The Research Progress of Silver Nanoparticles in the Medical Field

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Abstract. The increasing demand for medical products has accelerated the research and development in this field. Nowadays, the continuous advancement of nanotechnology has led to the integration of nanotechnology and healthcare. Nanosilver, in particular, has demonstrated significant potential in this regard. Nanosilver refers to materials with nanoscale dimensions, and its unique properties at the nanoscale have led to its medical application in various fields. Current research shows that silver nanoparticles possess remarkable antibacterial properties and can effectively kill a wide range of microorganisms, drug-less, and so on. Moreover, the unique characteristics of silver nanoparticles enable pathogen eradication on a nanoscale without inducing toxic reactions in the human body. The increasing demand for high-quality medical products has created a significant market for the widespread application of silver nanoparticles as antimicrobial agents. As a novel antibacterial material, silver nanoparticles have gained considerable attention from researchers for their potential applications in the medical field. This has prompted many researchers to conduct important studies to investigate the use of silver nanoparticles in healthcare settings. Therefore, this article comprehensively elaborates on the antibacterial mechanism of silver nanoparticles and emphasizes their various applications in the biomedical field, aiming to provide reference for future research and development of related antibacterial products.

Keywords: Silver nanoparticles, antibacterial, mechanism.

1. Introduction

Bacterial infections have become one of the main causes of death as public health concerns have gained in importance. Due to its excellent antibacterial capabilities, nanosilver has drawn considerable interest to antimicrobial materials. It is distinguished by its nanoscale shape, displays major differences from silver element, and has a considerable impact on the healthcare industry. Nanosilver has a tremendous amount of promise for the development of antibacterial agents, liquid dressings, and numerous biomedical applications due to the special combination of an enhanced surface area to volume ratio and distinctive physicochemical features. These innovative products demonstrate superior resistance to drug resistance and enhanced wound healing capabilities compared to conventional pharmaceuticals. Furthermore, in-depth exploration of nanosilver particles has revealed promising prospects in diverse areas, including targeted tumor treatment, drug resistance mitigation, and advancements in biomedical imaging. This comprehensive scholarly article aims to provide a coherent exposition elucidating the underlying mechanisms governing the existence of nanosilver, its current healthcare applications, recent developments, and the challenges encountered during its implementation.

2. Nanosilver

2.1. The concept of nanosilver

Silver nanoparticles are effective antibacterial agents. Nanosilver refers to metallic silver particles that have been reduced to the nanoscale, typically around 25nm in diameter. The size of nanosilver particles significantly affects their antibacterial performance, with smaller nanoparticles demonstrating higher antibacterial activity. Smaller nanoparticles have a greater surface area to volume ratio, which improves their interaction with bacteria and increases the effectiveness of their antibacterial properties. However, nanoparticles that are too tiny might result in issues like aggregation and deposition, which can lessen their antibacterial potency. Nanosilver antimicrobial agents are classified as non-antibiotic bactericidal agents. They possess noteworthy characteristics including broad-spectrum antibacterial properties and high effectiveness. Additionally, nanosilver has demonstrated anticancer activity [1]. Significant progress has been made in investigating the diverse biological activities of nanosilver, such as targeted therapy, drug resistance, and biomedical imaging. Therefore, it is crucial to unravel the biological mechanisms and potential cytotoxicity associated with nanosilver. These efforts will not only enhance our understanding but also facilitate the development of improved medical applications for nanosilver.

2.2. The antibacterial mechanism of nanosilver

Considerable research has been undertaken to investigate the antibacterial mechanisms of nanosilver, resulting in significant advancements in our understanding of these mechanisms. However, the precise antibacterial mechanisms of nanosilver particles at the nanoscale have not been fully elucidated [2]. The several antibacterial mechanisms of nanosilver are depicted in Figure 1. One method entails the destruction of bacterial cell walls, which causes pits to develop. Within the bacterial membrane, silver nanoparticles can collect and cause structural damage. Increased permeability in this modified membrane results in the leaking of biological components. Nano silver particles can then pass through the inner membrane and inactivate respiratory enzymes, preventing bacterial growth and respiration. Additionally, nanosilver particles may affect proteins and phospholipids, inducing membrane collapse, and ultimately leading to cell death [3, 4]. Simultaneously inhibiting DNA replication, causing noticeable condensation, promoting ribosome denaturation in the cytoplasm, and inhibiting enzyme activity through protein substrate phosphorylation (an important signaling mechanism in microbial growth and cellular activities, crucial in bacterial DNA replication, recombination, and metabolism) hinder protein synthesis, thereby suppressing bacterial growth. Generating reactive oxygen species: Adsorbing trace amounts of Ag^+ on the bacterial surface can activate water or oxygen in the air, generating hydroxyl radicals and reactive oxygen ions, further oxidizing the bacterial outer membrane to inhibit or kill bacteria. In addition to inactivating respiratory chain dehydrogenases, released Ag^+ from silver nanoparticles can also cause O_2 to acquire electrons and create O_2^-, which can then cause water to make -OH and other reactive oxygen species. Reactive oxygen species in excess interfere with electron transport in the respiratory chain, impeding cellular respiration and growth. This reduces ATP synthesis and interferes with bacterial life processes, which eventually results in bacterial death [5, 6]. Inducing bacterial apoptosis: Silver nanoparticles can induce cell apoptosis by upregulating or downregulating the expression of certain proteins. For instance, curcumin-cyclodextrin-loaded functionalized silver nanoparticles induce apoptosis in HepG2 cells by upregulating p53 protein expression and downregulating Akt protein expression. This activates the Akt-p53-caspase signaling pathway and causes apoptosis in HepG2 cells.

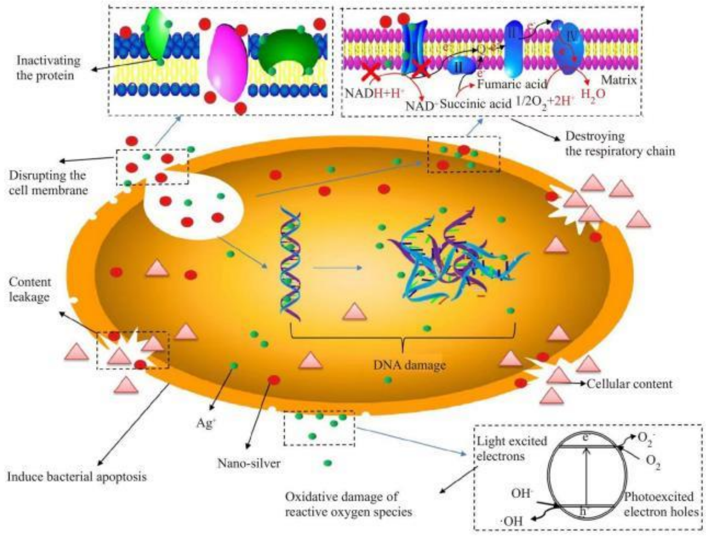

Figure 1. Antibacterial mechanism of nanosilver [7]

3. The application of nanosilver

3.1. Dressing

Silver nanoparticle dressings are widely used in the medical industry, including for wounds, ulcers, burns, and related dressings. Other researchers have found that dressings containing silver nanoparticles can more effectively reduce the proliferation of pathogenic microorganisms in burn wounds (including wounds with bacterial biofilms) compared to other dressings. They can reduce the microbial load in the wound. Additionally, silver nanoparticle dressings provide a moist environment that is conducive to wound healing. They can effectively promote cell proliferation, induce differentiation of myofibroblasts, stimulate angiogenesis, and accelerate granulation tissue formation in burn wounds, thereby accelerating wound healing. Silver nanoparticles can also promote wound healing by reducing leukocyte infiltration and affecting collagen formation. Furthermore, silver nanoparticle dressings have better breathability and permeability, reducing the risk of scar formation. It has been discovered that silver nanoparticles can encourage keratinocyte and fibroblast migration and proliferation [7]. Compared to non-silver dressings, dressings that continuously release silver have been proven to significantly reduce ulcer size and improve healing rates in ulcer patients. This is because nano dressings can achieve controlled drug release through the special structure and properties of nanomaterials, ensuring sustained drug release and providing long-lasting therapeutic effects. Furthermore, experimental evidence has shown that the therapeutic effect of nano dressings is far superior to that of nano ointments [8].

3.2. Antimicrobial agents

Compared to free silver, AgNPs are more toxic to common fungi including Aspergillus, yeast, and Candida. Additionally, to improve their therapeutic benefits, silver nanoparticles can be functionalized by being coated with the right polymers. HIV replication has been efficiently inhibited by AgNPs in a dose-dependent manner. The promise of silver-based nanomedicine in the treatment of viral infections has been highlighted by in vitro studies that show the antiviral activity of silver-based nanomedicine against many types of dangerous viruses [9]. Silver nanoparticles are a possible alternative resource since they are less likely to cause bacterial resistance than conventional antibiotics. They can deal with a variety of problems caused by germs that are multidrug resistant. Against common pathogens including Escherichia coli, Staphylococcus aureus, and Candida albicans, nanosilver demonstrates bactericidal properties. As an antimicrobial agent, nanosilver plays a significant role in treating gynecological diseases such as bacterial vaginosis, effectively killing pathogenic bacteria and reducing the recurrence rate and adverse reactions compared to other products. Additionally, nanosilver antimicrobial agents have been proven to be effective in disinfecting dental caries and root canal treatments by reducing bacterial adhesion and inhibiting bacterial growth.

3.3. Biosensors

The unique optical and electronic properties of silver nanoparticles enable the integration of nanotechnology with biosensors, leading to the miniaturization of biosensor structures. Compared to traditional optical probes, silver nanoparticles as optical probes exhibit excellent photostability, high brightness, resistance to bleaching, good photo biocompatibility, and easy surface modification with DNA, proteins, and other biomolecules. As a result, localized surface plasmon resonance (LSPR) effect-equipped silver nanoparticles are useful as signal probes for research into the interactions between particles and cells. Compared to fluorescence probes, the optical stability of LSPR probes makes them particularly suitable for studying the dynamic interactions between probes and cells. This article mainly provides examples of surface-functionalized silver nanoparticles (AgNPs) in biosensors. Compared to biosensors using AgNPs without surface modification, surface-functionalized AgNPs biosensors exhibit significant improvements in sensitivity and stability. Different modification methods and functional groups can not only impart new physicochemical properties to the surface of AgNPs but also enhance the dispersion and chemical stability of AgNPs in solution. The developed sensors in this category mainly include optical biosensors, surface plasmon resonance biosensors, and electrochemical immunosensors. Another extremely interesting research is the application of silver nanoparticles in photodynamic therapy and fluorescence imaging for the accurate detection and treatment of cancer.

3.4. Targeted therapy

The necessity of creating innovative anti-cancer medications with great selectivity towards cancer cells and little toxicity towards normal cells is highlighted by the critical and highly effective strategy of targeted therapy. The development of nanotechnology has allowed for the design and preparation of nanomaterials for three major uses, which will be covered in this article. The first method includes encapsulating therapeutic chemicals in nanocarriers to facilitate direct medication delivery to target locations, increasing effectiveness and minimizing unwanted effects. Silver-decorated gold nanorods (AuNR/Ag) were successfully used for targeted chemotherapy in breast cancer (MCF7) and prostate cancer (PC3) cell lines, according to research by ZeidA. Doxorubicin, an effective chemotherapy medication, and an anti-epithelial cell adhesion molecule (anti-EpCAM) antibody were covalently attached to AuNR/Ag that had been coated in thiolated polyethylene glycol. Drug delivery to cancer cells was effective, according to in vitro tests. Surface-enhanced Raman spectroscopy (SERS) also revealed that these nanoparticles have distinct spectrum characteristics that made it possible to accurately detect and track the distribution of these chemotherapeutic compounds inside the cells [10]. Another strategy is passive targeting, which takes use of tumor-specific traits such increased permeability and retention effect (EPR), low oxygen and pH levels in the tumor microenvironment, and other factors. By passively accumulating at the tumor site, nanosilver drug carriers can improve the anti-tumor effectiveness of medications and lessen their systemic negative effects [11]. Active targeting includes loading ligands onto nanocarrier systems that can precisely detect and attach to tumor cells based on changes in tumor metabolism or cell surface features. This permits the nanocarriers to actively concentrate at the sick spot [12]. Nanosilver focused treatment may be possible with these last two methods, although clinical confirmation is still needed. In conclusion, successful targeted treatment depends on the discovery of novel anti-cancer medicines with high selectivity towards cancer cells and minimal toxicity towards normal cells. To increase the effectiveness and lessen the negative effects of cancer therapy, nanotechnology provides a variety of techniques, such as encapsulating therapeutic compounds within nanocarriers, passive targeting based on tumor features, and active targeting through ligand recognition. For the use of nanosilver in targeted treatment, more clinical confirmation is necessary.

4. Conclusion

The article provides a scientific and comprehensive summary of nanosilver, particularly in the medical field. It describes its applications in targeted therapy, medical dressings, and antimicrobial agents, and provides an overview of the current understanding of the mechanisms involved. However, due to the unclear mechanisms and potential consequences of nanosilver, further research is needed to investigate its potential toxicity. Nanosilver can enter the human body through various routes such as skin contact and injection, and its small size allows it to cross biological barriers more easily, including the blood-brain barrier, leading to potential toxic effects. Currently, research on the toxic effects of nanosilver is limited to pathological studies, and further investigations into the underlying mechanisms are necessary. It is important to explore the antibacterial mechanisms of nanosilver, and its interactions with the environment, and to enhance the management and testing of nanosilver products, while also improving relevant regulations. Additionally, the antimicrobial efficacy of nanosilver agents may decrease over time, which is a challenge that needs to be addressed. Accelerating the research process requires continuous efforts to explore the potential of nanosilver particles in medical and other fields, as well as conducting thorough investigations into the issues associated with their use, to enhance their widespread application and safety.

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