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SILVER NANOPARTICLES: A PROMISING TECHNIQUE FOR DRUG DELIVERY

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ABSTRACT

Silver nanoparticles (AgNPs) are a class of nanomaterials that have been widely used in biomedical applications due to their practicality in contemporary society. AgNPs are composed of a variety of atoms, ions, and particles, which are characterized by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), XPS, dynamic light scattering (DLS), scanning electron microscope (SEM), transmission electron microscopy (TEM), atomic force microscopies (AFM), and a wide range of physicochemical and biochemical properties. Several studies have been conducted to evaluate the anti-inflammatory, antioxidant, antibacterial, and anticancer properties of AgNP-based nano systems. This review focuses on the recent advances in the field of nanotechnology and discusses the current status of silver nanotechnology.

Keywords : Silver nanoparticles, X-ray diffraction, scanning electron microscope, anti-inflammatory, antioxidant

INTRODUCTION

Silver nanoparticles (AgNPs) have special physical and chemical characteristics, they are being employed more and more in a variety of industries, including food, drug, healthcare, consumer, and industrial industries. These include of biological qualities, strong electrical conductivity, optical, electrical, and thermal characteristics. Due to their peculiar properties, they have been applied to a broad range of products and industries, including pharmaceutical, food, and medical device coatings; optical sensors; cosmetics; industrial, household, and healthcare products; and finally, they have enhanced the antibacterial properties of anticancer drugs. In recent years, AgNPs have been widely used in a variety of fabrics, wound dressings, keyboards, and biomedical equipment.[(1)(2)]

Metallic nanoparticles have found numerous uses due to their unique capacity to modify physical, chemical, and biological features in a significant way because of their surface-to-volume ratio. To fulfill the need for AgNPs, a range of synthesis strategies have been employed. Many people believe that conventional physical and chemical treatments are very expensive and dangerous. Interestingly, physiologically generated AgNPs show good production, solubility, and stability. Of the various synthetic methods for AgNPs, biological techniques seem to be the most simple, fast, safe, dependable, and eco-friendly. In the right conditions, they can provide well-defined size and form for translational research. All things considered, a green chemical approach seems to have a lot of promise for producing AgNPs. [(3)(4)]

Following synthesis, the particles must be precisely characterized because their physicochemical characteristics might have a big impact on their biological characteristics. It is vital to characterize the manufactured nanoparticles prior to use in order to address the safety issue and utilize all available nanomaterials for human health, nanomedicine, or other industries. Before determining a material's toxicity or biocompatibility, its size, shape, size distribution, surface area, form, solubility, aggregation, etc., must be examined. The synthesized nanomaterials have been evaluated using a variety of analytical techniques, such as dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), ultraviolet-visible spectroscopy (UV-visible spectroscopy), X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), and so on.[(5)(6)(7)]

AgNPs' biological activity is determined by a number of factors, such as their surface chemistry, size, shape, size/distribution, morphology, composition, coating, rate of agglomeration and dissolution, particle reactivity in solution, ion release efficiency, and cell type. When it comes to AgNPs' cytotoxicity, reducing agents used during synthesis play a critical role. The physico-chemical characteristics of nanoparticles enhance the bioavailability of medicinal compounds following both local and systemic administration. However, this may have an impact on the therapeutic benefit that results from cellular absorption, biodistribution, and biological barrier penetration. For this reason, the creation of AgNPs with regulated structures that are consistent in size, shape, and function is crucial for a range of biomedical uses.[8][9][10]

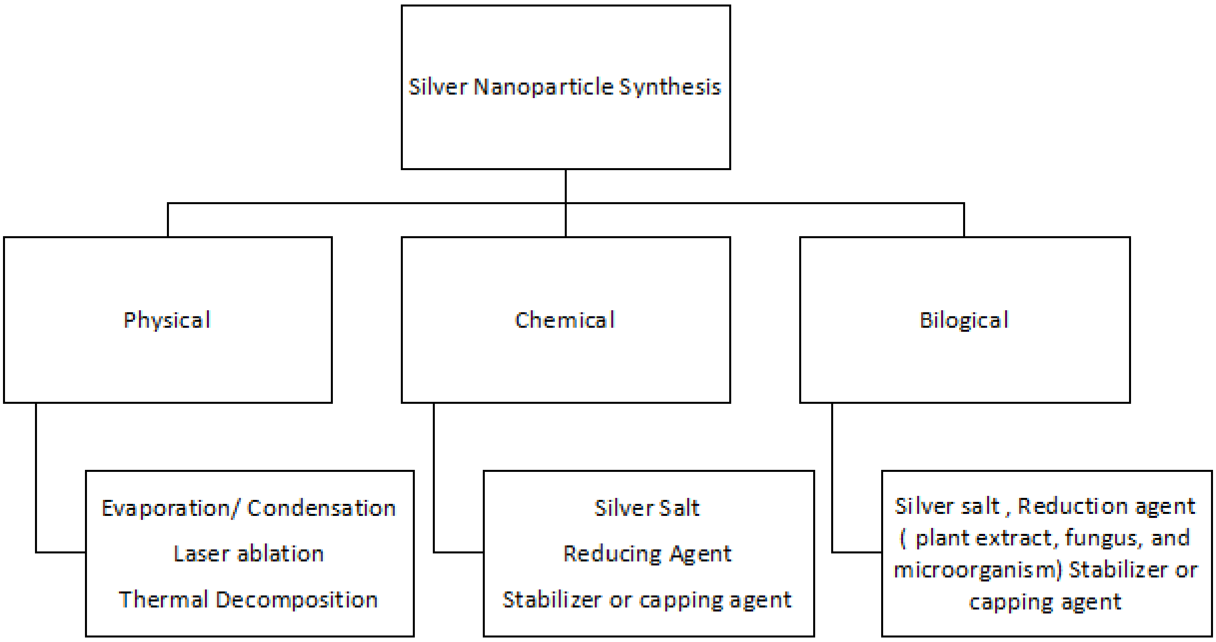
BACKGROUND:

Nanotechnology is a scientific and technique focusing on designing, manufacturing, and applying nanomaterials. Nanoscale items, typically between 1 and 1000 nm, are considered nanomaterials by the European Commission. NPs, such as coinage metals, have unique optical characteristics due to Localized Surface Plasmon Resonance (LSPR). Silver, among noble metals, has the lowest melting and boiling temperatures and highest electrical and thermal conductivities, but is the most reactive and harmful to microorganisms. Silver nanoparticles have diverse characteristics, enabling applications in various technical and medical fields like solar power, electronics, analytical methods, environmental applications, bioimaging, antibacterial/cancer therapies, SERS, and NALDI.[11][12]

Various nanoparticles like Cu, Au, Pt, and Pd are considered for plasmonic applications, but none can completely replace AgNPs due to their superior plasmonic ability and wide wavelength band. Metal sputtering-based AgNPs have the best analyte ion-desorption efficiency in NALDI applications. However, Au and Pt nanoparticles are expensive and more complex due to their oxidation susceptibility. Metal oxide NPs like ZnO or ZrO2 may eventually replace Ag NPs in antibacterial applications. Silver NPs, resistant to Ag+, are rarely changed entirely due to their native habitat.([13])

Many publications lack comprehensive information about the properties and synthesis circumstances of Ag nanoparticles (NPs). Only seven plant extracts showed potential to reduce Ag+, and no relationship was found between NP characteristics and biological activity. The toxicity of NPs is not solely due to Reactive Oxygen Species (ROS), but rather their potential harmful paths and interaction with cells.[14][15]

METHODS OF SILVER NANOPARTICLES SYNTHESIS :



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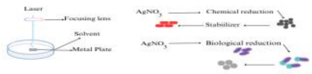

(c)

(a)

Figure 1 : Synthesis of Silver Nanoparticles[16][17]

SILVER NANOPARTICLES FOR DRUG DELIVERY SYSTEMS

Pharmacokinetics and pharmacodynamics are crucial in medicine, and nanoparticles have been explored for drug-delivery systems. AgNP-based nanosystems are suitable for various medicinal compounds with anti-inflammatory, antioxidant, antibacterial, and anticancer properties. Hybrid molecular units with AgNPs have been chosen for targeted diseases, but the process or method used during administration is crucial for specific therapeutic effects.[18]

Silver is not widely used in nanoparticle-based drug delivery due to challenges with synthesis and concerns about toxicity and stability. Gold or other nanomaterials are substituted for silver due to its intrinsic anticancer activity. AgNPs have been successfully evaluated as effective antitumor drug delivery systems. Strategies like organic water biphasic synthesis, microemulsion, radiolysis, and aqueous reduction have been used to prepare biocompatible

AgNPs. AgNPs may be used as medication carriers and vaccines to target particular cells or tissues, according to recent research.[19][20]

Therapeutic Agents delivered via silver nanoparticles

Antibacterial activity of Silver Nanoparticles:

Silver nanoparticles (AgNPs) have been used as antibacterial agents since ancient times, with studies showing their effectiveness against over 650 pathogens. The main mechanisms of action include adhesion onto cell wall and membrane surfaces, penetration of AgNPs inside cells, damage to biomolecules and intracellular structures, and generation of reactive oxygen species (ROS). AgNPs' positive surface charge and electrostatic interaction with the negatively charged cell membrane help them adhere to the cell wall. The antibacterial potential is also influenced by the cell wall composition and thickness, with Gram-negative bacteria having a stronger antibacterial effect than Gram-positive bacteria. AgNPs can also cause oxidative stress in cells by producing ROS and free radicals, which can damage the mitochondrial membrane and cause cell death. AgNPs' efficacy depends on dimensions, morphology, zeta potential, concentration, and colloidal state.[21][22]

Pal et al. investigated the antibacterial effectiveness of AgNPs against E. coli in three distinct shapes: triangular, spherical, and rod-shaped. Triangular NPs' greater surface-to-volume ratio and crystalline structure made them more active than spherical NPs. Rout et al. used Morus leaf extract to create AgNPs in various forms and discovered high reactivity. AgNPs' antibacterial activity was found by Sondi and Salopeck-Sondi to be dose-dependent. AgNPs in colloidal form shown enhanced antibacterial activity. AgNPs were created by Okafor et al. using a green synthesis of extracts from black cohosh, aloe, geranium, and magnolia, and their antibacterial effectiveness was examined against various bacterial species.[23][24][25]

Ahmed et al. synthesized AgNPs using Azadirachta indica leaves and Bagherzade et al. synthesized AgNPs using saffron extract. Gomathi et al. found that AgNPs were more effective against E. coli due to differences in cell wall membranes in these bacteria.

AgNPs exhibit antimicrobial activity when combined with antibiotics, with synergistic antibacterial activity identified. They also have bactericidal potential when used with monoclonal antibodies. AgNPs are most effective against E. Coli and S. Aureus when combined with gentamycin. When used with standard antibiotics, AgNPs significantly increase antibacterial activity, making them effective against antibiotic-resistant pathogens.[26][27]

Silver Nanoparticle for wound healing:

Wound infections are a major clinical issue affecting patient morbidity, death, and financial implications. Preventing surgical site infections and wound dehiscence is crucial in clinical practice. External causes can impair skin integrity, leading to permanent impairment or death. In healthcare, opportunistic pathogenic microorganism-caused wound infections are growing. Rapid tissue healing is essential for managing infected wounds.[28]

Silver compounds have been used for treating specific illnesses since ancient times. Nanosilver offers effective biocide activities against various bacterial strains. However, silver ions are inactivated, making it difficult for cells to absorb. Silver ions bind to proteins and can interact with bacteria in wound dressings. Experimental data supports nanoparticle skin absorption and increased permeation during skin injury. Incorporating biopolymers like collagen or chitosan into nanotechnology methods holds promise for wound treatment. Ionic silver modified biocomposites like Acticoat™, Bactigras™, Aquacel™, PolyMemSilver™, and TEGADERM™ have been approved by the US FDA for wound dressing applications. AgNPs can also be used for delayed diabetic wound healing and minor scars.[29][30]

Silver Nanoparticle for bone healing:

Bone-related disorders, such as infections, degenerative, hereditary, cancerous, and fractures, affect millions of individuals globally. In osseous tissue replacement procedures, orthopedic implants that become contaminated or colonized are a major source of worry. Implanting bone grafts can fix or replace significant flaws that have an irreversible impact on the ossifying tissue. High levels of inflammation are frequently present in conjunction with orthopaedic and bone implant-related infections, leading to implant loss and bone-damaging events. AgNPs have demonstrated the ability to support bone-like tissue mineralization and exhibit remarkable antibacterial activity, with bacterial resistance standing out. The main component of human bone, dentin, and dental finish is crystalline hydroxyapatite (HA), which is utilized in osseous-related therapeutic and regenerative procedures and is biocompatible with silver. [31][32]

AgNPs are often used as doping materials for manufactured and bio-inspired bone platforms, with important results being recently detailed.

The study highlights the potential of antimicrobial AgNPs in bone-tissue design, promoting osteogenesis and mesenchymal stem cell (MSC) proliferation to improve bone healing. It also highlights the relationship between NP intake and clathrin-dependent endocytosis in MSCs and osteoblasts. The study suggests the need for innovative, performance-enhanced implants to enhance bone recovery and anticipate clinical side effects.[33][34]

Silver Nanoparticles for Dental Applications:

Dental caries is a common oral cavity-related condition with financial costs. Nanotechnology treatments aim to reduce or eliminate its clinical effect by improving remineralization and managing biofilm formation. Dental barrier membranes (DBM) have specialized properties and biocompatibility. Metal-coated implants are effective against bacteria causing biofilm development and implant failure. Silver nanoparticles, used in dental amalgams and implantology, play a significant role in nanomaterial-related restorative, regenerative, and multifunctional biomedicine due to their practicality in contemporary society.(35)

World specialists are exploring the use of silver-based nanostructures to enhance the antimicrobial properties of general-use dental materials. While silver has positive effects on caries prevention, it can cause tooth recoloration. By reducing the size of AgNPs, the contact surface can be expanded, promoting silver's antimicrobial effects and preventing tooth recoloration. AgNPs can also be used in orthodontics and therapeutic dentistry, serving as filling or denture base materials. They have shown promising results in cement tars, orthodontic cements, and dental composites. AgNPs could also be used as biostatic coatings for traditional titanium-based dental inserts, but their potential in dentistry requires careful consideration of the optimal balance between physicochemical properties and biofunctional performance.(36)(37)

Benefits Of Silver Nanoparticle Therapy

Silver nanoparticle therapy has shown promising results in various case studies. One of the key benefits of this therapy is its antimicrobial properties, which make it effective in fighting against a wide range of pathogens, including bacteria, viruses, and fungi. This makes silver nanoparticles a valuable tool in treating infections that are resistant to traditional antibiotics. Additionally, silver nanoparticles have been found to have anti-inflammatory effects, which can help reduce inflammation and pain in certain conditions. (38)

Another benefit is their ability to enhance wound healing by promoting cell growth and tissue regeneration. Overall, the unique properties of silver nanoparticles make them a versatile and effective therapy for a variety of medical applications. (39)

Case Studies Highlighting Efficacy Of Silver Nanoparticle Therapy

Several case studies have been conducted to explore the potential benefits of using silver nanoparticles in therapy. One study focused on a patient with a chronic wound that was not responding to traditional treatments. After applying a silver nanoparticle-based dressing, the wound showed significant improvement in healing and reduction of infection. (40)(41)

In another case study, a patient with a drug-resistant bacterial infection was treated with silver nanoparticles as an alternative therapy. The results showed that the nanoparticles effectively inhibited bacterial growth and helped in clearing the infection.

These case studies highlight the promising efficacy of silver nanoparticle therapy in treating various medical conditions and suggest its potential as a valuable treatment option for patients resistant to conventional therapies.[42]

Application in diabetic wound healing

Silver nanoparticles are widely used in the therapy of diabetic wound healing due to their exceptional anti-inflammatory, antibacterial, and antioxidant qualities. AgNPs have the best knowledge in the medical field because of their exceptional chemical stability, high conductivity, catalytic activity, and localized surface plasma resonance.[43]

Silver is known to possess antibacterial and anti-inflammatory qualities that aid in the healing of chronic wounds, hence AgNPs can also be used as intrinsic therapeutic agents.

Additionally, due to AgNPs' broad antibacterial range, it is anticipated that they will have excellent potential for promoting wound healing in diabetic conditions.[44]

AgNPs have many advantages, chief among them being their remarkable efficacy against biofilm-forming and multiresistant bacteria, which are often present in chronic wounds.By encasing themselves in an extracellular polymeric material that they produce on their own, bacteria that form biofilms will become resistant to conventional antibiotics in this regard.

Silver nanoparticles can be used to functionalize a wide range of items, including bandages, gauzes, sutures, plasters, and numerous other lotions and ointments that are used to treat wounds. In addition to its antibacterial qualities, silver-treated surgical sutures and textile materials showed enhanced wound healing characteristics in vitro, suggesting that silver has a beneficial influence on cell migration and proliferation.[45]

Silver nanoparticles have strong antimicrobial effects, inhibiting the growth of a broad spectrum of bacteria, including those often present in diabetic wounds. This helps prevent infections, which are common complications in diabetic patients with impaired immune responses.[46]

Chronic inflammation is a characteristic feature of diabetic wounds. Silver nanoparticles have demonstrated anti-inflammatory properties, helping to control the inflammatory response in the wound area. This can contribute to a more conducive environment for healing.[47]

Collagen is essential for wound healing and tissue regeneration. Silver nanoparticles can stimulate collagen production, aiding in the formation of a robust extracellular matrix and facilitating the closure of the wound.

Diabetes frequently causes blood circulation problems in wounds, which delays healing. Angiogenesis, or the creation of new blood vessels, is essential for delivering nutrition and oxygen to the wound site, and silver nanoparticles have been shown to support this process.[48]

CONCLUSION

In conclusion, silver nanoparticles (AgNPs) exhibit unique physicochemical properties that make them invaluable in various industries, including pharmaceuticals, healthcare, consumer products, and industrial applications. Their unusual characteristics have led to their use in diverse products such as medical device coatings, optical sensors, cosmetics, and wound dressings, as well as in antibacterial and cancer therapy. The synthesis of AgNPs involves various techniques, with biological synthesis showing promise due to its safety, reliability, and environmental friendliness. Characterizing the nanoparticles is crucial for ensuring their safety and effectiveness in various applications, and several analytical techniques are employed for this purpose.

AgNPs have demonstrated significant potential as drug delivery systems due to their unique properties, and they have been explored for applications in antibacterial therapy, wound healing, bone healing, and dental treatments. The antimicrobial properties and anti-inflammatory effects of AgNPs make them effective in fighting infections and promoting wound healing. Furthermore, case studies have highlighted their efficacy in treating chronic wounds and drug-resistant bacterial infections.

In the realm of medical applications, it is essential to acknowledge the potential benefits of AgNPs in diabetic wound healing. Their antimicrobial, anti-inflammatory, and antioxidant properties contribute to their effectiveness in promoting wound healing, especially in diabetic conditions where chronic inflammation and impaired immune responses are common. Additionally, AgNPs have demonstrated capabilities in promoting angiogenesis and collagen production, essential for tissue regeneration and wound closure.

The potential and versatility of AgNPs in various medical applications are intriguing, and further research and exploration in this field may yield valuable insights and innovative treatment options. This prompts the need for continued research and development to harness the full potential of silver nanoparticles for improving healthcare outcomes and addressing challenging medical conditions.

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