



A Mini-review: Silver Nanoparticles (AgNPs) as Antimicrobial in Magical Socks

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Authors' contributions

This work was carried out in collaboration among all authors. Authors LA and YHAM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors YFA and AMH managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Silver nanoparticles vary in size from 1 to 100 nm. These have unique properties that assists in molecular diagnostics, therapies, and devices used in many medical procedures. The most popular methods for making silver nanoparticles are physical and chemical approaches. Chemical and physical methods are troublesome because synthesis is expensive. The biological approach is a feasible alternative one. The major biological processes involved are bacteria, fungi, and plant extracts. Silver nanoparticles are mainly used in diagnostic and therapeutic applications in medicine. Their medical uses rely on the antimicrobial property, while the anti-inflammatory property has its own range of applications. Silver nanoparticles are used in a number of medical therapies and instruments, as well as in a variety of biological sciences.

This article focuses on chemical and biological techniques for synthesizing AgNPs, which will subsequently be utilized to coat socks materials, testing antimicrobial activity and comparing the ability of these coated fabrics to minimize infections.

Keywords: Silver nanoparticles (AgNPs); antibacterial; athletes' socks; biological and chemical properties; therapeutics.

1. INTRODUCTION

The medical properties of silver were known for over 2,000 years. Since the Nineteenth century, silver-based compounds have been used in many antimicrobial applications [1]. Nanoparticles were known to be used for numerous physical, biological, and pharmaceutical applications [2]. Currently, AgNPs are being used as successful professional antimicrobial agents in many public places such as railway stations and elevators in China, and they are thought to show significant antimicrobial activities [3].

It is a well-known fact that silver ions and silver-based compounds are highly toxic to microorganisms which include 16 major species of bacteria [4,5]. This activity of silver makes it excellent choice for taking multiple roles in the medical field. Silver is generally used in the nitrate form to induce antimicrobial effect, but when AgNPs are used, there is a huge increase in the surface area available for the microbe to be exposed to. Though AgNPs applied as antibacterials, the action of this metal on microbes is not fully known. It has been hypothesized that AgNPs can cause cell lysis or inhibit cell transduction. There are various mechanisms involved in cell lysis and growth inhibition [2].

2. METHODOLOGY

2.1 Synthesis of Silver-Nanoparticles (AGNPS)

Physical methods such as evaporation-condensation and laser ablation are the most important physical approaches. The absence of solvent contamination in the prepared thin films and the uniformity of AgNPs distribution are the advantages of physical synthesis methods in comparison with chemical processes. Physical synthesis of silver AgNPs using a tube furnace at atmospheric pressure has some disadvantages, for example, tube furnace occupies a large space, consumes a great amount of energy while raising the environmental temperature around the source material, and requires a lot of time to achieve thermal stability. Moreover, a typical tube furnace requires power consumption of more than several kilowatts and a preheating time of several tens of minutes to reach a stable

operating temperature [6,7]. It was demonstrated that AgNPs could be synthesized via a small ceramic heater with a local heating area [8]. The small ceramic heater was used to evaporate source materials. The evaporated vapor can cool at a suitable rapid rate, because the temperature gradient in the vicinity of the heater surface is very steep in comparison with that of a tube furnace. This makes possible the formation of small AgNPs in high concentration. The particles generation is very stable, because the temperature of the heater surface does not fluctuate with time. This physical method can be useful as a nanoparticle generator for long-term experiments for inhalation toxicity studies, and as a calibration device for nanoparticle measurement equipment [8]. The results showed that the geometric mean diameter, the geometric standard deviation and the total number concentration of NPs increase with heater surface temperature. Spherical NPs without agglomeration were observed, even at high concentration with high heater surface temperature. The geometric mean diameter and the geometric standard deviation of AgNPs were in the range of 6.2-21.5 nm and 1.23-1.88 nm, respectively.

AgNPs could be synthesized by laser ablation of metallic bulk materials in solution [9-13]. The ablation efficiency and the characteristics of produced nano-silver particles depend upon many parameters, including the wavelength of the laser impinging the metallic target, the duration of the laser pulses (in the femto-, pico- and nanosecond regime), the laser influence, the ablation time duration and the effective liquid medium, with or without the presence of surfactants [14-17].

One important advantage of laser ablation technique compared to other methods for production of metal colloids is the absence of chemical reagents in solutions. Therefore, pure and uncontaminated metal colloids for further applications can be prepared by this technique [18]. Silver nanospheroids (20-50 nm) were prepared by laser ablation in water with femtosecond laser pulses at 800 nm [19]. The formation efficiency and the size of colloidal particles were compared with those of colloidal particles prepared by nanosecond laser pulses. As a result, the formation efficiency for femtosecond pulses was significantly lower than

that for nanosecond pulses. The size of colloids prepared by femtosecond pulses were less dispersed than that of colloids prepared by nanosecond pulses. Furthermore, it was found that the ablation efficiency for femtosecond ablation in water was lower than that in air, while in the case of nanosecond pulses, the ablation efficiency was similar in both water and air.

Tien and coworkers [20] used the arc discharge method to fabricate AgNPs suspension in deionized water with no added surfactants. In this synthesis, silver wires (Gredmann, 99.99%, 1 mm in diameter) were submerged in deionized water and used as electrodes. With a silver rod consumption rate of 100 mg/min, yielding metallic AgNPs of 10 nm in size, and ionic silver obtained at concentrations of approximately 11 ppm and 19 ppm, respectively. Siegel and colleagues [21] demonstrated the synthesis of AgNPs by direct metal sputtering into the liquid medium. The method, combining physical deposition of metal into propane-1,2,3-triol (glycerol), provides an interesting alternative to time-consuming, wet-based chemical synthesis techniques. AgNPs possess round shape with average diameter of about 3.5 nm with standard deviation 2.4 nm. It was observed that the NPs size distribution and uniform particle dispersion remains unchanged for diluted aqueous solutions up to glycerol-to-water ratio 1:20.

2.2 Chemical Methods of Silver-Nanoparticles Synthesis

The most common approach for synthesis of AgNPs is chemical reduction by organic and inorganic reducing agents. In general, different reducing agents such as sodium citrate, ascorbate, sodium borohydride (NaBH_4), elemental hydrogen, polyol process, Tollens reagent, N, N-dimethylformamide (DMF), and poly (ethylene glycol)-block copolymers are used for reduction of silver ions (Ag^+) in aqueous or non-aqueous solutions. These reducing agents reduce Ag^+ and lead to the formation of metallic silver (Ag^0), which is followed by agglomeration into oligomeric clusters. These clusters eventually lead to the formation of metallic colloidal silver particles [22-24]. It is important to use protective agents to stabilize dispersive NPs during the course of metal nanoparticle preparation, and protect the NPs that can be absorbed on or bind onto nanoparticle surfaces, avoiding their agglomeration [25]. The presence of surfactants comprising functionalities (e.g., thiols, amines, acids, and alcohols) for

interactions with particle surfaces can stabilize particle growth, and protect particles from sedimentation, agglomeration, or losing their surface properties.

Polymeric compounds such as poly (vinyl alcohol), poly (vinylpyrrolidone), poly (ethylene glycol), poly (methacrylic acid), and polymethylmethacrylate have been reported to be the effective protective agents to stabilize NPs. In one study, Oliveira and coworkers [25] prepared dodecanethiol-capped AgNPs, according to Brust procedure [26] based on a phase transfer of an Au^{3+} complex from aqueous to organic phase in a two-phase liquid-liquid system, which was followed by a reduction with sodium borohydride in the presence of dodecanethiol as stabilizing agent, binding onto the NPs surfaces, avoiding their aggregation and making them soluble in certain solvents. They reported that small changes in synthetic factors lead to dramatic modifications in nanoparticle structure, average size, size distribution width, stability and self-assembly patterns. Kim and colleagues [27] reported synthesis of spherical AgNPs with a controllable size and high monodispersity using the polyol process and a modified precursor injection technique. In the precursor injection method, the injection rate and reaction temperature were important factors for producing uniform-sized AgNPs with a reduced size.

AgNPs with a size of 17 ± 2 nm were obtained at an injection rate of 2.5 ml/s and a reaction temperature of 100 °C. The injection of the precursor solution into a hot solution is an effective means to induce rapid nucleation in a short period of time, ensuring the fabrication of AgNPs with a smaller size and a narrower size distribution. Zhang and coworkers [28] used a hyper branched poly (methylene bisacrylamide aminoethyl piperazine) with terminal dimethylamine groups (HPAMAM-N(CH₃)₂) to produce colloids of silver. The amide moieties, piperazine rings, tertiary amine groups and the hyper-branched structure in HPAMAM-N(CH₃)₂ are important to its effective stabilizing and reducing abilities. Chen and colleagues [29] have shown the formation of monodispersed AgNPs using simple oleylamine-liquid paraffin system. It was reported that the formation process of these AgNPs could be divided into three stages: growth, incubation and Ostwald ripening stages. The higher boiling point of 300 °C of paraffin affords a broader range of reaction temperature and makes it possible to effectively control the

size of AgNPs by varying the heating temperature alone without changing the solvent. Moreover, the size of the colloidal AgNPs could be regulated not only by changing the heating temperature, or the ripening time, but also by adjusting the ratio of oleylamine to the silver precursor.

AgNPs can be prepared at room temperature, by simple mixing of the corresponding metal ions with reduced polyoxometalates which serves as reducing and stabilizing agents. Polyoxometalates are soluble in water and have the capability of undergoing stepwise, multielectron redox reactions without disturbing their structure. It was demonstrated that AgNPs were produced by illuminating a deaerated solution of polyoxometalate/S/Ag⁺ [30]. Furthermore, green chemistry-type one-step synthesis and stabilization of silver nanostructures with MoV–MoVI mixed-valence polyoxometalates in water at room temperature has been reported [31].

2.3 Biological Synthesis of Silver-Nanoparticles

A number of reports prevailed in the literatures indicate that synthesis of nanoparticles by chemical approaches are eco-unfriendly and expensive. Thus, there is a growing need to develop environmentally and economically friendly processes, which do not use toxic chemicals in the synthesis protocols. This has conducted researchers to look at the organisms. The potential of organisms in nanoparticle synthesis ranges from simple prokaryotic bacterial cells to eukaryotic fungi and plants [32]. Some examples of nanoparticle production include using bacteria for gold, silver, cadmium, zinc, magnetite, and iron NPs; yeasts for silver, lead and cadmium NPs; fungi for gold, silver and cadmium NPs; algae for silver and gold NPs; plants for silver, gold, palladium, zinc oxide, platinum, and magnetite NPs [33,34].

Bio-based protocols could be used for synthesis of highly stable and well-characterized NPs when critical aspects, such as types of organisms, inheritable and genetic properties of organisms, optimal conditions for cell growth and enzyme activity, optimal reaction conditions, and selection of the biocatalyst state have been considered. Sizes and morphologies of the NPs can be controlled by altering some critical conditions, including substrate concentration, pH, light, temperature, buffer strength, electron donor

(e.g., glucose or fructose), biomass and substrate concentration, mixing speed, and exposure time. In the following section, we discussed the synthesis of NPs using microorganisms and biological systems.

2.4 Advantage of Biological Methods

Development in the nanotechnology field has stayed fast and with the advance of new synthesis procedures and account techniques [35]. But greatest of the synthesis devices are narrow to synthesis of nanoparticles in lesser amounts and poor morphology. Physical and chemical synthesis devices often consequence in synthesis of a mixture of nanoparticles with poor morphology, and these devices also show to be toxic to the environment due to the use of toxic chemicals and too of raised temperatures for synthesis procedure [36].

Thus, the biological way offers a varied range of capitals for the synthesis of nanoparticles. The ratio of reduction of metal ions by biological agents is established to be greatly earlier and also at ambient temperature and pressure conditions. For order, in case of synthesis of nanoparticles using *Aspergillus niger* synthesis was detected within 2 hrs of treatment of fungal filtrate with silver salt solution [37].

Thus, the biological process needs least time for the creation of nanoparticles pH or the temperature of the reaction fusion. Gericke and Pinches in 2006 found diverse shape morphologies (triangle, hexagons, spheres, and rods) by modifying the pH of reaction mixture to 3, 5, 7 and 9. Also, it was demonstrated that at 65 °C less amount of nanoparticles were synthesized, whereas at 35 °C much quantity of nanoparticles was synthesized [38]. The biological agents release a great amount of enzymes, which are accomplished of hydrolyzing metals and thus transfer about enzymatic reduction of metals ions [39]. In case of fungi, the enzyme nitrate reductase is found to be responsible for the synthesis of nanoparticles [40].

The biogenic beings are found to discharge big amount of proteins which are found to be responsible for metal-ion reduction and morphology control [41]. The microbial cultures are easy to holder and also the downstream treating of biomass is greener as associated to the synthetic devices [42].

Biogenic nanoparticles are closely a greener method and environment friendly, as no toxic chemical is complex in synthesis, and moreover the synthesis method proceeds place at pressure conditions and ambient temperature [43]. Hence, a number of researchers are concentrating toward the synthesis of biogenic nanoparticles related with the physically or chemically synthesized nanoparticles [44].

2.5 Silver-Nanoparticles (AGNPS) as Antibacterial

Recent research indicates that the shape of nano-silver may not be a factor in its germ-killing ability [45]. However, nano-silver differs from macro-silver in a few main respects. First, since the smaller type has a higher surface area to volume ratio, the capacity for silver ions to be emitted, which is the primary mode of silver and nano-silver toxicity, is significantly increased [46]. Nano-silver can also get to areas in the body where larger silver particles can't, and it's small enough to get into cells [47], or pass through the blood-brain barrier. The real-world consequences of this are still being investigated [48].

However, with antibiotic-resistant infections being a global concern, there is a strong incentive to develop new antimicrobial methods, and nano-silver holds a lot of promise in this regard. According to ABL Medical managing director Keith Moeller, a new nano silver-based gel known as Silver STATM—introduced in fall 2012 as a wound-care antimicrobial by Utah-based ABL Medical—was shown in laboratory tests to destroy methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococci* (VRE) strains within minutes. According to Moeller, the FDA has approved SilvrSTAT for use in octogenarian facilities to help treat diabetic and septic ulcers, surgical wounds, and grafted places, and the EPA approved it for use as a disinfectant for hard nonporous surfaces [40].

“We've never encountered a pathogen that we couldn't kill,” says Moeller. “That is why silver is used in so many places. It's a very broad-spectrum antimicrobial agent that's extremely effective. It's a naturally occurring substance that's extremely effective.” Nano-silver (n-Ag) is used in socks, paints, bandages, and food containers because of its antimicrobial properties. n-Ag can inhibit the growth of odor-causing bacteria in clothing such as socks [49-

56]. Nano-silver is also used to avoid trench foot, athlete's foot, and other fungal infections in diabetic socks, shoes, and bandages; in socks for combat soldiers operating in less-than-sanitary environments to prevent trench foot, athlete's foot, and other fungal infections; and in socks for diabetics to prevent foot, ankle, and leg ulcers from spreading and other bacterial infections linked to sports involving close contact [57].

Nano-silver also deserves a position in everyday objects, according to Rosalind Volpe, executive director of the Silver Nanotechnology Working Group. “Nano-silver antimicrobial treatments will add a range of functionalities to consumer articles, including longer shelf life (e.g., cosmetics) giving more safety,” according to a working group report, less waste and, as a result, lower costs for consumers; plastics that are resistant to bacteria's damaging action (e.g., discoloration); and textiles that are resistant to bacteria colonization that can cause odors (e.g., sportswear), resulting in greater comfort and longer usage. Additional advantages, such as decreased washing frequency at lower temperatures, will save a lot of water and energy [58].

While silver has been used in consumer goods since ancient Rome, its nanoparticle form has only recently become available. Nano-silver can also be used in bandages, athletic apparel, and cleaning materials. Most users, according to Benn, are unaware of these nano-additions. I've talked with a lot of people who aren't sure what nanotechnology is, but they are purchasing items that contain nanoparticles. “If the public is unaware of the potential environmental consequences of using these nanomaterials, they will be unable to make an informed decision on whether or not to purchase a product containing nanomaterials,” Benn said “To that end, the researchers propose that better product labeling could be beneficial. Clothing labels, according to Westerhoff, may imitate the labels on underwear, athletic clothing, and the back of food packages, along with a list of “ingredients” such as nano-silver”.

2.6 Magical Socks Nano-Technology with Silver-Nanoparticles (AGNPS)

One method of creating highly active surfaces with UV blocking, antimicrobial, and self-cleaning properties is to nano-coat the surface of textiles or footwear. Silver is a natural antibacterial agent

that works to destroy the majority of bacteria that cause foot odour and other sweaty foot problems like athlete's foot, keeping the feet dry and safe. Silver ions, which are an effective antimicrobial agent, pass through the silver fibers and bind with the DNA chains of odour-producing bacteria. Their ability to replicate is harmed as a result of this process. As a result, coating sock fabrics with AgNPs can be used to fight foot-borne bacteria, reducing foot-borne infections, foot odour, and perspiration, and acting as an important prophylactic agent. This project will use chemical and biological methods to synthesize AgNPs, which will then be used to coat socks fabrics, assessing antimicrobial activity and comparing the ability of these coated fabrics in reducing pathogens transmitted via the feet [59].

Exposing feet to air promotes evaporation and reduces moisture's growth-stimulating effect, which suppresses microbial growth. Prescription medications, salves, or foot soaks are used to treat a serious infection. Both aerobic bacteria and yeast-mold-fungi have been shown to be inhibited by baking soda, basil oil, tea tree oil, sage oil, and clove oil [60,61]. So many research on the bactericidal function of nanoparticles and their applications in the rubber, hygiene, textile, and paint industries have been performed [62,63]. Silver is a natural antibacterial agent that has been medically confirmed to destroy most bacteria that trigger foot odor and other sweaty foot issues [61]. Silver ions are released from the silver fibers and bond with the DNA chains of odor-producing bacteria [64]. By targeting the bacterial membrane, AgNPs destabilize plasma membrane potential and deplete levels of intercellular adenosine triphosphate, resulting in bacterial cell death. In a moist, enclosed atmosphere, common skin microbes multiply quickly, resulting in minimal to no athletic participation [65,66]. The heat atmosphere created by hot weather, sweating, exercise, and shoes encourages the overgrowth of both aerobic bacteria and fungi. The aim of this research is to determine the antibacterial activity of Ag-coated sock fabrics and evaluate their effectiveness in reducing foot-borne bacteria [67,68].

3. CONCLUSIONS

Inhibiting bacterial growth with nano-silver was found to be efficient. Bacterial growth was effectively inhibited by Ag-coated sock fabrics. Antimicrobial fabric with silver coating destroys

bacteria that cause foot odor. Nano-silver particles coated on the fabric of socks may be used as an anti-odor and anti-bacterial agent.

After achieving all of the project's goals and objectives, the concept can be further developed to improve fabric dirt, crease, and shrink resistance, as well as develop temperature adaptable textiles. Nano-silver coated fabrics may also be used to produce antimicrobial, self-cleaning nappies and underwear, wound dressings, and innerwear for soldiers serving in hostile areas, as well as astronauts. As a result, future research into antimicrobial nano-silver coated fabrics holds a lot of promise.

DECLARATION

Hereby, I Yasir Haider Al-Mawlah consciously assure that for the manuscript [A Mini-review: Silver nanoparticles (AgNPs) as Antimicrobial in Magical Socks] the following is fulfilled:

1. This material is the authors' own original work, which has not been previously published elsewhere.
2. The paper is not currently being considered for publication elsewhere.
3. The paper reflects the authors' own research and analysis in a truthful and complete manner.
4. The paper properly credits the meaningful contributions of co-authors and co-researchers.
5. All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
6. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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