A Glimpse of Silver Nanoparticles

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Silver (Ag) is a chemical element that has provided promising results in various fields such as medicine, electronics, and household applications, e.g., silver sulfadiazine has been used as a standard treatment for burn wounds to prevent the formation of biofilm on the wound area, thus enhancing the wound recovery progress. Silver is a part of transition metals and has been classified as a precious metal due to its decreasing availability. Silver has interesting properties, yet the uses of the materials are limited due to silver instability towards oxygen. Silver metal will oxidize spontaneously when exposed to free oxygen molecules. In these past few years, there has been an unprecedented rise in the application of nanoscience and nanotechnologies which lead to substantial progress in the production of nanomaterials. Thus, it had made possible to produce silver in nanoscale and these emerging nanoparticle products have attracted interest due to their physical, chemical, and biological properties in comparison with their macro-scaled counterparts. These properties are being assessed through various analytical techniques.

silver nanoparticles nanotechnology application

1. Analytical Evaluation of AgNPs

Evaluation of silver nanoparticles (AgNPs) involves various types of analytical techniques which includes X-ray diffractometry (XRD) at wavelength (λ) = 1.54056 Å, X-ray photoelectron spectroscopy (XPS) usually between 300–400 eV, Fourier transform infrared spectroscopy (FTIR) in wavelength range of 4000–400 cm^{-1}, ultraviolet visible spectroscopy (UV–vis spectroscopy) at the range of 400–500 nm, transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS) at scattering angle of 173°, and localized surface plasma resonance (LSPR) at wavelength of 300 nm to 1100 nm. These analyses are important to assess the behavior, bio-distribution, and reactivity of these fabricated nanoparticles. Table 1 shows the basic functions of the analytical techniques used for the characterization of AgNPs. However, the result of these analytical techniques depends on the synthesis of AgNPs which also alter the physicochemical properties of the nanoparticles. Recently, experiments with AgNPs have been conducted extensively due to their greater chemical, physical, and biological features compared to their bulk counterparts, such as their size, composition, crystallinity, shape, and structure.

Table 1. Analytical techniques and their basic functions in the characterization of silver nanoparticles.

Analytical Technique	Functions

X-ray diffraction	Measure the degree of crystallinity at the atomic scale. Used to analyze the structure of nanoparticles, particle sizes, for compounds identification, and to determine structure imperfections in the structures. The analysis depends on the formation of diffraction patterns
X-ray photoelectron spectroscopy	Determine the electronic states by atoms which include the oxidation state, and electron transfer in the nanoparticles. Estimate the empirical formulae by surface chemical analysis. Characterize the nanoparticles’ surface in the liquid forms.
Fourier transform infrared spectroscopy	Characterize various chemical bonding in nanomaterials.
UV–vis spectroscopy	Evaluate the stability and characteristics of AgNPs. Absorption of AgNPs depends on the dielectric medium, particle size, and the chemical environment. Size depends on surface plasmon for metal nanoparticles ranging from 2 to 100 nm.
Transmission electron microscopy	Measure of particle size, morphology, and size distribution. Provide better spatial resolution compared to SEM.
Scanning electron microscopy	Evaluate the morphology of AgNPs. Histogram obtains from images. Manually measure and count the particles or using specific software.
Dynamic light scattering	Measure nanoparticles size. Evaluate their stability over time in suspension at different pH and temperature conditions.
Localized surface plasmon resonance	Determine spatial oscillation of non-excited or excited (near-visible light) electron. Evaluate the molecular interaction on the surface of a nanoparticle. Depends on several factors: particle’s size and shape, electronic properties, dielectric media, and temperature

2. Properties of AgNP

The size, morphology, surface, and particle distribution of nanoparticles have proven to influence the physicochemical properties of AgNPs which can be altered through various synthesis methods, reducing agents, and stabilizers. Size has been the determining factor of biological properties of AgNPs and can be adjusted according to specific application typically in the range from 2 nm until 100 nm e.g., the size of AgNPs for drug delivery application need to be greater than 100 nm to accommodate for the quantity of the drug to be delivered. The toxicity of AgNPs is also dependent on the size of the nanoparticles: the smaller the particles, the higher the toxicity due the higher reactivity and ion release in cells. The shape of an AgNP also influences the toxicity as it can be applied in various types of nanostructures such as nanoplates, nanospheres, nanorods, and flower-like nanoparticles. Moreover, AgNPs are used in antimicrobial applications with proven antimicrobial characteristics of Ag^+ ions. These exceptional properties of AgNPs have enabled their use in the fields of nanomedicine, pharmacy, biosensing, and biomedical engineering.

Silver nanoparticles (AgNPs) are already in high demand in various fields which includ health care, medical, and industrial purposes, due to their unique physical and chemical properties. Their unique properties have been influenced by their surface-to-volume ratio which enables modification of their physical, chemical, and biological properties. AgNPs can be synthesized in different types of media—the liquid with different colloidal shapes, and infused into solid materials. The most intriguing properties of AgNPs is their biological activity which influenced by the size distribution, surface chemistry, particle morphology, chemical composition, agglomeration, capping agent, particle response in media, ion release, and the reducing agents used during AgNP synthesis. Understanding the physicochemical properties of AgNPs is crucial as it affects the cellular uptake, infiltration into biological membrane or barriers, the particles distribution, and the therapeutic effects. Therefore, the development of AgNPs that are uniform in morphology and functionality is important for various applications.

Additional insights into the characteristics of AgNPs are discussed in this review. This review presents comprehensive and detailed information on the synthesis of AgNPs by various methods as well as the antibacterial of a AgNP. In addition, the review also focuses on the antiviral effect, application, safety, and limitation of AgNPs.

3. Application of AgNPs

Silver nanoparticles (AgNPs) have been useful in different industrials, e.g., textiles, biomedicines, foods, and electronic applications, due to their unique physicochemical and biological properties. AgNPs are applied as antibacterial agents in disinfectants to water treatment. Moreover, the uses of AgNPs in the textile industry have gained quite a lot of attention due to the greater ion release and increasing catalytic activity as a result of the large surface area per mass of AgNP. The AgNPs are embedded into the fabric by two primary methods: (1) inserting the substrates with pre-formed nanoparticles and (2) inserting the substrates into a solution with silver salts and treating with reducing agents in order to convert silver salts into AgNPs. A silver nanocoated fabric shows a homogeneous distribution of AgNPs and excellent antibacterial activity. Next, the applications of silver in medicine have already been applied for a few decades. AgNPs have been applied as wound dressing products as it has been proven to significantly reduce the wound healing time while simultaneously prevent infection in the wound site [99]. Silver nanoparticles embedded in bacterial cellulose are able to perform the bactericidal activity on a Gram-negative bacterium (*E. coli*) and non-toxic to epidermal cells. Other than nanoparticles on their own, functionalized AgNPs also have been deemed useful in various industries.

4. Limitation of AgNPs

Silver nanoparticles (AgNPs) are known for their advantages in physicochemical properties in comparison with their bulk structure. However, these nanoparticles have their own limitations whereas one of the limitations is fast reaction with oxygen called oxidation. AgNPs are very sensitive with oxygen as the silver ion will bind to oxygen and form a strong bond called an ionic bond. The formation of this ionic bond will alter the structure of nanoparticles, thus changing the physicochemical properties of nanoparticles. The oxidized AgNPs also reduce the antibacterial properties of AgNPs due to its dependence towards silver ions. Another limitation in AgNPs is the tendency of these particles to be aggregated. There also a study that have tested AgNPs in different medium and the result shows that these nanoparticles tend to aggregate in dimethylformamide and tetrahydrofurane solutions which are an organic medium.

5. Conclusion

The occurrence of nanoparticles, particularly metallic nanoparticles, have been deemed very useful in numerous fields and have been acknowledged worldwide. This inclusive research on silver nanoparticles has been discussed in this review to have a better understanding on the characterization of physicochemical properties, synthesis, mechanisms of action, application, safety, and limitation of AgNPs. The unique physicochemical properties of the AgNP are dependent on various parameters of AgNPs such as size, surfactant, and structure morphology of these nanoparticles. Even though there are various methods in producing AgNPs, biological method or green synthesis have high yield and biocompatibility as it uses natural agents and nontoxic chemicals. In this review, we provide an inclusive discussion on the mode of action of AgNPs that have drawn attention as antimicrobial agents covering the antibacterial and antiviral properties of AgNPs towards various types of pathogenic viruses. Topics on the safety and limitation of AgNPs were also highlighted in this review where the aggregation and cytotoxicity of these nanoparticles have becoming the main concerns of AgNP applications. Lastly, research on a better understanding in cytotoxic mechanisms of AgNPs towards the environment by breaking the technologies limit could benefit the future prospects of AgNPs.
