karthik *et al.* (2017) elucidate that MgO nanorods possess prospective uses as an effective chemotherapeutic agent for the swift detection and identification of all cancer kinds. The cytotoxic effects of MgO nanoparticles on normal lung fibroblast cells and other malignant cells

demonstrated their remarkable ability to eradicate cancerous cells. These findings expand the potential applications of MgO nanoparticles in nanomedicine for cancer treatment as a feasible alternative to chemotherapy, due to their cytotoxic effects on cancer cells through apoptosis triggered by reactive oxygen species (Fahmy *et al.*, 2022).

4.3 MgO NPs role in tissue engineering:

Hickey *et al.* (2015) examined the impact of incorporating MgO nanoparticles into poly (L-lactic acid) and hydroxyapatite. The findings indicated that MgO nanoparticles improve the adhesion and proliferation of osteoblasts on PLLA-HA nanocomposite materials.

Tissue engineering is a study domain that utilizes living cells to enhance tissues and organs by cultivating and building three-dimensional structures from harvested cells on bioactive, degradable scaffolds. Recently, tissue engineering has advanced the treatment of orthopaedic problems by integrating engineering principles, biology, and chemistry, rendering it more successful than conventional procedures. Magnesium oxide nanoparticles (MgO NPs) are utilized in orthopaedic treatment by promoting osteoblast adhesion and proliferation on hydroxyapatite–poly (L-lactic acid) (HA–PLLA) nanocomposites, hence optimizing mechanical properties for cancellous bone applications. Moreover, MgO nanoparticles enhance osteoblast proliferation and can be utilized to alter the mechanical characteristics of additive biomaterials (Fahmy *et al.*, 2022).

4.4 Anti-insecticidal and Anti-biofilm activity:

Rao *et al.* (2018) showed that magnesium-based nanoparticles serve as carriers for cry proteins by adhering to these nanoparticles and subsequently transferring to the surface of cotton leaves. The findings of this investigation indicated an increased mortality rate among insects. Consequently, magnesium-based nanoparticles function as nanocarriers for the delivery of cry proteins, thus augmenting their use as bioinsecticides. These metal oxide nanoparticles are recognized for inducing systemic resistance against gram-negative, plant pathogenic bacteria by inhibiting biofilm formation. Therefore, it can be asserted that magnesium oxide nanoparticles are highly effective as antibacterial,

anti-insecticidal, and antibiofilm agents in the agricultural sector (Fernandes *et al.*, 2020).

4.5 MgO role in Dental implantation:

The dental implant is essential for addressing tooth loss. It must be biocompatible, robust, inert, and resilient. Recent modifications have been developed to decrease duration and enhance dental implantation (Fahmy *et al.*, 2022). (Gupta *et al.* 2017) indicated that nanotechnology represents one of the most promising future advancements in implant dentistry. Nano surface modification technologies are frequently employed to enhance the surface material properties of dental implants, leading to accelerated osseointegration and bone healing.

Recent reports indicate that nanoparticles may possess novel preventative and therapeutic implications in dental caries. Research demonstrates the efficacy of MgO nanoparticles in mitigating and regulating plaque biofilm, enhancing the antibacterial characteristics of dental materials, and rehabilitating primary tooth caries. Consequently, toothpaste with Mg hydroxide may serve as an effective means of mitigating corrosion effects (Saber *et al.*, 2024).

According to Passos *et al.* 2017), toothpaste with magnesium hydroxide can safeguard dental enamel from moderate acid erosion, but is ineffective against severe acid erosion. Consequently, toothpaste containing magnesium hydroxide may serve as an effective means of mitigating corrosion consequences. (Passos *et al.*, 2018) indicated that MgO nanoparticles exhibit antibacterial and anti-biofilm properties against several microbes, including the carcinogenic oral bacterium *S. mutans*.

4.6 MgO NPs utilized as Biosensor:

Patel *et al.*, (2014) study suggested that Magnesium oxide nanoparticles along with its composites can be used for the detection of *Vibrio cholerae* via biosensors manufactured for the detection of DNA. (Lei *et al.*, 2012) demonstrated that for biosensing of liver cancer the blend of magnesium oxide-based magnetic tunnel junction and magnetic nanoparticles have shown reliable results. MgO nanoparticles are utilized in gas sensing applications, particularly for detecting acidic gases. The high surface area and

defect density of MgO make it suitable for integration in photoactivated gas sensors (Deo *et al.*, 2025).

5. DISCUSSION

Due to their high surface area, physicochemical stability and tunable surface properties, magnesium oxide (MgO) nanoparticles have garnered quite a bit of interest as “multi-functional” nanomaterials for biomedical applications. The reported biological activities of MgO nanoparticles include antimicrobial, anticancer, antioxidant, tissue-engineering, drug-delivery, and biosensing applications, which are considerably influenced by the particle size, morphology, surface characteristics, synthesis method, and dosage (Nguyen *et al.*, 2023; Humaira *et al.*, 2024).

The antibacterial activity is one of the properties studied extensively with regard to MgO nanoparticles. They exhibit antimicrobial properties that have been linked to membrane disruption, surface interactions, generation of reactive oxygen species (ROS) and oxidative damage to cell components. The use of plant extracts and other biological materials to synthesize nanoparticles, such as MgO, can also provide potential surface modification and biological activity of the nanoparticles, which may be another beneficial feature of green synthesis (Asif *et al.*, 2021; Chandrasekaran *et al.*, 2023). Comparing the green synthesized and chemically synthesized MgO nanoparticles is challenging, however, due to the differences in their synthesis conditions and biological tests.

In the field of cancer research, MgO nanoparticles have been shown to have cytotoxic activity against various cancer cell models, and oxidative stress and the damage caused by ROS are suggested as significant mechanisms. The potential of MgO nanoparticles in anticancer applications is thus promising, though the selectivity of the nanoparticles towards cancerous cells and normal cells needs further studies (Chandrasekaran *et al.*, 2023; Humaira *et al.*, 2024). In the same way, the use of MgO nanoparticles in biomaterials and tissue engineering applications has been studied due to their ability to exert an antibacterial effect along with desirable biological responses.

Although these are promising results, there are some limitations that prevent clinical translation. Changes in synthesis methods may result in significant differences in particle size, shape, crystallinity, aggregation, and surface chemistry, which in turn can impact biological activity and toxicity. Moreover, overproduction of ROS may lead to unwanted cytotoxic effects and stress the importance of dose optimization and systematic toxicological testing. There is also a limited amount of standardized in vivo evidence regarding biodistribution, clearance, long-term safety, and pharmacokinetics (Nguyen *et al.*, 2023; Humaira *et al.*, 2024).

Future studies should therefore be directed towards the standardized synthesis and characterization, elucidation of ROS-mediated and surface-dependent mechanisms, comparative evaluation of green and conventional synthesis, controlled degradation, targeted surface modification, and extensive in vivo toxicity studies. Overall, MgO nanoparticles are a promising biomedical platform; however, reproducible structure–activity relationships and long-term safety and efficacy of these nanoparticles must be established for their successful clinical translation.

6. CONCLUSION

Magnesium oxide (MgO) nanoparticles have emerged as versatile and promising nanomaterials in biomedical research owing to their antibacterial, anticancer, antioxidant, and bioactive characteristics. Their high surface reactivity, catalytic efficacy, biocompatibility, biodegradability, and cost-effectiveness support their use in biosensors, medical imaging, tissue engineering, bone repair, and magnesium-based orthopaedic composites. MgO-reinforced Mg nanocomposites exhibit enhanced mechanical strength, corrosion resistance, and bioactivity, hence increasing their appropriateness for implant-related applications. Green synthesis methods enhance the potential of MgO nanoparticles by providing environmentally friendly, sustainable, and possibly safer production techniques. Despite these benefits, issues such as accelerated magnesium breakdown, potential cytotoxicity, and insufficient in vivo and clinical evidence remain major obstacles. Consequently, systematic and thorough biological research is vital to guarantee safety,

enhance performance, and promote effective clinical translation. MgO nanoparticles are exceptionally promising materials for future medicinal and industrial developments.

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