Vol. 5 Issue- 3, December 2023 (e-ISSN: 2582-8223)

Nanoparticle: A Thrilling Antibacterial Key

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ARTICLE ID: 32

Introduction

Over the past few decades, there has been a significant increase in microbial infections in underdeveloped and developing countries, primarily due to the rapid growth of the human population. Diseases like Tuberculosis, Cholera, and Pneumonia have become widespread in tropical regions, and inadequate treatment can lead to fatal outcomes. In 1928, the discovery of penicillin marked the advent of antibiotics, which were subsequently developed and used to combat these microbial infections. However, the indiscriminate use of antibiotics has given rise to a concerning issue known as antibiotic resistance. This phenomenon occurs when certain antibiotics become ineffective against resistant bacteria. In some cases, infections become even more serious when pathogenic bacteria develop resistance to most available antibiotics, leading to a condition called Multi-Drug Resistance (MDR), which is associated with high mortality.

Common MDR problems include methicillin-resistant *Staphylococcus aureus* (MRSA), first identified in 1961. This strain not only resists methicillin but also several other commonly used drugs. *Staphylococcus*, a prevalent gut bacterium responsible for skin infections, can become life-threatening when it develops methicillin resistance. Another example is Extended Spectrum Beta-Lactamases (ESBL) enzymes, which enable bacteria like *Escherichia coli* and *Klebsiella pneumonia* to resist antibiotics. Nowadays, Multi-Drug Resistance has become a global issue and a leading cause of death. Addressing this problem urgently requires the development of alternative approaches to antibiotics. Notably, nanoparticles (NPs) have surfaced as a promising substitute for antibiotics, offering novel avenues to combat bacterial pathogens owing to their distinctive antimicrobial characteristics.

History behind nanotechnology

Nanotechnology, a groundbreaking field of research that emerged in the last century, has ushered in a new era of scientific exploration. The term "nanotechnology" was coined by Richard P. Feynman in his renowned 1959 lecture titled "There's Plenty of Room at the

Bottom"[1]. The word "nano" is derived from the Greek term for "dwarf," signifying its focus on manipulating matter at the nanoscale, typically less than 100 nanometers in size. Nanotechnology involves working with microscopic particles of macromolecules at the nanoscale and has begun to significantly influence various aspects of human daily life. This technology enables the creation of different types of nanomaterials through three primary methods: physical methods, chemical methods, and green synthesis. These approaches encompass both top-down and bottom-up strategies, involving the transformation of bulk materials into nano-sized particles or the self-assembly of atoms to produce nanoscale particles[2].

Application of nanotechnology

Nanotechnology holds crucial importance due to its widespread applications in various fields. Presently, nanomaterials are making a significant impact in diverse sectors such as wastewater treatment, nanoremediation, food processing and packaging, improving fuel cell efficiency, household appliances, the petroleum industry, the textile industry, and the production of cosmetics, among others. NPs are also utilized in agriculture, where they serve as fertilizers that can substantially enhance crop production. Furthermore, nanotechnology is instrumental in seed technology, the development of nano pesticides, weed management, and soil enhancement in the field of agriculture[3].

Implication of nanotechnology in biology

In the field of biology, nanotechnology plays a crucial role in various biological applications, streamlining disease detection and diagnosis. Notably, gold NPs are employed for precise cancer cell therapy in cancer research, reducing mortality rates in cases of prostate and colon cancer. Nanoprobes are designed to bind with specific target proteins, facilitating diagnostic processes and aiding genetic sequencing and gene mapping. NPs are invaluable in gene therapy for addressing genetic disorders. Tissue Engineering leverages nanoscale biopolymers for tissue repair and cell regeneration through cell transplants, creating biological substitutes. NPs, often combined with lipids and polymers, serve as efficient drug delivery vehicles, enhancing drug delivery precision, including across the blood-brain barrier. Nanotechnology also contributes to food safety by detecting foodborne pathogens using gold NPs as biosensors. Additionally, it plays a role in food packaging, with bio-nanocomposite films incorporating bioconjugated nanomaterials and using carbon nanotubes and nanoscale titanium dioxide particles to block UV light in plastic packaging. Various nanomaterials, such as metal NPs, carbon nanotubes, polymeric NPs, nanosheets, and nanorods, have made substantial contributions across diverse applications[4].

Reason to use NPs against MDR bacteria

The indiscriminate use of antibiotics has led to the widespread development of multi-drug-resistant bacterial strains (MDR), which are challenging to treat. However, there is a glimmer of hope in the form of nanomaterials. Metal NPs, in particular, have emerged as up-and-coming antimicrobial agents due to their remarkable ability to penetrate the blood-brain barrier and enter cells. In the ongoing battle between microbes and our immune system, the problem of unspecific binding often renders many medicines ineffective. NPs offer a unique advantage as they can operate at the molecular level, interacting with MDR microbes with exceptional specificity. In recent years, researchers have made significant strides in utilizing various NPs like silver, gold, aluminum, copper, cerium, cadmium, magnesium, nickel, selenium, palladium, titanium, zinc, and super-paramagnetic iron against MDR bacterial strains, yielding surprisingly positive results[5].

Present scenario of AMR research with NPs

NPs effectively inhibit bacterial activity by damaging the bacterial cell wall, DNA, and proteins, and generating reactive oxygen species (ROS). Silver NPs are emerging as highly efficient nanomaterials against MDR bacteria, and other NPs like copper, silver, and iron also exhibit strong bactericidal effects. In a study, it was documented that gold NPs displayed robust antimicrobial activity against *E. coli*, *Salmonella typhi*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae* due to oxidative stress triggered by increased intracellular ROS production[6]. Recently, silver NPs have demonstrated antimicrobial effects against MDR strain by disrupting the bacterial cell wall[7]. Graphene oxide-iron oxide NPs have shown maximum antibacterial activity against methicillin-resistant *Staphylococcus aureus* (MRSA), as reported by Pan et al. (2016)[8]. In 2016, Md Ashfaq et al. highlighted the antimicrobial properties of copper oxide NPs[9]. Sometimes, silver, gold, or other nanohybrid compounds are employed to enhance antimicrobial activity against MRSA and other MDR bacteria[10].

Conclusion and prospect

The alarming rise of MDR bacteria poses a significant and urgent threat to human health. To address these serious health challenges, antimicrobial nanotherapy offers a promising solution, utilizing NPs as a novel tool. In addition to their extensive therapeutic applications, many NPs have shown remarkable antibacterial properties. NPs are not only recognized as effective drug delivery vehicles in various biological systems but also hold the potential to establish an alternative treatment approach for combating such pathogens. This avenue represents a hopeful prospect for the future of healthcare, where NPs can play a pivotal role in addressing the growing concerns surrounding MDR bacteria and their impact on human health.

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