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Silver Nanoparticles: A Modern Era of Nanotechnology

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ABSTRACT

Recently, Silver nanoparticlesare used for a wide range of applications, such as wastewater treatment, catalytic activity, wound heal targeted drug administration, antibacterial activity, because of their special and adjustable qualities. For the synthesis of silver nanoparticles, A variety of preparation techniques have been used noteworthy strategies include chemical methods, physical synthetic methods, and biological assisted methods. Characterization is carried out using a variety of entirely distinct methods, such as Fourier transform infrared chemical analysis (FTIR), X-ray Diffraction analysis (XRD), Energy-dispersive X-ray spectroscopy (EDX), transmission and scanning microscopy (TEM and SEM), and UV-Vis chemical analysis. This review paper's objective is to discuss the Synthesis, Characterization, Antimicrobial and Anticancer MOA of Silver nanoparticles and their toxicity and future prospectives.

Keywords: Silver nanoparticles, Synthesis of silver nanoparticles, Characterization, toxicity, Future prospects

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INTRODUCTION

The Greek word "nano," which means "extremely small," is equivalent with "dwarf." Because of their distinct chemical, optical, and mechanical qualities, nanoparticles are becoming more and more popular in the twenty-first century. the increasing microbial resistance to metal ions, antibiotics, and the emergence of resistant strains, researchers are becoming increasingly interested in metallic nanoparticles because of their promising antibacterial qualities and high surface area to volume ratio.[1,2]

Different types of nanomaterials like copper, zinc, titanium, magnesium, gold, alginate and silver have come up but silver nanoparticles have proved to be most effective as it has good antimicrobial efficacy against bacteria, viruses and other eukaryotic micro-organisms. They have virucidal, fungicidal, and bactericidal effects due to their antimicrobial qualities.[2]

Silver nanoparticles (AgNPs) are tiny particles of silver, typically measuring between 1-100 nanometers (nm) in diameter. They have unique physical, chemical, and biological properties, making them useful in various applications.[3]

Ag-NPs are currently being used for a wide range of applications, such as wastewater treatment, catalytic activity, targeted drug administration, and antibacterial activity, because of their special and adjustable qualities.[4]

several studies have reported applications in fields such as food processing, agriculture and agro-based industries, biomedical and medical remediation, health care products, consumer products, numerous industries, pharmaceuticals, in diagnostics, orthopaedics, drug de livery, imaging, filters as antitumour agents and as enhancer of tumour-killing effects of anticancer drugs.[5]

Silver nanoparticles (AgNPs) are used in wound healing because they have many beneficial properties, including they are effective against a wide range of microorganisms such as Gram-positive and Gram-negative bacteria, and biofilms that can cause chronic wounds.[6] They can reduce inflammation and the number of inflammatory cells in a wound[7] and can increase the amount of collagen deposited in a wound, which is linked to fibroblast and macrophage migration.[8] They are less toxic than conventional silver-based wound treatments[9] and also, they don't cause skin discoloration.[10] AgNPs are effective at lower concentrationsand they can be combined with other materials to promote healing.[11]

Mechanism of action of silver nanoparticles[12]

AgNP's antimicrobial MOA

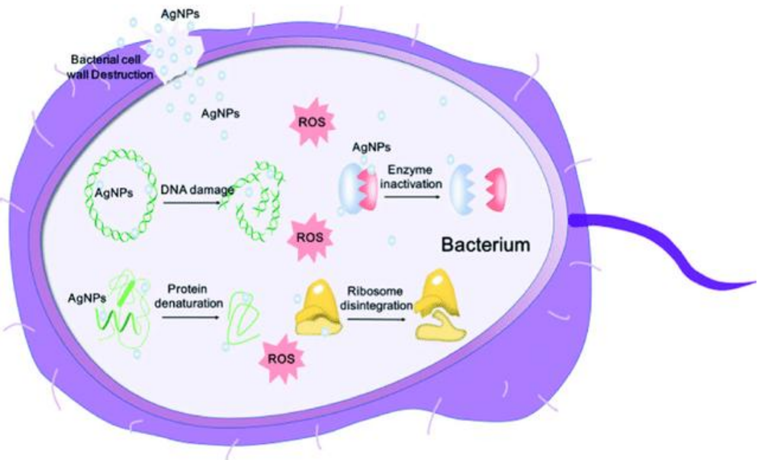

Figure 1: Mechanisms of AgNPs against bacteria[13]

AgNP releases Ag+ ions as it reaches the cell. These liberated ions subsequently interact with compounds in the cell wall that contain phosphorus and sulfur. Small pits and a disorganized cell wall development resulted from this. Ions and other external materials can enter the cell through the formed pit. The intracellular osmotic pressure rises as a result. The cell starts to inflate as the pressure inside it increases. Cell lysis occurs when the cell wall bursts as a result of all these events. Gram-negative cells have more of this kind of antibacterial action than gram-positive cells. Gram-positive cells have more teichoic acid in their cell wall and a cross-linked peptidoglycan layer.Gram-negative cells contain more lipopolysaccharide in their cell wall and less or no peptidoglycane layer. Because there is a lower barrier, AgNPs can interact with gram-positive cells more readily.

AgNP's anticancer MOA

As previously mentioned, Ag+ ions produced by AgNPs enter the cell when pit formation occurs in the cell wall. They then make their way to the mitochondria, where they interact with thiolgoups, adhere to the enzyme NADPH dehydrogenase, and release reactive oxygen species. These produced ROS in the mitochondria damaged the cell's respiratory cycle and ATP synthesis by interacting with respiratory enzymes. Additionally, formed ROS interact with cell components that contain phosphorus, sulfur, and proteins. Additionally, these generated ROS attach to phosphorus-containing DNA and RNA molecules, which prevents cell division and protein production. Cell death results from binding with DNA, which causes damage to protein synthesis and aggregation. Autophagy is a further potential mechanism.AgNPs can cause autophagy by inducing autophagolysosmes to accumulate in human ovarian cancer cells. Autophagy primarily functions in two ways: at a lower level, it boosts the survival rate of cells, but at a higher level, it causes cell death.

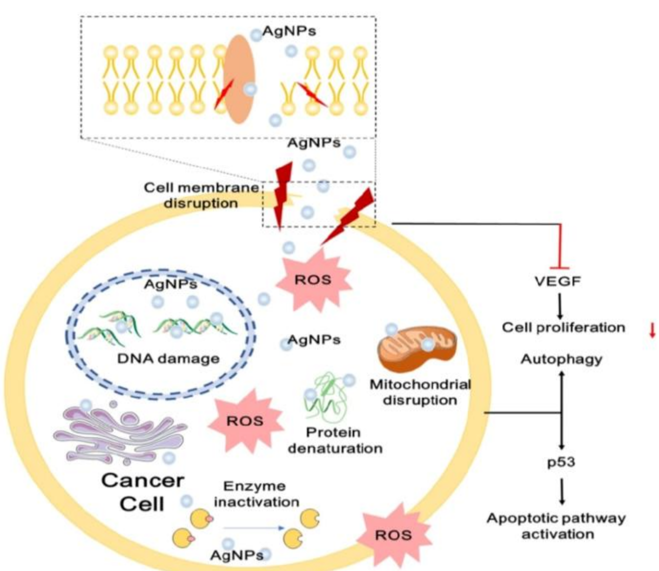

Figure 2: Anticancer mechanisms of AgNPs. [14]

SYNTHESIS OF AgNPs

Metal nanoparticles can be prepared by three ways, the first one is a physical approach that utilizes several methods such as evaporation/condensation and laser ablation. The second one is a chemical approach in which the metal ions in solution are reduced in conditions which favour the subsequent formation of small metal clusters. The third one is the biological methods mostly consist of green synthesis approaches, where extracts of different plants, prokaryotic bacterial cells, and eukaryotic fungi are used as reducing agents to reduce the metallic silver precursor for the preparation of AgNPs.[15]

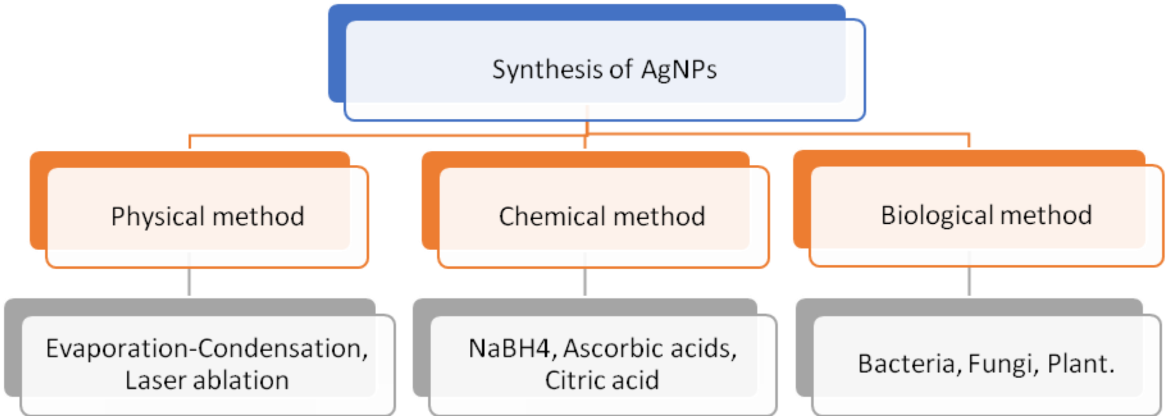

Figure 3: Methods to synthesize silver nanoparticles.

PHYSICAL METHOD[15]

Evaporation-condensation method

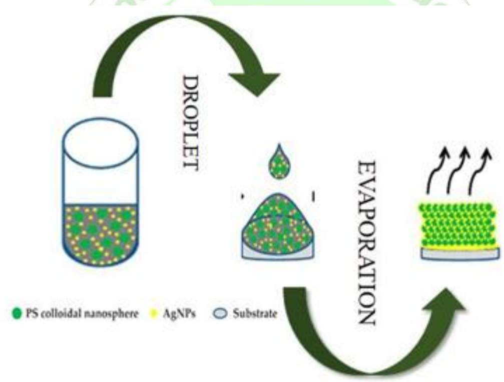

Figure 4: Synthesis of AgNPs by evaporation-condensation method

Laser ablation

Laser ablation is a method for fabricating various kinds of nanoparticles which also includes semiconductor quantum dots, carbon nanotubes, nanowires, and core shell nanoparticles. In this method, nanoparticles are generated by nucleation and growth of laser vaporized species with a background gas. The extremely rapid quenching of vapor is advantageous when production of high purity nanoparticles in the quantum size range (less than 10nm)

CHEMICAL METHOD[16]

The most frequently utilized technique to yield stable, colloidal AgNPs in water or organic solvents is chemical reduction. Citric acid is the most often used reductant. Silver is reduced in aqueous solution, and colloidal silver ions of nanosize are produced. Any colloidal dispersion must be stable, and this can be accomplished by using a stabilizing agent (dodecanethiol), which is adsorbed on the surface and creates a protective sheath. It can prevent the system from agglomeration and growing crystals. Small adjustments to the polymers' properties during the synthesis of AgNPs result in significant changes to their size, shape, morphology, polydispersibility index, self-assembly, and zeta potential (Stability).

The glycol derivatives polyvinyl pyrrolidone (PVP) and polyethylene glycol (PEG) are often utilized components in the synthesis of AgNPs and AuNPs. In the synthesis of AuNPs, polyacrylamide serves as both a stabilizing and reducing agent. The stability of colloidal dispersion, which guards against crystal formation, coaleseces, and agglomeration, is significantly improved by surfactants that include functional groups like amines, thoils, and acids. Currently, AgNPs in the range of 50–200 nm and 20–50 nm are produced by the modified tollens method, which uses saccharides, silver hydrosols, and a reducing agent to yield AuNPs.

BIOLOGICAL ASSISTED METHOD[17]

General method for biosynthesis of AgNPs by using plant extract

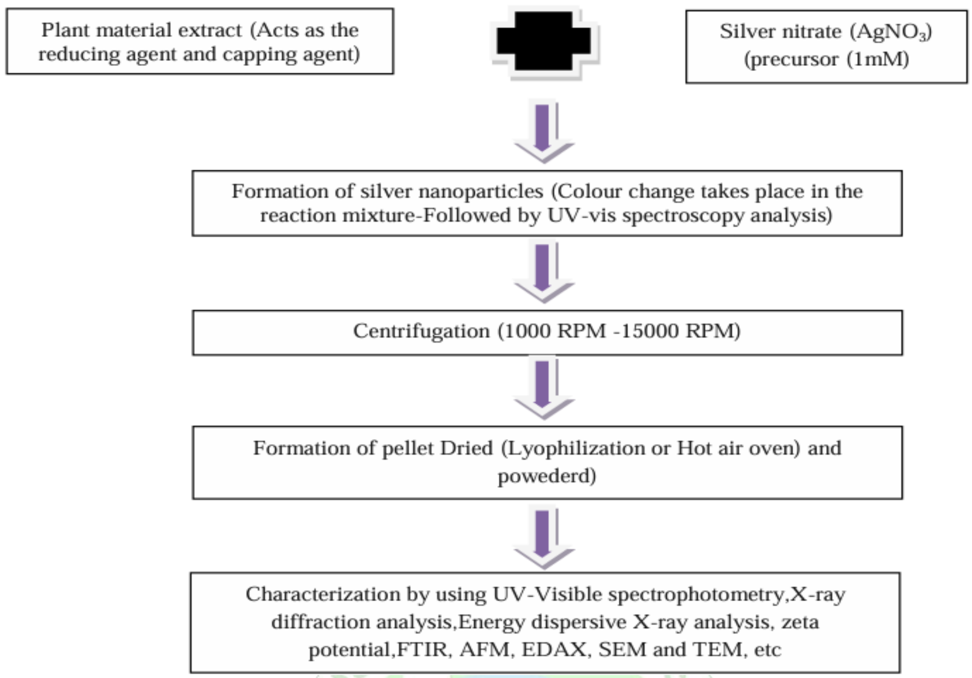

Figure 5: Biosynthesis of AgNPs By Using Plant Extract

General method for biosynthesis of AgNPs by using fungi (Shukla and sandhu et al.,2017)

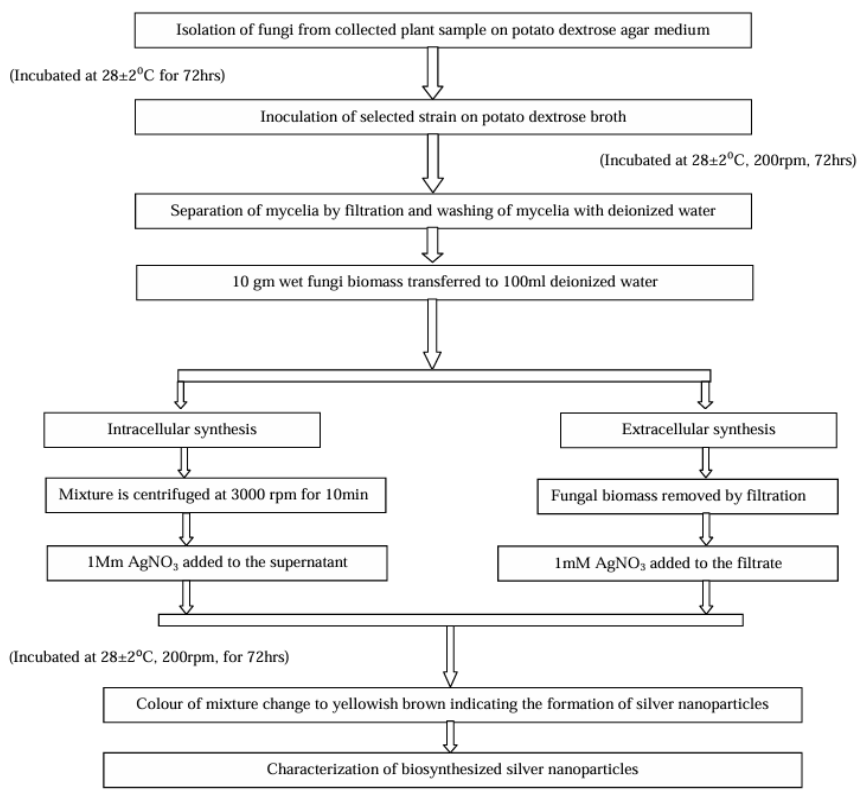

Figure 6: Biosynthesis of AgNPs By Using Fungi

General method for biosynthesis of AgNPs by using bacteria

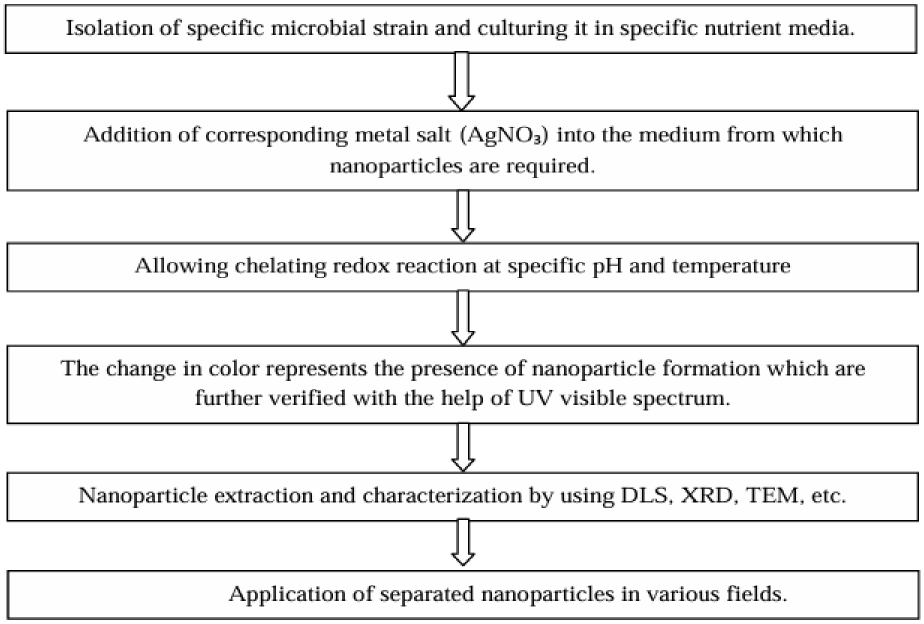

Figure 7: Biosynthesis of AgNPs By Using Bacteria

Characterization of Silver Nanoparticles

UV-Visible Spectroscopy

UV-vis spectroscopy is a very helpful and trustworthy method for the initial assessment of produced nanoparticles which is also used to monitor the stability and production of AgNPs. Silver nanoparticles interact intensely with particular light wavelengths due to their unique optical properties. Furthermore, UV visible spectroscopy is quick, simple, straightforward, sensitive, and selective for various kinds of nanoparticles and requires less measuring time. The valence and conduction bands of AgNPs are quite near to one another and in which electrons move freely. Because of the collective oscillation of electrons of silver nano particles in resonance with the light wave. These free electrons generate a surface plasmon resonance (SPR) absorption band. AgNPs absorption is depend onthe particle size, dielectric medium, and chemical surroundings.Observation of this peak—assigned to a surface plasmon—is well documented for various metal nanoparticles with sizes ranging from 2 to 100 nm. The SPR absorption for the produced nanoparticles was observed at 420 nm which was in correlation with literature and confirmed the formation of AgNPs.

Fourier transform infrared spectroscopy (FTIR)[5]

FTIR can be used to analyze various capping agents, investigate the surface chemistry of synthesized metal nanoparticles, and track the role of biomolecules in nanoparticle formation. Infrared rays are sent through the sample in FTIR; some of the rays are absorbed by the sample, while the rest pass through. The obtained spectra show the distinctive transmission and absorption of the sample material. A straightforward, practical, affordable, and non-invasive method for figuring out how biological molecules contribute to the reduction of silver nitrate to silver is FTIR.

X-ray diffraction analysis (XRD)[5]

By allowing X-rays to penetrate deeply into the material, XRD is a widely utilized analytical technique for observing the structure of crystalline metallic nanoparticles. The production of crystalline nanoparticles is confirmed by the diffraction pattern that results. The Debye–Scherrer equation is used to determine the width of the Bragg reflection law in order to calculate the particle size from the XRD data. This is done using the formula: $d = K\lambda/\beta \cos \theta$, where d is the particle size (nm), K is the Scherrer constant, λ is the X-ray wavelength, β is the full width half maximum, and θ is the diffraction angle (half of Bragg angle) that corresponds to the lattice plane. Consequently, XRD can be used to analyze the structural characteristics of a variety of materials, including proteins, polymers, glasses, and superconductors. Additionally, XRD is a powerful technique for researching nanomaterials.

Energy-dispersive X-ray spectroscopy (EDX)[18]

The elemental composition of a sample can be analyzed using EDX, a technique that has been shown to have applications in nanotechnology. The elemental composition of each nanoparticle can be determined using the distinct collection of peaks in the X-ray spectra that each element produces due to its various atomic structures.

Zeta analyzer[19]

The Zetasizer Nanoseries (Malvern instrument) was used to measure the size and zeta potential of silver nanoparticles.

Transmission Electron Microscopy (TEM)[20]

One of the most widely used and significant techniques for characterizing particles is TEM. We can determine the quantitative dimensions of particle size, particle size distribution, and particle morphological characters15 using this TEM approach. The distance between the objective lens and the specimen, as well as the distance between the objective lens and the image plane, will be used to calculate the TEM's magnification. Compared to SEM, TEM can offer superior resolution and analysis. SEM's drawbacks include the need for a high vacuum rate, the need for a very thin sample section, and occasionally the time commitment.

Atomic Force Microscopy (AFM)[3]

In addition to examining the size, shape, sorption, and structure of nanomaterials, AFM is typically used to examine their dispersion and aggregation. Three distinct scanning modes are available: contact mode, non-contact mode, and intermittent sample contact mode. Additionally, AFM may be used to characterize in real time how nanomaterials interact with supported lipid bilayers, something that is currently unable to do with electron microscopy (EM) techniques. Furthermore, AFM can measure up to the sub-nanometer scale in aqueous fluids, does not significantly harm many native surface types, and does not require oxide-free, electrically conductive surfaces for measurement. The overestimation of the samples' lateral dimensions as a result of the cantilever's size is a significant disadvantage, though. As a result, we must pay close attention to prevent inaccurate measurements.

Toxicity:

Silver nanoparticles can be toxic to cells, organisms, and the environment, and can cause a variety of effects, including:

1. **Cell death[21,22]**
   Silver nanoparticles can cause cell death through apoptosis or necrosis by stimulating the production of reactive oxygen species (ROS). ROS can damage the cell membrane, DNA, and gene expression.
2. **DNA damage[23]**
   Silver nanoparticles can cause DNA strand breaks and oxidative DNA damage.
3. **Mitochondrial toxicity[24]**
   Silver nanoparticles can affect mitochondrial function by changing the permeability of the mitochondrial membrane.
4. **Liver damage[24]**
   Silver nanoparticles can cause liver damage, as evidenced by elevated levels of liver enzymes in mice.
5. **Toxicity in fish[25]**
   Long-term exposure to high concentrations of silver nanoparticles can cause toxicity, fatality, and histological alteration in fish.
6. **Toxicity in shrimp**
   The toxicity of silver nanoparticles in shrimp depends on the concentration and exposure time.

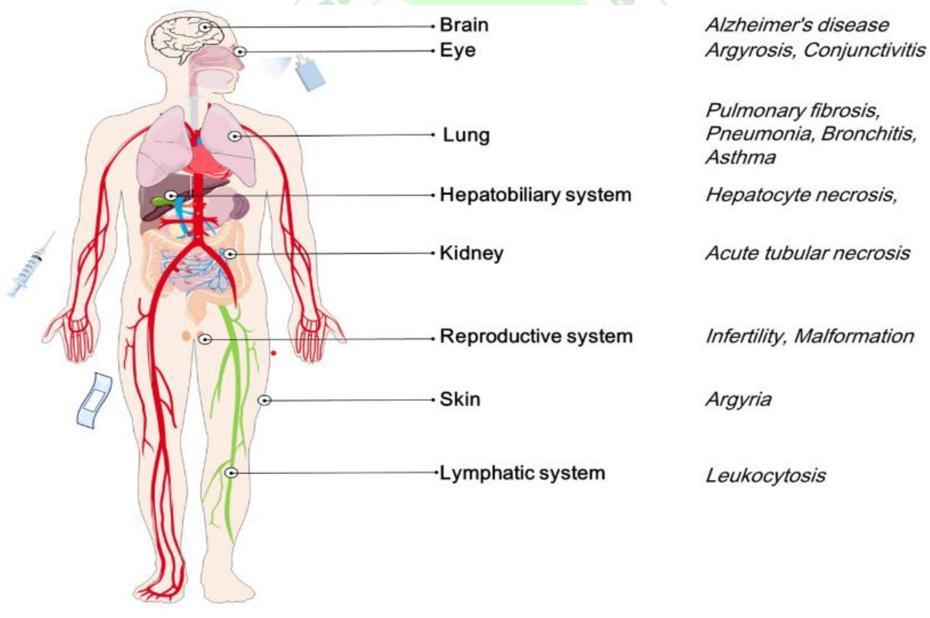

Figure 8: schematic representation of potential toxicities of AgNPs in the human body.[14]

Future Prospects:[12]

AgNPs are known for their anti-inflammatory properties and have potential uses in the healthcare system and in the treatment of infectious disorders. They are also becoming effective treatments for a wide range of bacterial infections that are resistant to treatment. In addition, it has several uses in biological and scientific domains like electrochemistry, biochemistry, the manufacture of nanoprisms, the clothing, detergent, and soap industries, and it is used in the development of surgical instruments and water purification systems. Ag-NPs have brought in a new era by being used in artificial implants that eliminate the need for antibiotics. According to studies, AgNPs have the potential to be used in the creation of novel pharmacological dosage forms and have a great deal of use in healthcare systems since they reduce bladder inflammation. AgNPs are helpful for biosensor detection in animal models.Future study is expected to focus on identifying a dependable mechanism that accounts for the remarkable biological activity of AgNPs. broad reach to improve the stability of AgNPs used in mechanical and medical devices and to consciously regulate the release of silver.

CONCLUSION:

Noble metal nanoparticles, like silver, have shown significantly distinct physical, chemical, and biological characteristics from their bulk counterparts over the last few decades. The production, characterisation, and future prospectives of silver nanoparticles are particularly covered in this review, with a focus on the antibacterial and anticancer properties. Silver nanoparticles are being developed by utilizing green chemistry. There are numerous techniques for producing silver nanoparticles that use plant extracts as capping or reducing agents. The current review illustrates various techniques for creating silver nanoparticles and their use in various industries.

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