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Silver Nanoparticles: Revival of the Warrior in War against COVID-19

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ABSTRACT

Silver has been used extensively used since recorded history for variety of medical purposes due to its broad spectrum of action against variety of microorganisms. Rediscovery of this metal in the present form as silver nanoparticles (AgNPs), is being explored in wide areas of research. With the current emerging COVID-19 pandemic, as we stand on the verge of this crisis with no vaccines available and no antidote to the rapid spread of the virus, nanosilver has shown a ray of hope in the fight against COVID-19 and also in healthy future after the pandemic.

Keywords: COVID-19, Silver-nanoparticles, vaccines, Microorganisms

INTRODUCTION

Since December 2019, when COVID 19 was detected in Wuhan, China, it has turned into a severe international health crisis and humanity is confronting a pandemic in severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing coronavirus disease known as COVID 19. So far there are over 36 million confirmed cases with COVID-19 worldwide, with an estimated death toll of over I million people.[1] In an effort to reduce its spread, implementation of strategies that requires participation of the whole society as well as innovative ways of social, work and health policies is needed. Suggested measures required stay at home implementation, timely SARS-COV2 testing, social distancing and efficient precautionary measures like wearing masks, washing hands and proper cleanliness. The antimicrobial properties of metal nanoparticles especially for the case of silver element, have received a considerable attention recently due to its physiochemical properties.[2]

HISTORY

Silver has been used extensively throughout recorded history for a variety of medical purposes. Metallic silver was known to Caldeans as early as 4000 B.C.E.[3] Herodotus, the father of History, also mentioned the importance of drinking water in silver vessels by Persian kings as water remained fresh for years in silver containers. This was particularly important in military conflicts where fresh water was not easily available.[4] The ancient Phoenicians, Greeks, Romans, Egyptians and others also were recorded to have used silver in one form or the other to preserve food and water. The likely use of silver nitrate as medical agent comes from pharmacopeia published in Rome in 69 B.C.E. Records also mention the use of silver nitrate by Paracelsus as a caustic for the treatment of wounds during 1520. Angelo Sala is reported to have given silver nitrate as a counterirritant, as a purgative and for the treatment of brain infections as early as 1614.[1] By 1800, it was well accepted that wine, water, milk and vinegar stayed pure for longer periods of time when stored in silver vessels and silver nitrate was also used successfully in treatment of skin ulcers, compound fractures and suppurating wounds.[5] In 1852, Doctor J. Marison Sims made an important contribution in medical uses of silver by introducing silver sutures to close fistulas and also silver catheters for urinary diversion until the healing of repair.[6]

Another seminal contribution was made in the 1880s by Doctor Carl Siegmund Franz Crede, a German obstetrician, who pioneered the use of silver nitrate eye drops to prevent ophthalmia neonatorium (gonorrheal ophthalmia) in newborn infants.[7] Colloidal silver was also reported to be used for treatment of puerperal sepsis, staphylococcal sepsis, acute epididymitis and other infections between 1900-1940.[8-10] Argyria, the complication of silver therapy was also known during this period and 357 cases were known by 1939.[3]

Rediscovery of Silver

Few of us are aware today that by 1940, before introduction of penicillin, in the USA alone, more than 50 silver-based antimicrobial products were marketed in different formulations (solutions, ointments, colloids, foils) for topical, oral and intramuscular injection. Also, the records mention that tens of thousands of patients consumed colloidal silver, with several million doses of silver administered intravenously. Though high doses had shown side-effects like convulsions and even death via parental route and gastrointestinal disturbances via oral route.[5]

The rediscovery of silver in the form of silver nanoparticles has mainly been driven by the continuous increase in multidrug-resistant human pathogenic microbes including *P.aeroginosa*, ampicillin-resistant *E.coli*, erythromycin resistant *Streptococcus pyogenes* and MRSA.[11] Nowadays, non-traditional antimicrobial agents are increasingly gaining importance to overcome multidrug resistance (MDR) and working in this direction, one among the priority areas of biomedical research focuses on novel, efficient nano-technological based antimicrobial agents especially silver nanoparticles[11] The advantage of using nano-silver lies in being less reactive than silver ions and thus being more suited for use in therapeutics and clinical practise.[12,13]

Antimicrobial effects of silver nanoparticle

It is well known that Ag^+ ions and Ag based compounds have strong antimicrobial effects[14] With the ongoing emergence of multidrug resistant microorganisms, there has been a resurgence in the use of Ag based antiseptics on account of their broad spectrum activity and low propensity to induce antimicrobial resistance.[15] Presently, silver still holds its utility in variety of application including dental work, catheters and burn wounds.[16,17] The biological activity of these silver nanoparticles has shown to be effective against over 650 microorganisms including bacteria (both Gram positive and Gram negative), fungi and viruses.[18] However, the use of silver as antimicrobial agent holds limitations due to the interfering effects of salts and the continuous release of Ag^+ ions concentration from the metal form. Thus it becomes essential to overcome these limitations and an effort to this approach was to prepare silver nanoparticles (AgNPs). However, it becomes mandatory to prepare these nanoparticles in a cost effective way and with enhancement of antimicrobial action. Several new silver-based antimicrobial products have been commercialized in the last two decades. Recently, Mecking and co-workers showed that hybrids of Ag nanoparticles with amphiphilic hyperbranched macromolecules exhibited effective antimicrobial surface coating agents.[19]

Mechanism of action

The mechanism of the inhibitory effects of Ag^+ ions on microorganisms is partially known. Some studies have reported that the positive charge on the Ag ion is crucial for its antimicrobial activity through the electrostatic attraction between negatively charged cell membrane of microorganism and positively charged nanoparticles. [20-22]

The antibacterial action of both Ag^+ and AgNPs has also been shown due to the entry into the bacterial cell membrane by porin proteins and causing membrane rupture, pore formation and cytoplasmic leakage. In the cell membrane, the Ag^+ ions lead to the formation of several highly oxidizing species like hydroxyl and superoxide free radicals, and H_2O_2 which quickly oxidize DNA, RNA and denature proteins.[23]

The antiviral action of AgNPs can be due to their direct virucidal action. Studies have shown that antiviral effect is based on the binding of AgNPs to the viral particles thus preventing them from binding to the host cells.[24-25] For example, in case of human immunodeficiency virus (HIV-1), there have been reports claiming AgNPs bind to the sulphur groups of gp120 protein spikes over the viral membrane, thereby preventing CD4 dependent virion binding, fusion, and infectivity.[26] In another report it was discovered that AgNPs are able to inhibit the formation of intracellular HBV RNA. [27]In vivo effect of AgNPs in controlling the Respiratory syncytial virus infection has been reported recently.[28] AgNPs capped with mercaptoethane sulfonate have also been shown to be effective in inhibition of herpes simplex virus type 1.[29]

Several studies also confirm the antifungal action of AgNPs[30-33], and also that antifungal activity of this nanosize silver is equal to amphotericin B, and higher to that of fluconazole and can be useful in clinical applications.

Antimicrobial Applications of Silver Nanoparticles

At present, new results pointing to the exceptional utility of AgNPs to prevent and control infections by micro-organisms are reported on regular basis. AgNPs in Silver-ActicoatTM dressing are used for healing of chronic wounds and it has superior property than silver nitrate and silver sulphadiazine, the latter is a formulation of silver and sulphadiazineas 1% water-soluble cream (AgSD)[34,35] Polyvinyl alcohol (PVA) nano-fibers impregnated with silver nanoparticles are considered suitable in wound dressings as they show improved antibacterial property against *E.coli* and *S.aureus*[36] Medical surface silicone elastomers and environmental surface bandage dressings functionalized with AgNPs have been found to inhibit the growth of *Candida auris* biofilms at very low concentrations.[37] Moreover, the susceptibility of inflammatory response in AgNPs based non-crystalline wound dressing therapy is very less.[38] Catheters as well as cardiovascular and bone implants are also impregnated with AgNPs for inhibiting biofilm formation and minimizing the chances of pathogenic growth.[39] In orthopedics, AgNPs are loaded along with polymethyl methacrylate (PMMA) to be used as bone cementing material in synthetic joint replacement therapy.[40] AgNPs have also been known to increase the antibacterial activities of antibiotics such as amoxicillin, clindamycin, erythromycin, penicillin, and vancomycin although it necessary to avoid prolonged exposure as AgNPs, like antibiotics, may result in development of resistance.[41] Various studies also prove the efficacy of nanosilver against varios viruses like HIV-1, Influenza virus, Hepatitis B virus etc.[42-47] Other viruses where silver nanoparticles have been shown to be effective are monkeypox virus[48], Tacaribe virus[49], Rift Valley Fever Virus[50] and also against influenza viruses like H3N2[51] and H1N1 [52] Conjugations of AgNPs with other types of polymers have shown beneficial results especially stabilizing the nanoparticles as well as providing a chemically stable system.[53] Functionalized AgNPs have shown to be useful in the medical industry as it helps in drug delivery or enhancing medical devices. Experiments on functionalization of AgNPs with reduced glutathione (GSH), polyethene glycol (PEG), and lipoic acid (LA) on human blood platelets have shown to reduce platelet aggregation caused by protein interaction of platelet surface and AgNPs.[54]

However, it is also beneficial to learn the hazards of AgNPs to prevent problems from occurring during application of AgNPs.

The Present Scenario

At present we confronting the pandemic of COVID-19 caused by Coronavirus SARS-CoV-2. Although the implemented protocols and rules, suggested by the World Health Organisation (WHO), together with the scientific community of specialists and all the governments of the world, help to ease the pandemic but still there is no antidote to the rapid spread of the coronavirus till date, as vaccines are not available. The strategies that are in practise are for most part ineffective. Face masks are of little use as viruses spread via hands and surfaces. Simple disinfection measures are even less fruitful as viruses, in general, are not living things but consist of RNA and DNA and require living cells to activate their pathogenic mechanism. Personal protective equipment that is available at present, comes without intrinsic antimicrobial/virucidal action with only temporary protect the users. With the opening of lockdown and functionality of public places like markets, universities, offices, sports complexes, malls etc, it becomes all the more important to adopt careful measures. One such aspect is air filtering media which are subject to microbial/viral colonization. These devises although limit the microorganism circulation in air, but do not inactivate or halt their proliferation[55] which can be an area of concern in closed spaces inspite of social distancing measures being followed. Moreover, the complex protein-protein interactions between the virus and host are yet to be determined for designing an effective drug. Overall, the present measures do not mitigate the risk of contagion either for an individual or in public. Thus, apart from individual protection, an efficient approach for increasing people protection in public places is essential to reinforce our health infrastructure and to better prepare and protect our health workers, patients and people in general.

Nanosilver as the last line of defence against COVID 19

With the unfolding of the pandemic, nanoparticles have gained prestigious reputation in the medical sector as a ray of hope to fight the infection and particularly AgNPs have emerged as promising materials in the biomedical sciences because of their antimicrobial activities towards wide range of microorganisms. We have a lot of evidence at present to show that silver nanoparticles are effective against several close relatives of the novel Coronavirus, including those that belong to the same family. In early 2020, a Swiss company even commercialized an antiviral and antimicrobial textile treatment based on the technology of microencapsulated AgNPs to cause deactivation of lipophilic viruses and was effective against human coronavirus, and led to a dramatic reduction in infectivity against several influenza viruses and respiratory syncytial virus.[56] There already is an opinion letter on using silver nanoparticles as antiviral therapy to treat COVID-19 patients with minimum side effects.[57] It is based on the hypothesis that AgNPs will bind to the spike glycoprotein of the virus thus inhibiting the binding of the virus towards the cells and the release of silver ions can decrease the environmental pH of respiratory epithelium (where the COVID-19 virus usually reside) to become more acidic which is hostile towards the virus.

It has also been demonstrated that silver nanocluster/silica composite coating deposited on facial masks possesses virucidal effect. It is reported that this coating can be deposited on practically every kind of filtering media and also on metallic, ceramic, polymeric and glasses surfaces and hence provide an effective contribution to safety of crowded areas like supermarkets, productions sites, schools, hospitals, etc, where surfaces are exposed to many contacts with body parts each day.[58]

CONCLUSION

The rediscovery of the medical uses of silver provides a noticeable example at the interface of chemistry and medicine of non-linear progress of scientific research. AgNPs have been deemed very useful in numerous fields especially in the field of medicine and have been acknowledged worldwide. However, AgNPs associated cytotoxicity, genotoxicity and inflammatory response in cells has raised concerns of their inadvertent use in humans.[59] These nanoparticles are viewed as potential hazards due to their ability to induce cytotoxic mechanisms such as production of reactive oxygen species (ROS), DNA damage, and heighten pro-inflammatory response in cells. Though these nanoparticles possess unique physiochemical properties, but these can prove to be a double edge sword as can cause sublethal adverse effects when the concentration or production of ROS is not properly controlled.[60] Argyria, a cutaneous discoloration due to over consumption of colloidal silver is known to mankind since long back in history. Thus taking into account these limitations, the application of AgNPs for human therapeutic interventions and disease treatment, clinical trials must be conducted. Collaborative efforts from chemistry, biology, pharmacist, physics, and medicine are necessary to consider the potential of AgNPs as candidates for inhibition of COVID-19. Finally, cost-effective, easy-to-synthesise antiviral AgNPs could reduce the burden of COVID-19 on challenging environments and in developing countries.

REFERENCES

1. Coronavirus Resource Center COVID-19 Map Available online: https://coronavirus.jhu.edu/map.html (accessed on Oct 09, 2020).
2. Guggenbichler JP, Boswald M, Lugauer S, Krall T. A new technology of microdispersed antimicrobial activity in central venous catheters. Infection. 1999; 27:16-23.
3. Hill WR, Pillsbury DM. Argyria- The Pharmacology of Silver. Baltimore. Williams & Wilkins, 1939.
4. Grier N. Silver and its compounds. In: Block SS, ed. Disinfection,Sterilization and Preservation. Philadelphia. Lea & Febiger,1968:375–398.
5. Alexander JW. History of the medical use of silver. Surgical Infections. 2009;10(3): 289-92.
6. Sims MJ. The Story of My Life. Marion-Sims H, ed. New York.D. Appleton & Co., 1884.
7. Schneider G. Silver nitrate prophylaxis. Can Med Assoc J. 1984;131:193–96.
8. Duhamel BG. Electric metallic colloids and their therapeutic applications. Lancet 1912;1:89–90.
9. Sanderson-Wells TH. A case of puerperal septicaemia successfully treated with intravenous injections of collosol argentum. Lancet 1916;1:258–259.
10. Van Amber Brown G. Colloidal silver in sepsis. Am J Obstet Dis Women Childr. 1916;20:136–43.
11. Furno F, Morley KS, Wong B, Sharp BL, Arnold PL, Howdle SM, et al. Silver nanoparticles and polymeric medical devices: a new approach to prevention of infection. J Antimicrob Chemother 2004; 54: 1019- 24.
12. Jones SA, Bowler PG, Walker M, Parsons D. Controlling wound bioburden with a novel silver-containing Hydrofiber dressing. Wound Repair Regen 2004; 12(3):288- 94.
13. Catauro M, Raucci MG, De Gaetano FD, Marotta A. Antibacterial and bioactive silver-containing Na2O X CaO X 2SiO2 glass prepared by sol-gel method. J Mater Sci Mater Med. 2004;15(7):831-7.
14. Crabtree JH, Burchette RJ, Siddiqi RA, Huen IT, Handott LL, Fishman A. The efficacy of silver-ion implanted catheters in reducing peritoneal dialysis-related infections. Perit Dial Int.2003;23(4):368-74.
15. Dakal TC, Kumar A, Majumdar RS, Yadav V. Mechanistic Basis of Antimicrobial Actions of Silver Nanoparticles. Front. Microbiol. 2016;7: 1831. PMID: 27899918.

PMCID: PMC5110546.
DOI: 10.3389/fmicb.2016.01831

16. Aymonier C, Schlotterbeck U, Antonietti L, Zacharias P, Thomann R, Tiller JC, et al. Hybrids of silver nanoparticles with amphiphilic hyperbranched macromolecules exhibiting antimicrobial properties. Chem Commun (Camb) 2002; 24:3018- 9.
17. Hamouda T, Myc A, Donovan B, Shih A, Reuter JD, Baker Jr JR. A novel surfactant nanoemulsion with a unique non-irritant topical antimicrobial activity against bacteria, enveloped viruses and fungi. Microbiol Res 2000;156:1 -7.
18. Dibrov P, Dzioba J, Gosink KK, H7se CC. Chemiosmotic mechanism of antimicrobial activity of Ag(+) in Vibrio cholerae. Antimicrob Agents Chemother 2002;46:2668- 70.
19. Dragieva I, Stoeva S, Stoimenov P, Pavlikianov E, Klabunde K. Complex formation in solutions for chemical synthesis of nanoscaled particles prepared by borohydride reduction process. Nanostruct Mater 1999;12:267- 70.
20. Gugala N, Lemire J, Chatfield-Reed K, Yan Y, Chua G, Turner RJ. Genes 2018;9:344.
21. You C, Han C, Wang X, Zheng Y, Li Q, Hu X, et al. The progress of silver nanoparticles in the antibacterial mechanism, clinical application and cytotoxicity. Mol Biol Rep. 2012;39: 9193-201.
22. Barillo DJ, Marx DE. Silver in medicine: a brief history BC 335 to present. Burns. 2014;4:3-8.
23. Lara HH, Ayala-Nunez NV, Ixtepan-Turrent I, Rodriguez-Padilla C. Mode of antiviral action of silver nanoparticles against HIV-1. J Nanobiotechnol. 2010;8,1.
24. Lu L, Sun RW, Chen R, Hui CK, Ho CM, Luk JM, et al. Silver nanoparticles inhibit hepatitis B virus replication. Antivir Ther. 2008;13:253–62.
25. Morris D, Ansar M, Speshock J, Ivanciuc T, Qu Y, Casola A, et al. Antiviral and Immunomodulatory Activity of Silver Nanoparticles in Experimental RSV Infection. Viruses. 2019;11:732.
26. Pinto DB, Shukla S, Perkas N, Gedanken A, Sarid R. Inhibition of herpes simplex virus type 1 infection by silver nanoparticles capped with mercaptoethane sulfonate. Bioconjug Chem.2009; 20:1497–502.
27. Panacek, A., Kola, M., Vec, R., Prucek, R., Soukupova, J., Hamal, P., et al. Antifungal activity of silver nanoparticles against Candida spp.. Biomaterials. 2009; 30:6333–40.
28. Kim KJ, Sung WS, Suh BK, Moon SK, Choi JS, Kim JG, et al. Antifungal activity and mode of action of silver nano-particles on Candida albicans. Biometals. 2009;22:235–42.
29. Roe D, Karandikar B, Bonn-Savage N, Gibbins B, Roullet J–B. Antimicrobial surface functionalization of plastic catheters by silver nanoparticles. J. Antimicrob Chemother. 2008;61:869–76.
30. Monteiro DR, Silva S, Negri M, Gorup LF, de Camargo ER, Oliveira R, et al. Antifungal activity of silver nanoparticles in combination with nystatin and chlorhexidine digluconate against Candida albicans and Candida glabrata biofilms. Mycoses. 2013;56:672–80.
31. Rai M, Deshmukh S, Ingle A, Gade A. Silver nanoparticles: the powerful nanoweapon against multidrug-resistant bacteria J. Appl. Microbiol. 2012; 112:841–52.
32. Chen X, Schluesener HJ. Nanosilver: a nano product in medical application. Toxicol Appl Pharmacol Lett. 2008;176,1–12. doi:10.1016/j.toxlet. 2007.10.004
33. Kim JY, Sungeun K, Kim J, Jongchan L, Yoon J. Thebiocidal activity of nano-sized silver particles comparing with silver ion. KoreanSoc. Environ.Eng. 2005;27:771–76.
34. Dunn,K, Edwards-Jones V. The role of Acticoat with nanocrystalline silver in the management of burns. Burns. 2004;30:S1–S9. doi:10.1016/S0305-4179(04)90000-9.
35. Pasupuleti VR, Prasad TNVKV, Shiekh RA, Balam SK, Narasimhulu G, Reddy CS, et al. (2013). Biogenic silver nanoparticles using Rhinacanthus nasutus

leaf extract: synthesis, spectral analysis, and antimicrobial studies. Int. J.Nanomed. 2013;8,3355–64. doi:10.2147/IJN.S49000

36. Jun,J.,Yuan-Yuan,D.,Shao-Hai,W.,Shao-Feng,Z.,andZhongyi,W. Preparation and characterization of antibacterial silver-containing nanofibers for wound dressing applications. J.US China Med. Sci. 2007;4:52–4.
37. H. H. Lara, L. Ixtepan-Turrent, M. Jose Yacaman, J. Lopez-Ribot, ACS Appl. Mater. Interfaces. 2020;12:21183–91.
38. Fong J, Wood F. Nanocrystalline silver dressings in wound management: are review. Int.J.Nanomed. 2006;1:441–49. doi:10.2147/nano.2006.1.4.441
39. Tran QH, Nguyenm VQ, Le AT. Silver nanoparticles: synthesis, properties, toxicology, applications and perspectives. Adv Nat Sci Nanosci Nanotechnol. 2013;4:033001. doi:10.1088/2043-6262/4/3/ 033001
40. Alt V, Bechert T, Steinrücke P, Wagener M, Seidel P, Dingeldein E, et al. An invitro assessment of the antibacterial properties and cytotoxicity of nanoparticulate silver bone cement. Biomaterials 2004;25:4383–91. doi:10.1016/j.biomaterials.2003.10.078
41. Graves JL Jr, Tajkarimi M, Cunningham Q, Campbell A, Nonga H, Harrison SH, et al. Rapid evolution of silver nanoparticle resistance in Escherichia coli. Front Genet. 2015;6:42. doi:10.3389/fgene.2015.00042
42. Fayaz AM, Ao Z, Girilal M, Chen L, Xiao X, Kalaichelvan P et al. Inactivation of microbial infectiousness by silver nanoparticles-coated condom: a new approach to inhibit HIV- and HSV-transmitted infection. International Journal of Nanomedicine. 2012;7:5007–18.
43. Galdiero S, Falanga A, Vitiello M, Cantisani M, Marra V, Galdiero M. Silver nanoparticles as potential antiviral agents. Molecules. 2011;16:8894-8918. doi:10.3390/molecules16108894
44. Lara HH, Ayala-Nuñez NV, Liliana Ixtepan-Turrent L, Rodriguez-Padilla C. Mode of antiviral action of silver nanoparticles against HIV-1. Journal of Nanobiotechnology. 2010; 8(1):1. doi:10.1186/1477-3155-8-1
45. Mehrbod P, Motamed N, Tabatabaian M, Estyar RS , Amini E, Shahidi M , Kheiri MT. In Vitro Antiviral Effect of "Nanosilver" on Influenza Virus. DARU. 2009;17(2):88-93.
46. Lu L, Wai-Yin Sun R, Chen R, Chee-Kin Hui, Chi-Ming Ho, Luk JM, et al. Silver nanoparticles inhibit hepatitis B virus replication. Antivir Ther. 2008;13(2):253-62.
47. Elechiguerra JL, Burt JL, Morones JR, Camacho-Bragado A, Gao X, Lara HH, et al. Interaction of silver nanoparticles with HIV-1. Nanobiotechnol. 2005;3:6 doi: 10.1186/1477-3155-3-6.
48. Rogers JV, Parkinson CV, Choi YW, Speshock JL, Hussain SM. A preliminary assessment of silver nanoparticle inhibition of monkeypox virus plaque formation. Nanoscale Res. Lett. 2008;3:129–133.doi:10.1007/s11671-008-9128-2.
49. Speshock JL, Murdock RC, Braydich-Stolle LK, Schrand AM, Hussain SM. Interaction of silver nanoparticles with Tacaribe virus. J. Nanobiotechnology. 2010;8:1–9. doi:10.1186/1477-3155-8-19.
50. Borrego B, Lorenzo G, Mota-Morales JD, Almanza-Reyes H, Mateos F, López-Gil E, et al. Potential application of silver nanoparticles to control the infectivity of Rift Valley fever virus in vitro and in vivo. Nanomedicine Nanotechnology, Biol.Med. 2016;12: 1185–92. doi:10.1016/j.nano.2016.01.021.
51. Xiang D, Zheng C, Zheng Y, Li X, Yin J, O' Conner M, et al. Inhibition of A/Human/Hubei/3/2005 (H3N2) influenza virus infection by silver nanoparticles in vitro and in vivo. Int. J. Nanomedicine. 2013;8:4103. doi:10.2147/IJN.S53622.
52. Mori Y, Ono T, Miyahira Y, Nguyen VQ, Matsui T, Ishihara M. Antiviral activity of silver nanoparticle/chitosan composites against H1N1 influenza A virus. Nanoscale Res. Lett. 2013;8:93. doi:10.1186/1556-276x-8-93.
53. Quaroni L, Chumanov G. Preparation of Polymer-coated functionalized silver

nanoparticles. J Am Chem Soc. 1999;121:10642–43.
54. Hajtuch J, Hante N, Tomczyk E, Wojcik M, Radomski MW, Santos-Martinez MJ, et al. Effects of functionalized silver nanoparticles on aggregation of human blood platelets. Int. J. Nanomed. 2019;14:7399–417.
55. Moritz M, Peters H, Nipko B, Rüden H. Capability of air € filters to retain airborne bacteria and molds in heating, ventilating and air-conditioning (HVAC) systems. Int. J. Hyg Environ. Health. 2001;203:401–9. https://doi.org/10.1078/1438- 4639-00054.
56. Hei Q Materials, Hei Q Viroblock NPJ03 Antiviral Textile Technology Tested. Effective against Coronavirus, 2020, https://heiq.com/2020/03/16/heiqvirobloc k-antiviral-textiletechnology- against-coronavirus (last accessed10 July 2020).
57. Sarkar DS. Silver nanoparticles with bronchodilators through nebulisation to treat COVID 19 patients. J Curr Med Res Opin. 2020;3:449–50.
58. Balagna C, Perero S, Percivalle E, Nepita EV, Ferraris M. Virucidal effect against Coronavirus SARS-CoV-2 of a silver nanocluster/silica composite sputtered coating. Open Ceramics. https://doi.org/10.1016/j.oceram.2020.100 006
59. Chopra I. The increasing use of silver-based products as antimicrobial agents: a useful development or a cause for concern. J Antimicrob Chemother. 2007;59:587–90. doi:10.1093/jac/dkm006
60. Calderón-Jiménez B, Johnson ME, Montoro Bustos AR, Murphy KE, Winchester MR, Baudrit JRV. Silver nanoparticles: Technological advances, societal impacts, and metrological challenges.

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