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Antibacterial Activity of Nanoparticle Biosynthesis by Bacteria

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النشاط المضاد للبكتيريا للتخليق الحيوي للجسيمات النانوية بواسطة البكتيريا

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Abstract

Background: The world's most common cause of illness and death is still bacterial infections. According to a World Health Organization report, bacterial resistance to antibiotics poses a serious threat to global public health. In recent years, the use of nanoparticles (NPs) as an antibiotic alternative has increased. **Results:** Due to the nanoparticles' inherent antibacterial activity, metal and metal oxide nanoparticles are the most promising nanomaterials for biological applications. Although nanoparticles have intriguing antibacterial properties, their use in medical applications is currently restricted due to the lack of clear understanding of the mechanisms underlying their action. **Conclusion**: The main focus of this review was the interactions between bacteria and the antibacterial capabilities of nanoparticles. Membrane contact, cation release, biomolecule oxidation, production of reactive oxygen species, and reactive oxygen species are some ways bacteria can kill themselves. Examining how NP affects gene and protein regulation patterns (transcriptomic and proteomic) is crucial.

Keywords: bacterial resistance, antibacterial processes, nanotechnology, and nanomedicine.

الخلاصة:

الخلفية: لا تزال العدوى البكتيرية هي السبب الأكثر شيوعًا للمرض والوفاة في العالم. وفقًا لتقرير منظمة الصحة العالمية، تشكل مقاومة البكتيريا للمضادات الحيوية تهديدًا خطيرًا للصحة العامة العالمية. في السنوات الأخيرة، زاد استخدام الجسيمات النانوية كبديل للمضادات الحيوية.

النتائج: نظرًا لنشاط الجسيمات النانوية المضاد للبكتيريا المتأصل، فإن الجسيمات النانوية المعدنية وأكسيد المعادن هي أكثر المواد النانوية الواعدة للتطبيقات البيولوجية. على الرغم من أن للجسيمات النانوية خصائص مضادة للبكتيريا مثيرة للاهتمام، إلا أن استخدامها في التطبيقات الطبية مقيد حاليًا بسبب عدم وجود فهم واضح للآليات الكامنة وراء عملها.

الخلاصة: كان التركيز الرئيسي لهذه المراجعة على التفاعلات بين البكتيريا والقدرات المضادة للبكتيريا للجسيمات النانوية. ملامسة الغشاء، إطلاق الكاتيون، أكسدة الجزيئات الحيوية، إنتاج أنواع الأكسجين التفاعلية، وأنواع الأكسجين التفاعلية هي بعض الطرق التي يمكن للبكتريا ان تقتل بها نفسها. يعد فحص كيفية تأثير الجسيمات النانوية على أنماط تنظيم الجينات والبروتينات (النسخية والبروتينية) امرا بالغ الاهمية.

الكلمات المفتاحية: المقاومة البكتيرية, آليات مضادة للجراثيم, تكنولوجيا النانو, طب النانو.

1. Introduction

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Each year, millions of individuals throughout the world experience sickness and mortality due to microbial pathogenesis (1). Soon after their discovery, Before the establishment of bacterial drug resistance, antibiotics were widely acknowledged as an efficient treatment for illnesses. Recently, numerous strategies to treat antibiotic resistance have been created in an effort to discover fresh, broad-spectrum medications with protracted half-lives (2).The concept of using nanoparticles as cutting-edge, unconventional antibacterial agents has been one of these methods (3). Current developments in nanotechnology have produced nanoparticles that have been proven to be powerful, all-purpose antibacterial agents (4)To create biodegradable nanoparticles with diameters ranging from 1 to 100 nm, metals or metal oxides are biologically reduced to their elemental states (3,5).

At low concentrations, nanoparticles (NPs) deliver efficient, focused, and long-lasting antibacterial effects (6). Since they are more compact and have a larger surface area -to- volume ratio than bacteria, metallic nanoparticles interact with bacteria and biofilms in a major antibacterial way (7). The ability of metal-based NPs to prevent bacterial growth is evaluated critically. An extensive review of the literature on bacterial interactions with metal and metal-oxide NPs is done to determine their potential as antibacterial agents. Nanomedicine greatly improves the stability and physicochemical properties of antibiotics, increasing the potency of already-approved medications. Compared to equal-free drugs, adverse effects are reduced by prolonging antibiotic release, internalizing biofilms, adjusting the dose to the site of infection, and increasing systemic circulation (6, 8).

The ongoing rise in bacterial resistance has forced researchers to create new antibiotic medications. Metal NPs are one of the most promising of these new antibiotic drugs, having demonstrated exceptional antibacterial activity in numerous trials. Furthermore, the functionalization, surface/volume ratio, size, and form of the surfaces influence the metal nanoparticles' biocompatibility and bactericidal properties, which are both crucial to their antibacterial effect. Through the use of nanotechnology, NPs can be created to have acceptable physicochemical properties in order to lessen their cytotoxic effects and the risk associated with their use in biological applications (9, 10). The primary subjects of this review are the mechanisms of bacterial resistance and the antibacterial properties of nanoparticles. Research into fundamental antimicrobial processes is necessary to produce more effective antibacterial agents.

2. How Nanoparticles Work Against Microbes

By utilizing the bacterial metal transport system and metalloproteins, metallic NPs and antibiotic-like compounds may be able to distinguish between eukaryotic (cells found in mammals) and prokaryotic (cells found in bacteria) cells. Contrary to antibiotics, metal-based NPs increase bactericidal activity in a variety of ways. According to (1), silver nanoparticles derived from the Parmand Aspergillus andotrema praesorediosum can effectively suppress eight different pathogenic pathogens, including gram-positive and gram-negative bacteria. They found that the gram-negative bacterial growth was greatly inhibited by the antibacterial activities of silver nanoparticles generated from P. praesorediosum. According to **Siddiqi *et.al.*** (11), three gram-negative bacteria (*Escherichia coli*, *klebsiella*, *pseudomonas aeruginosa*) and six gram-positive bacteria (*Staphylococcus aureus*, *Streptococcus mutans*, *Streptococcus*

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pyrogenes, *Streptococcus viridans*, and *Corynebacter*) *S. mutans*, *C. diphtheriae*, and *P. aeruginosa* are susceptible to the nanoparticles, whereas *E. coli* and *K. pneumoniae* are not. The antibacterial and antifungal characteristics of ZnO/TiO2/SiO2 and Fe3O4/SiO2 nanocomposites driven by *Lecanora muralis* were studied by **Abdullah *et.al*.**(12).

who discovered that they were effective against three harmful microorganisms (*Pseudomonas sp.*, *Candida albicans*, and *S. aureus*). (*Candida albicans*, *Aspergillus flavus*, *Aspergillus niger*, and *Aspergillums terreus*). With a specific emphasis on the bacterial strains investigated, the mechanism of action, and the production processes used, there are three basic ways in which metal NPs physically interact with bacterial cells. Antibiotics and metal-based nanoparticles can differentiate.

2.1. Bilayer Phospholipid Interactions

By electrostatically adhering to the cell wall and/or releasing metallic ions, metal-based nanoparticles (NPs) can affect the potential and integrity of bacterial cell membranes (13). These interactions cause membrane rupture and increased oxidative stress, both of which lead to the destruction of bacterial proteins. A significant amount of water is released into the cytosol when the cell membrane is breached.

To try to make up for this loss, cells use proton efflux pumps and the transfer of electrons from bacteria. These transmembrane systems suffer significant harm from the extreme need for these ions (14). The result of this imbalance between the stability of the ions and the membrane is reduced respiration. A disruption in the energy flow, which leads to cell death (15). This effect has been demonstrated by the interaction of titanium oxide, silver, gold, zinc oxide, and magnesium oxide NPs. Silver nanoparticles preferentially interact with the parts of the cell membrane that contain sulfur to stop the formation of cell walls (13).

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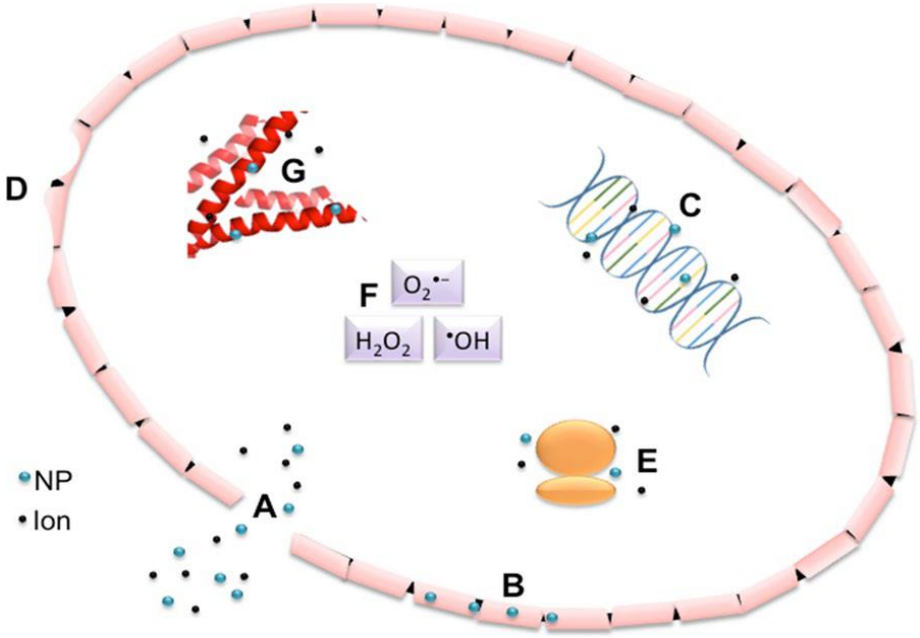

Fig. 1 An illustration of the conduct of NPs exposed to Gram-negative *E. coli* bacterium. (A) The disintegration of the cell wall enables the release of intracellular components. (B) The cytosol and membrane are beginning to drift apart as NPs enter the periplasm. DNA and NP interactions are (C). (Reactive oxygen species (ROS) generation may result from inhibition. Cell pits that develop upon exposure (D). (E) Improper DNA function, misaligned or suppressed proteins, and suppression of the normal ribosome activity all result in the production of ROS. ROS production is (F). interaction with proteins, particularly with cysteine (G).(13)

2.2 The section on Binding to Cytosolic Proteins Metallic-based NPs

by attaching to cytosolic proteins including DNA and enzymes, fight against pathogens. By the inhibition of the respiratory, metabolic, and ATP generation processes, this interaction decreases function. For example, silver binds to respiratory chain enzymes and DNA to prevent DNA replication and division (16). On the other hand, gold influences DNA by turning on cellular genes (17). As a result, the integrity of the membrane is harmed, and ROS start to build up in the cytoplasm of the cell.

2.3 Forming Reactive Oxygen Species, Section

By producing oxygen free radicals or reactive oxygen species (ROS), such as superoxide anions or hydrogen peroxide, NPs also kill bacteria (H2O2). The NPs themselves indirectly contribute to the generation of ROS. Significant oxidative stress and damage from ROS lead to lipid peroxidation. These adverse effects include altered proteins, enzyme inhibition, and RNA and DNA damage to the cell's macromolecules (14). This extreme oxidative stress may cause the bacterial membrane to develop holes or pits, which would cause cell lysis (18).

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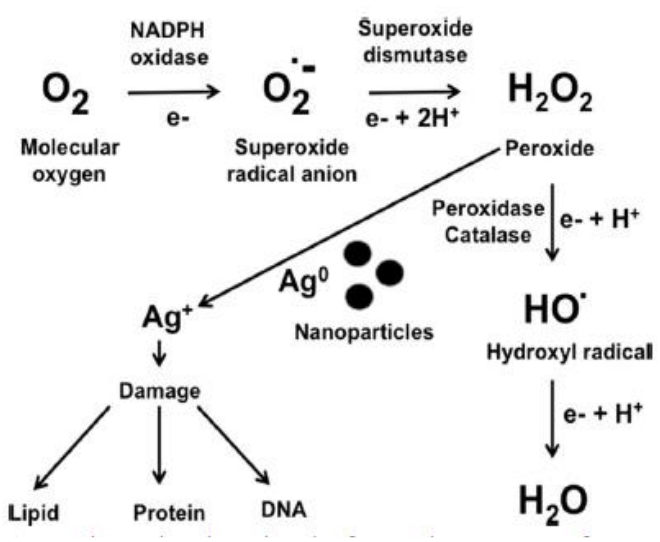

Fig. 2 shows a scheme outlining how NPs contribute to the production of ROS.(14).

3. Antibacterial Uses of Metal NPs

Researchers are interested in using metal nanoparticles (NPs) in a variety of medicinal applications as antibacterial agents due to the rise in bacteria that are drug-resistant. The versatility to change physical parameters to change the antibacterial properties of NPs, as well as their ease of manufacture, are only a few of their benefits. Implantable technology is one of the most popular applications for NPs. Implantable devices must have the necessary biocompatibility, tissue affinity, corrosion resistance, and most important of all, antibacterial capabilities [19].

Several metal and metal oxide nanoparticles (NPs) can now be added to implants to augment their antibacterial characteristics (20,21). AgNPs significantly reduced surface colonization and biofilm formation in PMMA-based bone cement, (22). While using hydroxyapatite- and silver-doped titanium nails during arthroplasty surgery, Kose *et. al.* saw equivalent results. They observed strong antibacterial activity, no prosthetic-related edema, and no evidence of the cytotoxic effect of the silver ions. Dental implants, catheters, and other medical devices have all demonstrated strong antibacterial properties. According to research, adding NPs to catheters could potentially stop the growth of biofilms and bacteria (23). In addition to creating an AgNP-coated collagen membrane for dental implants, showed that it was highly effective against *S. aureus* and *P. aeruginosa* while exhibiting low cytotoxicity. Adding copper and zinc oxide to dental plaque chalk significantly reduced the number of *streptococcus mutans* for 6 to 24 hours (24). NPs are frequently used in bandages for skin wounds as antibacterial components. Gram-positive and Gram-negative pathogenic bacteria can both cause long-lasting infections in skin wounds. AgNPs significantly reduced bacterial growth and accelerated wound healing when combined with poly (vinyl alcohol) and chitosan (25,26). The public's health is directly impacted by the work done by NPs in the agro-food sector, which includes, in particular, the food packaging sector, in identifying and eliminating diseases (27).

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4. Physico-Chemical Properties of Metal Nanoparticles and Antibacterial Activity

It is obvious that heavy metals with densities of more than 5 g/cm3 have antibacterial properties (28). A metal nanoparticle's antibacterial and antibiofilm capabilities are mostly determined by its physicochemical qualities (29). Due to the high surface area -to- volume ratio, size, and shape effects of nanoparticles, these substances drastically alter their physical and chemical properties (30). As a result, changes are made to ion release, hardness, plasmon, and superparamagnetism (31). The reaction to external stimuli, such as light for photocatalytic and photothermal activity and magnetism for magnetically induced hyperthermia activity, differs from that of the bulk metal as well (32).

4.1 sizes

Smaller NPs frequently exhibit superior antibacterial activity because they can enter cells and halt bacterial growth (4). Furthermore, smaller NPs produce more ROS than bigger NPs because of their higher surface area - to - volume ratio. When *Escherichia coli* resistance to AgNPs of three different sizes was examined (33). Found that the antibacterial efficacy of particles of the same size was rigidly dose- and time-dependent [Skomorokhova et al., 2020]. As antibacterial agents, smaller NPs performed better than larger ones. (34). came to the same conclusions as well. The ability of nanoparticles to kill bacteria was found to be negatively correlated with their size. Additionally, they found that smaller AgNPs generated more ROS than larger AgNPs. In another experiment, it was found that AgNPs with an average diameter of 18 nm were more toxic in water than those with an average diameter of 80 nm, but their toxicity decreased to a similar level in the PBS buffer. The exceptional antibacterial and antioxidant activity of these NPs varied depending on shape and size, per studies on ZnONPs by Zare *et.al*. .

4.2 shape

The shapes that can be made with NPs, such as spheres, dots, wires, rods, stars, flowers, and 2D materials, can have an impact on how well they fight germs. 2021 publications by (9,36). Although spherical nanoparticles are more common, nanocubes and nanorods have advantages over other shapes. This might be because of the metal's levels of oxidation and exposed surfaces. Theoretically, oxygen vacancies can be created with less energy in less stable planes. According to (37) this would link NP's bactericidal action to the stability of (36). Additionally, NPs become more toxic when they have corners, edges, or defects. Most likely, this is due to the increased surface area, which has an impact on their ability to bind chemicals or produce ROS. According to (36) their potent bactericidal activity significantly inhibited Propionibacterium acne. Antibiotics may not be necessary to treat acne if gold nanostars are used instead of them (38). Drug-resistant bacteria were completely eradicated by silver nanoflowers when combined with a small number of antibiotics. This was probably because NPs were the primary mediators for the generation of ROS and the activation of antibiotic uptake (36). This study shows that NPs' ability to fight bacteria is significantly influenced by their shape.

4.3 surface charge

The degree to which NPs are antibacterial is greatly influenced by their surface charge. Negatively charged NPs are known to be more harmful than positive ones (39). Negatively charged bacterial cell walls interact electrostatically with other molecules. When compared to negatively charged magnetic NPs (NP), positively charged magnetic NPs (NP+) were found to successfully attract over 90% of *E. coli*, according to (40). Our results show that NPs+ has strong electrostatic attraction and microorganism-trapping abilities. Abbaszadegan *et.al*. examined the antibacterial efficacy of three distinct AgNP types—positively, negatively, and neutrally charged. They found that the level of bactericidal activity was highest for positively charged NPs and lowest for negatively charged NPs (42).

study .'s focused on four AgNPs with a range of surface charges, from strongly negative to extremely positive. According to their study (43), AgNPs kill the tested bacterial species in a way that depends on surface charge. Ag-polyethyleneimine (BPEI) nanoparticles with a positive charge adhered to bacteria's surface more firmly than those with a negative charge, according to a different study. However, Agnihotri *et al.* discovered that *S. aureus* and *E. coli* growth was significantly inhibited by negatively charged AgNPs (stabilized by citrate). A smaller particle size was also found to enhance the antibacterial effect (44).

5. Nanoparticles and multidrug resistance (MDR)

Because they can lead to treatment failure, which can have devastating repercussions, especially in patients who are already extremely ill , MDR bacteria offer a serious danger to all areas of medical science (4). Through a variety of acquired or natural pathways, many microorganisms can evolve bacterial antibiotic resistance (45). The lack of a target or the existence of low-affinity targets, poor cell permeability, antibiotic inactivation, and the presence of efflux mechanisms are a few examples of intrinsic or "natural" resistance that exists in every bacterial species. The spread of resistance genes via mobile genetic materials like plasmids and antibiotic-targeted gene changes are two more methods I learned about. Transposons, bacteriophages, and other elementsThis exchange is typically carried out by transduction, conjugation, and transformation in bacteriophages, plasmids, and conjugative transposons (by integrating plasmids, additional DNA from extinct creatures, and chromosomal DNA into the chromosome). A few brand-new drugs have been developed in recent years to combat these MDR infections.

Nanoparticles have been found to cling to bacterial cell walls before entering, altering the structure of the membrane and ultimately causing cell death. In comparison to other salts, silver nanoparticles have a very large surface area, which allows for more contact with microbes and more potent antibacterial actions. The bacterial membrane may be targeted by SNPs, which would result in the proton motive force dissipating and stopping oxidative phosphorylation (46).

Another mechanism linked to microbicidal action is the generation of free radicals by nanoparticles, which have the capacity to harm and porosity the cell membrane and ultimately lead to cell death. Metal nanoparticles are drawn to DNA bases and other phosphorus and sulfur-containing parts of bacterial cells. These soft bases interact with the metal nanoparticles,

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which can kill cells and damage DNA (47). According to **Singh** *et al.* , it has been proven that nanoparticles have an impact on bacterial signal transduction (6).

The dephosphorylation of peptide substrates on tyrosine residues by the nanoparticles inhibits bacterial growth and signal transmission. Moreover, it has been shown that silver ions from released Ag nanoparticles can attach to thiol groups on a variety of significant enzymes, inactivating them and impacting cellular processes. Also, by compressing the membrane potential, NPs can hinder the ATPase enzyme's capacity to lower the level of ATP or stop the ribosomal component from adhering to tRNA. A brief summary of some recent studies on the bactericidal abilities of various NPs and nanoconjugate systems is given in the preceding sections (48).

6. The Use of Nanosystems to Combat Antibiotic Resistance

Because there is a shortage of new antibacterial drugs and aggressive bacteria are on the rise, current antibiotic therapy is ineffective, which has detrimental effects on human health. The availability of novel antibacterial pharmaceuticals appears to be a highly challenging process that normally takes 10 to 15 years (6, 8). This is because it is possible to generate new antibacterial drugs. This is a result of the expensive production costs and drawn-out approval procedures for new medications. According to (48), many antibiotics completed clinical assessment in 2016 and were given the go-ahead to be sold in the United States.

Yet prior to recently, only the newly discovered antibiotic teixobactin and the drug linezolid had licenses (14). By improving the stability and physicochemical properties of antibiotics, facilitating biofilm internalization, extending antibiotic release, permitting targeted antibiotic administration to the site of infection, improving systemic circulation, and minimizing associated side effects, nanomedicine significantly contributes to increasing the efficacy of current therapeutics (14, 48).

7. Worldwide gene and protein modification following NP exposure

Its NPs have been demonstrated to alter the genomic and proteomic profiles of bacterial cells, indicating that the cells' capacity to adapt to their new environment has been enhanced by the presence of its NPs. For instance, it was shown that after exposure to Ag-NPs and Ag+, *E. coli* downregulated 27 genes and overexpressed a common set of 161 genes. It's interesting to note that 309 and 70 genes, respectively, were under the control of Ag-NPs and Ag+ alone (49). MgO-NPs in *Escherichia coli* differently regulated 109 proteins, with 83 of them being downregulated (50).

These proteins were mostly engaged in cellular processes like gene transcription and central metabolism. The increased genes were found in periplasmic proteins that bind thiamine and those involved in riboflavin metabolism, indicating that they might not be important for understanding MgO-NP exposure toxicity. Several ways may allow NP to affect the genes and proteins of bacteria.

7.1 DNA replication and repair effects of NP, paragraph

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TiO2-NPs prevented Escherichia coli from expressing two genes necessary for DNA replication [51]. It is likely that exposure to TiO2-NP reduced DNA synthesis by downregulating the genes that produce guaC, pyrC, and glutaredoxin (grxA). According to (20)., this shows that the cell is under stress and does not prioritize DNA synthesis (2015). According to (52)., several genes involved in amino acid transport (argT, glnH, livK, tdtC) and glutamine synthesis (glnA) are also upregulated (2015) This suggests that the cell is attempting to adapt to its environment. An intriguing gene called RecA is created after DNA damage and, when it is downregulated, it produces a phenotype that has been exposed to Ag+ [43].
It is unclear whether DNA repair is prevented by Ag+ directly inhibiting the gene or if other toxicity mechanisms are to blame *E. coli* cells exposed to Ag-NPs exhibited little to no overall change in their protein composition.., but distinct protein groups were controlled differently. The total protein-protein interactions in cells are not considerably changed by Ag-NPs' selective protein group binding [53].

7.2 The impact of NPs on proteins associated with sulfur

Genes involved in the metabolism of sulfur were found to be increased in bacterial cells exposed to NPs, suggesting that sulfur and NPs may be related. The majority of these genes are involved in sulfate metabolism, including those that reduce and assimilate intracellular sulfate during the synthesis of cysteine and sulfate/thiosulfate transporter elements of the ABC family. Each of these genes starts to work when exposed to Ag+. One of the primary causes of this upregulation may be the increased requirement for cysteine, an Ag+ target whose intracellular depletion initiates its production cycle (16). Only a few proteins have Fe-S clusters, including ferredoxins, hydrogenases, succinate-coenzyme Q reductase, bacterial respiratory complexes I–III, metalloproteins, and hydrogenases (17). The genes iscX and hscB, which are both involved in the formation of Fe-S clusters, were found to be significantly downregulated when TiO2 was present in *E. coli* cells (54, 49), revealing that the Fe-S cluster encoding operons isc and suf are activated by Ag+.

7.3 ROS and gene regulation in metabolism

Among the proteins that have Fe-S clusters are ferredoxins, hydrogenases, succinate-coenzyme Q reductase, bacterial respiratory complexes I–III, metalloproteins, and hydrogenases (50). The genes iscX and hscB, which are both involved in the production of Fe-S clusters, were shown to be significantly downregulated when TiO2 was present in *E. coli* cells (55). It has been discovered that Ag+ activates the operons isc and suf, which encode Fe-S clusters (50). Another gene that is activated by high levels of peroxide is KatE, a catalase that degrades H2O2 to protect cells from ROS damage. An AG-sensitive phenotype is created when the katE gene is deleted (43). As a result of exposure to Ag-NP, the expression of a different gene called OxyR has increased. In addition to being involved in peroxide metabolism and defense, this gene controls redox reactions. The ADD, ASD, ADD C, KatG, and other genes have also been linked to increased activity in these pathways. When these genes work together, an oxidative species is produced, which converts oxygen first into the potentially harmful H2O2 and then back into oxygen. After 90 minutes of exposure, the amount of oxyR

produced started to decrease (30). This prevents the entire cell from controlling gene expression and may be caused by both a delayed membrane breakdown and a feedback loop in the gene-regulating enzyme.

7.4 Stress condition proteins

A variety of environmental factors can stress out bacteria. A complicated network of genes is activated and coordinated in response to stress in bacteria in order to effectively respond to external stimuli . One of the two most important stress responses is the overexpression of envelope stress and heat shock proteins. Both were discovered when NPs were administered to bacterial cells. The majority of the data is ambiguous, indicating that more research is required to fully understand cell envelope gene control. Aside from changes in Omp protein activity, the response of membrane protein regulation to NP exposure is unknown. This is because, despite membrane disruption stimulating it (49), lipid and fatty acid production are downregulated. Heat shock proteins have chaperone activities to be activated when protein denaturation is detected and to defend against stress (50). Heat shock genes increased the expression of groL and groS as well as inclusion body binding proteins A and B in response to exposure to Ag-NP (ibpA and ibpB). These genes all encode S6, groL, additional 30S ribosomal subunits, and groS. Furthermore (49), there was an increase in the expression of the chaperonin genes dnaK, dnaJ, and grpE. Given the presence of heat shock response genes, Ag+ most likely modifies the stress response system, which in turn affects protein structure.

8. Future study

Antibiotic resistance will worsen if antibiotics are administered carelessly, overprescribed, or frequently in husbandry methods. As germs with established resistance can flourish unchecked in the absence of effective management, the lack of novel treatments worsens the situation. Because of their multitarget method of action, NPs have the potential to offer a solution to this issue, but additional study is needed. Before NP medications are used on a regular basis, formulation, characterization, and testing must be standardized. It is challenging to support the current study's findings with a conclusion that might lead to an antibiotic alternative because NP methods vary across the literature. Also, there hasn't been much study on how NP affects human cells. In order to reconcile the minimum amount of cytotoxicity and immunological reactivity with the concentration required for desired activity, it is crucial to analyze cytotoxicity and immune response alongside medicinal use. It has been demonstrated that NP concentrations of 5–10 g/mL are dangerous in eukaryotic cells. Practical usage may be restricted if effective antibacterial concentrations are higher than cytotoxic values.

9. Conclusion

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To address the major global public health concern of the evolution of bacterial resistance to antimicrobial drugs, novel antimicrobial therapies are urgently needed. As a consequence of innovative developments in nanotechnology, particularly nanoparticle engineering, new antibacterial agents should be created. Such nanoparticles have been created and tested for antibacterial activity by several research teams. Both gram-positive and gram-negative bacteria are impacted by anti-quorum sensing and antibiofilm activity. Nevertheless, NPs also have disadvantages, such as their small size, surface properties, and aggregation potential. Nanoparticle research is now one of the most studied areas in science since there are so many possible uses.

Nanoparticles (NPs) are a potent antibacterial alternative to antibiotics in the field of new antibacterial materials. These nanoparticles are efficient antibacterial agents against a variety of bacteria, including drug-resistant types, by concentrating on multimolecular biotic targets. A low dosage does not entirely eliminate germs while promoting the horizontal transfer of resistance genes and raising bacterial cell membrane permeability. At large doses, it could be lethal to eukaryotic cells. Due to their bactericidal properties, numerous metal (Ag, Zn, and Cu) and metal oxide (ZnO, CuO, MgO, and TiO2) NPs have been extensively used in a variety of biomedical applications. Finally, standard NP production practices should be taken into account.

To increase the validity of these techniques in subsequent studies, cytotoxicity, and the inflammatory response must be taken into consideration.

Additionally, in order to address the rising prevalence of multidrug-resistant bacterial strains, clinical isolates rather than common microbial collection strains should be studied.

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Conflict of interests.

There are non-conflicts of interest.

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