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Review Article

A review on silver nanoparticles focusing on applications in biomedical sector

Ankush Kumar[1], Vishakha[2], Anjana Devi[1], Kamal Jeet[1], Sanjay Kumar[1] and Rohit Bhatia[2]*

[1]School of Pharmaceutical and Health Sciences, Career Point University Bhoranj (Tikker - kharwarian), Hamirpur, Himachal Pradesh 176041, India

[2]Department of Pharmaceutical Chemistry, ISF College of Pharmacy Moga-142001, India

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***Corresponding authors:** Rohit Bhatia, Associate Professor, Department of Pharmaceutical Chemistry, ISF College of Pharmacy Moga-142001, India, Tel: +91 7807216646; E-mail: bhatiarohit5678@gmail.com

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Abstract

Considering that nanosilver-based materials have shown to have a novel, demanding, and promising properties appropriate for a variety of biological applications, silver nanoparticles (AgNPs) have evolved into one of the most researched and examined nanostructures created from nanotechnology in recent years. Silver nanoparticles (AgNPs) have been the subject of research due to their special characteristics, and they have considerable interest in medical applications such as highly excellent antimicrobial agents even without toxic effects, and industrial applications such as inkjet inks comprising well-unified dispersions of nano-sized silver particles that are useful for creating electronic circuits. Due to the remarkable activities shown by silver nanoparticles, they have been the focus of many researchers for developing new medications with less toxic effects. In this study, we have highlighted some entitled applications of silver nanoparticles. This review will be helpful for the researchers working on silver nanoparticles.

Introduction

Due to their unique and authentic chemical, biological, and physical traits, metallic nanoparticles made of noble metals, such as silver and gold, have attracted a considerable amount of interest and significant research efforts in the past several decades [1-3]. Silver nanoparticles (AgNPs) are one of many metals that are of concern because of their phenomenal antimicrobial and localized surface plasmon resonance characteristics, which give them special qualities including broad-spectrum antimicrobial, surface-enhanced Raman spectroscopy (SERS), chemical/biological sensors as well as biomedicine materials, biomarker, and so forth [4,5]. The biomedicine-related evaluation of silver nanoparticles (AgNPs), which first drew global interest as novel antibacterial agents, received particularly noteworthy attention [6,7]. AgNPs have been used for a very lot longer as antibacterial agents in the health industry, cosmetic products, storage of food, textile coatings, and some environmental services, despite the fact that there is little information available about their toxic effects and in vivo biological behavior [8,9] [10,11]. With sizes ranging from 1 nm to 100 nm, AgNPs are a family of zero-dimensional compounds with characteristic morphologies [12] [13,14]. Due to the inherent adaptability of silver metal and silver-based compounds, several ways to synthesize AgNPs, such as physical, chemical, physicochemical, and biological synthetic techniques, have been effectively applied [15,16]. Each approach has some merits and demerits, with basic issues including prices, scalability, particle sizes, size distribution, and other similar issues [17]. Among the existing methods, the method most frequently used in the synthesis of AgNPs is the chemical reduction of silver salts by sodium citrate or sodium borohydrate [18,19]. Due to their intriguing physicochemical aspects, AgNPs have a significant impact on the study of biology and medicine [20]. According to studies, silver nanoparticles have antiviral, antifungal, anti-inflammatory, and antiplatelet properties [21,22]. It is known that AgNPs have been synthesized for a wide range of physical, biological, and pharmacological uses [23]. There are many factors which affect the manufacturing process such as synthetic procedure, pH,

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temperature, particle size, pore size, environmental factors and pressure.

Nanoparticles by nature will have a higher surface area and hence provide a larger reaction substrate than bulk material.

The number of nanoparticles that can cover the surface of bacterial cells or the extent to which they will penetrate the bacterial cell wall depends on the nanoparticle size, which is crucial in the interaction with bacterial surfaces. The degree of acquired anti-bacterial activity is directly correlated with these characteristics. The type of nanoparticle has an impact on how the particles work, including whether they adhere to cell wall structures or internalize inside cells. Nanoparticles with a diameter of 50 nm or less have the capacity to break through the bacterial cell wall and target the DNA inside. The utilization of AgNPs with a diameter of 10 nm was described by Morones and colleagues [4]. Additionally, Hsueh and colleagues discovered that silver nanoparticles with a 10 µm in diameter had anti-microbial activity against Bacillus subtilis, which prevented B. subtilis from growing [24].

Applications of silver nanoparticles

Silver nanoparticles as potent antibacterial agents: Due to their intriguing and distinct nano-related characteristics, such as their high inherent antibacterial efficacy and non-toxic character, silver nanoparticles have attracted a significant amount of interest in the biomedical area [25,26]. Maintaining AgNPs' nanoscale size, enhancing their dispersion and stability, and preventing aggregation are some fundamental features connected to the particular antibacterial qualities of AgNPs that imply their inherent physical and chemical properties [27]. AgNPs are strong contenders for the creation of brand-new, powerful, biocompatible nanostructured materials for innovative antibacterial treatments based on nanotechnology [28]. AgNPs are some of the most popular metallic nanoparticles employed in existing antimicrobial applications because of their inherent wide bactericidal activities demonstrated against both Gram-negative as well as Gram-positive bacteria and their physicochemical characteristics [29]. According to much research, AgNPs engage with the bacterial membrane and enter the cell, drastically disrupting correct cell function and causing structural damage and cell death [30,31]. Nowadays, it has been demonstrated that AgNPs may be effectively utilized to design and construct enhanced wound and burn dressings because solitary metallic nanoparticles have inherent antibacterial and anti-inflammatory properties [32].

Use of silver nanoparticles in drug-delivery systems: In healthcare, a drug's pharmacodynamics and pharmacokinetics are just as significant as its inherent therapeutic benefits [33,34]. Nanoparticles have drawn a lot of interest in the design and development of new and improved drug-delivery platforms as the precise and selective administration and action of therapeutic agents have become one of the most researched areas for enhancing existing human healthcare practice [35]. Hybrid molecular units made of AgNPs were effectively selected for the creation of novel and performance-enhanced drug-delivery platforms supportive of thermal, optical, or pH alterations to aim inflammatory, infectious, and malignant illnesses, particularly because of their remarkable biocompatibility and practical characteristics for nanoscale-derived health care settings [36,37]. Due to challenges in AgNP synthesis and concerns about the toxicity and decreased stability of nanosilver-based systems when functionalized using traditional salt-aging methods, silver is not commonly used in nanoparticle-based drug delivery systems [38] [39]. Rather, gold or any other nanomaterials are employed in its place. AgNPs were given special consideration for this field because of their inherent anticancer properties, and they were successfully tested as efficient anti-tumor drug delivery systems, serving as passive or active nanocarriers for anticancer medicines [40-42]. Different methods were employed to create biocompatible AgNPs, including organic-water two-phase synthesis, micro-emulsion, radiolysis, and—most frequently—reduction in aqueous solution. Thanks to the exceptional characteristics of nanosilver, such as its ability to bind a wide variety of organic particles, its tunable and strong absorption characteristics, and its low toxicity, remarkable recognition, scientific understanding, and financial support have recently been focused toward the preparation of AgNP-based drug-delivery systems. AgNPs may be used as vaccine and medication transporters for precise and selective cell or tissue targeting, according to recent investigations [43].

Role of silver nanoparticles in bone healing: Each year, unique and complicated issues impact millions of individuals globally [44]. Diseases affecting the bones, such as tumors, viral infections, and degenerative and hereditary disorders also break [45]. However, since the accompanying infections are linked to high mortality, opportunistic infection and colonization of orthopedic implants constitute significant issues in osseous-tissue replacement schemes [46]. Orthopedic and bone-implant-related diseases are frequently accompanied by intense inflammatory conditions, implant failure, and bone-decaying events. According to earlier research, as compared to other NPs, AgNPs naturally enhance the differentiation of MC3T3-1 pre-osteoblast cells and the subsequent mineralization of bone-like tissue [47,48]. Presently, the prevention of significant trauma-related diseases and tumor-related diseases uses silver-coated prostheses, a novel strategy [49]. However, there have been no documented clinical trials analyzing the long-term clinical effects of nanosilver-coated devices for revision arthroplasty [50]. When bacteria grow in bone flaws, the bone's capacity to heal itself may be restricted. AgNPs have inherent antibacterial action with a wider scope than standard antibiotics. Additionally, the rarity of bacterial resistance to AgNP activity highlights the synergistic action of nanosilver's bactericidal processes [51]. In order to provide novel and functionally enhanced biomaterials for orthopedic applications, several investigations examined the viability and clinical potential of modifying acrylic cements using AgNPs [52].

Use of silver nanoparticles in dental care: One of the most widespread oral disease-related conditions in the world, dental caries is also a financial burden[53,54]. A number of microorganisms that cause dental-related biofilm development

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and consequent implant failure were tested against metal-coated implants[55,56]. Proper teeth brushing methods, preventive antibiotics, and antimicrobial mouthwashes are especially advised to avoid the bacterial contamination of dental implants[57]. By playing a significant role in dental amalgams, which are used to restore teeth, silver, which had been employed for millennia in oral care, came to the focus of the world in the 19th century[58,59]. Dental prostheses, restorative and endodontic dentistry, and implantology are only a few of the dental specialties where AgNPs have been employed. Silver nanoparticles have a significant position in nanomaterial-related restorative, regenerative, and multipurpose biomedicine because of their special qualities that make them practical for several sectors of genuine interest in contemporary society [60,61]. Modifying or incorporating silver-based nanostructures into general-use dental products is an appealing method utilized by professionals all over the world to add more bactericidal effects [62]. Although nanosilver diamine fluoride (SDF), a type of silver, has beneficial benefits in caries prevention, using this specific product has several drawbacks, with tooth discoloration being one of the most obvious. The contact surface will be significantly expanded by shrinking AgNPs, which will enhance the antibacterial properties of silver and help avoid the black coloration of teeth that typically happens following the usage of SDF [63,64].

Wound healing with the help of silver nanoparticles: With significant effects on patient morbidity and mortality as well as significant cost ramifications, wound infections pose a significant therapeutic problem [65]. A difficult and crucial part of the modern therapeutic practice is preventing wound dehiscence and surgical-site infection. The skin is the largest and one of the most complicated organs in the human body, but it is susceptible to damage from a variety of detrimental outside influences [66]. Depending on the degree of the injury, physically or chemically caused cutaneous wounds may seriously impair skin structural and functional integrity at various stages, resulting in lifelong impairment or even fatality. Silver-based substances and materials have been employed for the novel and successful treatment of certain illnesses from the dawn of time [67,68]. Nanosilver offers a wide spectrum of effective biocide actions against an astounding variety of anaerobic and aerobic, Gram-negative, and Gram-positive bacterial strains due to its inherent physicochemical characteristics and biological characteristics. It is generally known that due to chemical deactivation, metallic or elemental silver is weakly absorbed by bacterial and mammalian cells [69]. Therefore, the ionization of silver is necessary to provide particular antibacterial actions within physiological circumstances (along with the existence of bodily fluids or secretions). Silver ions combine with enzymatic and structural proteins after entering cells [70].

In absorbent wound dressings, AgNPs or silver ions can react with and kill the germs present in the exudate. In a nutshell, new findings reveal the following details about AgNP skin absorption: In vitro skin permeability by nanoparticles is well supported by experimental data in I, and (ii) there is a significant increase in permeability in the case of injured skin. When naturally occurring biopolymers (such as chitosan or collagen) are used in revolutionary nanotechnology techniques, they have a significant amount of potential for creating new and functionally better platforms for products that effectively heal wounds [71,72].

Modification of catheter using silver nanoparticles: Since Niederhuber's initial description of central venous catheters (CVC) in 1982, these devices have become crucial therapeutic tools for a variety of clinical disorders needing malnutrition and replacement treatment (e.g., renal disease and cancer) [73]. In chronically sick patients, CVCs often allow access to intravenous fluid infusion, hemodynamics surveillance, medication delivery channels, and nutritional assistance[74]. Nevertheless, such medical equipment is a significant contributor to hospital-derived infections and is regarded as a particularly high-risk group of equipment vulnerable to microbial contamination and colonization events. According to a recent analysis, different Staphhylococcus aureus strains, including 82% methicillin-resistant strains with many genes involved in bacterial dispersion and biofilm development, are to blame for catheter-related infections[75,76]. AgNPs were thoroughly investigated for the alteration of one-dimensional and two-dimensional surfaces, including cotton textiles, natural and synthetic fibers, thin polymer films, as well as wound patches, in order to impart antibacterial properties to therapeutically important products and devices [77]. Recent investigations have highlighted the usefulness of AgNP-modified catheters as non-toxic tools with prolonged bactericidal silver release and prevention of infection-related consequences. The efficacy of AgNPs and AgNP-coated catheters towards coagulase-negative staphylococci (CoNS), one of the primary groups of microorganisms responsible for device-related infections, were thoroughly investigated [78]. CVCs coated with AgNPs showed significant inhibitory effects on the growth including both Gram-positive as well as Gram-negative bacterial biofilms. Patients who use peritoneal catheters can reduce dialysis-related illnesses by having their catheters treated with silver ions; nevertheless, the antibacterial effectiveness and procedures for acquiring Ag^+ vary. Infections caused by methicillin-resistant Staphylococcus aureus (MRSA) may be prevented with the use of silver/copper-coated catheters because their antibacterial activity may be enhanced by reducing non-specific plasma protein adsorption [79,80]. Due to their small size and mobility, nanoparticles often have a higher cell absorption rate than microparticles and are accessible to a greater variety of cellular and intracellular targets. So, the nanowire can not do a better job in the catheter.

Benefits and drawbacks of nanoparticles: The fact that bacteria produce silver nanoparticles far more slowly than plant extracts is a significant disadvantage [81]. Consequently, with the usage of plants, it is now possible to create silver nanoparticles using extracts. Silver nanoparticles are good candidates for a variety of everyday tasks due to their distinctive physical and chemical properties [82]. They are also excellent candidates for numerous medical applications due to their antibacterial and anti-inflammatory qualities. However, there are studies and reports that suggest that nano-silver can allegedly cause adverse effects on humans as well as the

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environment [83]. However, other research and publications contend that nano-silver may have negative consequences on both people and the environment. Tonnes of silver are reportedly released into the environment through industrial waste, and free silver ions in the aqueous phase are thought to be primarily responsible for Ag environmental toxicity. Nano-silver has been used in practically every industry since the dawn of the twenty-first century, but most significantly in the medical industry. According to some accounts, nano-silver can, however, harmful germs that are helpful to the ecosystem since it is unable to distinguish between different bacterial strains. Only a small number of researches have been done to evaluate the toxicity of nano-silver. In one study, in vitro toxicity assay of silver nanoparticles in rat liver cells has shown that even low-level exposure to silver nanoparticles resulted in oxidative stress and impaired mitochondrial function [84].

Additionally, silver nanoparticles were found to be hazardous to mouse germline stem cells grown in a dish because they interfered with mitochondrial function and induced membrane leakage. According to some reports, nano-silver aggregates are more cytotoxic than asbestos [85]. At quantities that do not even limit Na, K, ATP, or mitochondrial activity, silver ions have been shown to alter the membrane fluidity to K^+ and Na^+ ions [86].

Conclusion

Exploration of silver nanoparticles (AgNPs) in nanostructures for novel due to their appealing physicochemical properties related to size, they have improved biological applications. characteristics and biological performance, such as their potent antibacterial effectiveness and non-toxic nature. A sizable body of research evidence supports the usefulness of AgNPs for contemporary treatment techniques, safe and nanomaterials materials and devices have been designed. The most recent difficulties and existing restrictions on traditional healthcare practices. The amazing potential of silver nanoparticles is demonstrated by research using nano-silver as a basis in applications for biomedicine. Whether we consider modifying the readily available materials and AgNPs are excellent prospects for achieving nanostructured devices or the creation of innovative nanostructured ones, the aspiration of contemporary biomedicine.

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