Article type:
Review Article
Volume 2, Issue 2, pp 19-23
Article history:
Received 11 October 2024
Revised 18 December 2024
Accepted 23 December 2024
Published online 01 April 2025

Antibacterial Efficiency of Nano Silver Particles: A Comprehensive Review

1. Erfan. Khaksar: Cyprus Health and Social Sciences University, Guzelyurt, Cyprus*

Corresponding author email address: Khaksar1233@gmail.com

ABSTRACT

Silver nanoparticles (AgNPs) have gained significant attention due to their remarkable antibacterial properties, offering a promising alternative to traditional antibiotics in the fight against microbial infections. These nanoparticles, with sizes ranging from 1 to 100 nm, exhibit superior antibacterial efficacy compared to bulk silver due to their high surface area and unique physicochemical properties. The antibacterial mechanisms of AgNPs involve multiple pathways, including the disruption of bacterial cell membranes, the release of silver ions (Ag+), the generation of reactive oxygen species (ROS), and the interaction with bacterial DNA. These mechanisms contribute to the inhibition of bacterial growth and cell death. AgNPs have been applied in various fields, including medicine, consumer products, water treatment, and food preservation, due to their broad-spectrum antibacterial activity. However, concerns regarding their potential toxicity to human cells, environmental impact, and the development of bacterial resistance need to be addressed for their widespread use. This review provides an overview of the antibacterial efficiency of AgNPs, highlighting their synthesis, mechanisms of action, applications, challenges, and future prospects for improving their safety and efficacy.

Keywords: Antibacterial Efficiency, Silver Particles, Nanotechnology.

How to cite this article:
Khaksar, E. (2025). Antibacterial Efficiency of Nano Silver Particles: A Comprehensive Review. *Journal of Oral and Dental Health Nexus*, 2(2), 19-23. https://doi.org/10.61838/jodhn.2.2.3

Introduction

Nanotechnology is revolutionizing various fields, including endodontics (1, 2), bioactive materials (3), cancer treatment (4),biosensors (4), and early diagnosis of malignant conditions (5). Nanotechnology improves less invasive drug delivery systems by using natural polymers like starch and cellulose (6)

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 (7),because 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. One of the most widely explored applications of nanotechnology is in the development of antimicrobial agents. Among these agents, silver nanoparticles (AgNPs) have emerged as one of the most promising candidates due to their remarkable antibacterial properties. These nanoparticles exhibit superior efficacy compared to bulk silver and other conventional antimicrobial agents due to their high surface-to-volume ratio, unique physicochemical properties, and ability to release silver ions (Ag+) effectively. The growing concern of antibiotic resistance in bacteria (8) has led to an increased interest in alternative antimicrobial agents, with AgNPs being one of the most studied alternatives (9).

Silver has been used for centuries in medicine for its antimicrobial properties (10). However, the advent of nanotechnology has significantly enhanced the efficacy of silver, allowing for better utilization in a range of therapeutic and industrial applications. AgNPs are now being incorporated into medical devices, wound dressings, and water treatment systems, as well as consumer products such as clothing and cosmetics, owing to their broad-spectrum antimicrobial activity (11).

Properties of Silver Nanoparticles

Silver nanoparticles are defined as particles with a size range of 1 to 100 nm, with a significant portion of their atoms located on the surface. The small size of AgNPs allows for an extensive surface area relative to their volume, making them highly reactive. These unique properties result in a higher reactivity and efficiency in bactericidal activity when compared to bulk silver. The size, shape, and surface charge of AgNPs are key factors that influence their interaction with bacterial cells and their antimicrobial effectiveness (12).

Size: The size of AgNPs plays a crucial role in their antimicrobial activity. Smaller nanoparticles exhibit higher surface-area-to-volume ratios, allowing them to interact more effectively with bacterial cell walls and membranes (13) . This interaction leads to increased antibacterial activity.

Shape: The shape of silver nanoparticles, such as spherical, triangular, or rod-shaped, can influence their ability to penetrate bacterial cells and their overall antimicrobial effectiveness. For instance, triangular and rod-shaped nanoparticles tend to have greater antibacterial activity than spherical ones due to their increased surface area and more efficient penetration into the bacterial cells (14) .

Surface Coating: The surface characteristics of AgNPs, such as the type of stabilizing agent or coating material used, also play a role in determining their antimicrobial properties. Surface coatings can enhance the stability of nanoparticles and modify their interaction with bacterial cells, which can either increase or decrease their antibacterial effectiveness (15) .

Mechanisms of Antibacterial Action

The antibacterial properties of silver nanoparticles are attributed to several mechanisms, which include physical, chemical, and biological interactions between the nanoparticles and bacterial cells.

1. Disruption of Bacterial Cell Membranes: One of the primary mechanisms of action is the interaction of AgNPs with the bacterial cell membrane. The nanoparticles can physically interact with the cell membrane, disrupting its structure and leading to leakage of cellular contents, which ultimately results in bacterial cell death. The interaction with the cell membrane can also lead to the generation of pores, further destabilizing the membrane and contributing to bacterial lysis (16).

2. Release of Silver Ions (Ag^+): When AgNPs come in contact with bacteria, they release silver ions (Ag^+). These ions are highly toxic to bacteria because they interfere with vital cellular processes such as respiration, protein synthesis, and DNA replication .The release of Ag^+ ions disrupts the electron transport chain in bacteria, leading to energy depletion and, ultimately, cell death (17).

3. Generation of Reactive Oxygen Species (ROS): Silver nanoparticles can generate reactive oxygen species (ROS) such as superoxide anions ($O_2^{\bullet-}$), hydrogen peroxide (H_2O_2), and hydroxyl radicals ($OH^\bullet$) upon contact with bacterial cells .ROS are highly reactive molecules that can damage various cellular components, including lipids, proteins, and nucleic acids. The oxidative stress caused by ROS disrupts the normal functioning of bacterial cells and induces cell death (18).

4. Interaction with DNA: Silver nanoparticles can also interact directly with bacterial DNA. This interaction can lead to DNA damage and inhibit the replication and transcription processes in bacterial cells. By binding to DNA and causing structural changes, AgNPs prevent the bacteria from reproducing and proliferating, thus halting the infection process (19).

Applications of Silver Nanoparticles in Antibacterial Therapy

The unique antibacterial properties of silver nanoparticles have led to their widespread use in various fields, ranging from medical treatments to industrial applications.

Medical Applications: AgNPs have demonstrated significant potential in the medical field, particularly in wound healing and infection control. Due to their broad-spectrum antibacterial activity, AgNPs are used in wound dressings, burn creams, and surgical tools to prevent infections.They also show promise in the treatment of chronic wounds, where bacterial infection is a major complication. Moreover, AgNPs are incorporated into medical devices, such as catheters, to reduce the risk of infection (20) .

Consumer Products: AgNPs are found in various consumer products such as antimicrobial clothing, deodorants, cosmetics, and household items. The antibacterial properties of AgNPs help prevent bacterial growth, reduce odors, and increase the shelf life of products. For example, AgNPs are often used in the production of socks, shirts, and underwear, where they inhibit the growth of odor-causing bacteria (21).

Water Treatment: The antimicrobial activity of silver nanoparticles makes them useful in water purification and treatment processes. AgNPs are used in water filtration systems to eliminate harmful pathogens, including bacteria, viruses, and fungi. They are also employed in antimicrobial coatings for water treatment devices to enhance their efficacy in removing contaminants (22).

Food Preservation: The antibacterial properties of AgNPs are increasingly being explored for use in food packaging and preservation. By preventing the growth of bacteria on food surfaces, AgNPs can extend the shelf life of food products and reduce the risk of foodborne illnesses. The incorporation of AgNPs into food packaging materials can act as a barrier against bacterial contamination (23).

Challenges and Limitations

Despite the numerous advantages of silver nanoparticles, several challenges and limitations must be addressed before they can be widely adopted in clinical and industrial applications.

Toxicity to Human Cells: One of the major concerns regarding the use of AgNPs is their potential toxicity to human cells. While AgNPs are effective against bacteria, they can also exhibit cytotoxicity in mammalian cells, including human cells (24). The potential for AgNPs to cause adverse effects such as cell death, inflammation, and immune system disruption is a significant issue that needs to be addressed in future research (25).

Environmental Impact: The environmental impact of silver nanoparticles is another concern. The release of AgNPs into the environment, especially through wastewater and industrial effluents, could pose a risk to aquatic ecosystems. The toxicity of silver ions to aquatic organisms and other wildlife needs to be carefully evaluated to prevent environmental contamination (26).

Antibiotic Resistance: Although silver nanoparticles exhibit antimicrobial properties, there is a potential for bacteria to develop resistance to AgNPs over time, similar to the resistance observed with conventional antibiotics. The overuse and misuse of AgNPs could contribute to the development of resistant bacterial strains, which would limit their effectiveness as an antimicrobial agent (27).

Future Prospects

The future of silver nanoparticles in antimicrobial applications looks promising, with ongoing research aimed at improving their efficacy and safety. The development of more stable, biocompatible, and environmentally friendly AgNPs is a key area of research. Additionally, the combination of AgNPs with other antimicrobial agents, such as antibiotics or plant-derived compounds, could enhance their antibacterial activity and reduce the risk of resistance development. The use of AgNPs in combination therapies is expected to provide more effective and sustainable solutions to bacterial infections (28).

Moreover, researchers are exploring novel methods of synthesizing silver nanoparticles, such as green synthesis methods using plant extracts, which offer environmentally friendly alternatives to traditional chemical synthesis. These approaches could lead to the development of AgNPs with improved antibacterial properties, reduced toxicity, and lower environmental impact (29).

Conclusion

Silver nanoparticles have demonstrated significant antibacterial efficiency, making them valuable candidates for a wide range of applications, including medical devices, consumer products, water treatment, and food preservation. Their antibacterial mechanisms, including the release of silver ions, disruption of cell membranes, and generation of reactive oxygen species, contribute to their effectiveness against both Gram-positive and Gram-negative bacteria. Despite their promising applications, concerns regarding toxicity, environmental impact, and the potential for resistance development need to be carefully addressed. Future research should focus on improving the safety and effectiveness of silver nanoparticles to maximize their potential as antimicrobial agents.

Authors' Contributions

All authors equally contributed to this study.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

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.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

Declaration

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

References

1. Moazzami F, Ghahramani Y, Tamaddon AM, Dehghani Nazhavani A, Adl A. A histological comparison of a new pulp capping material and mineral trioxide aggregate in rat molars. Iran Endod J. 2014;9(1):50-5. Epub 2014/01/08. PubMed PMID: 24396376; PubMed Central PMCID: PMC3881302.
2. Moazami F, Gholami A, Mehrabi V, Ghahramani Y. Evaluation of the antibacterial and antifungal effects of ProRoot MTA and nano-fast cement: an in vitro study. J Contemp Dent Pract. 2020;21(7):760-4.
3. Ghahramani Y, Tabibi SS, Khan MMR, Asadi A, Mohammadi E, Khaksar E, et al. Recent advances in bioactive materials: Future perspectives and opportunities in oral cancer biosensing. Talanta. 2025;286:127494. Epub 2025/01/13. doi: 10.1016/j.talanta.2024.127494. PubMed PMID: 39799882.
4. Mousavi SM, Hashemi SA, Fallahi Nezhad F, Binazadeh M, Dehdashtijahromi M, Omidifar N, et al. Innovative Metal-Organic Frameworks for Targeted Oral Cancer Therapy: A Review. Materials (Basel). 2023;16(13). Epub 2023/07/14. doi: 10.3390/ma16134685. PubMed PMID: 37444999; PubMed Central PMCID: PMC10342828.
5. A Asadi MR, Y Ghahramani. recent advances in bioactive materials for diagnosis and treatment of oral cancer. advances in applied nano biotechnology. 2023;4(1):21_35.
6. Asadi A, Rezaei M, Mohammadi E, Khaksar E, Khaksar E, Abbasi F, et al. Emerging Trends in Natural Polymers for Dental Regeneration.
7. Zerafat M, Enteghad M, Baghaei S, Asadi A, Ghahramani Y. Maxillary Second Molar with Five Root Canals and a Root-Like Enamel Pearl: A Rare Case Report. Iranian Endodontic Journal. 2025;20(1):e6.
8. Ghahramani Y, Yaghoobi F, Motamedi R, Jamshidzadeh A, Abbaszadegan A. Effect of endodontic irrigants and medicaments mixed with silver nanoparticles against biofilm formation of enterococcus faecalis. Iranian Endodontic Journal. 2018;13(4):559.
9. Abbaszadegan A, Ghahramani Y, Farshad M, Sedigh-Shams M, Gholami A, Jamshidzadeh A. In vitro evaluation of dynamic viscosity, surface tension and dentin wettability of silver nanoparticles as an irrigation solution. Iranian Endodontic Journal. 2019;14(1):23.
10. Adl A, Abbaszadegan A, Gholami A, Parvizi F, Ghahramani Y. Effect of a new imidazolium-based silver nanoparticle irrigant on the bond strength of epoxy resin sealer to root canal dentine. Iranian Endodontic Journal. 2019;14(2):122.
11. Burdușel A-C, Gherasim O, Grumezescu AM, Mogoantă L, Ficai A, Andronescu E. Biomedical applications of silver nanoparticles: an up-to-date overview. Nanomaterials. 2018;8(9):681.
12. Polívková M, Hubáček T, Staszek M, Švorčík V, Siegel J. Antimicrobial treatment of polymeric medical devices by silver nanomaterials and related technology. International journal of molecular sciences. 2017;18(2):419.
13. Kong IC, Ko K-S, Koh D-C. Evaluation of the Effects of Particle Sizes of Silver Nanoparticles on Various Biological Systems. International Journal of Molecular Sciences. 2020;21(22):8465. PubMed PMID: doi:10.3390/ijms21228465.
14. Mukherji S, Bharti S, Shukla G, Mukherji S. Synthesis and characterization of size-and shape-controlled silver nanoparticles. Physical Sciences Reviews. 2019;4(1):20170082.
15. Zahran M, Ahmed HB, El-Rafie M. Surface modification of cotton fabrics for antibacterial application by coating with AgNPs–alginate composite. Carbohydrate polymers. 2014;108:145-52.
16. Ahmed B, Hashmi A, Khan MS, Musarrat J. ROS mediated destruction of cell membrane, growth and biofilms of human bacterial pathogens by stable metallic AgNPs functionalized from bell pepper extract and quercetin. Advanced Powder Technology. 2018;29(7):1601-16.
17. Vazquez-Muñoz R, Meza-Villezcas A, Fournier P, Soria-Castro E, Juarez-Moreno K, Gallego-Hernández A, et al. Enhancement of antibiotics antimicrobial activity due to the silver nanoparticles impact on the cell membrane. PloS one. 2019;14(11):e0224904.
18. Ansari MA, Khan HM, Khan AA, Ahmad MK, Mahdi AA, Pal R, et al. Interaction of silver nanoparticles with Escherichia coli and their cell envelope biomolecules. Journal of basic microbiology. 2014;54(9):905-15.
19. Ramalingam B, Parandhaman T, Das SK. Antibacterial effects of biosynthesized silver nanoparticles on surface ultrastructure and nanomechanical properties of gram-negative bacteria viz. Escherichia coli and Pseudomonas aeruginosa. ACS applied materials & interfaces. 2016;8(7):4963-76.
20. Naganthran A, Verasoundarapandian G, Khalid FE, Masarudin MJ, Zulkharnain A, Nawawi NM, et al. Synthesis, characterization and biomedical application of silver nanoparticles. Materials. 2022;15(2):427.
21. Fernandez CC, Sokolonski AR, Fonseca MS, Stanisic D, Araújo DB, Azevedo V, et al. Applications of silver nanoparticles

in dentistry: advances and technological innovation. International Journal of Molecular Sciences. 2021;22(5):2485.
22. Marassi V, Di Cristo L, Smith SG, Ortelli S, Blosi M, Costa AL, et al. Silver nanoparticles as a medical device in healthcare settings: A five-step approach for candidate screening of coating agents. Royal Society open science. 2018;5(1):171113.
23. Istiqola A, Syafiuddin A. A review of silver nanoparticles in food packaging technologies: Regulation, methods, properties, migration, and future challenges. Journal of the Chinese Chemical Society. 2020;67(11):1942-56. doi: https://doi.org/10.1002/jccs.202000179.
24. Nabavizadeh MR, Moazzami F, Gholami A, Mehrabi V, Ghahramani Y. Cytotoxic Effect of Nano Fast Cement and ProRoot Mineral Trioxide Aggregate on L-929 Fibroblast Cells: an in vitro Study. J Dent (Shiraz). 2022;23(1):13-9. Epub 2022/03/17. doi: 10.30476/dentjods.2021.87208.1239. PubMed PMID: 35291684; PubMed Central PMCID: PMC8918640.
25. de Lima R, Seabra AB, Durán N. Silver nanoparticles: a brief review of cytotoxicity and genotoxicity of chemically and biogenically synthesized nanoparticles. Journal of Applied Toxicology. 2012;32(11):867-79. doi: https://doi.org/10.1002/jat.2780.
26. Akter M, Sikder MT, Rahman MM, Ullah AKMA, Hossain KFB, Banik S, et al. A systematic review on silver nanoparticles-induced cytotoxicity: Physicochemical properties and perspectives. Journal of Advanced Research. 2017;9:1 - 16.
27. Kaweeteerawat C, Na Ubol P, Sangmuang S, Aueviriyavit S, Maniratanachote R. Mechanisms of antibiotic resistance in bacteria mediated by silver nanoparticles. Journal of Toxicology and Environmental Health, Part A. 2017;80(23-24):1276-89.
28. Miller JH, Novak JT, Knocke WR, Young K, Hong Y, Vikesland PJ, et al. Effect of silver nanoparticles and antibiotics on antibiotic resistance genes in anaerobic digestion. Water environment research. 2013;85(5):411-21.
29. Rai M, Kon K, Ingle A, Duran N, Galdiero S, Galdiero M. Broad-spectrum bioactivities of silver nanoparticles: the emerging trends and future prospects. Applied microbiology and biotechnology. 2014;98:1951-61.