

# Antimicrobial effect of silver nanoparticles (AgNPs) and their mechanism – a mini review

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Published in Micro & Nano Letters; Received on 5th September 2017; Revised on 1st November 2017; Accepted on 10th November 2017

Silver nanoparticles (AgNPs) are widely utilised in the industry and health care. This review demonstrates an exhaustive report on the toxicity of AgNPs towards pathogenic microbes. AgNPs are the most abundant antimicrobial agent for bacteria than other species and less harmful to human cells than to bacterial cells. This report suggests the relatively high acute toxicity of AgNPs to the microorganism. In addition, the toxicity mechanism of AgNPs is briefly discussed.

**1. Introduction:** The synthesis of a variety of drug particles of nano size along with their specific physical and chemical properties has been involved in the preparation of novel pharmaceutical commodities [1–5] and that silver nanoparticles (AgNPs) are long familiar as one of the best innovations towards biomedical applications. Typically, AgNPs can be synthesised by physical and chemical methods but the chemical reduction is the most often used technique for the synthesis of AgNPs as an unchanging and colloidal dispersion in water or in organic solvents [6, 7]. Borohydride, citrate, ascorbate, and elemental hydrogen are the mostly common reactants [8–15]. Metal particles of nano size exhibited bioactivity and their molecular functions are being investigated in relevant fields [16, 17]. These particles have prominent surface area and high reactivity as equated with the bulk solid; particles of nano size exhibit significant physical, chemical, and biological properties [18–21]. Furthermore, the use of nanosilver as a particular category of antimicrobial agents having an extraordinary bioactivity of silver has raised concern [22–30]. As wound dressings material holding clambered nano-crystalline silver nanocomposites are presently enforced in objective apply to inhibit the microbic infection of wound burning [28]. In addition, different silver-containing stuffs having nanosilver exhibit a participating antimicrobial factor [22, 23, 25–27, 29, 31]. The bactericidal effects of silver-holding materials have been frequently examined based on their silver ion substance. They have been described to act with cytoplasmic portions and nucleic acids, to suppress the chain of respiratory enzymes, and to interpose with membrane permeability [32]. A number of reports have disclosed the contact of nanosilver with bacteria using electron microscopy [33]. Morones *et al.* [34] disclosed that the most of the nanosilver has been placed on the membranes of treated bacterium cells. Over the years, Xu *et al.* have performed dark field optical microscopy to study a number of silver-holding bactericidal nanomaterials. Lv *et al.* investigated a formulation of Ag-decorated silicon nanowires with long-term operational antibacterial activity [35]. Furthermore, the broad use of commercially produced AgNPs as disinfectant agents necessarily extends to AgNPs discharged into the environment and poses danger to human beings [36, 37]. Herein, we have briefly discussed AgNPs as an antimicrobial agent and their mechanism towards the microbial cell.

**2. AgNPs as an antimicrobial agent:** Several disinfectant substances have been formulated in public health medicine and antigen in biomedical diligence for healing illnesses [38–43]. Amongst, Ag<sup>+</sup> and AgNPs have been distinguished as great germicide agents due to their effective antimicrobial power and

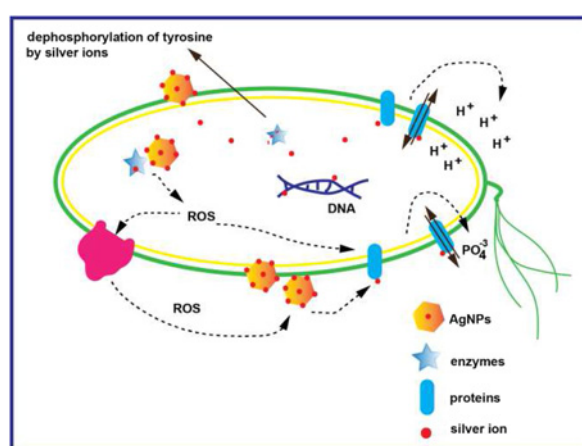
no toxicity to human cells [25, 44–47]. Silver infused polymeric material supplies antimicrobial efficaciousness with a sustained discharge of Ag<sup>+</sup> [48–50]. The combined silver and polymeric composite derogate the channel of infectious materials and increase patient console as well as fluent use for wellness [27].

Since ancient times antibacterial activity of AgNPs has been well studied [51, 52]. Previous literature provides reports of AgNPs having antimicrobial effects with and without any supportive material. The basic physiological and chemical properties of AgNPs are accountable for bioactivity [18, 19]. Polished and molten Ag cooled under H<sub>2</sub> did not demonstrate bactericidal effects. Although molten silver cooled in air present bactericidal effects, silver films having silver oxides exhibited bactericidal effects. Oxidised Ag films might be in the shape of Ag(I) and (Ag<sub>0</sub>) [53]. The sizes of AgNPs are well demonstrated and their size can be reduced or oxidised [54]. Even though, size has an effect on antibacterial activity [55]. Smaller size AgNPs have exhibited higher inhibition activity than bigger size AgNPs because around 10 nm AgNPs can easily reach the nucleus of microbes and their contact with bacteria has been good because of their superior surface area [56]. According to some researchers, silver ions discharged from the surface of AgNPs are responsible for antibacterial effects [26, 34, 48, 57, 58]. Nowadays, a variety of AgNPs are being studied for biomedical applications, Table 1, such as wound burn. Moreover, a variety of polymers and their compounds have been broadly utilised for wound burn purpose [68–71] and some bactericidal agents can be simply immobilised through the electrospinning process to achieve nanofibrous membranes, which can be used for different functions [72–74]. In addition, the electrospinning technique is a great support to wound burn applications [75]. AgNPs have been identified as a more effective antimicrobial agent than other present bactericidal agents [76]. Recently, AgNPs have been used as wound-dressing material with mesoporous silica nanotubes and polycaprolactone [77]. Pathogenic bacteria (such as *E. coli* and *S. aureus*) are creditworthy for healing burn wound infections [78].

**2.1. Toxicity mechanism of AgNPs:** Different actions of AgNPs against microorganisms are illustrated in Fig. 1. Perniciousness mechanisms of AgNPs are well known for surface oxidation and finally the generation of Ag<sup>+</sup> [79]. Ag<sup>+</sup> possible killing mechanism for microbes are silver ion controls Adenosine triphosphate (ATP) production through attaching to the ATP synthesis enzyme in the cell wall, it enters into the cell wall and attaches to DNA which leads to the DNA alteration or these ions

**Table 1** Antimicrobial effect of AgNPs in various forms

AgNPs	Key aspect	References
AgNPs of different sizes	antimicrobial effect is size dependent and 1–10 nm AgNPs can interact with bacteria directly	[34, 55]
uniform linoleic acid capped AgNPs	AgNPs possessed nearly the same toxicity as antibiotic (kanamycin and erythromycin)	[59]
biosynthesised AgNPs from <i>Carica Papaya</i> peel extract	5 µg/ml concentration of AgNPs showed antibacterial activity	[60]
biosynthesised AgNPs from proteins of sea grass	minimum concentration inhibition found at (0.24 nM; maximum activity=14.3–0.12 mm and minimum activity=11.2–0.38 mm)	[61]
radiation synthesised AgNPs	small amount of AgNPs (21.81 µg/cm <sup>2</sup> ) coated on cotton fabric exhibited antimicrobial effects	[62]
mycosynthesised AgNPs	bacterial species were found sensitive at 20 mg/ml	[63]
AgNPs with silica and lignin hybrid materials	inhibition activity was found at the highest concentration of 500 µg/100 µl	[64]
AgNPs with sponges	AgNPs increased chitosan antimicrobial effects	[65]
AgNPs with coaxial nanofibres	zone of inhibition measured as 13 and 11 mm	[66]
drug and AgNP complex	tetracycline – AgNP complex inhibited because it released a higher amount of silver ions	[67]



**Fig. 1** Different ways of action of AgNPs on the bacterial cell. AgNPs release silver ions, which can produce ROS and affect membrane protein, enzyme or DNA. Arrows indicating: (I) release Ag<sup>+</sup> and make ROS; (II) act with membrane proteins striking on their proper function; (III) generation and release of ROS

resist the respiratory chain of enzymes [80, 81]. AgNPs are likely to act against microbes as silver ions [82]. Nanosilver may restrain three kinds of Ag such as Ago solids, free Ag<sup>+</sup>, or surface adsorption [83–85]. Either release of silver ions [86] or stimulated reactive oxygen species (ROS) in both activities may enhance the toxicity of AgNPs [87, 88]. As aforementioned, Ag ions may not simply relate to toxicity or expiry of inhibition activity of microbes [88]. At the time of polymerase chain reaction, frequencies of DNA increase due to silver ions [89]. Bacteria having silver ions of mM concentration endure structural effects for example cytoplasm shuffling and breakup of the cell wall, DNA compression and determination in an electron light area in the middle of the cell, and leakage of intercellular contents due to cell membrane breakup [90, 91]. In addition, Ag<sup>+</sup> at the µM level acts on the enzymes of the respiratory chain which breaks the pair of respiratory electrons of ATP and well attaches with proteins extending the outflow of ions [51, 56, 82]. Silver controls the ingestion of phosphate and creates the outflow of phosphate from inside the cell [92]. Silver ions with the thiol group have high affinity, which introduces the cysteine portions of the proteins that act with respiratory proteins [51, 93, 94].

**3. Conclusions:** We studied the toxicity of AgNPs against microorganisms and their mechanism. At the millimolar level, AgNPs are more dangerous for bacteria because they can interact

with the nucleus of the cell. Additionally, size has an effect on antimicrobial activity. AgNPs or Ag<sup>+</sup> ions have antimicrobial properties. AgNPs discharge ions which enter the cell and disturb its respiratory system, resulting in death. AgNPs can also be used as a biomaterial for antimicrobial studies.

**4. Acknowledgements:** This research was supported by the National Natural Science Foundation of China (grant no. 21675086), the Qing Lan Project of Jiangsu Province, the Fundamental Research Funds for the Central Universities (grant no. 30915015101), and a project funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

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