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The Biological Activity and Surface Plasmon Resonance Effect of Gold and Silver Nanoparticles

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SILVER and gold have long been utilized as currency; they have also been used for clinical instruments for their antibacterial properties, which occur in metallic and salt structures. The utilization of metallic nanoparticles for restorative and sterile applications has become more acceptable recently because of advances in nanoscience and nanotechnology. Expanding the utilization of metallic nanoparticles in human well-being is an essential issue. As a general rule, the potential harmfulness of metallic nanoparticles requires safe application tactics. Nanocomposites are an excellent solution since the flexibility of the nano-objects is limited, but their mobility is maintained. This review aims to enhance the current understanding of the effectiveness of nanomaterials in eliminating dangerous bacterial species, improving human health and eliminating many diseases that may appear in the future. These materials will significantly and effectively reduce the future spread of diseases caused by the main bacteria that are resistant to traditional antibiotic treatments.

Keywords: Antimicrobial, Bacterial activity, Nanoparticles, Surface plasmon resonance.

Introduction

A nanoparticle acts as a solitary unit with regard to transport and qualities. Nanoparticles range from 1 to 100 nanometres in diameter. Nanoparticles kill microorganisms in various ways (El-Shounya et al., 2019; Elsayed et al., 2022; Ismail et al., 2022). Protection from nanoparticles requires the modification of various qualities, so organisms cannot oppose them in advance. Nanoparticles are the subject of emerging research in different fields because of their tremendous surface area-to-volume ratio and capacity to bond successfully with different particles and various elements. Nanoparticles have many uses, including hardware, beauty care products, biotechnology, and medical services. Processes such as weakening, pyrolysis, and different wet compound strategies can be utilised to make nanoparticles (LewisOscar et al., 2016).

Nanotechnology is a dynamic and quickly developing discipline that includes nanoscale science, design, and innovation . Nanotechnology consists of nanoparticles (NPs) or nanomaterials with sizes going from 10 to 100 nanometers. NPs are classified as normal, unintentional, and made (Buzea et al., 2007). Their enormous surface area-to-volume ratio and ability to bond with different particles and elements make them significant assets in various industries. Nanotechnology is a brilliant accentuation region due to the good crystallographic and physiochemical properties of NPs. The usual technique for the production of nanoparticles is the wet strategy (Kim et al., 2007). Because of their surface area, number, and tiny size, nanoparticles have superior biocompatibility, great adsorption capacity, and easy surface modification (Khlebtsov & Dykman, 2011), and they have potential applications in medical imaging, drug administration , and disease detection (Mukherjee et al., 2016). Due to the presence of other compounds, such as the citrate and Au(III) ions used in the gold nanoparticle (AuNP) photo-mutagenicity test (Wang et al., 2011), the toxic effects of AuNPs are complex.

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Nanomaterials have emerged as a promising and efficient choice for replacing traditional materials in most applications across all disciplines of science and technology. Nanomaterials have a larger surface area-to-volume ratio and a higher number of active atoms on their external surfaces due to their ultra-small scale (Azam et al., 2009). Some metallurgical nanoparticles, such as silver and gold, have been certified as bactericidal and bacteriostatic agents with diverse characteristics and activity (Lansdown, 2006; Zhou et al., 2012). AuNPs are widely utilised in medical and gene therapy, as well as biosensors, for the diagnosis of key biological conditions. Gold nanoparticles are easier to co-precipitate and have lower toxicity than silver nanoparticles (AgNPs) (Shamaila et al., 2016). The challenge of antibiotic-resistant bacteria, as well as the focus on healthcare costs, has prompted researchers to devise novel strategies for producing more effective antimicrobial drugs to combat bacterial resistance and lower costs (Kim et al., 2011).

Gold nanoparticles (AuNPs)

AuNPs have attracted interest due to their optical and electrical properties, which depend highly on their shape and size (Verissimo et al., 2016). By varying their components and concentrations, AuNPs of various forms and sizes may be easily synthesised (Wiley et al., 2007). Circular, rod-like, cage-like, and various other AuNPs forms can be synthesised in laboratory and industrial settings. Most AuNP research has focused on the functionalisation of biomolecules, such as medicines, genes, peptides, and other targeted ligands. Compared to antibiotics or other medications alone, AuNPs conjugated with antibiotics or pharmaceuticals have shown better antibacterial or antiviral action. According to the evidence, bare AuNPs do not affect bacterial growth or function; however, AuNPs coupled with biomolecules have been shown to reduce bacterial cell proliferation. Some researchers have claimed that the permeability of cells by AuNPs with specific, small diameters causes harmful consequences, while others have claimed that AuNPs are not poisonous in the same organisms. Recent work on the antibacterial activity and toxicity of AuNPs needs to be revisited due to these contradicting findings (Burygin et al., 2009).

Silver nanoparticles (AgNPs)

Drug-resistant bacteria produce infectious illnesses that are severe public health problems. Antimicrobial drugs are constantly being developed by scientists to combat these infections. The antimicrobial activity of AgNPs against multidrug-resistant bacteria is well-known (Allawadhi et al., 2021). The amount of research on AgNPs has recently increased dramatically. The first reason is that AgNPs can be made by altering the nucleation and development processes with different engineered synthetic substances. Second, special atomic layers, for example, proteins and substance gatherings, can be utilised to unequivocally functionalise AgNPs . Third, AgNPs have strong antibacterial properties that help remedial treatment (Oves et al., 2018). In particular, AgNPs have a wide range of uses in healthcare, including wound infection treatment, tumour targeting, medication administration, and sensors (Singh et al., 2018; Singh et al., 2021). Biological approaches are the most promising of the many nanoparticle production methods because of their effectiveness, adaptability, and benign environmental approach. Given the wide range of biological uses for AgNPs and AuNPs, several biological systems for generating AuNPs must be investigated. AgNPs can be synthesised by various microbes, including bacteria, yeast, and fungi. Bacterial systems are a great choice among these options because they are simple to handle and may be genetically altered with ease (Vaidyanathan et al., 2010). One of the most promising possibilities is the development of stabilised polymer–metal nanocomposites containing MNPs. In both basic and applied research, AuNPs have piqued interest. As the number of AuNPs used grows, human safety issues become more prevalent (Domènech et al., 2012; Hussain et al., 2015).

Surface plasmon resonance (SPR) effect

The significant surface plasmon resonance (SPR) effect of AuNPs, which results from the interaction of an electromagnetic wave with the conductivity of electrons in a metal (Bankar et al., 2010), has also garnered greater attention. Chitosan, which is positively charged, is required for bacterial interactions and has been linked to antibacterial activity (Sarwar et al., 2015). Positively charged AuNPs can penetrate the anionic cell film of gram-positive and gram-negative microscopic organisms, causing AuNPs to accumulate on the bacterial cell layer, followed by bacterial cell lysis (Hayden et al., 2012). In addition, the babbling prompted by charged AuNPs invades the oppositely charged bacterial cell film, causing DNA to leak through the fragile cell layer. Accordingly, chitosan can improve the biocompatibility of AuNPs (Zhao et al., 2010).

One sterilisation method under study is photodynamic treatment (PDT), which uses light-absorbing colours to generate hazardous oxygen radicals that kill germs. However, this treatment may not be beneficial for infections in hypoxic circumstances. Using metal nanoparticles and laser radiation in photothermal therapy (PTT) to physically destroy bacteria is another potential technique (Zharov et al., 2006). Surface plasmon resonance (SPR), which is classed as localised surface plasmon resonance (LSPR) when restricted to small colloids, has been associated with the optical attributes of conductive nanoparticles (NPs), for example, those made of gold. When the surface electrons are affected by the particular wavelength of light that resonates with their LSPR, they vibrate, causing a frequency-dependent photothermal impact. AuNPs retain full light energy and discharge heat, making them important for phototherapy applications, for example, focusing on malignant growth and killing bacterial cells. Bacterial cells are disrupted by photothermal laser-activated events, resulting in death (Millenbaugh et al., 2020).

Because of their small particle size, nanoparticles have a high surface area-to-volume ratio, allowing them to incorporate a variety of functional ligands that can improve target–bacterium interactions (Li et al., 2014). Furthermore, particle size and surface charge alter the antibacterial action of metal nanoparticles, including AgNPs and AuNPs (Martínez-Castañon et al., 2008). AuNPs stand out as new antibacterial treatments. Nonetheless, harmful impacts and insecurity of AgNPs have been recently noticed (Ahamed et al., 2008). The harmfulness of AgNPs has recently been connected to their introduction to and accumulation in the mitochondrial film, which results in mitochondrial dysfunction (Akter et al., 2018). Contrasted with AgNPs, AuNPs are more stable, inactive, and non-poisonous. Their size is also more easily controlled than AgNPs (Cui et al., 2012). Moreover, the antibacterial impact of AuNPs did not cause reactive oxygen species (ROS), which can prevent unsafe aftereffects in mammalian host cells.

Effective methods of measuring biological activity

Spread plate technique

Prevention of bacterial action is a significant factor in the appraisal of the capacity of nanoparticles to kill or hinder the development of yeast. The technique we depict here can determine the capacity of a nanoparticle to eliminate bacterial cells in a contact-dependent way when co-refined on an agar surface. It is especially valuable since it allows for a reasonably objective measurement of cell recovery and subsequent measurement of the antibacterial activity (Ajah et al., 2018a). This method was performed by adding 1 ml of nanomaterial to 2 ml of the culture medium. After that, original broth suspension dilutions were made up to 10^{-7} dilution. The agar medium was melted and poured into sterilised Petri dishes, and the plates were then allowed to solidify. About half an hour after the media were poured, 0.5 ml of 10^{-5} to 10^{-7} dilution suspension was taken and placed aseptically in separate Petri dishes. Next, a glass spreader was sterilised by burning, and the suspension was spread carefully and aseptically over the medium within the Petri dish. The plates are kept inverted within an incubator for 2–3 days and examined for the appearance of colonies. Each treatment was replicated. After 24–48h of incubation, the plates were examined, and the number of colonies was counted, as shown in Fig.1.

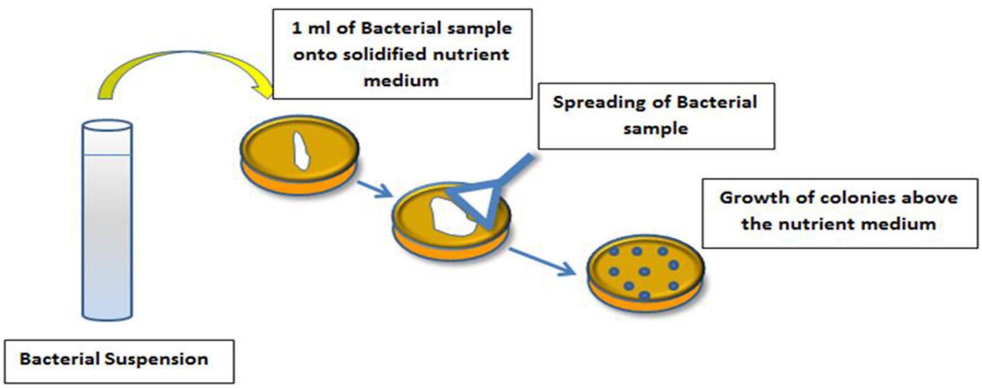

Fig. 1. Spread plate technique

Well diffusion method (WDM)

The biological activities of the test nanoparticle were evaluated by the well diffusion method (WDM) against different types of bacteria such as *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Streptococcus* spp., *Escherichia coli*, *Klebsiella* spp., and *Pseudomonas auruginosa*. The biological activities of metallic nanoparticles against these different bacterial isolates are shown in Table 1. In this technique, the antimicrobial activities of several agents can be tested on a single Muller–Hinton agar plate (Hi Media, Mumbai, India) using a sterile swab. The plates were allowed to dry, and an 8.0-mm diameter sterile stopper drill was used to drill two wells in each agar plate. A 10µL aliquot of each nanoparticle was applied by micropipette in the wells in the Muller–Hinton agar plate. The plates were allowed to develop for 1 hr while dispersion occurred. Afterwards, it remained at 37°C for 24h. Figure 2 shows the zone of hindrance recorded (Ajah et al., 2018b).

Microscopic factor calculation

Our results showed that the reduction in bacterial numbers was 100% after treatment with the nanomaterial in this study for all types of bacteria. All kinds of bacteria were completely killed after the nanomaterials were added to the culture medium, as shown in Table 2.

A is the number of viable microorganisms before treatment and is the number of viable microorganisms after treatment.

Conclusion

This study found that gram-positive bacteria are more impacted by the nanoparticles utilised, with the highest observed diameter of inhibition, compared to other types of bacteria (gram-negative) that showed varying degrees of influence. Where the diameters of the inhibition zone of *Staphylococcus epidermidis* for the nanoparticles in this study were smaller, it could be that the structural composition of the bacterial wall prevented the bacteria from triggering an entrance to the layer of the external membrane, as opposed to gram-negative bacteria. Silver nanoparticles integrated into dental materials might work on the mechanical and antibacterial characteristics of the materials. Numerous analyses show that AgNPs constantly emanate Ag particles that kill microorganisms, although the mechanism for the antibacterial activity of AgNPs remains unknown. For prosthetic, helpful, endodontic, orthodontic, periodontal, and embedded treatment, dental materials containing AgNPs are being developed. Human cells have been described as cytotoxic by AgNPs in a few studies. However, the clinical meaning of this theoretical toxicity of AgNPs is unclear. Since clinical information is presently restricted, more exploration is required.

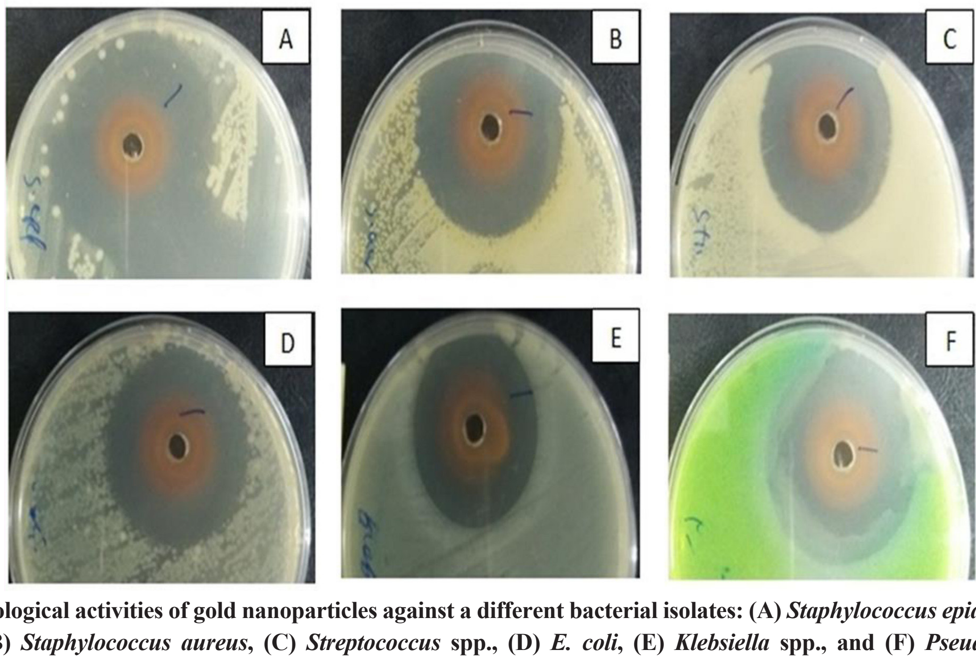

Fig. 2. Biological activities of gold nanoparticles against a different bacterial isolates: (A) *Staphylococcus epidermidis*, (B) *Staphylococcus aureus*, (C) *Streptococcus* spp., (D) *E. coli*, (E) *Klebsiella* spp., and (F) *Pseudomonas auruginosa*

TABLE 1. Summary of research on the biological activity of Au and Ag nanoparticles against various bacterial strains

No.	Article title and content outlines	Results
1	An inexpensive, rapid, single-step technique for synthesising AgNPs using the endophytic fungal supernatant of Alternaria sp. was developed.	(1) The results of TEM and AFM have confirmed that the synthesised AgNPs are mostly spherical, with an average size of 4–30nm, as shown in Fig.3. (2) The XRD, EDS, and SAED results confirmed the crystalline nature and elemental composition of the synthesised AgNPs. (3) These AgNPs showed antibacterial activity against human pathogenic bacteria (Singh et al., 2017).
2	Using Solanum lycopersicum extract, a green biogenic approach for manufacturing Au and AgNPs was developed.	(1) The surface plasmon reverberation top is seen in the UV-visible spectra at 546nm and 445nm, relating to Au and AgNPs, respectively. (2) The TEM images showed that the normal size of the incorporated Au and AgNPs was 14nm and 12nm, respectively. (3) The resulting Au and AgNPs show great detection and antibacterial properties (Bindhu & Umadevi, 2014).
3	The electrolysis approach was used to create AuNPs (AuNPs).	(1) The TEM images showed that the AuNPs prepared by electrolysis were approximately spherical and had a diameter of about 16 nm, as shown in Fig. 4. (2) The X-ray diffraction patterns of a gold thin film on a glass substrate showed that the film is a multifaceted structure. (3) The results showed that the nanoparticles have an inhibitory effect against all types of pathogenic bacteria of 30 and 25 mm for aerosols, E. coli, Bacillus subtilis, and Staphylococcus aureus, respectively (Jabbar et al., 2020).
4	AuNPs were biosynthesised using Citrobacter freundii isolate (C2) was isolated from chicken meat samples by the pour plate method and identified using culture characteristics and biochemical tests. The identification to the species level was completed by the Vitek-2 system, and this identification was confirmed by sequencing 16sr RNA.	(1) The results revealed the biosynthesised AuNPs were roughly spherical and poly-dispersed. (2) The AuNPs were exceptionally effective in repressing bacterial development at a concentration of 62.5 g/ml. The MIC of antimicrobial activity in clinical settings has not been established as 500g/mL. (3) The mix of AuNPs and AMC showed a large range of antibacterial activity against the bacterial isolates in this study (Hashim, 2019).
5	Chemically produced spherical AuNPs (Au).	(1) The prepared AuNPs were almost spherical and separated from each other. The particle size is mainly in the range of 11–22nm. (2) The AuNPs were exceptionally effective at a concentration of 62.5g/mL in repressing bacterial development (3) The inhibitory concentration of AuNPs is well below the generally accepted limit for clinically acceptable MICs of 500 g/ml. Meanwhile, a mixture of AuNPs and AMC showed an expansive range of antibacterial activity against the bacterial isolates examined in this study (Zawrah et al., 2011).

TABLE 2. Reduction percentage in bacterial numbers of nanoparticles against a different bacterial isolates

Bacterial isolates	Reduction percentage (100%)	
	After treatment	Before treatment
Staphylococcus epidermidis	100%	0 %
Staphylococcus aureus	100%	0 %
Streptococcus spp.	100%	0 %
E. coli	100%	0 %
Klebsiella spp.	100%	0 %
Pseudomonas auruginosa	100%	0 %

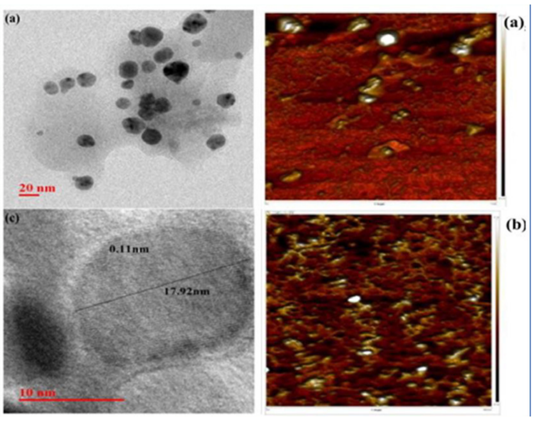

Fig. 3. TEM and AFM of silver nanoparticles

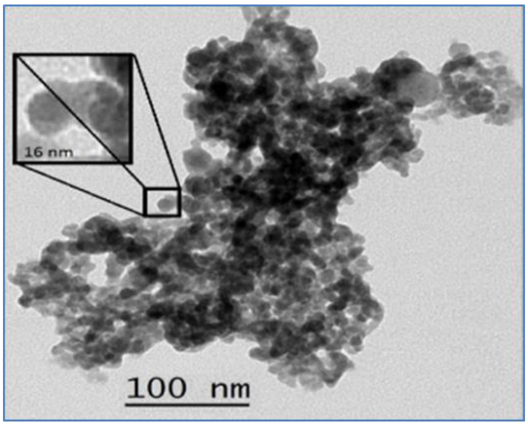

Fig. 4. TEM of gold nanoparticles

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Authors' contributions: The authors made contributions to all aspects of this review.

Ethical approval: Not applicable.

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النشاط البيولوجي وتأثير رنين البلازمون السطحي لجسيمات الذهب والفضة النانوية

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لفترة طويلة، تم استخدام الفضة والذهب في نطاق العناصر التي يمكن الوصول إليها نقديًا والمعدات السريرية نتيجة لخصائصها المضادة للبكتيريا، سواء في الهياكل المعدنية أو الملحية. أصبح استخدام الجسيمات النانوية المعدنية للتطبيقات الترميمية والمعقمة أكثر طبيعية في الآونة الأخيرة بسبب التقدم في علوم النانو وتكنولوجيا النانو. بشكل جيد وشامل يعد استخدام الجسيمات النانوية المعدنية في رفاهية الإنسان أحد القضايا الأساسية. كقاعدة عامة، فإن ضرر الجسيمات النانوية المعدنية هو الذي يتطلب استخدام أساليب آمنة لتطبيق الجسيمات النانوية المعدنية. تعتبر المركبات النانوية حلاً ممتازًا نظرًا لأن مرونة الأجسام النانوية محدودة ولكن يتم الحفاظ على حركتها. ستعزز نتائج المراجعة المفهوم الحالي لفعالية المواد النانوية في القضاء على الأنواع البكتيرية الخطرة، والتي بدورها ستحسن صحة الإنسان والقضاء على العديد من الأمراض التي قد تظهر في المستقبل، حيث سيكون لهذه المواد تأثير مستقبلي لتقليل انتشار الأمراض التي تسببها البكتيريا الخبيثة المهمة التي تقاوم العلاج بالمضادات الحيوية التقليدية.