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Application of Magnesium Oxide Nanoparticles in Dentistry: A Literature Review

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Abstract

Magnesium oxide (MgO) nanoparticles' biocompatibility and degraded by-products are the two most important factors that make this material preferable in dental care. Their specific characteristics, such as antibacterial action against cariogenic microbes, are potential antibacterial agents for dental applications. This paper investigates the properties of MgO in dentistry and sets the groundwork for future research. Electronic databases, including PubMed/Medline, Scopus, Google Scholar, and scientific-research journals of domestic universities were reviewed from 1972 to 2022, and all the relevant papers were surveyed. After a search in electronic databases, 60 articles were involved, and the needed details were extracted. The biochemical features and application of magnesium oxide nanoparticles (MgONPs) in dentistry and new fields have been discussed in detail. Nanoparticles (NPs) may provide a unique method for treating and preventing dental infections. MgO nanoparticles are a good choice in several fields because their unique properties, such as antibacterial activity against cariogenic microorganisms, make them ideal antibacterial agents for dental applications.

Keywords
- ► magnesium oxide
- ► antibacterials
- ► dental caries
- ► nanoparticles
- ► dentistry

Introduction

Nanoparticles are minuscule materials (with at least one dimension less than 100 nm) with unique properties, making them more appropriate for novel applications and attractive for medical developments.[1] Nanomaterials are recently reported to have novel preventive and therapeutic usage in dental caries. More studies demonstrated novel applications, including reducing and controlling dental plaque biofilms, improving the antibacterial properties of dental materials, and remineralizing initial dental caries lesions.[2] One of the emerging concerns in the usage of this nanoparticle is its biosafety in medicine. The accumulation of these non-biodegradable nanoparticles in different body organs, including the brain, may have a bad effect on their normal functions.[3] The most frequent nanometals that have been used in dental materials include gold, silver, copper oxide, magnesium oxide, iron oxide, cerium oxide, aluminum oxide, titanium dioxide, and zinc oxide.[4] The antibacterial characteristics of magnesium oxide (MgO) nanoparticles are piqued for usage in medicine.[5] MgO nanoparticles outperform other metal oxide nanoparticles in terms of biocompatibility and

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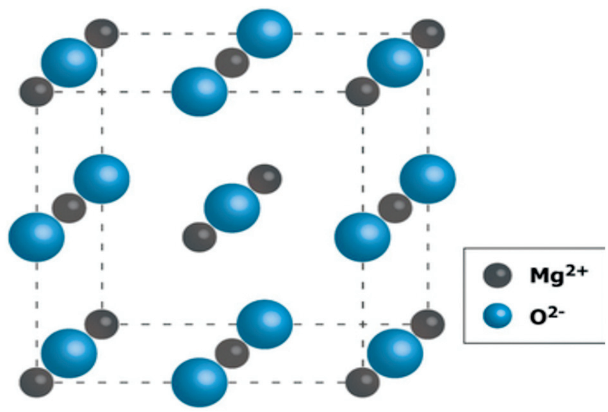

Fig. 1 Magnesium oxide crystal structure (adapted from Shand 2006).

degradation by-products, and the U.S. Food and Drug Administration has declared them to be safe.[6] MgO is also known as periclase, and its empirical formula is MgO, and its lattice is made up of Mg^{2+} and O_2 ions linked by ionic bonds (►**Fig. 1**). The two most important factors that made MgO nanoparticles superior in use to other nanoparticles are their biocompatibility and their biodegradable by-products (namely magnesium ion).[7]

MgO is an inorganic molecule found in nature as the mineral percales (►**Table 1**). It rapidly reacts with water in aqueous environments to create magnesium hydroxide. It is used as an antacid and a moderate laxative and for a variety of other purposes (American National Library of Medicine, 2017). Calcination of magnesium hydroxide $Mg(OH)_2$ or magnesium carbonate $MgCO_3$ produces magnesium oxide.[8]

Magnesium oxide (MgO) nanoparticles are appealing for medical usage because of their antibacterial capabilities against bacteria, spores, and viruses and their non-toxicity, high thermal stability, biocompatibility, and inexpensive manufacturing costs.[9] *Streptococcus mutans* play a vital role in the formation of cariogenic biofilms, causing dental caries.[10] According to the findings of Passos et al,[11] dentifrices containing magnesium hydroxide may protect enamel against modest acid erosion but not from severe acid erosion. Therefore, magnesium hydroxide-containing kinds of toothpaste might be a valuable method for reducing the impacts of erosive problems Passos et al[12] reported that MgO nanoparticles have antibacterial and antibiofilm action against various microorganisms, including oral bacteria such as *S. mutans* cariogenic species.[13] The major pathogenic bacteria for dental caries are *S. mutans*. The two bacteria that are usually isolated from the human oral cavity are *S. mutans* and *Streptococcus*, and they are recognized as the primary cariogenic bacteria.[14] Nanoparticles may impact bacteria in various ways, and germs are less likely to acquire resistance to nanoparticles because most antibiotic resistance pathways are not applicable to nanoparticles.[15] MgO nanoparticles, in addition to disrupting membranes and producing reactive oxygen species, block the critical enzymes of bacteria.[16] MgO nanoparticles' high pH (alkaline pH) may contribute to their antibacterial activity.[17] MgO nanoparticle suspensions are primarily alkaline in nature, enabling them to fight the acidogenic bacteria responsible for forming dental caries and favoring the surrounding environment for enamel remineralization.[18] Hence, it is essential to reduce the bacteria load in the oral cavity to prevent the disease,[19] and antibiotics and chemical bactericides affect the natural microbial ecology of the digestive system and may lead to bacterial resistance, limiting their use in the development of novel antimicrobial dental materials, this review study was performed to evaluate MgO in dentistry and biomedical.

Table 1 Magnesium oxide's characteristics (theoretical)

Formula for compounds	MgO
Molecular mass	40.3
Appearance	White powder
Temperature of melting	2,852°C (5,166°F)
Temperature of boiling	3,600°C (6,512°F)
Density	3.58 g/cm^3
In H_2O, solubility	N/A
Precise mass	39.98
Mass monoisotopic	39.98

By searching the information sources, no study was found that provides a comprehensive understanding of the uses of this material, and due to the increasing attention to the uses of this material in dentistry, there is a need for a comprehensive study that can provide detailed information about the properties of this material. There are current applications and future needs for this topic.

Methods

This study was conducted in concordance with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines (►**Fig. 2**.) Studies that surveyed the atypical focal nodular hyperplasia have been included in our study; this article reviews the various features of MgO nanoparticles in dentistry and reviews the relevant literature. The texts were searched using PubMed/Medline, Scopus, Google Scholar electronic databases, and scientific-research journals of domestic universities. All published articles (all article types; case reports, original articles, clinical trials, etc...) with the following search strategy surveyed. The search strategy and key words included Magnesium Oxide nanoparticles, Magnesium Oxide nanoparticles AND dentistry, Magnesium Oxide nanoparticles AND Preparation, Magnesium Oxide nanoparticles AND Nanotechnology, Magnesium Oxide nanoparticles AND bacteria AND biofilm AND dentistry, Magnesium Oxide nanoparticles AND antimicrobial effects.

In total, 60 articles with publication periods from 1972 to 2022 were reviewed. Articles whose findings in the summary section were not relevant to the subject of our study were

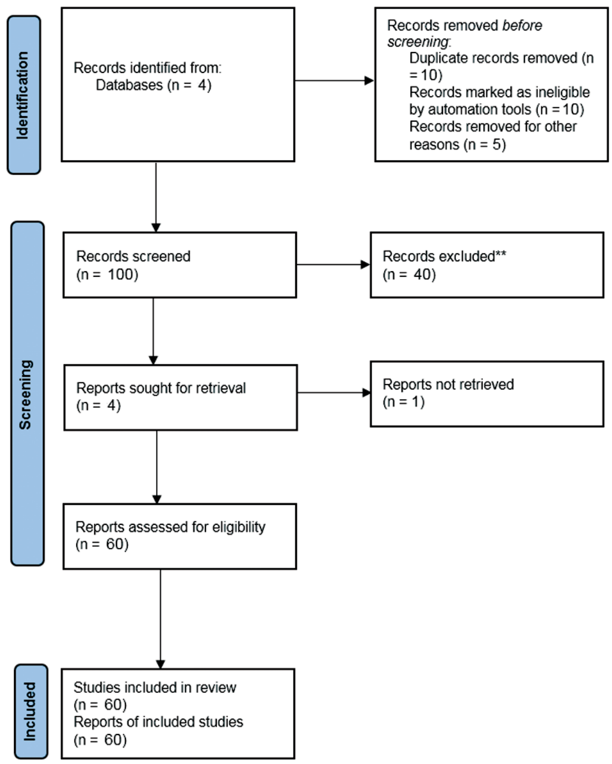

Fig. 2 Identification of studies via databases and registers.

deleted. The search was performed using the following keywords in combination or separately: Magnesium oxide, Antibacterial, Dental caries, Nanoparticles, Dentistry.

►**Figure 2**

Results

MgO nanoparticles need more study and development of glass-ionomer cement (GICs) and other preventative and restorative dental materials because of their biocompatible nature and degradable by-products. All applications of MgO nanoparticles were extracted from the involved articles. The extracted usage included anti-bacterial, restorative, and using in stem cell regeneration. Details are mentioned below.

Magnesium Oxide Particle Preparation and Characterization

Magnesium oxide nanoparticles (MgONPs) are antibacterial agents and harmless in nature that are easy to obtain between various inorganic metal oxides.[20] A MgO powder can have particle sizes between 30 and 75 nanometers, depending on its annealing temperature.[21] Several papers in the field of the production of nanocrystalline oxides with large surface areas and strong reactivity have been published in recent years. Magnesium oxide is a fascinating basic oxide with several uses. MgO, for example, has shown tremendous potential as a destructive adsorbent for hazardous chemical agents due to its ultrafine, nanoscale particles and high specific surface area.[22,23] MgO nanoparticles are light metal-based antibacterial nanoparticles that may be metabolized and resorbed entirely in the body. MgO nanoparticles have bactericidal/fungicidal impacts on common pathogenic bacteria and yeasts[24]

Magnesium Oxide as Biomaterial in Dentistry

Any substance or device utilized within the mouth cavity to diagnose and treat oral problems, illnesses, and disorders is considered a dental biomaterial.[25] MgO is a good choice for various usage due to its physical characteristics. Biodegradable magnesium (Mg)-based alloys are the subject of current implant research.[26,27] Magnesium can dissolve in bodily fluid, which means that the implanted Mg can decay during the healing process, leaving no debris behind if the degradation is regulated; thus, there would be no need for secondary surgical operations for implant removal. As a result, the necessity for additional surgical procedures to remove the implant might be avoided.[28] The presence of MgO-reduced corrosion resistance and compressive strength of implants.[29] When zirconia is added to metal oxides, including magnesium oxide (MgO), calcium oxide (CaO), and yttrium oxide (Y_2O_3), it generates high molecular stability.[30] Nanomaterials are excellent prospects for various applications in research and industry due to their unique characteristics and capabilities.[31] Magnesium oxide is one of the most valuable materials in this sector because of its high melting point, catalytic characteristics, nanocomposite for dental types of cement,[32] and other qualities.[31] ZnO and MgO nanostructured and ZnO/MgO nanocomposite can be employed as active materials in dental types of cement because of their tiny homogeneous sizes.[33] Recently, study researchers have focused more on making ZnO and MgO nanoparticles and nanocomposites due to their applications in advanced technologies.[34]

Indirect restorations have been a more popular option due to the increase in esthetic demand in society.[35] Recurrent caries is one of the most important complications that occur as a result of decreasing the microorganism growth in relation to dental materials.[36] So, the use of antimicrobial agents such as MgO, which has well-documented antimicrobial properties and do not affect mammalian cells, in dental cement is warranted.[37,38] Nanoparticles of MgO have an agglomeration problem that changes them into micro-ones.[39] To solve this problem, some studies recently suggested coating MgO nanoparticles with natural zein polymer, so the particles were adequately dispersed in nano form.[40] There is evidence that zein coating improves MgO dispersion In addition to enhancing their ability to bind to bacteria and interfere with their metabolism, they also have enhanced antimicrobial properties.[13] Naguib et al first in 2018 surveyed different concentrations of zein polymer on different organisms. Zein samples had no antimicrobial effect; however, MgO and zein-coated MgO demonstrated bactericidal effects on different agents. Commercially available cement formulations could be enhanced by the well-distributed MgO nanoparticles in the substrate.[40] In another study by Naguib et al in 2022, test the antimicrobial effects of cement modified with zein-coated MgO nanoparticles against four common oral microorganisms. It showed that the concentrations of 0.3% and 0.5% of MgO nanoparticles had consistently shown similar antimicrobial values as the 1%.[41]

One of the attractive fields in dentistry is using human dental pulp stem cells (HDPSCs) as regenerative therapy.[42] These cells can differentiate to odontoblasts and osteoblasts that are enabled to replace the injured tissue with healthy ones.[43] Because of this reason, HDPCs are a clinically relevant cellular model for evaluating the impact of endodontic materials. So, as for dental pulp capping, selecting the right material can be crucial in promoting dentin regeneration through dentinogenesis when treating damaged pulpal tissues.[44] The most important features of these materials are biocompatibility, cytocompatibility, antibacterial capacity and properties that induce tissue healing, and the ability to seal the lesion.[45] Mg^{2+} ions made a new hope in regenerative pulp therapy due to their capacity to mobilize endogenous cells and regulate the proliferation and differentiation of HDPCs.[46] Recently, Salem et al surveyed the *in vitro* effect of MgO on HDPCs in different concentrations and demonstrated a beneficial effect of Mg^{2+} ions (0.5 mM) of low concentration on HDPCs in terms of attachment, proliferation, differentiation, and mineralization.[47]

Because of its lower calcination temperatures, using reactive MgO as a cement binder has certain benefits over.[48] Nanotechnology usage in the creation of restorative Optimal Pressable Ceramic (OPC) materials in dentistry has been successful.[49] As polymeric filling and restoration materials, MgO NPs are excellent candidates due to their biocompatibility. A composite does not exhibit antibacterial activity unless it contains a sufficient amount of nanoparticles, which is over 1 wt.%.[7,50] I*n vitro* and *ex vivo* investigations have shown that metal oxides, such as MgO nanoparticles, might be utilized as a possible root canal irrigants with good antibacterial effect.[51] Studies by Noori et al[7] showed that the MgO NP-modified glass-ionomer cement demonstrated good antibacterial and antibiofilm actions against two cariogenic microorganisms so that it may be developed further as a biocompatible antibacterial dental restorative cement. Nanoparticles may offer a novel approach to treating and preventing dental infections.[52]

The most important factors that make NPs interact with the negatively charged surface of bacterial cells and increase bactericidal activities are their vast surface area and high charge density.[53] *Streptococcus mutans* and *Streptococcus sobrinus*, as well as their biofilms, have recently received attention in the fight against dental caries because they have a critical function in the onset and progression of dental caries.[54] Krishnamoorthy et al[5] discovered that the minimum inhibitory concentration for MgO NPs against both *S. mutans* and *S. sobrinus* was 500 g/mL, and comparable results were also observed against *Escherichia coli*. MgO nanoparticles have been shown to exhibit varying levels of antibacterial and antibiofilm activities against just *S. mutans* in a previous study using different application scenarios and different techniques.[13] Studies have found that both *S. mutans* and Streptococcus mitis are associated with higher caries prevalence and activity in children.[55] In addition, it has been shown that MgO NPs, due to bacterial attachment prevention, were more effective against biofilms of *Klebsiella pneumoniae* and *Staphylococcus aureus*. MgO NPs reduced the biofilm growth of *Ralstonia solanacearum*, and the biofilm formation gradually decreased with the bulk MgO treatments.[56,57] Bacteria in biofilms are resistant to antimicrobial treatments; for instance, biofilms may withstand concentrations of antimicrobial agents 1,000 times those needed to kill planktonic bacteria.[58] Previous research has attempted to enhance the antibacterial characteristics of GIC by including antimicrobial compounds such as propolis, chlorhexidine, *Salvadora persica* (miswak) extracts, casein phosphopeptide-amorphous calcium phosphate, nanoparticles, and antibiotics.[59] According to the findings of Noori et al,[7] adding MgO NPs to GIC material may improve its antibacterial and antibiofilm properties, and the impact is proportional to the percentage of nanoparticles added.

Discussion

MgO nanoparticles have always been considered as an antibacterial substance due to its biochemical properties. The use of Mg in dentistry is mainly based on these well-known properties. This article reviewed several available studies from half a century ago, that is, since the first time the use of this substance in dentistry was reported.

Nanomaterials are microscopic solid particles having a dimension of 1 to 100 nanometers and promised in antibacterial aspects due to the improved and unique physicochemical characteristics, including ultra-small diameters, high surface-area-to-mass ratios, and heightened chemical reactivity. Metal oxide nanoparticles have sparked much interest because of their potential antibacterial action and their biocompatibility with human cells. Nanoparticles (NPs) may provide a unique method for treating and preventing dental infections. MgO nanoparticles are preferred to other metal oxide nanoparticles, and their unique properties, such as antibacterial activity against cariogenic microorganisms, make them ideal antibacterial agents for dental applications. Considering their biocompatibility and degradable by-products, MgO NPs may be suitable candidates for further study and development of GICs and other preventative and restorative dental materials.

In this article, more usage of Mg has been discussed. One of them is the biodegradable magnesium (Mg)-based alloys that recently have been more attractive for implant researches.

Another application of Mg is corrosion-resistant and can reduce compressive strength.

It demonstrated that Mg could be added to some other metals, including ZnO and zein. ZnO/MgO nanocomposite can be employed as active materials in dental cement because of their tiny homogeneous sizes. Zein solely had no antibacterial effects but when it was added to MgO made it more dispersible. This combination is used in indirect restoration, which is a novel field.

One of the more novel fields that is less than two decades old in dentistry is the human dental pulp stem cells that Mg ions have been used as the material to regulate the proliferation and differentiations of HDPCs.

The old known feature of Mg is its bactericidal characteristics. It had been demonstrated that Mg had a proven effect on *Streptococcus* subtypes, and recently more types, including biofilm of *K. Pneumoniae* and *S. aureus*. The MgO NP-modified GIC demonstrated good antibacterial and antibiofilm actions against two cariogenic microorganisms so that it may be developed further as a biocompatible antibacterial dental restorative cement. Also, it has been shown that adding MgO nanoparticles to GIC material may improve its antibacterial and antibiofilm properties, and the impact is proportional to the percentage of nanoparticles added.

As polymeric filling and restoration materials, MgO NPs are excellent candidates due to their biocompatibility. This study aimed to create a complete view of MgO in dentistry. Without a doubt, this material can be tested on many bacteria, and it seems that there are many unknown fields in which Mg can be used. It is hoped that this study has provided a comprehensive view for those interested.

The most attractive and novel field is HDPCs, which we suggest to be more studied. Our limitation was the access to some original articles due to not being free.

Conclusion

MgO has been used repeatedly as an antibacterial agent and is still being used now. The use of this substance in the field of stem cells is the newest application of this substance, which still needs a more detailed evaluation, considering that many of the advantages and disadvantages of this substance have not been determined so far. More studies and a higher population of statistics are needed for evaluation.

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Conflict of Interest
None declared.

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