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Role of Nanomaterials as Antibacterial Agents

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Introduction

A significant contributor to chronic illnesses and death are bacterial infections. Due to their efficacy and potent results, antibiotics have been the primary treatment option for bacterial illnesses. However, a number of studies have offered concrete proof that the extensive use of antibiotics has contributed to the creation of bacterial strains that are multidrug resistant. Three bacterial targets are presently the focus of the main classes of antibiotics: the machinery responsible for DNA replication, translation, and cell wall construction. Unfortunately, bacterial resistance can arise to any of these ways of action. Since nanoparticles (NPs) work by coming into direct contact with bacterial cell walls rather than penetrating them, the majority of antibiotic resistance mechanisms do not apply to them, which gives optimism that NPs will not be as likely to induce bacterial resistance as antibiotics. As a result, interest has been drawn to cutting-edge NP-based materials that exhibit antibacterial activity.

Materials that have at least one dimension (1-100 nm) in the nanometer scale range or whose fundamental unit in three-dimensional space is in this range are referred to as nanomaterials. Particularly NPs have proven to provide broad-spectrum antibacterial effects against both Gram-positive and Gram-negative microorganisms. For instance, Ag NPs show concentration-dependent antibacterial action against *Escherichia coli* and *Pseudomonas aeruginosa*, and ZnO NPs were discovered to inhibit *Staphylococcus aureus*. One of three models-oxidative stress induction, metal ion release, or non-oxidative mechanisms, is often used to characterize the antibacterial mechanism of action of NPs. These three different mechanisms can all take place at the same time. Existing research indicates that the following key mechanisms underlie the antibacterial actions of NPs: 1) disruption of the bacterial cell membrane; 2) production of ROS; 3) penetration of the bacterial cell membrane; and 4) induction of intracellular antibacterial effects, including interactions with DNA and proteins.

Antibacterial application of NPs

Antibacterial coating of implantable devices

Based on pore morphology, with calcium, silicon, phosphorus, and silver particle enrichment, titanium oxide coatings are applied to implants. The coating reduces the development of inflammation surrounding the implants by inhibiting the adherence and proliferation of bacteria such *Streptococcus mutans*, *Streptococcus epidermis*, and *E. coli*. To specifically slow the development of catheter biofilms, nano polymers can be employed as antibacterial materials. Invasive neurosurgery catheters can benefit from NP coatings to lower their risk of problems and bacterial infection, with sustained release of NPs over 6 days dramatically slowing the development of *S. aureus*.

Wound dressings

Antibiotic resistance and various bacterial species infections are frequent complications of chronic infection, although NPs have broad-spectrum antibacterial capabilities that can greatly reduce bacterial growth and reproduction. In this context, the interaction of nano silver with a solution of poly (vinyl alcohol) and chitosan (CS) has been investigated, and the resultant fibre mat can be used to the treatment of wounds. Since Nano silver has a large specific surface area, it makes good contact with germs, greatly reducing their growth and speeding up the healing of wounds.

Bone cement

Polymethyl methacrylate (PMMA) or modified PMMA and methyl methacrylate are the main components of bone cement, a self-curing plastic that may be used at room temperature (MMA). By bridging the space between the implant and bone, bone cement is frequently used to secure joint prostheses, such as in knee or hip replacement surgery. According to the Kirby-Bauer method and the time-kill method, PMMA-based bone cement combined with Ag NPs greatly suppresses the development of surface biofilms; the major mechanism of this Ag NP-PMMA is inhibition of bacterial surface colonization. Including methicillin-resistant *S. aureus* (MRSA), *S. aureus*, *S. epidermidis*, and *Acinetobacter baumannii* infections, arthroplasty surgery-related infections can be dramatically decreased at concentrations of Nano silver as low as 0.05%.

Dental materials

Plaque is a crucial ecological habitat that permits microorganisms to colonise the teeth and is the primary cause of many infectious disorders that are widespread in the mouth. Following nanocrystallization, the performance of several dental materials has improved. For instance, root canal therapy using gutta-percha and amoxicillin with nanodiamond functionality can get rid of any leftover germs.

Antibacterial mechanisms of NPs

Oxidative stress

A key antibacterial mechanism of NPs is oxidative stress caused by reactive oxygen species (ROS). The four distinct kinds of ROS, which have varying degrees of dynamism and activity, are the superoxide radical (O_2^-), the hydroxyl radical (·OH), hydrogen peroxide (H_2O_2), and singlet oxygen (O_2). For instance, zinc oxide NPs can produce H_2O_2 and ·OH but not O_2^-, but calcium oxide and magnesium oxide NPs can. Copper oxide nanoparticles (NPs) may create all four varieties of reactive oxygen.

Dissolved metal ions

Metal ions are slowly released from metal oxide and are absorbed through the cell membrane, where they directly interact with the functional groups of proteins and nucleic acids, such as mercapto (-SH), amino (-NH), and carboxyl (-COOH), damaging the activity of enzymes, altering the structure of the cell, impairing typical physiological functions, and ultimately inhibiting the microorganism. However, during the antibacterial process of metal oxide suspension, the effect of metal ions on the pH within lipid vesicles is minimal and has poor antimicrobial action. Therefore, the primary antibacterial mechanism of metal oxide NPs is not dissolved metal ions.

Non-oxidative mechanisms

Researchers have examined the antibacterial processes of a MgO nanomaterial using electron spin resonance, liquid chromatography-mass spectrometry, proteomics techniques, transmission electron microscopy (TEM), Fourier transform infrared (FTIR) analysis, and flat cultivation. Under UV light, ambient light, or total darkness, three different forms of MgO NPs show effective antibacterial actions on *E. coli*.

Conclusion

It is becoming increasingly difficult to treat patients and combat infectious illnesses in an era of rising MDR, in which bacteria are gaining resistance to many different antibiotics. It has major morbidity and mortality consequences. NPs are an effective substitute for antibiotics and seem to have a great chance of resolving the issue of the rise of bacterial MDR. The creation of effective antibacterial NPs and the avoidance of NP cytotoxicity may both benefit from the present in-depth examination of the antibacterial processes.

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