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Nano Silver in Modern Dentistry: A Promising Strategy Against Dental Caries

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ABSTRACT

Nano silver has emerged as a promising agent in the management of dental caries, leveraging its potent antimicrobial properties to combat cariogenic bacteria. This review explores the role of nano silver in caries prevention and treatment, focusing on its mechanisms of action, applications, and potential benefits. Nano silver disrupts bacterial cell membranes, inhibits biofilm formation, and reduces the viability of pathogens such as Streptococcus mutans and Lactobacillus , which are key contributors to tooth decay. Its incorporation into dental materials, including composites, glass ionomer cements, and varnishes, offers sustained antimicrobial effects, enhancing the longevity of restorations and reducing the risk of secondary caries. Additionally, nano silver-based solutions and gels are effective in cavity disinfection and pulp therapy. Despite its advantages, challenges such as potential cytotoxicity, tooth discoloration, and the risk of bacterial resistance necessitate further research. This article highlights the current advancements, limitations, and future directions of nano silver in caries management, emphasizing the need for optimized formulations and rigorous clinical validation to ensure its safe and effective use in modern dentistry.

Keywords: Nano Silver, Antimicrobial Properties, Dental Caries Management, Biofilm Inhibition, Ag^+ Ion Release, Secondary Caries Prevention

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Introduction

Nanomaterials are substances designed at the nanoscale (1–100 nanometers), where their distinct physical and chemical characteristics arise from higher surface-area-to-volume ratios and quantum phenomena. At this microscopic dimension, materials display improved mechanical, electrical, or reactive traits absent in their bulk counterparts (1). Examples range from carbon nanotubes (2) for high-strength, low-weight applications to quantum dots for accurate light emission and metal-based particles such as gold or silver (3, 4). However, their minute scale prompts concerns about biological compatibility (5, 6), ecological effects, and chronic safety, demanding thorough investigation and oversight (7).

Advanced nanotechnology plays a crucial role in dentistry, particularly in managing complex cases like a maxillary second molar with five root canals and a root-like enamel pearl. Nanoparticles improve high-resolution imaging for accurate diagnosis, while nanocarriers deliver bioactive agents to promote regeneration or antimicrobial effects. Additionally, nano-engineered biomaterials can mimic natural polymers in enamel and dentin, offering potential solutions for repairing such rare anatomical variations (8).

One of the most promising application of nanomaterials in dentistry is enhancing antibacterial efficacy of irrigators with nanoparticles of silver. Nano silver, consisting of silver nanoparticles (AgNPs), is a renowned nanomaterial prized for its robust antimicrobial properties (9). Its efficacy arises from the gradual release of Ag^+ ions, which compromise bacterial cell walls, block enzymatic activity, and degrade genetic material, effectively fighting pathogens such as Streptococcus mutans in dental decay (10). Outside dentistry, it is applied in antimicrobial coatings, water filtration systems, and healing bandages. In caries treatment, it is incorporated into fillings, sealants, and cleaning agents to inhibit biofilm growth and recurrent infections (11). Although beneficial, issues like possible cell toxicity at elevated doses and environmental accumulation necessitate fine-tuning particle dimensions, protective layers, and concentrations to harmonize effectiveness and safety (12). Current studies emphasize sustainable production methods and intelligent release mechanisms to optimize its clinical and industrial applications (13).

Antimicrobial Properties

Nano silver has emerged as a groundbreaking antimicrobial agent in dentistry, particularly for managing dental caries (14). Its efficacy stems from its ability to disrupt bacterial cell walls and membranes through electrostatic interactions between positively charged silver ions (Ag^+) and negatively charged bacterial surfaces (15). This disruption compromises membrane integrity, leading to cell lysis and death Beyond physical damage, nano silver interferes with bacterial enzymatic processes by binding to thiol groups in proteins, deactivating critical metabolic pathways (16). It also intercalates with microbial DNA, inhibiting replication and transcription.

In caries management, nano silver's specificity against Streptococcus mutans and Lactobacillus species—key pathogens in biofilm formation and acid production—makes it invaluable (17). Studies demonstrate that nano silver reduces bacterial adhesion to tooth surfaces by up to 90%, effectively curbing plaque accumulation (18). Its antifungal properties further address secondary infections caused by Candida albicans in immunocompromised patients, broadening its clinical utility. Unlike traditional antibiotics, nano silver's multi-targeted mechanism minimizes the likelihood of resistance development, though prolonged exposure risks remain under investigation (19).

Mechanism of Action

The antimicrobial potency of nano silver hinges on the controlled release of Ag^+ ions, which induce oxidative stress via reactive oxygen species (ROS) generation. ROS damage lipids, proteins, and nucleic acids, destabilizing bacterial cells. Nano silver's high surface-area-to-volume ratio enhances ion release efficiency, ensuring sustained antimicrobial activity even at low concentrations (20).

Biofilm inhibition is another critical mechanism. Nano silver penetrates the extracellular polymeric matrix of biofilms (21), disrupting quorum sensing—a communication system bacteria use to coordinate virulence and biofilm formation. By interfering with signaling molecules like autoinducer-2 (AI-2), nano silver prevents bacterial aggregation and acid production, halting caries progression (22). Research also highlights its role in downregulating glucosyltransferase (GTF) enzymes, which synthesize sticky glucans essential for biofilm adhesion.

Applications in Caries Management

Dental Restoratives

Nano silver is integrated into dental composites and glass ionomer cements (GICs) to enhance their antimicrobial efficacy. For instance, nano silver-modified GICs exhibit a 50–70% reduction in S. mutans colonization compared to conventional materials (23). These restoratives provide long-term protection against secondary caries by continuously releasing Ag^+ ions, even in acidic environments (24). Adhesives containing nano silver also strengthen the resin-dentin interface, reducing microleakage and bacterial infiltration (25).

Cavity Disinfection

Pre-filling cavity disinfection with nano silver solutions (e.g., 25–50 ppm AgNPs) significantly lowers residual bacterial loads (26). A 2022 clinical trial reported a 95% reduction in viable bacteria after nano silver irrigation, outperforming chlorhexidine (27). This step minimizes postoperative sensitivity and secondary infection risks.

Prophylactic Agents

Nano silver-infused mouthwashes and toothpastes reduce plaque indices by 30–40% in clinical studies (28). Varnishes containing nano silver form a protective film on enamel, releasing ions over weeks to inhibit demineralization. These products are particularly beneficial for high-risk patients (29), such as those with xerostomia or orthodontic appliances (30, 31).

Pulp Therapy

In deep caries cases, nano silver solutions disinfect the pulp-dentin complex without compromising viability (32, 33) . A 2023 study demonstrated that 1% nano silver gel promoted odontoblast activity and collagen synthesis, enhancing pulp repair (34). This approach reduces the need for invasive procedures like pulpectomy (35).

Advantages

Nano silver's broad-spectrum activity eliminates diverse cariogenic pathogens, reducing reliance on antibiotics (36). Its sustained ion release ensures prolonged efficacy, ideal for long-term restorations. Compatibility with dental polymers and ceramics allows seamless integration into existing workflows (36). Economically, nano silver lowers treatment costs by minimizing repeat interventions.

Challenges and Concerns

Toxicity

While low concentrations (≤50 ppm) are biocompatible, higher doses (>100 ppm) induce cytotoxicity in human gingival fibroblasts and pulp cells. Particle size matters: Smaller nanoparticles (10 nm) penetrate cells more readily, triggering apoptosis. Rigorous dose optimization and surface coatings (e.g., chitosan) are being explored to mitigate toxicity (37, 38).

Staining

Silver sulfidation can cause grayish tooth discoloration, particularly in porous enamel (39). Researchers are testing silica-coated nano silver to prevent sulfidation while retaining antimicrobial effects (40).

Resistance and Regulation

Though rare, silver resistance genes (*silE*, *silP*) have been identified in *E. coli* and *Salmonella* (41). Regulatory bodies like the FDA and EMA require long-term safety data before approving nano silver for routine use (42).

Current Research

Recent studies focus on dual-functional materials combining nano silver with fluoride or calcium phosphate for remineralization (43). For example, nano silver-fluoride varnishes reduce caries incidence by 60% in pediatric trials (44). Another innovation involves pH-responsive hydrogels that release Ag^+ ions only in acidic (cariogenic) environments, minimizing off-target effects (45).

Future Directions

Smart nanomaterials with bacterial-sensing capabilities are under development. These materials use quorum-sensing inhibitors to trigger Ag^+ release only when pathogens are detected. Nanorobots for targeted biofilm disruption and gene-editing tools (CRISPR) to silence bacterial virulence genes represent frontier innovations.

Conclusion

Nano silver demonstrates significant potential in caries management due to its potent antimicrobial and biofilm-disrupting properties. Its integration into dental materials, cavity disinfectants, and preventive agents offers sustained protection against cariogenic bacteria like *Streptococcus mutans*, reducing secondary infections and enhancing restoration longevity. However, challenges such as cytotoxicity, tooth discoloration, and regulatory concerns necessitate careful optimization of nanoparticle size, concentration, and coatings to balance efficacy with safety. Current advancements, including pH-responsive hydrogels and nano silver-fluoride hybrids, aim to improve targeted delivery and remineralization. Future innovations, such as smart nanomaterials and nanorobots, could revolutionize caries treatment by enabling pathogen-specific interventions. While promising, further clinical studies and rigorous safety evaluations are critical to ensure nano silver's safe and effective integration into mainstream dental practice.

Authors' Contributions

All authors equally contributed to this study.

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Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

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