Biological Times Volume No. 3 | Issue No. 6 | Pages 25-26

Silver Nanoparticles as an Antibacterial Agent

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ABSTRACT

Ag-NPs meet the global demand for opening new doors to the development of antibacterial strategies in contrast to the increasing prevalence of antibiotic-resistant bacteria. Ag-NPs are ideal candidates for the emerging problems of resistance due to their excellent physio-chemical characteristics and targeted drug delivery system. They have been proven efficient in treating various types of bacterial infections in humans and animals. This article presents the use of Ag-NPs as antibacterial substances, their mechanism of action, and medical applications for the control of bacterial diseases.

1. Introduction:

Silver nanoparticles (Ag-NPs) are nanoparticles made of silver metal by chemical, physical, or biological methods (1). They are less toxic, nonreactive, and safe tools to be used in the field of medicine (2). Ag-NPs are being widely searched to deliver several drugs against various infectious and non-infectious diseases. Ag-NPs have been proven to deliver the drugs safely, accurately, and precisely to target tissues (3). They have shown promising effects against pathogens including bacteria as therapeutic and preventive measures (4). The use of antibiotics is being restricted because of their abnormal dosage which leads to toxicities and resistance issues. Conventional antibiotics are less effective due to improper delivery to the targeted cells that's why there is a high need for alternative anti-microbial strategies (5). Several drugs do not reach target tissues because of metabolism in various systems so the issue of proper delivery makes them unviable to be used for control of bacterial infections. Similarly, several vaccines are being failed because of lower antibody titers in the system due to improper delivery in the circulation (6).

Researchers are focusing on various types of delivery agents to deliver the drugs and vaccines accurately and safely to targets so that desired results may be achieved (7). Numerous drug delivery agents are being used commercially which include liposomes, micelles, dendrimers, and nanoparticles (8). However, silver nanoparticles possess significant importance for effective drug delivery with reduced drawbacks as compared to other drug delivery agents. Their high surface area-to-volume ratio enables them to show anti-bacterial properties and greater interaction with bacterial cells which makes Ag-NPs a potent antimicrobial agent (9). Conventional antibiotics are less effective due to improper delivery to the targeted cells that's why there is a high need for alternative anti-microbial strategies so the drug may reach to required site for conclusive and proper functioning to fight against the infections. In upcoming sections, we will get to know about the mechanism of anti-bacterial action, its application in the medical field, its advantages over other antibiotics, and future challenges.

2. Mechanism of antibacterial action:

Ag-NPs have multiple mechanisms to combat bacterial cells that include cell wall and cell membrane disruption, cellular toxicity, denaturation of ribosomes, generation of reactive oxygen species (ROS), inhibition of a cellular enzyme, and inhibition of DNA replication as an antibacterial agent (10). However, the exact mechanism pathway is still not known and under research (11). The Ag-NPs are mainly involved in the disruption of the cellular membrane of gram-negative and gram-positive bacteria, layers of lipopolysaccharide and peptidoglycans, respectively (12). They cause structural changes in bacterial cell membranes and therefore permeability increases. Leakage of cellular content and cell death occurs as a result of it. In bacterial cells, Ag-NPs increase the production of ROS. These ROS responsible for oxidative stress and the destruction of lipids, proteins, and DNA in bacterial cells and lead to cell death (13). Inhibition of bacterial growth and proliferation occurs. Silver (Ag^+) ions released from Ag-NPs bind to the thiol group (-SH) present in bacterial enzymes (14) . When Ag^+ ions bind, the activity of enzymes is inhibited, and it disrupts many critical biochemical processes ongoing in the bacterial cell. Moreover, Ag^+ ions also cause the denaturation of ribosomes and inhibition of protein synthesis occur. The process of transcription and translation is prevented when Ag-NPs interact with bacterial DNA (15).

3. Medical application of Ag-NPs:

The efficacy of Ag-NPs is enough to fight against bacterial infections (16). There is a need for effective anti-bacterial alternatives because of an increasing number of infections due to multi-resistant drug bacteria (17). The antibacterial properties of Ag-NPs have gained attention in numerous medical applications which comprise wound dressings, implants, medical devices, prosthetics, topical antibacterial treatment, and surgical instrument coating (18). With the help of the integration of Ag-NPs in multiple applications, the risk of bacterial infections is typically minimized with no harm. Dressing with Ag-NP coating is proven effective against wound infections because it promotes wound healing and repair (19). Researchers proved that silver sulfadiazine has a lot of curative effects when applied to extensive burns as compared to other topical treatments (20). Similarly, their usage in medical devices is remarkable and has a high success rate due to the prevention of complications of prosthetic surgeries. Sterilization of surgical equipment is necessary to avoid bacterial contamination (21). Although, we know they are incorporated via drug delivery systems (DDS) because of their no toxic effects and are safe for the patient (22).

4. Challenges and Perspectives:

Besides the promising effect of Ag-NPs as anti-bacterial, a few challenges need to be addressed such as toxicity issues, environmental risks, and standard regulations (23). Proper size, shape, formulation, and surface modification must be considered while manufacturing the drug against bacterial infections to prevent toxicity (24). As we know, Ag-NPs are being used with various commercial antibiotics but there is a lack of proper knowledge related to its transport system to avoid their release into the environment. Regulatory agencies should develop the proper framework to ensure the efficacy of Ag-NPs as antibacterial while minimizing the potential risks and monitoring the controlled disposal system (25). To sum up, there is a need to overcome future challenges by making continuous efforts to make its ideal use against many infectious diseases.

5. Conclusion:

Ag-NPs are a versatile tool to combat bacterial infections as compared to other conventional antibiotics. Their high efficacy, broad-spectrum activity, and ability to mask bacterial resistance are highly efficient for the development of modern antibacterial strategies. Similarly, their use in medical applications has a great impact that highlights their importance against many bacterial diseases. Ag-NPs play a crucial role as nanomedicine for infectious disease; however, continued development and research are important to overcome future challenges and ensure healthy outcomes.

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To cite this article: Maheen N, A Raza, MZ Khalil, A Raheem & Baheej-un-Nisa. Silver nanoparticles as an antibacterial agent. Biological Times. 2024 June 3(6): 25-26

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