ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/347822643

Antibacterial and anti-viral effects of silver nanoparticles in medicine against COVID-19 - A review

Article *in* Laser Physics · January 2021

DOI: 10.1088/1555-6611/abc873

CITATIONS
2

READS
843

4 authors:



Edmunds Teirumnieks
Rezekne Academy of Technologies
44 PUBLICATIONS **58** CITATIONS
SEE PROFILE



Ivaylo Balchev
Bulgarian Academy of Sciences
23 PUBLICATIONS **76** CITATIONS
SEE PROFILE



Risham Singh Ghalot
Rezekne Academy of Technologies
3 PUBLICATIONS **2** CITATIONS
SEE PROFILE



Lyubomir Lazov
Rezekne Academy of Technologies
57 PUBLICATIONS **121** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Laser Technology View project

Project Mobility BG05M2OP001-2.009-0001 on topic: „Laser marking technology for civil and military products“ View project

All content following this page was uploaded by Lyubomir Lazov on 19 February 2021.

The user has requested enhancement of the downloaded file.

ANTIBACTERIAL AND ANTI-VIRAL EFFECTS OF SILVER NANOPARTICLES IN MEDICINE AGAINST COVID 19 – A REVIEW

Dr.sc. Ing. Edmunds Teirumnieks, Prof.

Rezekne Academy of Technology, Latvia

E-mail – Edmunds.Teirumnieks@rta.lv, Phone: +371 20225595

Ivaylo Balchev, PhD

Researcher at Rezekne Academy of Technology, Latvia

E-mail - ivobalchev@gmail.com, Phone: +359 898307357

Ing. Risham Singh Ghalot, PhD student

Rezekne Academy of Technology, Latvia

E-mail – singhrisham93@gmail.com, Phone: +371 28131325

Corresponding Author

Dr. Sc. Ing. Lyubomir Lazov, Prof.

Leading Researcher at Rezekne Academy of Technology, Latvia

E-mail – Lyubomir.Lazov@rta.lv, Phone: +371 28327234, +359 888869092

Address: Atbrīvošanas aleja 115, 4601 Rezekne, Latvia

KEY POINT:

The research contributes: -

The use of laser-ablated Ag NPs through air filters or ventilation system in public and private places as well as in inhalation systems for disease prevention

Significance of research: -

- First-line therapy to prevent the virus from entering the hospital's infectious wards
- Study shows the optimal size and shape of the silver nanoparticles, interacting most effectively with the virus.
- Provides, the basis for the development of successful filters and inhalation systems with appropriate saline, as its concentration should be based on the patient's condition and severity of symptoms.

ABSTRACT

The article reviews the research on disinfecting the air through air filters and ventilation systems using silver nanoparticles (encouraged from the present situation of COVID-19) focusing on to stop the spreading of deadly viruses. The primary goal of the research is to demonstrate possible anti-viral silver nanoparticles formulations to be delivered by inhalation, to minimise the worsening of respiratory system infections. The basic design of the study includes a bibliometric analysis of the study of the effect of silver nanoparticles on the disinfection of viral infections. The research will discuss the idea of the use of laser ablation with silver nanoparticles for anti-viral and antibacterial effects. The research article results in the compelling use of silver nanoparticles in medicinal purpose for infectious diseases/viruses and will contribute to the progress of medical science to protect health care workers from dangerous viruses at medical institutions. Practically, the research will generate a sterile system, which might be employed by every public or personal place economically with silver nanoparticles (because of its antimicrobial properties).

1. OPENING

In the context of the current global pandemic, hygiene and disinfection issues in hospitals, schools, colleges, industrial and public buildings are becoming increasingly important for public health. Today, infectious diseases resulting from the spread of COVID-19 are a major challenge for all of humanity. Therefore, research into new types of effective and innovative disinfection strategies is paramount. Disinfectants are physical and chemical reagents applied to the surface to interact with microorganisms and viruses that encounter to destroy them. They are mainly used for disinfection of various surfaces in public and medical premises and equipment used in them. Disinfectants can be successfully used in our daily lives because they do not pose a danger to humans, but successfully affect the virus by destroying it. In addition, disinfectants in quantity must be sufficient to be used periodically for short periods of time [1].

Today, chemical compounds such as aldehydes, alcohols, and oxidants such as sodium hypochlorite, hydrogen peroxides, iodine and others are successfully used for disinfectants. In some cases, these compounds show certain disadvantages such as corrosive effects on metal surfaces, resistance to certain types of bacteria, as well as other negative environmental effects.

With the discovery and practical application of nanomaterials, wide opportunities have been opened to overcome some of these shortcomings. As defined by the International Organization for Standardization, "nanomaterial" means material particles with an outer diameter in the range of 1 nm and 100 nm. Today, various types of nanomaterials are successfully used as effective disinfectants. The main efforts of researchers in the field of nanotechnology today are focused on optimising their physicochemical properties and increasing the effectiveness of their disinfectant effect on emerging or mutated viruses. Various nanomaterials of metals, such as copper, silver, and gold, are now successfully used as antiseptics.

Antimicrobial agents of silver ions and products based on them have been well known since 1000 BC. They were widely used by the ancient Chinese and Indians in their folk medicine as a remedy [2].

The antimicrobial action of silver nitrate is widely known today, but with the advent of Ag NPs, its effect and impact have increased significantly. This is explained by the new

physicochemical properties that Ag NPs have. As well as with a higher surface/volume ratio that they have, because of which a higher interaction with the surface of the microbes is realised, and ultimately to better antimicrobial protection. The size and shape of Ag NPs also play an important role in this phenomenon. These physiochemical characteristics of Ag NPs are again crucial and relevant today in the search for new ways to successfully combat and deal with the COVID-19 pandemic.

These phenomenal physiochemical characteristics of Ag NPs are also widely used in other areas of our lives, such as ecology, industry, and others. The table below summarises the research of different research teams, indicating their areas of application.

Table 1: Important physicochemical properties of Ag NPs & compounds as an antiseptic.

Element	Physicochemical properties of Ag NPs	Disinfectant activity
Ag/TiO_2	Reduction in band gap leads to the visible active material	Visible active antibacterial activity [3] [4]
Ag ZnO	O_2-, OH	Photo-oxidative killing of bacteria [5] [6]
Ag NPs	Surface functionalisation	Photocatalytic, self-cleaning bacterial inactivation [7] [8] [9] [10]
Ag polyamide	Size 40–60 nm	Sustainable release of Ag^+ ion for antibacterial effect. [11]
LA/ZnO:Cu/Ag Bio-nano composites	Mechanical/structural, antibacterial and barrier property to UV light	Enhance the shelf life of food [12]
Ag NPs	Anti-viral	Elimination of aerosolised bacteriophage MS2 virus particles [12]
Ag Co-NPs	Magnetic and antibacterial	Water distillation [13]
AgNP-SiO2	Spherical morphology	Prompt and synergic antibacterial activity of air filter [14]

Ag NPs / Chitosan	Porosity, moisture retention capability, blood-clotting capability	Wound healing ability [15]
Ag / BC	Porosity	Wound healing ability. [16]

As can be seen from table 1, Ag NPs play an important role in air and water purification, as well as a therapeutic agent in a few medical activities. They show highly effective action in contact with several bacteria and viruses such as Staphylococcus aureus, Pseudomonas aeruginosa coli, Bacillus cereus, Listeria innocua, Salmonella Choleraesuis and others [17]. The wide range of action of Ag NPs is due to their ability to bind to sulphur and phosphorus, as well as functionalised biomolecules, which also leads to an increase in their physicochemical parameters and their ability to successfully destroy various viruses [18].

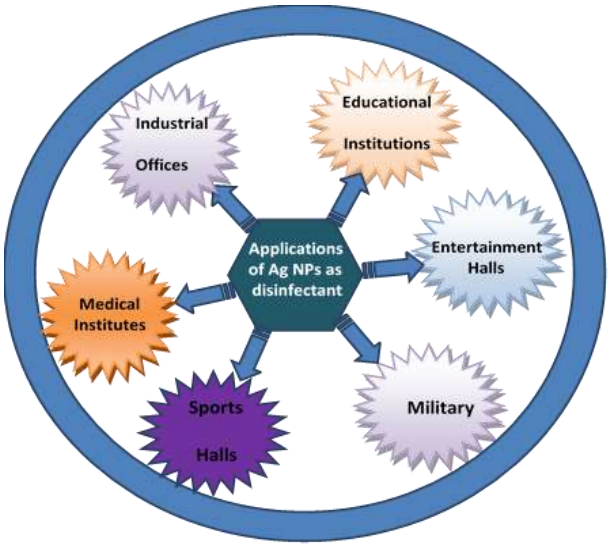


Figure 1: Applications of silver nanoparticles as a disinfectant

Due to multi-domain use of Ag NPs, the broad spectrum of the biomedical field for the innovative formulation, as a contemporary innovation related to the current universal situation caused by the Coronavirus and its spread in many countries around the world. This review is majorly focused on the role of Ag NPs as a disinfectant for controlling the spread of COVID-19, to control possible indoor airborne infections in which people are potentially infected with the virus (hospitals, schools, colleges, offices and industrial buildings). Schematic representations for potential applications of silver nanoparticles (Ag NPs) are shown in Fig. 1.

2. STERILISATION OF AIR

In the present era, numerous human actions during distinct development practices lead to having a negative effect on air quality. Currently, the main challenge is to make a clean environment freed from airborne viruses, fine dust particles, volatile organic compounds, toxic gases, and pathogenic bacteria. The removal of harmful microorganisms in the air such as bacteria, viruses and fungi attract the attention of researchers because these microbes are responsible for chronic infectious disease and are the most serious challenges of airborne infections. This requires increasing the requirements for air purification for the benefit of human health. As a result, it will reduce the presence of various viruses, bacteria, fungi, and all biological living organisms in the air. They are capable of various diseases like Severe Acute Respiratory Syndrome (SARS), anthrax, asthma etc.

Practice shows that these bioaerosols get deposited on the filter of air conditioning systems in enormous amount and breed due to the higher moisture content [19]. Nowadays, various engineering solutions for bioaerosol removal using photocatalytic oxidation, ultraviolet irradiation with germicides, and aerial ozonolytic methods are available.

We believe that the successful approach and solution to today's COVID-19 pandemic worldwide may also be linked to the use of Ag NPs and Cu NPs (Copper nanoparticles) as a disinfectant. Ag NPs have been shown to improve air quality when impregnated in air filters [20]. Therefore, we believe that nanomaterials and filters based on them can be a good engineering solution.

Mono-circulation Ag NPs dressed up with silica exhibits symbiotic antibacterial activity with gram-positive and gram-negative bacteria in the air filtration system. Also, the solution of Ag NPs and SiO_2 was steady for about six months and performed 99.99% antibacterial efficiencies of both bacteria. We consider it is appropriate to generate silver aerosol NPs in an inhaler as an anti-viral agent against Hay Bacillus and COVID-19 aerosols under close medical supervision and control. In summary, we can say that such hybrid materials are useful for embedding into air filters (Fig. 2) and for elements in air purification devices [12] [14].

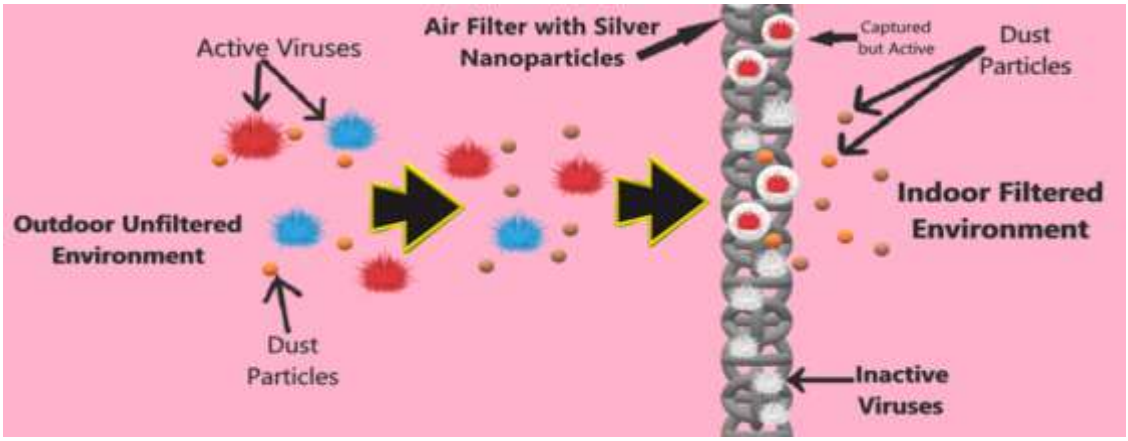


Figure 2: Anti-viral effect of silver nanoparticles on bioaerosols

Fig. 2 shows a schematic diagram of the anti-viral action of Ag NPs impregnated in an air filter. In their publication, Herzong et al. demonstrate the possibility of creating an airway barrier using aerosolised Ag NPs exhibiting minimal cytotoxicity [21]. Our analysis of publications in this field shows that the use of products based on nanotechnology Ag NPs increases the effectiveness of protection and prevention of viral diseases of the upper respiratory tract. This is because the transmission of viral infections is realised primarily through inhalation, ingestion, and dermal routes. Of course, airborne transmission and inhalation by nearby individuals are crucial.

Therefore, emissions of airborne particles and silver compounds from nano-based technology sprays have been studied to improve human health. In this way, the air quality in such halls and rooms can be significantly improved by providing good protection for workers and patients with COVID-19 virus infection within the initial stage. Thus, existing standard aspiration systems and air conditioners can easily be fitted with additional Ag NPs- based filters without incurring high financial costs, and the efficiency of air filtration are going to be significantly higher [22] [23].

3. NOSOCOMIAL INFECTIONS

The prevailing ultimatums in the biomedical zone are the antibiotic-resistant of the organism, product progress protocols and its services in terms of toxicity, healing period and a side effect on the human cells. Moreover, the disclosure of infection-causing non-bacterial pathogen, monitoring infection control and prevention of nosocomial infections are key confront towards the scientific community [24].

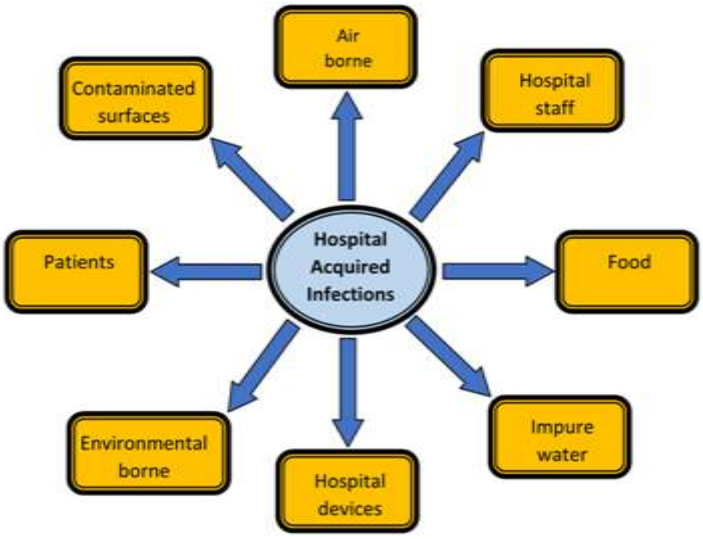


Figure 3: Factors responsible for nosocomial infections.

Nosocomial Infections are not just a patent for the current pandemic situation. A worldwide survey conducted by WHO [25] revealed average 8.7% peoples are suffered by nosocomial disease, and about 1.4 million people got affected with Nosocomial Infections. Eastern Mediterranean and south-east Asia regions are sensitive to Nosocomial Infections, as compared to the western world. Nosocomial Infections include surgical wounds, urinary and lower respiratory tract infections. The latter is particularly pronounced in the current pandemic associated with COVID- 19 infections.

Prevention of nosocomial infections demands an integrated and monitoring program in which different aspects are essential to be considered. The transfer of microorganism from patient to caretaker has been reduced by personal hygiene, including handwashing, hand gloves, masks, working clothes, shoes, and sterilisation of hospital equipment [26]. Moreover, increasing bacterial resistance has a higher influence on health and boosting economic burdens. Many policies have been applied for campaigning against Nosocomial Infections in different countries.

In the aspect, it can be observed that the use of Ag NPs is emerging one to control the Nosocomial Infections and efficient nano-weapon against multidrug resistance bacteria [27]. Ag NPs generated with bio-methods using Bacillus marisflavi showed high antibacterial activity against bacteria causing Nosocomial Infections [28]. Today, the uncontrolled and excessive use of antibiotics and their bacterial resistance is a modern threat in front of the

medicinal zone, which is also addressed by synergetic combinations of antibiotics with Ag NPs [29].

In medical centres, the most common source of infection spreading is the medical instruments used there. The solution to this problem can be found in coating the instruments with Ag NPs to avoid bacterial contamination. Ag NPs are used effectively in catheters for better antimicrobial activity and zero thrombogenicity [30]. The authors also investigated the effect of Ag NPs on contact blood coagulation, and the results are encouraging. It can also be strongly noted that the antimicrobial effect of titanium instruments coated with Ag NPs is enhanced by exposure to UV light [31].

Research in this direction shows a complete killing of MRSA bacteria due to the synergic effect of Ag NPs as a photocatalyst and visible light has been realised [32] [33]. The same strong bactericidal effect was observed with stents and catheters used in cardiovascular applications [34]. So, the Ag NPs are useful elements for various functions to control distinctive infections occurring in medical institutions. Also, cautions are required to avoid their harmful effects on human.

4. ANTIBACTERIAL MECHANISMS OF Ag NPs

Numerous investigators have proclaimed the antibacterial techniques of Ag NPs. The bacterial cell membranes contain sulphur constituting proteins and containing amino acids; in & out of cell membrane Ag can merge with them, which results in bacterial discontinuity. Also, Ag NPs generate Ag-ions which merge with phosphorus in DNA and with sulphur containing proteins, inhibit enzymes activities. Size and shape of a particle are one of the parameters to figure-out antimicrobial actions. It can perform greater attachment of sulphur-containing protein of membrane resulting in maximum permeability via a membrane and then cell death of bacteria if a size of NPs is < 20 nm [35].

It can bind more sulphur-containing protein from the membrane, resulting in maximum membrane permeability, and thus encourage bacterial destruction and death (if the NPs size is <20 nm) [35].

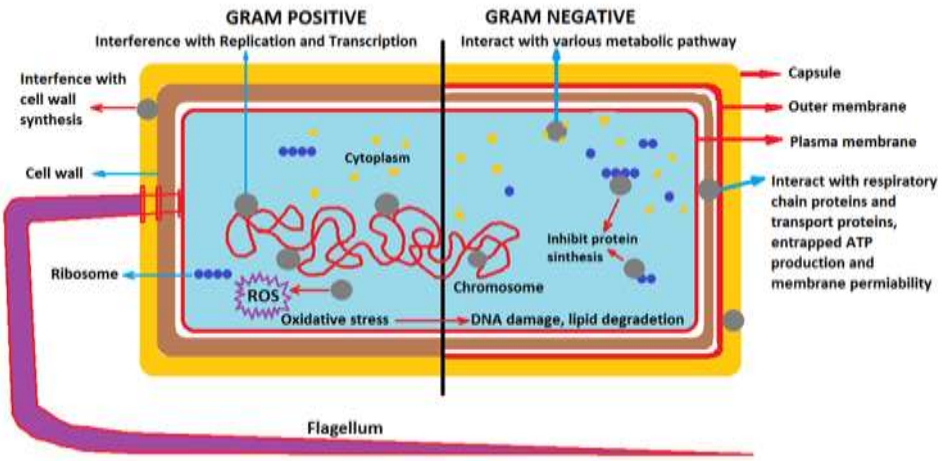


Figure 4: Antibacterial mechanism of Ag NPs.

FIG. 4 shows the mechanism of interaction of Ag NPs with the virus schematically. The role of the surface-to-volume ratio of Ag NPs must also be considered in this interaction. It is characteristic of nanomaterials that the smaller the nanoparticles, the greater the exposed interaction surface, and as a result, a greater microbicidal effect can be expected [36] [37]. We can emphasise that another important parameter of nanoparticles in the interaction with the walls of bacteria and viruses is their shape. Studies in [38] indicate that the truncated triangular shape of Ag NPs demonstrates higher antibacterial activity against E. coli bacteria compared to spherical and rod-shaped NPs. It is also stated that Ag NPs <10 nm creates pores in the cell wall because of these pores the cytoplasmic amount is released into the medium, which controls cell death without interaction between intracellular and extracellular proteins and bacterial nucleic acids. The authors in [39] point out that the interaction of Ag NPs with virus cells can lead to an intensification of the process of their programmed cell death, i.e. apoptosis.

In short, Ag NPs are compelling disinfectant as compared to products such as Acticoat™ for wound dressing, Silverline® for polyurethane ventricular catheter, ON-Q SilverSoaker™ as a catheter for drug delivery [34]. Also, they are used in numerous products such as medical masks, toothpaste, hand wash, shampoo, detergent as well as humidifiers. Nevertheless, using Ag NPs in consumer products is safe or not is the trending debate.

5. INHALATION METHODS WITH Ag NPs FOR TREATMENT OF EARLY STAGE COVID-19

The antimicrobial properties of Ag NPs are widely known, and lots of them are utilised in drug practice. It has been well established within the scientific literature that silver has both antibacterial and anti-viral properties [40] [41].

The purpose of this article is to analytically substantiate the potential antimicrobial properties of Ag NPs as a disinfectant component for several medical purposes, and their role in the treatment and prevention of viral infections when used in inhalers is emphasised. Two scenarios can be differentiated with today's discussion:

- Viral infections,
- Bacterial infections risk due to ventilator-associated pneumonia (VAP) in intensive care units (ICU) patients with respiratory support

A typical pathogenesis facet of both is that the infections are simply initiated moderately in the nasopharynx and/or bronchial tree section of the respiratory system (Fig. 5) [42] [43].

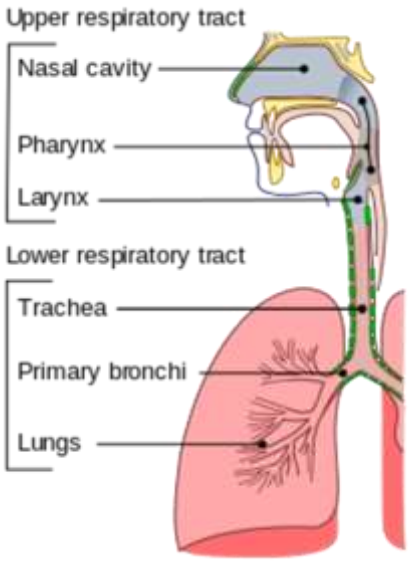


Figure 5: Sites of influenza entry in the respiratory tract. The anatomical and functional scheme of human airways. Influenza first affects the upper airway and the ciliated cells in the bronchus and bronchiole.

The situation worsens due to the travelling of the pathogens and associated inflammation to the lower part of the respiratory system. Moreover, as the disease advances, the increased immune response is intensified and may cause great damage (Fig.6) [44] [45]. Therefore, we urge that a preferable practical treatment should be available to suppress the growth of the pathogens at the beginning of the infection when it is cantered in the upper respiratory system. For example, when most patients are still at home with mild symptoms, and from the very first-day patient's arrival to the hospital ICU before the signs of any VAP infection.

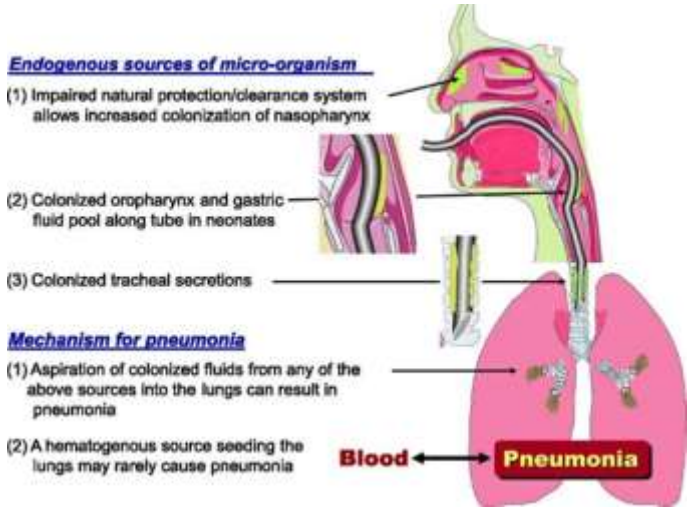


Figure 6: Pathogenesis of hospital bacterial ventilator-associated pneumonia (VAP) [46]

In our article, a capable formulation for upper and lower respiratory system treatment is introduced. For inhalations, Ag particles suspensions or solution in water is the relevant structure and variation between ionic silver solution and colloidal silver should be known. Ionic silver is the case were atomic Ag-ions are dissolved in water. Colloidal silver has nano-sized Ag pieces of silver matter sizing between 1nm – 100nm diameter. Both ionic silver and colloidal silver MIC levels are well cited in antibacterial properties, and it is expected that the silver ions are the most effective agent [46]. It is contradicted that the colloidal particles are about ten times more influential than ionic silver for anti-viral properties [48], as exemplified in Table 2 below for HIV. To assess the anti-viral activity of colloidal silver, it would be good in future research to focus on the analysis of the concentration of particles during inhalation.

Table 2: Anti-viral effect of Ag salts (ionic silver) and NPs against HIV-1 [48]

Silver compound	IC50*
Ag NPs	0.44 mg/mL (± 0.3)
Silver sulfadiazine (ions)	39.33 μg/mL (± 14.60)

The major point for calculating any effective dosage is to establish the required target Minimum Inhibitory Concentration (MIC) of the effective agent. According to microbiology, MIC is the lowest concentration of a chemical, which prevents visible hike of a pathogen. The leading dilemma in collecting clarified numerical results from the published research is that the MIC – given as μg/ml – is delicate to the NPs size. For the same weight fraction, smaller NPs have a higher density than larger NPs. Higher the density of nanoparticles leads to a higher probability of interaction with pathogens, and we would predict that smaller NPs to be higher influential than larger NPs. Thus, the MIC of smaller NPs will be smaller than the MIC of larger NPs, which experimentally is certain in the case (see Table 3) [46]. The resulting MIC values surely vary significantly between one publication to another because of the various sized NPs used. It has been expressed in the research of the effect of Ag NPs size on anti-viral efficacy in HIV treatment.

Table 3: Antibacterial MIC of colloidal silver [46]

Sample	**Minimum Inhibition Concentration MIC (μg/mL)**	
	Bacteria	
	E. coli	**S. aureus**
7 nm Ag NPs	6.25	7.5
29 nm Ag NPs	13.02	16.67
89 nm Ag NPs	11.79	33.71

NPs of size less than 10nm are effective than larger NPs, e.g., 25nm or 50nm [48] [49]. It can be because of the virus size itself, being on the order of 100nm (HIV size is about 120nm, and SARS virus size is also about 100nm). i.e., to be effective in interacting with the virus, the Ag NPs must be minuscule (approx. of 10nm) as compared to the virus size.

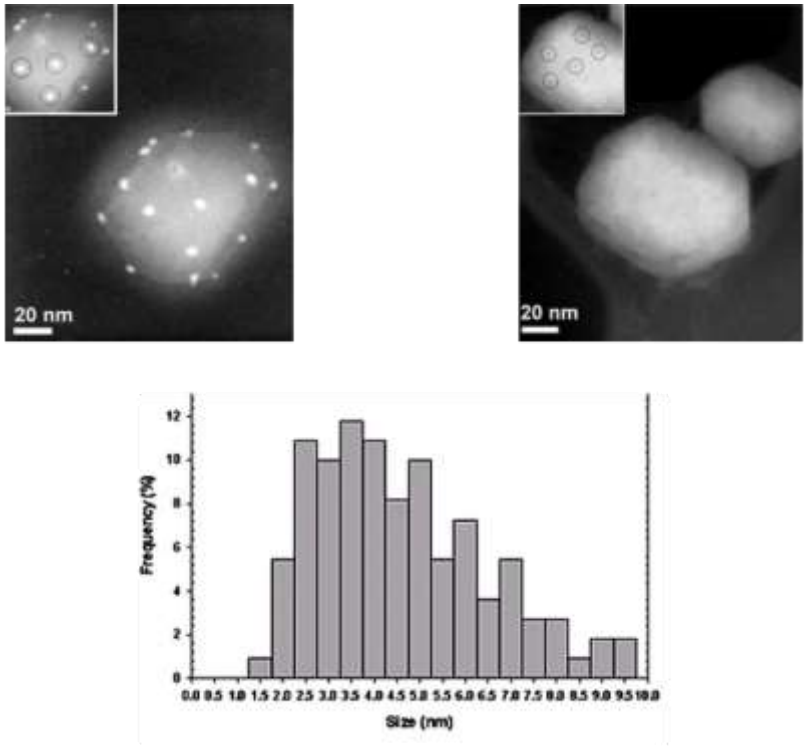


Figure 7: a) image of HIV-1 virus interaction with silver; b) image of HIV-1 viruses without silver nanoparticles treatment; c) Composite size distribution of silver nanoparticles bound to the HIV-1virus, derived from all tested preparations, seems [50]

This thought is given support by direct imaging of NPs mandatory to viruses [50]. Interestingly, the observed sizes of NPs bound to the virus (see Fig.7) were solely within the range of 1–10 nm, with peak virus attachment effectiveness for NPs size in the range of 3-7 nm. The fact that no NPs greater than 10 nm in diameter were observed to interact with the virus is significant [50]. Hence, it confirms the size-dependence of interaction.

Today, various research laboratories around the world are actively conducting research related to the application of Ag NPs in the biomedical field; in our review, only a small part of them are considered. However, in summary, we can say that:

- Today we have well-established research on the antibacterial and anti-viral properties of colloidal silver.

- Its possible utilisation is for the treatment of respiratory infections, which is still not well studied, and exploration in this direction needs to be deepened and internationalised.

- At this stage, a few studies show that colloidal silver with Ag NPs sizes between 3-7 nm can be very effective in suppressing the viral mechanisms of infections.

- An appropriate concentration of such colloids is in the range between 10µg / ml and 25µg / ml (these values can be considered as indirect conclusions and therefore a more focused study is needed in specific clinical conditions).

Assumed, that these formulations can be effective for prevention and treatment of respiratory viral infections in the beginning, including COVID-19 / SARS-CoV-2. For bacterial infections, particularly in ICU's (intensive care units), prevention of clinical ventilator-associated pneumonia (VAP), the same formulations can be useful, only at dosages of about half those of antibacterial.

There are high expectations regarding the use of nanoparticles, but in some cases, the potential toxic effect of Ag NPs on the patient or the treated person should be considered. As indicated in [51], this can occur when their concentration exceeds a certain level. For example, high blood pressure may be induced by Ag NPs [52]. However, when the Ag is present as NPs, the toxicity is lowered because they can be eliminated via the urine and hair [53]. Silver accumulated in the body is difficult to wipe out.

The harmful effects of Ag NPs are currently known through in vitro tests and animal experiments. Therefore, the harmful effects of Ag NPs are not well known. Therefore, the effective and safe use of Ag NPs for treatment requires further research and analysis.

6. CONCLUSION

The use of Ag NPs in medicine is very encouraging, especially when it comes to infectious diseases due to the extremely wide microbicidal spectrum that they have. The effect of Ag NPs on viruses thought to be resistant to antibiotic treatment has been confirmed in recent years by many scientific studies.

We believe that in the future, the effective use of Ag NPs will help prevent both contact infection in HCW and infection in patients. Studies to increase the microbicidal properties of biocompatible medical devices using Ag NPs also show very good positive

results. Therefore, we believe that the active use of Ag NPs will contribute most to the advancement of medical science in the treatment of infectious diseases.

Although good research has been done in this area so far, there is a broad field of research and development to optimise and analyse the long-term effects of NPs on a living organism, as well as the optimal concentration on the various stages and phases of the disease in patients without toxic effect on the body. This also requires the combined efforts and actions of teams of scientists from different laboratories around the world, on the one hand, both in optimising technologies for obtaining NPs with different characteristics and properties, as well as conducting clinical observations and specific purpose analyses.

References

[1] W. D. Rutala W.A., *Guideline for Disinfection and Sterilisation in Healthcare Facilities,* 2008.

[2] S. S. Gupta A., *Molecular genetics: silver as a biocide: will resistance become a problem?,* 16 ed., vol. 888, Nat. Biotechnol, 1998.

[3] S. M. V. K. e. a. S.P. Deshmukh, *Ag Nanoparticles Connected to the Surface of TiO2 Electrostatically for Antibacterial Photoinactivation Studies,* vol. 94, Photochem. Photobiol., 2018, p. 1249–1262.

[4] P. A. C. M. L. N. C. C. L. a. L. B. T. A. Cozmuta Mihaly A., *Active Packaging System Based on Ag/TiO2 Nanocomposite Used for Extending the Shelf Life of Bread. Chemical and Microbiological Investigations,* vol. 28, 2015, p. 271–284.

[5] P. K. A. Z. e. a. Dunnill C.W., *Nanoparticulate silver coated-titania thin films—photo-oxidative destruction of stearic acid under different light sources and anti- microbial effects under hospital lighting conditions,* vol. 220, J. Photochem. Photobiol., 2011, pp. 113-123.

[6] G. S. S. N. S. N. R. R. Manna J., *Biomimetic method to assemble nanostructured Ag@ ZnO on cotton fabrics: application as self-cleaning flexible materials with visible-light photocatalysis and antibacterial activities,* vol. 7, ACS Appl. Mater. Interfaces , 2015, pp. 8076-8082.

[7] C. M. H. S. D. S. Atiyeh B.S., *Effect of silver on burn wound infection control and healing: review of the literature,* vol. 33, Burns, 2007, pp. 139-148.

[8] N. R. S. M. L. A. Pal S., *Silver-functionalised bacterial cellulose as antibacterial membrane for wound-healing applications,* vol. 2, ACS Omega, 2017, p. 3632–3639.

[9] D. N. J. H. e. a. Wagener S., *Textile functionalisation and its effects on the release of silver nanoparticles into artificial sweat,* vol. 50, Environ. Sci. Technol. , 2016, p. 5927–5934..

[10] F. M. F. A. e. a. Zille A., *Size and aging effects on antimicrobial efficiency of silver nanoparticles coated on polyamide fabrics activated by atmospheric DBD plasma,* vol. 7, ACS Appl. Mater. Interfaces, 2015, p. 13731–13744.

[11] R. M. Ș. M. e. a. Vasile C., *New PLA/ZnO: Cu/Ag bio nanocomposites for food packaging,* vol. 11, Express Polym Lett., 2017.

[12] P. D. H. J. Joe Y.H., *Evaluation of Ag nanoparticle coated air filter against aerosolised virus: anti-viral efficiency with dust loading,* vol. 301, J. Hazard. Mater., 2016, p. 547–553.

[13] M.-B. X. V. N. e. a. Alonso A, *Superparamagnetic Ag@co-nanocomposites on granulated cation exchange polymeric matrices with enhanced antibacterial activity for the environmentally safe purification of water.,* vol. 23, Adv Funct Mater, 2013, p. 2450–2458.

[14] J. Y. S. M. L. K. H. J. W. K. Ko Y.-S., *Prompt and synergistic antibacterial activity of silver nanoparticle-decorated silica hybrid particles on air-filtration,* vol. 2, J. Mater. Chem., 2014, p. 6714–6722.

[15] L. Z. Y. H. G. J. C. R. Liang D., *Novel asymmetric wettableAgNPs/ chitosan wound dressing: in vitro and in vivo evaluation,* vol. 8, ACS Appl. Mater. Interfaces, 2016, p. 3958–3968.

[16] N. R. S. M. L. A. Pal S., *Silver-functionalised bacterial cellulose as antibacterial membrane for wound-healing applications,* vol. 2, ACS Omega, 2017, p. 3632–363.

[17] P. I, *Application of silver nanoparticles in experimental physiology and clinical medicine: current status and future prospects,* vol. 37, Rev. Adv. Mater. Sci., 2014.

[18] S. R. S. K. e. a. Pandey J.K., *Silver nanoparticles synthesised by pulsed laser ablation: as a potent antibacterial agent for human enteropathogenic gram-positive and gram-negative bacterial strains,* vol. 174, Appl. Biochem. Biotechnol., 2014, p. 1021–1031.

[19] R. H. Schleibinger H., *Air filters from HVAC systems as possible source of volatile organic compounds (VOC)–laboratory and field assays,* vol. 33, Atmos. Environ., 1999, p. 4571–4577.

[20] B. J. P. J.-H. J. J. B. G. Yoon K.-Y., *Hwang J., Antimicrobial characteristics of silver aerosol nanoparticles against Bacillus subtilis bioaerosols,* vol. 25, Environ. Eng. Sci., 2008, p. 289–294.

[21] C. M. P. F. e. a. Herzog F., *Exposure of silver-nanoparticles and silver-ions to lung cells in vitroat the air-liquid interface,* vol. 10, Part. Fibre Toxicol., 2013, p. 11.

[22] H. T. M. C. e. a. Calderón L., *Release of airborne particles and Ag and Zn compounds from nanotechnology-enabled consumer sprays: implications for inhalation exposure,* vol. 155, Atmos. Environ., 2017, p. 85–96.

[23] D. S. P. D. A. G. M. K. V. D. S. D. Patil S. M, *Different strategies for modification of titanium dioxide as heterogeneous catalyst in chemical transformations,* vol. 21, Curr. Org. Chem, 2017, p. 821–833.

[24] G. A. T. S. e. a. Mehta Y., *Guidelines for prevention of hospital acquired infections,* vol. 18, Indian J. Crit. Care Med., 2014, p. 149–163.

[25] F. J. N. L. Ducel G., *Prevention of Hospital-acquired Infections: A Practical Guide,* WH Organization, 2002.

[26] G. D. J. J. e. a. Shlaes D.M., *Society for Healthcare Epidemiology of America and Infectious Diseases Society of America Joint Committee on the prevention of antimicrobial resistance guidelines for the prevention of antimicrobial resistance in hospitals,* vol. 18, Infect. Control Hosp. Epidemiol. , 1997, p. 275–291.

[27] D. S. I. A. G. A. Rai M., *Silver nanoparticles: the powerful nano-weapon against multidrug-resistant bacteria,* vol. 112, J. Appl. Microbiol., 2012, p. 841–852.

[28] K. S. Nadaf N., *Antibacterial activity of silver nanoparticles singly and in combination with third generation antibiotics against bacteria causing hospital acquired infections biosynthesised by isolated Bacillus marisflavi YCIS MN 5,* vol. 10, Dig. J. Nanomater. Biostruct., 2015, p. 1189–1199.

[29] A.-H. S. R.-S. M. I. M. Rad-Sharifi J., *Antimicrobial synergic effect of Allicin and silver nanoparticles on skin infection caused by methicillin resistant Staphylococcus aureus,* vol. 4, Ann. Med. Health Sci. Res., 2014, p. 863–868.

[30] B.-C. O. B. v. d. E. e. a. Stevens K.N., *The relationship between the antimicrobial effect of catheter coatings containing silver nanoparticles and the coagulation of contacting blood,* vol. 30, Biomaterials, 2009, p. 3682–3690.

[31] G. A. M. A. N. K. S. A. G. V. B. L. M G Strakhovskaya, *Photoinactivation of coronaviruses: going along the optical spectrum,* vol. 17, Laser Physics Letters, 2020.

[32] P. K. A. Z. a. Dunnill C.W., *Nanoparticulate silver coated-titania thin films—photo-oxidative destruction of stearic acid under different light sources and anti- microbial effects under hospital lighting conditions,* vol. 220, J. Photochem. Photobiol., 2011, p. 113–123.

[33] D. A. V. S. D. S. D. S. Patil S., *Multi-applicative tetragonal TiO2/SnO2 nanocomposites for photocatalysis and gas sensing,* vol. 115, J. Phys.Chem. Solids., 2018, p. 127–136.

[34] M. Y. S. A. Chaloupka K., *Nanosilver as a new generation of nanoproduct in biomedical applications,* vol. 28, Trends Biotechnol., 2010, p. 580–588.

[35] E. J. C. A. e. a. Morones J.R., *The bactericidal effect of silver nanoparticles,* vol. 16, Nanotechnology, 2005, p. 2346.

[36] T. D. A. P. F. e. a. Wigginton N.S., *Binding of silver nanoparticles to bacterial proteins depends on surface modifications and inhibits enzymatic activity,* vol. 44, Environ. Sci. Technol., 2010, p. 2163–2168.

[37] S. N. K. D. D. S. C. S. A. P. Khanna P., *Water based simple synthesis of re-dispersible silver nanoparticles,* vol. 61, Mater. Lett. , 2007, p. 3366–3370.

[38] T. Y. S. J. Pal S., *Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli,* vol. 73, Appl. Environ. Microbiol., 2007, p. 1712–1720.

[39] S.-S. B. Sondi I., *Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria,* vol. 275, J. Colloid Interface Sci., 2004, p. 177–182.

[40] A. BA., *Metal-Based Nanoparticles for the Treatment of Infectious Diseases,* 8 ed., vol. 22, Molecules. , 2017, p. 1370.

[41] E. A. R. M. e. a. Haggag EG, *Anti-viral potential of green synthesised silver nanoparticles of Lampranthuscoccineus and Malephora lutea,* vol. 14, Int J Nanomedicine., 2019, pp. 6217-6229.

[42] B. G. a. S. Matthias, *Pathogenesis and Immunology, in Influenza Report,* 2006.

[43] Garland S. Jeffery, *Ventilator-Associated Pneumonia in Neonates: An Update,* vol. 15, Neo Reviews, 2014, pp. e225-e235.

[44] R.-O. D. P. G.-G. L. H. D.-O. R. a. C.-G. C. Manjarrez-Zavala Ma. Eugenia, *Pathogenesis of Viral Respiratory Infection, Respiratory Disease and Infection – A New Insight,* 2013.

[45] V. S. B. Lucas D Dias, *An update on clinical photodynamic therapy for fighting respiratory tract infections: a promising tool against COVID-19 and its co-infections,* vol. 17, Laser Physics Letter, 2020.

[46] M.-N. N. G.-M. F. e. a. Castañón-Martínez G.A., *Synthesis and antibacterial activity of silver nanoparticles with different sizes.,* vol. 10, J Nanopart Res., 2008, p. 1343– 1348.

[47] L. Y.-C. T. H.-K. T. T.-T. Tien Chi Der, *Identification and quantification of ionic silver from colloidal silver prepared by electric spark discharge system and its antimicrobial potency study,* vol. 473, Journal of Alloys and Compounds, 2009, pp. 298-302.

[48] H. H. e. a. Lara, *Mode of anti-viral action of silver nanoparticles against HIV-1,* 1 ed., vol. 8, Journal of nanobiotechnology , 2010.

[49] B. J. M. J. e. a. Elechiguerra J.L., *Interaction of silver nanoparticles with HIV-1*, vol. 3, J Nanobiotechnol, 2005.

[50] Galdiero, F. A., V. M., C. M., M. V. and G. S. M., *Silver Nanoparticles as Potential Anti-viral Agents,* vol. 16, Molecules, 2011, pp. 8894-8918.

[51] L. Ge, Q. Li, M. Wang, J. Ouyang, X. Li and M. Xing, *Nano-silver particles in medical applications: Synthesis, performance, and toxicity.,* vol. 9, Int. J. Nanomed., 2014, p. 2399–2407.

[52] L.-R. M.A., B.-A. P. and C.-M. e. al., *Evaluation of cardiovascular responses to silver nanoparticles (AgNPs) in spontaneously hypertensive rats.,* vol. 14, Nanomedicine, 2018, p. 385–395.

[53] G. DiVincenzo, C. Giordano and L. Schriever, *Biologic monitoring of workers exposed to silver,* vol. 56, Int. Arch. Occup. Environ. Health, 1985, p. 207–215.

View publication stats