The Mechanism and Application of Some Nano-Antibacterial Agents

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Abstract. Since the birth of antibiotics, humans have often used antibiotics to treat diseases caused by bacteria, but in recent years, humans have been using common antibiotics to fight the emergence of new bacteria. Humans began to find that many bacteria began to show increasingly strong resistance, so humans must study new drugs or new materials with a wide range of effective antibacterial activities. Among them, nano-antimicrobials have been deeply studied as a promising direction because of their different antibacterial mechanism from traditional antibiotics. Although the mechanism of sterilization of some nanoparticles is unclear, the understanding of nano-antibacterial technology for humans has been more deeply understood, and some nano-antibacterial technology has been put into the food and medical fields. Different nanoparticles not only have antibacterial properties but also have unique characteristics such as biocompatibility and porous structure. Therefore, in order to better understand and utilize nano-antibacterial technology, the past analysis of some representative nano-antibacterial agents and the application status of these nano-antibacterial technologies are reviewed in this paper.

Keywords: Nanomaterials, antimicrobials, nanotechnology.

1. Introduction

At present, with the development of human society and the progress of science and technology, in the medical field, human beings have long had enough ability to deal with various diseases, especially some diseases with bacterial and fungal infections. Humans usually take antibiotics (e.g., Penicillin, a type of antimicrobial invented in the 1930s [1].) to destroy these bacteria. The antibacterial effect of antibiotics is particularly strong, but over time, humans have found that the antibacterial effect of antibiotics is gradually declining, and many bacteria have gradually developed resistance to antibiotics [2]. In order to avoid this problem, humans have begun to look at nano-antibacterial materials, the bactericidal mechanism of these nanomaterials is very different from that of traditional antibiotics, therefore, nano-antibacterial agents can alleviate the problem of resistance to a certain extent. At present, there are already some nano-antibacterial materials on the market in various fields, mainly covering the medical and food industries. This is enough to reflect the importance of research on nano-antibacterial materials. In this paper, the current common nano-antibacterial materials will be introduced in detail. Nano-antibacterial materials can be divided into four parts: metal nano-antibacterial materials, metal oxide nano-antibacterial materials, non-metal nano-antibacterial materials and organic nano-antibacterial materials.

2. Nano-Metal Antimicrobial

2.1. Nano Silver

Nano silver is currently the most effective antibacterial agent available on the market. It can be easily found in the field of treatment or food because nano silver can change the permeability of cell membranes, causing bacteria and fungi to leak and eventually die [3].

For the preparation of nano silver antibacterial agents, there are a variety of preparation technologies for the synthesis of silver NPs, which can be roughly classified into three categories, which can be physically, chemically and biologically prepared nano silver (Fig. 1).

For the physical method: the normal pressure tube furnace is generally prepared by evaporation and condensation, but this method will occupy a great deal of space and consume a lot of heat energy in order to stabilize the operation. This preparation method has high consumption [4].

For chemical methods: Chemical reduction is the most common way to prepare AgNPs. Silver ions in an aqueous solution were reduced to nano-sized silver particles by a reducing agent [4].

For biological methods: Nano-silver is obtained by reducing metal-containing biological extracts from fungi, plants, bacteria, etc. [5].

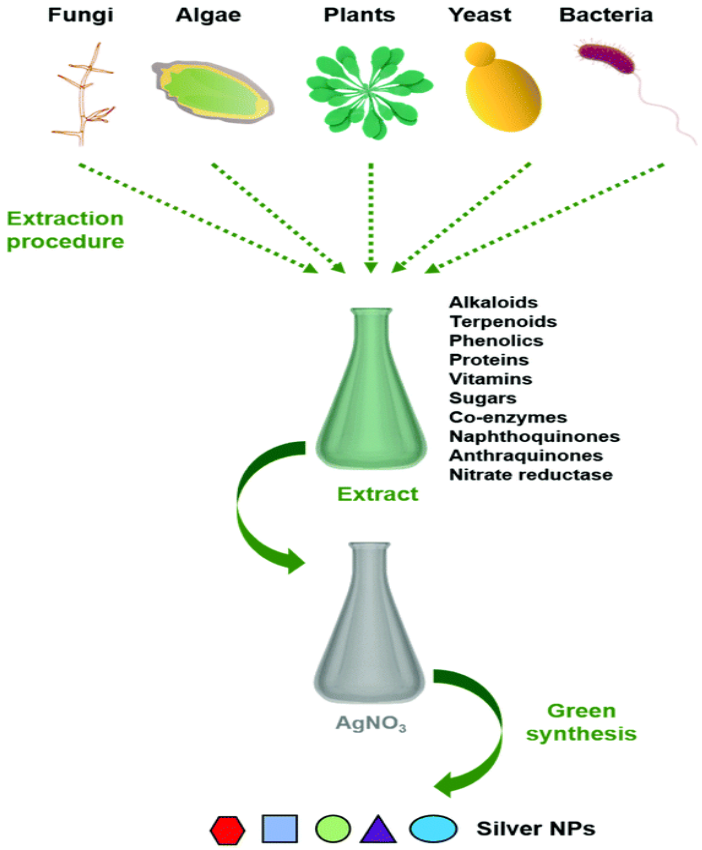


Fig. 1 biological methods of producing nano Ag [5].

The application of nano silver covers various fields such as hospital facilities disinfecting, electronic devices, water purification, textile industries, and food packaging or preservation [4].

While antibiotics are usually used to minimize this risk, some bacteria are becoming resistant to them. However, nano silver is not significantly affected by bacterial resistance, making it a reliable antibacterial agent. Furthermore, its use does not pose a significant risk to human life as it does not cause high cytotoxicity. The smaller the radius of the nano silver, the more effective it is at killing bacteria [3].

2.2. Nano Copper

Copper is a common metal with antibacterial properties. It is relatively abundant, friendly to nature, and inexpensive. Additionally, it is a type of essential element for most creatures, making it widely used. Although the antibacterial principle of nano copper is still unclear, there are three confirmed reasons: The first mechanism: When copper nanoparticles accumulate or dissolve on the cell membrane, enzymes on the cell membrane are inactivated, so the permeability of the cell membrane is changed, resulting in cytoplasmic efflux. Secondly, reactive oxygen species (ROS) made by nano Cu particles cause oxidative damage to cell structure. Finally, the third mechanism: nano copper or copper ion permeates into cells and then nano copper or copper ions denature the protein (Fig. 2). As a result, DNA cannot replicate anymore [6].

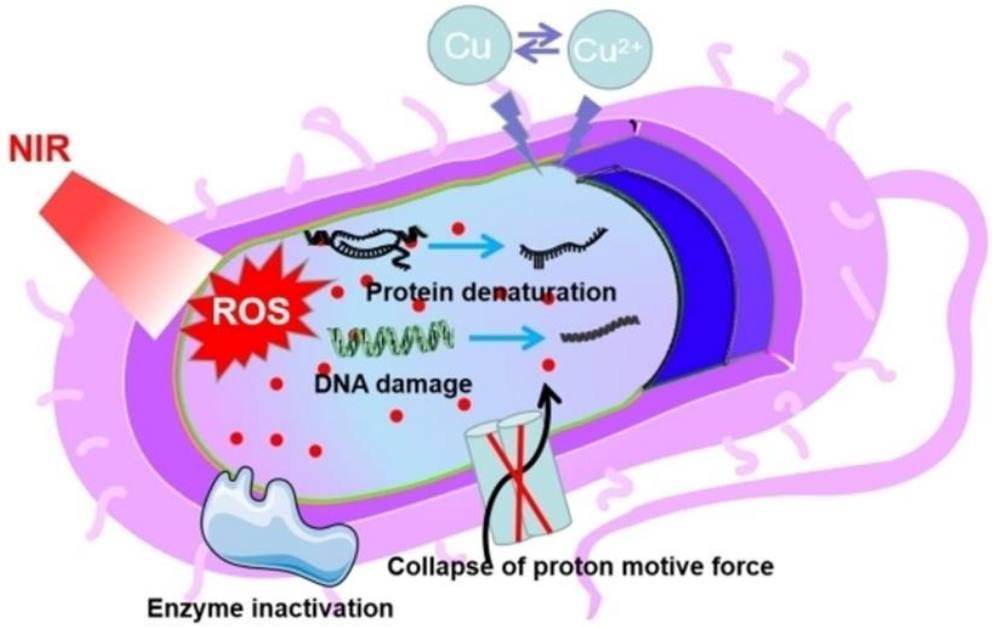


Fig. 2 The mechanism of nano copper antibiotics [6].

2.2.1 Application of nano copper

(1) Food package

Nano biocides are commonly used antibacterial agents in the processing and production of food, owing to their chemical stability and high thermal stability. Among these agents, copper nanoparticles are always one of the top priorities of food antimicrobial agents due to their strong antibacterial efficiency, require minimal effort to prepare, and higher safety for human health. For example, copper-based nanoparticles attached to polymers are often used to make the package of food (e.g. carrageenan, polylactic acid, polyethylene, etc) [7].

(2) Antibacterial nanoparticle dressing

At the same time, nano-copper antibacterial materials are also used in medical textiles, and wound dressings are essential to prevent wound re-injury or infection. To promote wound healing, various wound dressings have been invented, among which, antibiotics are usually added to the wound dressings, but human beings use antibiotics to treat for a long time. The phenomenon of bacterial resistance would occur, but copper nanoparticles can effectively avoid that [7].

3. Nano Metal Oxide Antimicrobial

3.1. Nano Titanium Dioxide

Firstly, photoactivated TiO_2 can kill the majority of bacteria. Also, nano TiO_2 is an effective method against fungi, algae, protozoa, mammalian viruses and phages. The antimicrobial mechanism involves the degradation of cell walls and plasma membranes because of the ROS. This contributes to the cell contents leaking and ultimately the destruction of the cell [8].

Titanium dioxide is a versatile material that finds use in a variety of applications. It has been used to sterilize some facilities in hospitals and it can be an ingredient in the production and delivery of medicine and drug. Also, titanium dioxide is applied in the production of pain. As a biocompatible material, it is safe to use in medical applications. Additionally, it is an effective tool in purifying water due to its good antibacterial activity. the free radicals generated from titanium dioxide, such as superoxides and singlet oxygen, can interact with bacteria and kill them. However, it has been found that titanium dioxide is more effective at inactivating microorganisms when it is irradiated [8,9].

3.2. Nano Zinc Oxide

ZnO is a safe material with photooxidation and photocatalysis for chemical and biological species. ZnO nanoparticles have effective antimicrobial properties because they enhance the particle surface reactivity by increasing the specific surface area and reducing the particle size. ZnO nanoparticles can induce intracellular ROS production, which is fatal to bacterial cells [10].

ROS, such as hydrogen peroxide (H_2O_2), Ohio − (hydroxyl radical), and O_2^{2-} (peroxide) are major factors in several bactericidal and inhibitory mechanisms [10].

The reason why nano zinc oxide can kill the bacteria may involve free radicals, destruction of membranes of cells, or denaturation of proteins, which is very similar to TiO2. Also, due to its stability under harsh processing conditions, nano zinc oxide is often widely used in food additives for food preservation [10].

4. Non-Metal Antimicrobial Nanomaterials

4.1. Carbon Nanotubes

Because of its porous nature and excellent sterilization effect, carbon nanotubes are widely used in drug delivery purposes. SWCNTs can carry some medicine by their porous structure [11].

There are three principles of antibacterial action in carbon nanotubes.

The first principle involves the use of nanotube edges and tips to physically damage bacterial cell walls, thereby achieving antibacterial effects. The second principle involves the generation of oxygen-free radicals and other active substances on the surface of carbon nanotubes, which interfere with the normal physiological activities of bacteria and destroy them. The third principle involves the use of carbon nanotubes' high electrical conductivity to disrupt the electrochemical balance of bacteria, affecting their cell membrane potential and ultimately leading to their destruction and leakage of the cytoplasmic membrane (Fig. 3) [12].

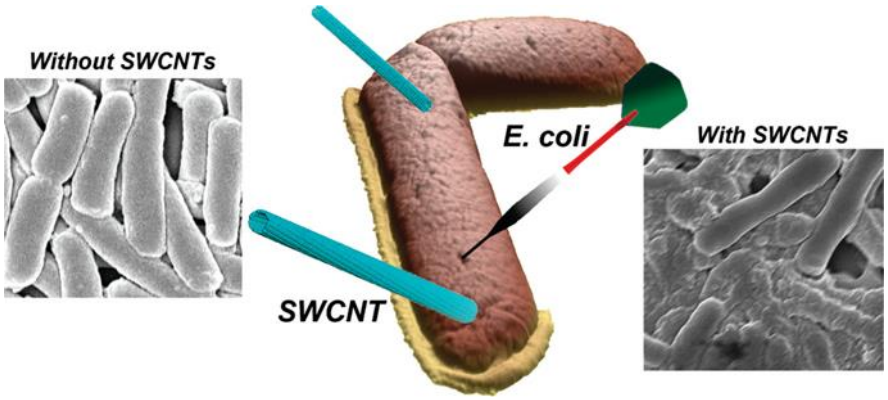


Fig. 3 SWCNT physically damaged the cell wall of E. coli [12].

4.2. Nano Silicon Dioxide

Nano silicon dioxide and carbon nanotubes have a similar antibacterial principle.

firstly, the antimicrobial activity of nano silicon dioxide will be due to the increased surface area, antibacterial effect will be increased. Silica nanoparticles can inhibit or affect bacterial functions such as cell differentiation, adhesion, and diffusion by attaching to bacterial surfaces. In addition, silica has a certain degree of biocompatibility [7]. Secondly, nanometer silicon dioxide under certain conditions (compared to other more complex metal oxides) is able to react and generate ROS material, using the cell membrane of ROS to destroy the bacteria content of the logistics [13].

Compared with carbon nanotubes, humans value the biocompatibility of the nanometer silicon dioxide, with almost no toxicity, as well as the strong antibacterial effect. Therefore, nano-silica is used in the medical field, especially in drug delivery [13].

5. Organic Antibacterial Nanomaterials

5.1. Chitosan

Chitosan is a natural biopolymer that is abundant and biodegradable. Its polymer structure is similar to that of the extracellular matrix, making it biocompatible. Chitosan nanoparticles that contain quaternary ammonium salts have demonstrated that they can kill various microbes. Because the charges of nano organic antimicrobials and the bacterial cell outer layer are different, it alters the cell wall permeability and membrane permeability by voltage difference. Chitosan nanoparticles exhibit stronger antifungal activity than bulk chitosan, making them ideal as organic nanofillers in nanocomposites like nanofibrous cellulose. This application confers antimicrobial activity and enhances the mechanical properties of polymer substrates [14].

5.2. Polyaniline and Its Derivatives

These organic antimicrobials have excellent electrical conductivity, they can cause cell death by electrostatic adhesion to microorganisms, and they can also destroy cell membranes by interacting with microorganisms to protonate. Some nano polyaniline and poly (3-aminobenzoic acid) coating are components of antimicrobial material on the surface of walls or doors in the place about medical field [14].

6. Conclusion

After analyzing various nano-antibacterial materials, it is clear that some nano antibiotics possess some common points. Some antibiotics damage or alter the bacterial cell membrane to release the cytoplasm or release active oxides through reactions like photocatalysis, which affects the normal physiological function of bacteria. Some of these materials have unique properties such as biocompatibility, high-temperature resistance, or porous structure, making them ideal for use in other environments such as surgery, food packaging, and water purification. However, despite their potential benefits, some antibacterial materials have harmful effects that are not visible to humans. For instance, nano titanium dioxide food additives are possible carcinogens. Zinc oxide, used in food packaging, has a negative impact on plants and animals. Silver nanoparticles, often used in the medical and food industries, are cytotoxic and can damage human cells. Thus, while there is some knowledge about nano-antibacterial materials, much research is necessary to reduce their negative effects and to determine how to use them safely.

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