Silver Nanoparticles as a New Generation of Antimicrobials

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Abstract

Bacterial drug resistance is a persistent issue in hospital therapy. The main mechanism of bacterial pathogenicity in human infections is the ability of germs to cling to surfaces and create biofilms. Numerous methods, such as treating the infection with antibacterial biomolecules, have been developed to solve this issue; however, these methods have certain drawbacks, such as enzymatic breakdown and short shelf life. Since silver nanoparticles (AgNPs) have special and potent antibacterial qualities, they could be a viable substitute for these tactics. Here, we describe the manufacture of AgNPs using extracellular yeast Saccharomyces cerevisiae. Hydrodynamic scattering of light (DLS) verified good colloid durability and a uniform dispersion, while transmitted electron microscopy (TEM) provided information on the metallic nanoparticles' shape and organization. Antimicrobial investigations show that while AgNPs do not affect the growth of fungus, they do hinder the growth of bacteria. Additionally, the assessed NPs demonstrated a potent ability to suppress the formation of new bacterial biofilms while concurrently breaking down pre-existing ones. Four mammal normal and cancer cell lines were exposed to the cytotoxic effect of the NPs using tests for wound-healing, metabolic rate, and cell viability.

Keywords: Silver nanoparticles, treatments, bacterial infections, antimicrobial agent, pathogenic bacteria

1. INTRODUCTION

A few of the antimicrobial actions of NPs include the cidal destruction of cell membranes, blockage of enzyme pathways, alteration of the microbial cell wall, and disruption of the nucleic materials route. However, because many of the NP's medications are still in the early stages of development, the antibacterial mechanisms behind their activities are still poorly understood. With their effective antiviral, antibacterial, antifungal, and antiprotozoal characteristics, NPs have the potential to revolutionize and enhance the field of pharmacological therapy to a great extent. As a result, as Fig. 1 illustrates, nanomaterials are currently a viable alternative to antimicrobial agents due to their broad spectrum of action, ability to cross difficult membrane barriers, ability to deliver and maintain inhibition of intracellular bacteria, and sterilizing power. The current state of multifunctional NP antibacterial agents will have a significant impact on disease therapy.

The surge in infectious diseases brought on by various hazardous bacteria as well as the emergence of antibiotic resistance has pharmaceutical corporations and researchers searching for new antibacterial medications. Nanoscale materials have emerged as novel antibacterial agents in the modern environment due to their unique combination of chemical and physical properties and high surface area to volume ratio (Morones et al., 2005, Kim et al., 2007).

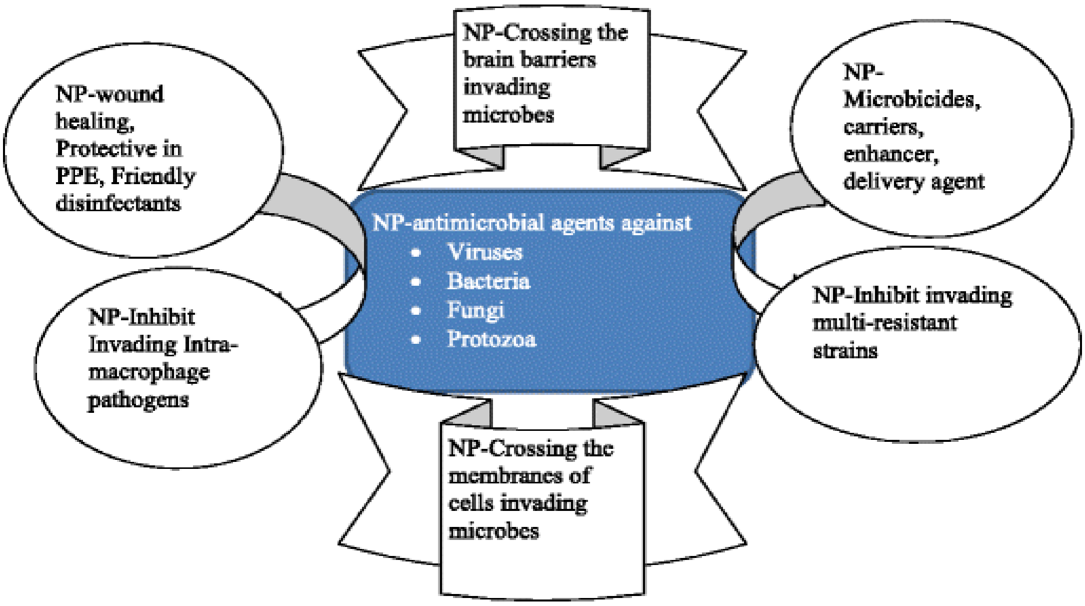

Fig .1. Nanoparticles as potential new generation broad spectrum antimicrobial agents [15]

2. LITERATURE REVIEW

Prasher, et. al., (2018) [1] presented and potential future problems of silver nanoparticles as antibacterial treatments are described. The long-established use of silver metal in antimicrobial therapy has gradually decreased because of the contemporary era's discovery of a few kinds of bacteria that are resistant to silver. One antibiotic after another emerged fast. But due to careless and uncontrolled use, insufficient legal controls, insufficient experience managing critical cases, and the rise of multi-drug resistant "superbugs," which are extremely difficult to treat, the use of antibiotics has already drastically decreased in recent decades. Once more, the lack of specific strategies and the scarcity of available drugs raised hopes for novel, MDR-focused drug discovery to combat the "superbugs," which in turn accelerated the development of AgNPs in antimicrobial research.

Yun, et. al., (2017) [2] conducted differ noticeably from their macroscaled counterparts in terms of their physical, chemical, and biological characteristics, specified nanoparticles are believed to provide solutions to technological and environmental issues in the disciplines of catalysis and medicine. They are therefore thought to offer solutions to environmental and technical problems in the medical and catalysis industries. The creation of stable nanoparticle dispersions has been the primary use for metals such as copper, silver, and gold. In the realm of medical microbiology, silver nanoparticles are particularly noteworthy because of their strong antibacterial properties. For this reason, there has been continuous interest in creating silver nanoparticles for a variety of uses. Through a variety of processes, such as membrane rupture, apoptosis, and synergy, silver nanoparticles exhibit potent antibacterial activities. The interactions of silver nanoparticles with membranes result in the rupture of membranes in fungal cells. The malfunctioning of mitochondria and the rise in hydroxyl radicals are important components of the apoptosis induced by silver nanoparticles. Silver nanoparticles also cause death in bacteria, which is an interesting observation about the primary causes of apoptosis: exposure to phosphatidylserine and DNA fragmentation. Silver nanoparticles also increase the antibacterial activity of conventional treatments by cooperating to prevent the creation of biofilms and address the issue of resistance. Consideration of these mechanisms and effects on germs can lead to the synthesis of silver nanoparticles as a potential antibacterial agent.

Durán, et. al., (2016) [3] described silver nanoparticles is an innovative perspective on the mechanisms behind antibacterial action. Nanomedicine: nanotechnology, biology and medicine. Strong antibacterial agents such as silver nanoparticles are widely recognized. Despite significant progress in our understanding of silver nanoparticles' antibacterial activity, the exact mechanism of action is still unknown. The paper is to give a succinct synopsis of the current understanding of silver nanoparticles' antibacterial capabilities. Additionally highlighted is the potential for pathogenic bacteria to become resistant to silver nanoparticles.

Yah, et. al., (2015) [4] described as possible broad spectrum antibacterial drugs of the next generation in nanoparticle form. The quick spread of strains resistant to traditional antimicrobial drugs has complicated and lengthened the treatment of infections and raised the risk of mortality worldwide. The treatment of intracellular pathogens is further limited by the fact that some standard antibacterial drugs are unable to penetrate specific cell membranes. As a result, the pathogenic microorganisms frequently survive in these cells. In actuality, the limitations that traditional antimicrobial agents have can be overcome by NP-antimicrobial agents. The current state of NP-antimicrobial agents as strong, all-purpose antimicrobials, wound-healing and sterilizing agents, and long-acting inhibitors of intracellular pathogens is covered. In fact, the prospect of creating highly effective NP-antimicrobial drugs with numerous functions will transform clinical medicine and significantly reduce the burden of disease.

Varaprasad, et. al., (2010) [5] described composites of hydrogel and silver nanoparticles: A novel class of antimicrobials. In the field of antibacterial bionanotechnology application, the development of consistent and environmentally acceptable synthesis methods for AgNPs represents a major advancement. Hydrogel templates are a handy tool that can be utilized to accomplish this objective. Hydrogel AgNP composites have several applications, including antibacterial and wound treatment, made possible by the simple, rapid, and easy way of producing nanocomposite materials. Every aqueous solution of the nanocomposite has displayed absorption peaks in the UV–visible absorption spectra at 420 nm, which correspond to the Plasmon absorbance of AgNPs. Silver nanocrystal-like 2θ values were observed in the X-ray diffraction spectrum of the HSNC. Images of nanocomposites obtained using transmission electron microscopy show distinct AgNPs ranging in size from 2-3 nm across the gel networks. On E. coli, the produced nanocomposites were assessed for their antibacterial potential.

Table .1. Comparative table of given information-

Author and Year	Main Finding	Result
Varaprasad et. al.,	Creation of hydrogel-silver	Hydrogel AgNP composites have

(2010)	nanocomposites (HSNCs) of poly(acrylamide) and poly(vinyl alcohol) for the manufacture of approximately 2-3 nm-sized silver nanoparticles (AgNPs) in gel networks.	potential applications in wound dressing and antibacterial properties. In the UV–visible absorption spectrum, nanocomposites exhibit absorption maxima at 420 nm. Silver nanocrystals are confirmed to be present by X-ray diffraction. Discrete AgNPs (two to three nm) are visible throughout the gel networks in TEM pictures. assessed for use against E. Coli using antibacterial agents.
Prasher et. al., (2018)	Focused on the utility of silver nanoparticles (AgNPs) in antimicrobial therapy. Highlights of the manner of microbial suppression, the synergistic action of antibiotics, the green routes for AgNP synthesis, and the obstacles that lie ahead in the development of nano-silver-based treatments.	Highlights the historical use of silver in antimicrobial therapy, challenges posed by silver-resistant strains, and the resurgence of interest in AgNPs due to the rise of multi-drug resistant ‘superbugs’.
Yah et. al., (2015)	discussing the potential of nanoparticles (NPs) as broad-spectrum antimicrobial agents. NPs offer advantages in overcoming limitations of conventional antimicrobial agents.	As long-lasting inhibitors of intracellular infections, sterilization and wound-healing agents, and broad-spectrum agents, NP-antimicrobial drugs exhibit potential. Multifunctional NPs have the potential to completely transform clinical medicine.
Durán et. al., (2016)	An overview of silver nanoparticles' antibacterial properties. The topics covered are the release of ions and silver nanoparticles, damage to cell membranes, DNA interaction, production of free radicals, resistance of bacteria to silver nanoparticles.	Highlights the potent antimicrobial activity of silver nanoparticles and explores various mechanisms of action, emphasizing the need for a comprehensive understanding of their antimicrobial properties.
Yun, et. al., (2017)	Pay attention to silver nanoparticles as a cutting-edge antibacterial agent. focus on the distinct alterations in the biological, chemical, and physical characteristics of nanomaterials.Recent studies reveal mechanisms such as membrane disruption, apoptosis, and synergy with conventional drugs.	Strong antibacterial effects of silver nanoparticles are exhibited by several pathways, including as rupture of membranes, induction of apoptosis in bacterial and fungal cells, and combination with traditional medications. Offers potential as a novel antimicrobial agent.

3. RESEARCH METHODOLOGY

Atoms in clusters ranging in size from 1 to 100 nm are called nanoparticles. The Greek term for dwarf, "nano," also means incredibly little. Because nanoparticles have distinct chemical, optical, and mechanical capabilities, their utilization is growing in the twenty-first century. The rise of resistant strains and the increasing microbial resistance to metal ions and antibiotics have piqued the interest of researchers in metallic nanoparticles. These nanoparticles seem to have promising antibacterial capabilities because of their huge surface area to volume ratio.

Many kinds of nanomaterials have been produced, including silver, alginate (Ahmad et al., 2005), gold , copper, zinc, titanium, and magnesium. However, silver nanoparticles have shown to be the most successful due to their strong antibacterial action against bacteria, viruses, and other eukaryotic pathogens . Because silver is harmful to mammalian cells, there are risks when employing silver nanoparticles as drug disinfectants, such as the possibility of argyria and agyrosis .

- **Silver as antimicrobial agent:** For generations, burns and chronic wounds have been treated with silver. Water could be made drinkable as early as 1000 B.C. by using silver The terms "Lunar caustic" in English, "Lapis infernale" in Latin, and "Pierre infernale" in French were used to describe solid silver nitrate when it was used .By 1700, salivary gland fistulae and other sexually transmitted infections were treated with silver nitrate.
- **Metallic silver:** The metallic silver's antibacterial properties are the result of an intriguing interaction between the dynamics of its release and abundance. In its natural metallic condition, silver is inert and inconspicuous. But its metamorphosis begins when it comes into contact with the sweat of the skin and the secretions from an open wound. This connection starts an amazing ionization process that makes silver extremely reactive and has significant effects on microorganisms.
  As it bonds with tissue proteins, the ionized form of silver starts a molecular dance, choreographing its moves. The bacterial cell wall and nuclear membrane undergo structural transformation as a result of this binding, which sets off a series of processes. These changes have important ramifications since they cause cell deformation, jeopardize the integrity of the bacterial structure, and ultimately cause the microbial entity to die. Silver's complex binding mechanism upsets the fragile equilibrium inside bacterial cells, making them more susceptible to the pressures of cellular deformation and disintegration. This focused strategy highlights how silver uses its reactivity to precisely counteract microbial dangers.
  Moreover, silver has an effect that goes beyond the actual world of biological structures. Silver exhibits its ability to interact with the genetic material that controls bacterial existence in a subtle demonstration of its antibacterial capabilities. To be more precise, silver binds to bacterial DNA and RNA and exerts its effect by denaturing the molecule. This interference stops the genetic material of bacteria from functioning normally, which prevents the important activities that are necessary for the survival of bacteria. Silver is a versatile therapeutic agent because of its dual nature, which targets both the physical and genetic components of bacterial organisms. In addition to interfering with the basic genetic machinery of bacteria, it can also cause structural alterations in the nuclear membrane and cell wall of bacteria. Silver's antibacterial qualities are used in a variety of medicinal contexts, which attests to its clinical importance. Silver's medicinal potential is especially beneficial for wound care, as it has been shown to be an excellent tool for promoting healing and preventing infections. Silver's antibacterial properties are harnessed through controlled release in medical goods, which also helps to minimize any potential negative effects that may arise from prolonged exposure.
- **Silver sulfadiazine:** Silver's antibacterial qualities are used in a variety of medicinal contexts, which attests to its clinical importance. Silver's medicinal potential is especially beneficial for wound care, as it has been shown to be an excellent tool for promoting healing and preventing infections. Silver's antibacterial properties are harnessed through controlled release in medical goods, which also helps to minimize

any potential negative effects that may arise from prolonged exposure. The composition of the cream is designed to establish a silver reservoir inside the wound, guaranteeing a steady and gradual release of silver ions. In addition to optimizing silver's medicinal benefits, this regulated release technique reduces the possibility of side effects from sudden or excessive exposure. The slow release of silver ions is a calculated move that guarantees an antibacterial effect that lasts the entire healing duration. The remarkable effectiveness of AgSD in the treatment of burn wounds is one of its unique characteristics. Because the skin's protective layers are damaged, burn injuries pose a special set of difficulties. AgSD's clinical usefulness is demonstrated by its capacity to function as a potent antibiotic when applied to burn injuries. The cream takes on a proactive role in the healing process by creating an atmosphere that supports tissue regeneration and protects against microbiological hazards at the same time. The cream's complex antimicrobial effect is demonstrated AgSD interacts with cellular elements, especially DNA. AgSD attaches itself to cell components and interferes with microbial DNA's ability to function normally, hence reducing bacterial viability. AgSD's ability to disrupt membranes further strengthens its antimicrobial defenses and makes environments unsuitable for harmful organisms. Atiyeh have emphasized how well AgSD works to treat wounds. The study confirms that sulfadiazine was the most effective sulfa medication tested in combination with silver. The clinical preference for AgSD in the field of wound care is supported by this empirical validation, especially given the complex nature of burn injuries. AgSD is used in medicine for purposes other than antibacterial activity. It functions as a therapeutic ally, aiding in the prevention of infections as well as the general advancement of wound healing. The use of the cream extends beyond the surface, exploring the cellular nuances that control the healing process.

- **Silver zeolite:** The ability of silver zeolite, a remarkable antibacterial substance, to stop the growth of different microbes has drawn a lot of interest. Using the ion exchange method, which involves the interaction of alkaline earth metals with crystal aluminosilicate, a complex process is used to manufacture this unique molecule. Silver ions are used to partially replace some of the metal ions. This leads to the production of a powerful, adaptable substance with significant antibacterial qualities, especially against bacteria and fungus. To include silver ions, the crystal structure of aluminosilicate, a form of zeolite, must be carefully altered in order to create silver zeolite. Zeolites are porous, crystalline minerals with a three-dimensional web of voids and channels. They can absorb and exchange ions without changing their crystalline structure because of their structure. Silver ions are added to the zeolite structure using the ion exchange method, a key approach in zeolite chemistry.

  There are several practical uses for silver zeolite in Japan, especially in the ceramics industry. Silver zeolite is used to these ceramics to give the finished goods antibacterial qualities. This invention has been used in a variety of industries, including as food preservation, material decontamination, and medical product disinfection. Silver zeolite is a great option for a variety of sectors since it has a long-lasting and strong antibacterial impact when added to ceramics. Scientific literature has provided ample evidence of silver zeolite's antibacterial capabilities. Research by

Matsumura has provided important new information about the effectiveness of silver zeolite in a variety of applications. These studies demonstrate how silver zeolite can stop bacteria and fungi from growing, highlighting its potential to stop contamination and maintain product integrity. Silver zeolite-coated ceramics serve as a barrier against microbial contamination in the field of food preservation. Silver zeolite's antibacterial properties help food goods last longer on the shelf by halting the growth of bacteria and fungus that cause spoiling. This use lowers the requirement for chemical preservatives while simultaneously improving food safety. Silver zeolite is essential for disinfecting medical supplies in medical environments. Silver zeolite's natural antibacterial qualities make it a useful tool for lowering the risk of illnesses related to medical devices and equipment. A prolonged antibacterial action is ensured by the regulated release of silver ions from the zeolite structure, improving the general safety of medical procedures. Silver zeolite also aids in the purification of materials used in a variety of industries. Because of its capacity to stop bacteria from growing, it is useful for preserving hygienic conditions in areas where contamination is a possibility. Whether it is utilized in consumer goods or industrial operations, silver zeolite offers a dependable and long-lasting defense against microbiological dangers.

- **The state-of-the-art:** The inhibitory effects of silver ions on two bacterial strains, Escherichia coli (E. coli) and Staphylococcus aureus (S. aureus), through a comprehensive mechanistic investigation. This work aimed to analyze the finer points of silver ion-bacterial interactions to provide light on the underlying processes of inhibition. Feng et al. used an experimental design in which they inoculated S. aureus and E. coli on Luria Bertoni (LB) medium. The bacterial cultures were then cultured for 16 hours at 37 °C on a rotary shaker spinning at 200 rpm. It was during this period of incubation that the bacteria multiplied and developed a stable culture. After the first incubation period, 10 µg/ml of silver nitrate was added to the liquid bacterial culture. To mimic the presence of silver ions in a regulated setting and track their effects on bacterial growth, this step was essential. After that, the culture was given another 4 to 12 hours to mature, giving researchers a window of opportunity to evaluate the antibacterial effects' temporal features. A sample of the culture was taken in order to evaluate the effect of silver ions on the biomass of the bacteria. Five milliliters of the liquid culture were extracted in this process, and it was then centrifuged. A more focused examination of the effects of silver ions on the bacteria was made possible by the centrifugation procedure, which made it easier to separate the bacterial biomass from the liquid medium. It's possible that the findings of Feng et al.'s investigation shed light on the dynamics of the interaction between bacterial strains and silver ions. In the context of creating potent antibacterial drugs and treatments, this research advances our knowledge of the molecular and cellular mechanisms behind silver's antimicrobial characteristics. The selection of S. aureus and E. coli bacterial strains is notable since they are prevalent and clinically relevant pathogens. Controlling bacterial infections is crucial in medical settings, therefore knowledge on how silver ions directly impact these bacteria is important for future uses. The work by Feng et al. is a prime example of the cutting edge approaches applied to examine the antibacterial drugs' mechanisms of action. The dedication to scientific quality in deciphering the complexity of antimicrobial interactions is reflected in the mix of experimental rigor, such as controlled bacterial cultures, and meticulous analytical techniques, including centrifugation.

- **Mechanism of action:** Even though silver has long been recognized to have antibacterial properties, its precise mode of action is currently being researched. Despite the lack of a definitive explanation, scientists have conjectured tenable routes based on documented morphological and structural modifications in bacterial cells with exposure to metallic silver, silver ions, or silver nanoparticles. Understanding these routes is necessary to fully utilize silver's antibacterial agent potential. It is thought that metallic silver interferes with microbial cell function in a number of ways when it comes into touch with them. A plausible mechanism entails the interplay between silver and the membranes of microorganisms. Silver's interference with the permeability and integrity of the cell membrane may jeopardize its structural integrity. This disruption has the potential to induce cell death and leak out the contents of the cell. Silver interacts with proteins inside the bacterial cell, potentially affecting their structure and functionality. This interaction with essential cellular components is responsible for the antibacterial effect of metallic silver. Silver ions has strong antibacterial capabilities and are obtained from substances such as silver nitrate or silver zeolite. Silver ions work by penetrating bacterial cells as part of their mode of action. Once within the cell, silver ions may interact with nucleic acids and proteins among other components. According to one theory, silver ions can attach to substances in microbial cells that contain phosphorus and sulfur, interfering with essential biological functions. Key biological components can be interfered with, which can hinder vital functions and prevent bacteria from growing and surviving. The vast surface area and compact size of silver nanoparticles confer unique antibacterial properties. Nanoscale interactions between microbial cells and silver nanoparticles are how they function. By penetrating bacterial cell walls and membranes, these nanoparticles can infiltrate the cells. Within the body, silver nanoparticles can modify the structure and function of proteins and genetic material, among other biological components. Silver ions are also released by nanoparticles, which influence a range of biological processes and functions and improve their antibacterial qualities. It is vital to keep in mind that although these theoretical mechanisms offer useful information, silver's antibacterial action is most likely context-specific and multifaceted. The specific interactions may vary depending on the type of microbe, the sort of silver used, and the environment. The complex ways that microbes react to silver highlight the need for more research to completely comprehend how it works.
- **Effect of size and shape on the antimicrobial activity of nanoparticles:** Having a larger surface-to-volume ratio allows for more interactions with microbial cells due to their size. This property affects how much a particle can disrupt and alter the biological structures of microbes, which is important information for assessing the antibiotic activity of a particle. Surface plasmon resonance (SPR), affects metal nanoparticle absorption spectra, and as particle size grows, this resonance phenomena switches to longer wavelengths. Understanding how SPR and particle size interact is

especially important for comprehending how size affects a nanoparticle's ability to fight microbes. These studies often point to the greater surface area of smaller nanoparticles as the reason for their improved antibacterial capabilities. Smaller nanoparticles have more surfaces on which to interact with bacterial cells due to their increased surface area. This enhanced propensity for contact raises the possibility of damaging biological components, like the cell membrane, which would amplify the bactericidal effects. Additionally, because of their tiny size, nanoparticles are better able to enter microbial cells, reach intracellular targets, and affect important biological functions. Furthermore, a key factor in determining a nanoparticle's antibacterial efficacy is its form. There are many other forms that nanoparticles can take, such as spheres, rods, triangles, and other geometries. Every shape has distinct qualities that affect how it interacts with microbes. When it comes to antibacterial applications, rod-shaped silver nanoparticles may be superior to their spherical counterparts. Higher aspect ratios may be present in rod-shaped nanoparticles, giving them more edges and corners to interact with microbial cells. The possibility of rupturing cell membranes and interfering with cellular functions is raised due to this increased surface complexity, which boosts the effectiveness of antibiotics. The composition of nanoparticles affects their antibacterial action in addition to their size and structure. In particular, silver nanoparticles are well known for having strong antibacterial qualities. The antibacterial actions of nanoparticles are partly attributed to the production of silver ions, which interact with microbial cells and cause disruptions to critical biological operations. Nanoparticles' antibacterial effect goes beyond simple physical interactions.

- **Silver coated medical devices:** Silver nanoparticles offer a viable substitute for metallic silver coatings on medical equipment, thereby resolving some of the latter's drawbacks. The healthcare industry has found success with this novel method because of the enhanced efficacy and distinct antibacterial characteristics provided by silver nanoparticles. Remarkable outcomes were reported in clinical trials utilizing metallic silver or silver ion-coated medical equipment. The inactivation of metallic silver when it comes into touch with blood plasma and the coatings' lack of stability were determined to be two of the main disadvantages. Furthermore, there was no discernible increase in antimicrobial activity with these coatings, which raises questions regarding their efficacy in preventing infections linked to medical equipment. presented a paradigm change by investigating the application of silver nanoparticles as coatings for medical devices in light of these difficulties. This constituted a noteworthy divergence from conventional methodologies and presented a propitious resolution to the constraints linked to metallic silver coatings. Silver nanoparticles have certain qualities that make them ideal for covering medical equipment. These nanoparticles' vast surface area and compact size enable improved interactions with microbial cells. This feature is essential for enhancing the coated medical equipment' antibacterial efficiency. Moreover, the application of nanoparticles solves the issues with earlier attempts using metallic silver by providing a more consistent and long-lasting covering. Silver nanoparticles have been shown to be useful in avoiding microbial colonization on medical equipment . Beyond their antibacterial qualities, silver nanoparticles are advantageous when applied to medical equipment. Biocompatibility of these nanoparticles has been demonstrated, reducing negative effects on host tissues. Maintaining the coating's compatibility with the surrounding biological environment is critical for successful clinical applications, making it a significant factor in the development of medical devices. Furthermore, worries about the emergence of microbial resistance are addressed by the introduction of silver nanoparticles. The complex antibacterial actions exhibited by silver nanoparticles hinder the development of resistance in microbes, hence prolonging the longevity of these coated medical equipment.

4. RESULT AND DISCUSSION

4.1 Assays for minimum inhibitory concentrations

The gram-negative bacterium E. Coli, the gram-positive bacteria S. aureus and B. subtilis, and the fungus P. phoeniceum were used in the minimum inhibitory concentration (MIC) tests for electrically produced silver ions and silver nanoparticles . In the case of silver nanoparticles, there is a combination of effects, including (i) that associated with Ag ions released from the nanoparticles and (ii) that of direct cell-nanoparticle interaction, which must be taken into consideration for an appropriate interpretation of the results obtained . Our nanosilver MIC experiment was designed to quantitatively evaluate the total antibacterial efficacy of nanosilver, not to identify which effect predominates. Therefore, it was required to apply higher concentrations of nanosilver than the concentration of electrically generated silver ions in order to suppress the growth of gram-positive and gram-negative bacteria and fungi . Silver ions have a strong antibacterial impact, but their application as antimicrobial agents in clothes, household items, and medical products is limited. This is because different compounds in a medium quickly bond to them or inactivate them. Because silver nanoparticles emit Ag ions continuously, they can be used as an antibacterial agent to get around this restriction .

4.2 Water-soluble paint that has been altered

We used our nanosized silver colloids to impregnate paints that are water soluble. Due to attractive contact forces, the majority of the original silver nanoparticles clumped together into clusters as large as 200 nm (Fig. 2). The growth of A. pullulans, P. phoeniceum, and S. aureus cultures on pasteboard samples treated with silver nanoparticles is depicted in the images in Figure 3. Here is a summary of the test findings for the water-soluble paint containing nanosilver and its antibacterial and antifungal properties. The plus sign denotes the presence of visible microbial growth, while the minus sign denotes its absence. B. subtilis and E. coli growth was suppressed when the concentration of nanosilver in water-soluble paint was increased to 5–6 μg/cm2. Over time, paint that dissolves in water may experience unfavorable color changes due to higher nanosilver concentrations. We saw a house in Tashkent, Uzbekistan, with paint on its outside that had been changed with nanosilver (0.8 μg/cm2). There was no discernible loss of silver nanoparticles in the wall paint during the eight months of the NAA tests.

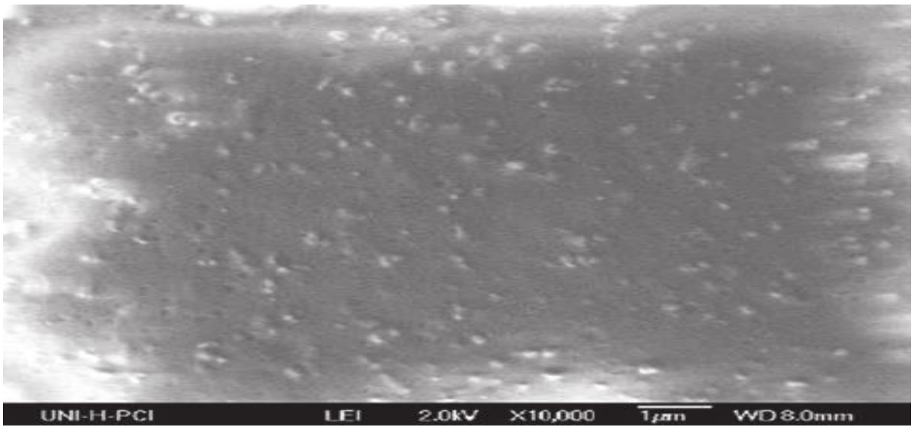

Fig.2. A sample of water-soluble paint with immobilized silver nanoparticles

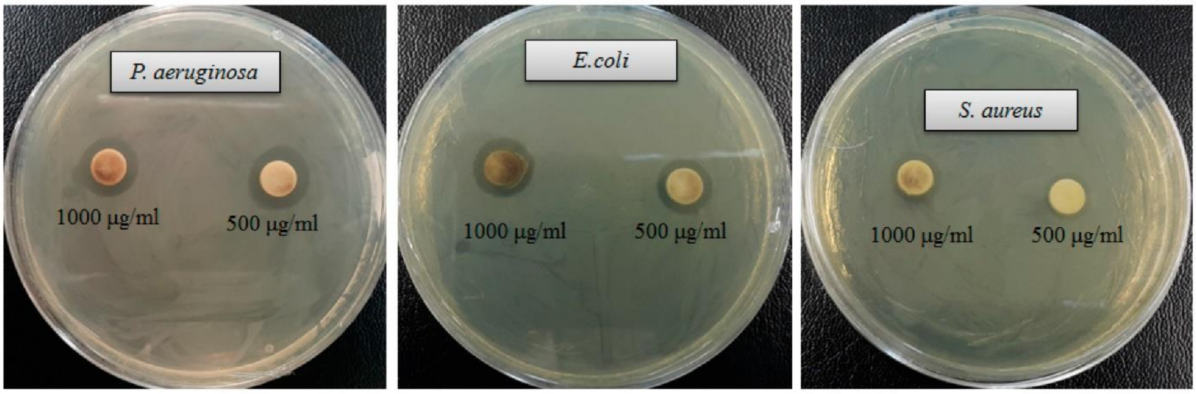

Fig.3. Growth of A. pullulans (left), P. phoeniceum (middle), and S. aureus (right) cultures on pasteboard samples modified by silver nanoparticles (note, the white spots correspond to microbial colonies). Sample #1 is a control sample, i.e., it was covered with nonmodified paint; sample #2 was covered with the paint modified by silver nanoparticles at a density of 0.8 μg/cm2

4.3 Cotton cloth altered

Additionally, we used the electrochemical method to produce nanosized silver colloids to saturate 100% cotton garment. On the surface of a cotton spread that had been changed, the particles' dispersibility was comparatively good. Nevertheless, it was also noted that silver nanoparticles aggregated into bigger clusters, measuring up to 200 nm (Fig. 4). A cotton cloth containing immobilized silver nanoparticles (mean particle size of 15 nm) at concentrations of 5 μg/cm2, 3 μg/cm2, and 1 μg/cm2 can prevent the growth of A. niger, P. phoeniceum, and S. aureus cultures on beef extract agar, as previously demonstrated. Silver nanoparticles measuring 7±3 nm were dissolved in water during the finishing step. By using this method, the silver particles on the 100% cotton fabric's surface were shrunk from micron size to approximately 100 nm. Thus, with nanosilver concentrations on the cotton fabric surface as low as even 1 μg/cm2, the antifungal/antibacterial effects for A. niger, P. phoeniceum, and S. aureus were confirmed. The same tests carried out on cultures of E. Coli, B. subtilis, and A. pullulans showed a strong antibacterial action at nanosilver concentrations of 7 μg/cm2, 5 μg/cm2, and 3 μg/cm2, respectively.

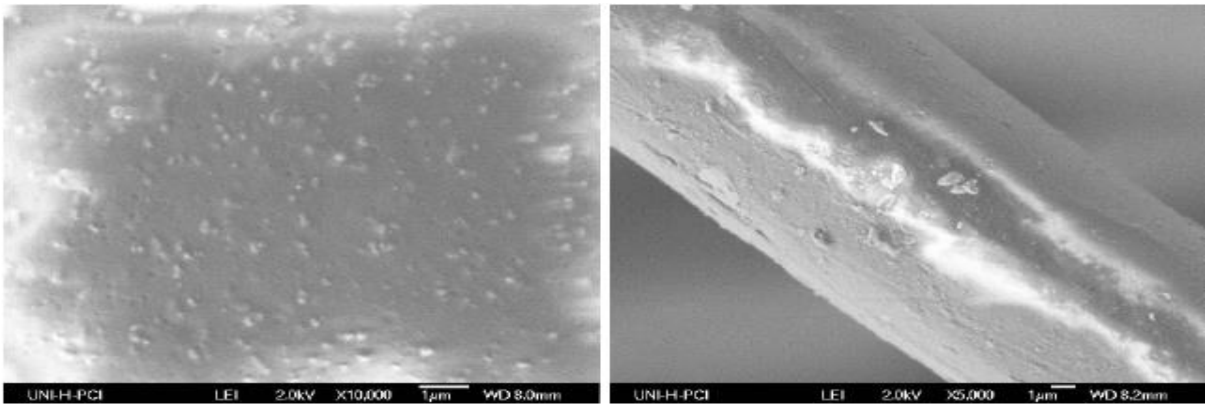

Fig. 4. A sample of 100% cotton with immobilized silver nanoparticles

4.4 Fibrous sorbent coated with silver nanoparticles for water treatment

In the old USSR, fibrous chemisorbents were extensively employed to treat industrial wastes and eliminate hazardous materials such as lead, zinc, copper, iron, and heavy metals as well as compounds including chromate anions, sulfate, and chlorine . The high rate of sorption (about 100 times higher than that of resins) and low pressure drop of the sorbent layer for purified water are two benefits of fibrous ion-exchange sorbents over resins. When fibrous sorbents are used as materials for water treatment, microorganisms have the ability to adhere to their surface and form biofilms, i.e., the sorbents can act as a reservoir of pathogenic microorganisms and potentially can lead to the risk of infection. We coated fiber ion-exchange sorbents with silver nanoparticles to stop microbiological growth and the development of a biofilm on the sorbents while they were being used. Due to the unique surface properties of the fibers, which are known to have a large surface area and high porosity, nanosilver not only attaches to the sorbent's surface but also penetrates and associates beneath it. The majority of the original silver nanoparticles aggregated into clusters as large as 300 nm in diameter due to forces of attraction between them. Our microbiological research unequivocally showed that the growth of these bacteria on the surface of the fibrous ion-exchange sorbents could be reliably prevented at a silver concentration of 20 mg/kg.

Conclusion

In conclusion, a new class of antimicrobials known as silver nanoparticles has surfaced, providing creative ways to counteract microbial dangers in a range of applications. Silver nanoparticles have special qualities that make them a viable solution for problems with conventional antimicrobial agents. These characteristics include their small size, vast surface area, and strong antibacterial activity. Silver nanoparticles' use in a variety of industries, including healthcare, demonstrate how versatile they are. Silver nanoparticles have shown great promise in medical settings for coating medical equipment, offering a practical way to stop microbial colonization and lower the risk of illnesses related to these devices. The prolonged antibacterial action of silver nanoparticles is ensured by their ability to release silver ions, which adds to the overall safety and effectiveness of medical therapies. Silver nanoparticles are used in more than only medical equipment; they are also used in antibacterial textiles and wound treatments. Silver nanoparticles have demonstrated efficacy in wound care by fostering healing and preventing infections, demonstrating its adaptability in managing intricate healthcare issues. In a similar vein, the introduction of silver nanoparticles into textiles has facilitated the creation of antimicrobial materials, which are used in home textiles, healthcare, and clothing, among other areas. Modern research on silver nanoparticles has shed light on important aspects of their methods of action. Exact mechanisms are still being investigated, but research has shown that the size and form of nanoparticles affect their ability to fight microbes. Silver nanoparticles' small size allows for improved interactions with microbial cells, and their various forms each have their own special benefits when it comes to upsetting cellular systems.

Despite the progress, problems including cytotoxicity and environmental harm still exist. The biological compatibility of silver nanoparticles is a crucial consideration. The goal of current research is to strike a compromise between human safety and antibacterial efficacy. Furthermore, addressing the environmental impacts of widespread nanoparticle use is necessary for ethical technical advancement.

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