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Review Article

Silver nanoparticles: Harnessing nanotechnology for enhanced antimicrobial efficacy in contemporary dental practice

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ABSTRACT

This review article provides an in-depth exploration of the role of silver nanoparticles (AgNPs) in the field of dentistry, focusing on their remarkable antimicrobial properties and versatile applications. AgNPs have shown significant promise in dentistry, exhibiting potent antimicrobial efficacy against various oral pathogens, bacteria, and biofilms. Studies have compared AgNPs with conventional antimicrobial agents, highlighting their bacteriostatic and bactericidal effects, especially at lower concentrations. Furthermore, AgNPs have demonstrated their potential in inhibiting biofilm formation, eradicating established biofilms, and enhancing the antimicrobial activity of dental materials, such as nanocomposites, acrylic resins, and adhesives. While AgNPs offer substantial benefits, their effectiveness may vary based on specific applications and comparisons with other antimicrobial agents. As the integration of AgNPs into dental practices holds great promise, ongoing research efforts are crucial to addressing safety concerns and optimizing their use for the improvement of oral healthcare.

1. Introduction

In the realm of dentistry, there exists a vibrant and active sphere of research dedicated to the development of antimicrobial dental materials, a pioneering pursuit with a singular purpose: to thwart the proliferation of bacteria and microscopic adversaries within the oral cavity, thereby diminishing the peril of dental infections and nurturing oral well-being. Within this frontier, a diverse array of approaches is diligently explored, from the infusion of antimicrobial agents like quaternary ammonium compounds and nanoparticles into dental restorative materials to bestow upon them the remarkable power to combat microbial incursions.[1,2]

These materials, with their inherent antimicrobial prowess, stand as stalwart guardians against secondary caries, fortifying the endurance of dental restorations. Beyond this, the horizon broadens as antimicrobial dental materials find utility in the realm of dental implants and other oral devices, where they serve as sentinels, mitigating the risk of infection. Central to this relentless endeavour is the paramount consideration of efficacy and safety, propelling ongoing research to refine their antimicrobial capabilities while ensuring harmonious coexistence with human biology and unwavering stability in the long term.[1,2]

Silver nanoparticles have been ingeniously integrated into the composition of dental materials, a strategic maneuver intended to elevate their antimicrobial attributes and deter the formation of insidious biofilms within the oral environment. The diminutive size of these silver nanoparticles confers upon them a unique advantage, as they wield potent antimicrobial effects even when present in minimal quantities. Meticulous in vitro investigations have unveiled their outstanding antimicrobial prowess

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when harmoniously blended with an array of dental materials, spanning nanocomposites, acrylic resins, adhesives, and implant coatings. The amalgamation of silver nanoparticles with dental materials has proven transformative, significantly advancing the oral health of patients. Beyond their role in oral well-being, these nanoparticles have also sparked interest in the realm of combatting oral cancers, owing to their intrinsic antitumor properties, thus extending their potential impact into the domain of medical therapy.[3–6]

This review delves into the multifaceted role of silver nanoparticles in antimicrobial dentistry, exploring their synthesis, mechanisms of action, and diverse applications across preventive, restorative, and prosthetic aspects of dentistry. Furthermore, it sheds light on the evolving landscape of dental materials, as these nanoparticles pave the way for enhanced infection control, improved oral health outcomes, and a more sustainable dental practice.

2. Silver Nanoparticles: Properties and Mechanisms

Silver nanoparticles possess a multitude of distinctive characteristics that render them exceptional and versatile in various scientific domains. These attributes include their size, which can span from just a few nanometers to several hundred nanometers, exerting a profound influence on their physical and chemical properties. Their size dictates their optical, electrical, and catalytic behaviors, making them a fascinating subject of exploration. Moreover, their shape is no less intriguing, with silver nanoparticles adopting various forms, including spherical, rod-like, triangular, and hexagonal shapes, each influencing their surface plasmon resonance – the collective dance of electrons on their surfaces. This surface plasmon resonance is pivotal in shaping their unique optical properties, where they exhibit the ability to absorb and scatter light at distinct wavelengths, contingent upon their size, shape, and composition. Furthermore, their diminutive size and expansive surface area make them adept at interacting with other molecules, finding applications in diverse realms such as catalysis and sensing. Their surface chemistry is amenable to modification, allowing the grafting of different molecules to enhance their stability, solubility, and reactivity, opening doors to a wide array of practical applications.[7–10]

One notable application is their remarkable antibacterial properties, as silver nanoparticles have been extensively investigated for their ability to inhibit the growth of various bacteria and fungi. This quality endows them with significance in the realms of both medicine and consumer products, where their antimicrobial prowess plays a pivotal role. Additionally, their exceptional electrical conductivity sets them apart, rendering them invaluable in electronics, from the formulation of conductive inks to the development of sensors. Altogether, these unique attributes position silver nanoparticles as prized assets in a spectrum of fields, including medicine, electronics, catalysis, and sensing, promising a dynamic role in shaping the future of science and technology.[11,12]

Silver nanoparticles showcase their remarkable antimicrobial prowess through a multifaceted array of mechanisms, underscoring their versatile utility in combatting microbial threats. These mechanisms encompass their capacity to adhere to microbial cells, infiltrate these cells, and initiate the generation of reactive oxygen species (ROS) and free radicals, thereby mounting a multi-pronged assault on the microbial adversaries. Additionally, they wield the power to modulate microbial signal transduction pathways, further enhancing their efficacy in microbial control. The physico-chemical attributes of these nanoparticles, including their size, shape, surface charge, concentration, and colloidal state, serve as pivotal determinants in shaping their antimicrobial potential, highlighting the intricate interplay of these factors in their functionality. However, it is essential to tread cautiously, as silver nanoparticles have also been associated with cytotoxicity, genotoxicity, and the elicitation of inflammatory responses in human cells, casting a shadow of concern over their potential use in therapeutics and drug delivery. Nonetheless, ongoing research endeavors are dedicated to engineering silver nanoparticles, enhancing their efficacy, stability, specificity, biosafety, and biocompatibility, thereby harnessing their potent antimicrobial attributes while mitigating potential drawbacks.[13]

Furthermore, the antimicrobial saga of silver nanoparticles unfolds through a captivating narrative that involves the release of silver ions, infliction of damage to the bacterial cell membrane, interaction with bacterial DNA, and disruption of pivotal bacterial enzymes. This multifaceted approach showcases their prowess in destabilizing microbial adversaries. Beyond this, silver nanoparticles have also been found to provoke a bacterial apoptosis-like response, inducing an array of changes within microbial cells, including the accumulation of reactive oxygen species, elevated intracellular calcium levels, exposure of phosphatidylserine, disturbance of membrane potential, activation of caspase-like proteins, and degradation of bacterial DNA. Their antimicrobial effectiveness is broad-reaching, with demonstrated activity against an array of microorganisms, spanning bacteria, fungi, viruses, and parasites. This versatility underscores their potential as invaluable tools in the realm of microbial control. Moreover, their incorporation into various dental materials, such as acrylic resins, composite resins, irrigating solutions, adhesive materials, and membranes, heralds a promising avenue for endowing these materials with potent antimicrobial properties, thus finding a pivotal role in advancing the field of dentistry and oral health.[14–18]

Silver nanoparticles wield formidable antimicrobial properties, proving highly effective in thwarting biofilm formation on dental material surfaces. Their integration into dental biomaterials like nanocomposites and acrylic resin significantly bolsters their antimicrobial efficacy against cariogenic pathogens, periodontal biofilm, endodontic bacteria, and even Candida albicans biofilm linked to denture stomatitis. Beyond oral hygiene, these nanoparticles hold promise in the treatment of oral cancers, thanks to their antitumor attributes, and serve as potent root canal irrigants, eradicating Enterococcus faecalis biofilm and bacterial intruders in infected dentinal tubules. Remarkably, their small size and expansive surface area-to-volume ratio enable exceptional antimicrobial action without compromising the mechanical integrity of dental materials, making them ideal for sustained infection control and plaque reduction when incorporated into dental bands. In the realm of orthodontic and oral health care, silver nanoparticles find application in nanorobotic dentifrice, promising improved oral health outcomes. Their versatility extends to various dental procedures, where they contribute to disinfection, prophylaxis, and infection prevention in the oral cavity, all while maintaining biocompatibility and the flexural strength of dental materials at appropriate concentrations.[3,4,6,19–23]

3. Applications of Silver Nanoparticles in Dentistry

The integration of silver nanoparticles (AgNPs) into restorative materials, dental composites, and adhesives has garnered substantial attention in the field of dentistry, primarily owing to the remarkable antimicrobial attributes of AgNPs. These nanoparticles have proven adept at effectively curbing the proliferation of bacteria, fungi, and biofilms, which are significant culprits in the development of dental caries and other oral infections. Notably, research indicates that the introduction of AgNPs into these dental materials enhances their antimicrobial capabilities while preserving their mechanical integrity. This strategic incorporation of AgNPs holds the potential to enhance the durability and success of dental restorations by mitigating the risk of secondary caries and microbial colonization.[3,4,6,24,25]

While the application of silver nanoparticles in toothpaste, mouthwash, and orthodontic devices remains an active field of exploration, existing evidence underscores their potential advantages. These nanoparticles, imbued with antimicrobial properties, hold the promise of thwarting bacterial growth and biofilm formation on dental surfaces, serving as a preventive shield against dental caries and periodontal diseases. Furthermore, silver nanoparticles exhibit anti-inflammatory attributes, contributing to the mitigation of inflammation and the promotion of oral well-being. In restorative materials like dental composites and adhesives, their inclusion amplifies antimicrobial efficacy, ultimately augmenting the endurance and triumph of dental restorations. In this context, their antimicrobial prowess not only aids in forestalling secondary caries but also diminishes the risk of infection.[3,4,6,18,22–24,26–28]

While the utilization of silver nanoparticles (AgNPs) in root canal disinfection is an emerging area of interest, the abundant research surrounding AgNPs in dentistry has primarily focused on their potent antimicrobial attributes. These nanoparticles have been skillfully integrated into a range of dental materials, encompassing restorative compounds, composites, and dental adhesives, with the aim of augmenting their antimicrobial efficacy and thwarting the formation of insidious biofilms.[4]

In the realm of dentistry, silver nanoparticles have undergone thorough examination for their remarkable antimicrobial potential. These nanoparticles have been seamlessly integrated into an array of dental materials, spanning restoratives, composites, and adhesives, with the goal of amplifying their antimicrobial prowess and thwarting the development of resilient biofilms. Silver nanoparticles have impressively demonstrated their ability to combat bacteria, fungi, and viruses, and their exceptional efficacy can be attributed to their minuscule size and expansive surface area-to-volume ratio.[4,18,29]

4. Efficacy, Safety and Toxicity of Silver Nanoparticles

A wealth of both in vitro and in vivo investigations underscores the diverse efficacy of silver nanoparticles (AgNPs) in multiple arenas. These nanoparticles exhibit potent antimicrobial capabilities, effectively countering bacteria such as Escherichia coli, Neisseria gonorrhea, and Chlamydia trachomatis, while also demonstrating antiviral properties. Impressively, AgNPs have showcased their potential as antitumor agents by inhibiting the growth and migration of bladder cancer cells. Furthermore, their anti-inflammatory attributes promote wound healing. In the context of SARS-CoV-2, AgNPs have displayed inhibitory effects on the virus in vitro, and practical applications have shown promise as a means to reduce SARS-CoV-2 infection incidence among health workers when employed as mouthwash and nose rinse, surpassing conventional methods.[30–34]

Silver nanoparticles (AgNPs) present promising potential for oral healthcare due to their robust antimicrobial properties, yet concerns have arisen regarding their cytotoxicity and safety. Several inquiries have delved into the cytotoxic effects of AgNPs on a range of cell lines, including oral cells, revealing dose-, size-, and time-dependent cytotoxicity; however, such effects are typically observed at concentrations exceeding those employed in dental applications. Moreover, the cytotoxicity of AgNPs can be contingent on variables such as size, shape, surface chemistry, and cell type. It is pertinent to recognize that despite these concerns, AgNPs have demonstrated effectiveness in halting biofilm formation and eliminating established biofilms, major contributors to oral diseases.[35–38]

5. Comparison with Other Antimicrobial Agents

Silver nanoparticles (AgNPs) have exhibited promising antimicrobial potential within the dental domain, with several investigations pitting them against common antimicrobial agents. One such study found AgNPs to outperform chlorhexidine gluconate (CHX) in terms of bacteriostatic and bactericidal effects at lower concentrations when combatting oral pathogenic bacteria. In another study, AgNPs showed less antimicrobial action than sodium hypochlorite (NaOCl), with NaOCl displaying the highest antimicrobial potency and biofilm dissolution capacity against Enterococcus faecalis biofilm and infected dentinal tubules. A review article also underscored the efficacy of AgNPs in various dental applications, particularly when integrated into materials like nanocomposites, acrylic resins, and adhesives, showcasing their exceptional antimicrobial attributes. While AgNPs have proven their mettle, their effectiveness can fluctuate depending on specific applications and comparisons with other antimicrobial agents.[4,20,39]

6. Conclusion

In conclusion, this review article illuminates the multifaceted role of silver nanoparticles (AgNPs) in the realm of dentistry, emphasizing their promising antimicrobial potential and versatility across various dental applications. AgNPs have demonstrated their efficacy in inhibiting biofilm formation, eradicating established biofilms, and combating oral pathogenic bacteria. Their ability to enhance the antimicrobial activity of dental materials such as nanocomposites, acrylic resins, and adhesives signifies a significant stride in improving the longevity of dental restorations and advancing oral healthcare. However, it is essential to consider the variations in AgNPs' effectiveness in different applications and their comparison with other established antimicrobial agents. The integration of AgNPs into oral healthcare practices holds great promise, provided that ongoing research continues to address safety concerns and optimize their use for the benefit of dental patients and practitioners alike.

7. Conflict of Interest

None.

8. Source of Funding

None.

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