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Nanomaterial as Layer of Protection from Coronavirus: A scoping review

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Abstract

Nanomaterials have excellent potential in dealing with range of serious health problems including viral infections. However, present pandemic situation of COVID-19 have become worsen due to unavailability of effective antiviral drug and approved vaccine. Since, positive case count continues to climb at fast pace, availability of ICUs has been under huge pressure in countries like India. Hence, more efforts must be devoted to limit the virus spread. Effectiveness of preventive procedures like mask, hand sanitizer, surface disinfectants and coatings entirely depend on anti-viral efficacy of the formulation. Specifically, this review informs about research reported on various nanomaterials for preventive measures.

Keywords: COVID-19, anti-viral, masks, nanomaterials, nanocellulose

Introduction

Lockdown, social distancing, Pandemic situation due to novel coronavirus disease (COVID-19) has created a heart-wrenching turmoil in survival of human race. Coronaviruses are single-stranded RNA viruses with a crown-like shape and size of 120 nanometers in diameter. The virus resides in bats and wild birds, these are susceptible to mutation and recombination. Due to the gene modifications, it can infect humans and animals, causing COVID-19. These viruses are thought to have originated in bats and then spread from China's meat markets during late December 2019. Genome sequence of this virus resembles with SARS-CoV, the virus that caused severe acute respiratory syndrome (SARS) in 2002-2003, hence, it was named as SARS-CoV-2. Unlike some viruses, coronavirus can remain on metal, glass, wood, fabrics and plastic surfaces for several hours to days and infect. Since this outbreak began, researchers have been racing to learn more about coronavirus [1].

Emerging and re-emerging viruses are a painstaking threat to human health because of their dreadful ability to adapt to their current host, switch to a new host. As a result, they escape antiviral measures and evolve stronger. Till today around 4.5 lakhs people infected by coronavirus in India. India has only 2.3 critical care beds per 100,000 of the population. At the same time, the number of ventilators available in the country by May 2020 is a maximum of 57,000. Huge cost is involved for its usage and some of those cannot be put to use as COVID-19 patients require a specific featured ventilator. Rapid scale-up for ventilators production is supported by Maruti Suzuki India, Mahindra & Mahindra, Bharat Forge, Tata Motors, Hyundai and other public sector companies like BHEL, BEL and DRDO. This massive shortage of health care facility reiterates the significance of precaution and prevention. Hence, it's a challenging time for the scientific community in developing PPE's to prevent the virus from entering into the body and of course a vaccine for prevention of infection. Especially, Nanoscience and Nanotechnology plays a vital role in protecting humans from viruses by early detection and treating of the disease. At present, various nanomaterials are under testing trials for their use as coating materials for masks, wipes, and sprays to destroy the virus. Further, some nanomaterials are under clinical trials to assess their efficacy in detection and destruction of the new virus. The quest for an effective personal protection against COVID-19 is still open and under research. In this review, we focus on the research progress of the nanomaterials for personal protection and their efficiency in killing viruses. Nano-sensors and nanomedicine used to treat COVID-19 are not the scope of this article [2].

Nanomaterials for Masks, coatings and smart anti-viral materials

Surface contamination was found to be more contagious than any other means of expected spreading of the corona virus. The infectious aerosol virus particles can transfer to nasal/oral mucosa while coming in contact with them. Mainly, the infection in health-care workers were observed due to environmental, and PPE contamination. Hence, the first measure was to develop a new generation of nanomaterials, which can used as air filters with high-efficiency; as it is safe, effective from multifunctional antibacterial, and antiviral. Nanomaterials based masks kills viruses and bacteria, rather than just trapping them. Furthermore, commonly used surgical masks and N95 respirators are good in protecting from dust particles but have no ability to stop and kill the virus. Nanomaterial containing wipes and sprays are used for decontamination of hard, smooth polymeric and metal surfaces (such as door handles, elevator buttons, screens etc.). So far, sodium hypochlorite, 70–85% ethanol, iodine-based and quaternary-ammonium-salt were used in development of disinfectants [3].

Screens, respirators, gas masks, filters were inefficient at stopping nano-range organism's penetration in the airway passage of the user. Moreover, micro-organisms caught in the mesh structure of the equipment can stay for longer time and become a source of infection. Nano-scientists have risen-up to challenge and address this issue carefully. Identified that Copper was effective in deactivating the virus in a shorter time due to the generation of Reactive Oxygen Species

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(ROS) by Cu ions on copper and copper alloy surfaces. Copper, silver, and zinc species are well known for their antimicrobial properties and hence their nano-sized formulations are on the way to test against SARS-CoV-2 contamination. Various metal (Ag, Fe, Cu, Zn, etc.) grafted Graphene Oxide (GO) and photo-catalysts (TiO_2, CdS, MnS_2, etc.) were reported to have effective antimicrobial properties. Furthermore, Ag and Cu nanoparticles decorated on GO and copper oxide-loaded polypropylene were reported as an effective PPE material to use against both enveloped and non-enveloped viruses.

Similarly, Prof. Agarwal and his team made use of N9 blue nano-silver as antiviral coating material for producing anti-Covid-19 three-layer medical masks and N95 respirators in large quantities. Scale up of masks will be carried out in collaboration with two of its industrial partners Resil Chemicals Pvt Ltd, Bengaluru and Nanoclean Global Pvt. Ltd., New Delhi. Prof. Biman B. Mandal and his team from IIT Guwahati have been trying to prepare affordable spray-based antimicrobial coating for PPEs. Their spray uses a cocktail of copper and silver metal nanoparticles and other ingredients. Dr. Syed Dastager and a team of scientists from CSIR-NCL, Pune have prepared masks using spun-bound polypropylene medical-grade. The prototype masks were tested by the South India Textile Research Association (SITRA) for bacterial filtration efficiency using human pathogen Staphylococcus aureus and particulate filtration efficiency, the results were found to be 99.9 and 92.63 % effective respectively. Choi Hyo-jick, an assistant professor in the Department of Chemical and Materials Engineering at the University of Alberta, has been working on a product with metal salt ingredients, that can provide an anti-viral coating to surgical masks to make them safer and reusable. Sodium chloride salt coated fibrous filtration unit of surgical mask can stop and destroy pathogens more effectively than conventional mask filtration layer. Study on efficiency of salt-coated mask in mice against influenza viruses was observed to be effective 100% against the infection. Promethean Particles Ltd. a pioneering UK based manufacturer of nano-copper for a printed electronics market, has been working on Cu nanoparticles embedded polymer fibres/fabrics via a melt extrusion process. They reported that fabric was found to be effective for antimicrobial property than the rest of fabrics in the market with just surface coatings of nanoparticles. Manufacturers claim that their virus-resistant fabrics can be used to make garments, face masks, hats, uniforms and bed linens. An Israeli start-up company Sonovia Ltd. developed an ultrasonic, fabric-finishing technology to infuse the desired chemicals onto the textile materials. They have used low-cost, metal-oxide nanoparticles, such as zinc oxide and copper oxide. Moreover, the finished fabrics showed anti-bacterial activity even after 100 wash cycles at 75 degrees Celsius or 65 wash cycles at 92 degrees Celsius. Sonovia ltd. will be testing its fabrics's anti-viral activity against corona virus soon in a Singapore lab. Nova Surface-Care Centre Pvt. Ltd., working on surface coatings can deactivate the spikes glycoproteins as well as viral nucleotides [4]. They have developed a product named NANOVA HYGIENE+TM an antimicrobial coating consists of non-migratory Quaternary ammonium cations (QUATs) and positively charged Ag NPs mixed with polymer binders. They can coat surfaces such as fabrics, plastics, metals, concretes, and has proven test reports on protection against bacterial pathogens. Further, a coating material for virus deactivation was tested against a small non-enveloped RNA virus MS2 bacteriophage (Poliovirus, of the family Leviviridae) and prevention capability was proven to be good. The antimicrobial coating is yet to be tested against corona virus for a validation (Figure 1).

Figure 1: Lifespan of new corona virus on common surfaces (at 23oC temp. and 40%-65% relative humidity)* * Source: New England Journal of Medicine*, the lancet microbe**, Image: Business Insider India.

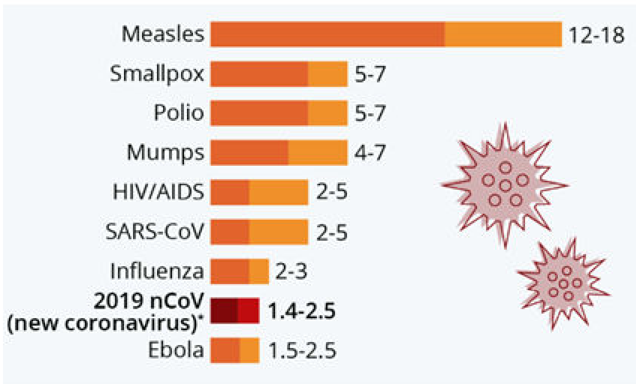

Figure 2: Comparison of highly contagious viruses with new corona virus (Average number of people infected by a specific deceased individual)* * Source: WHO via Spigele.de, estimated on 23/01/2020, Image: statista.com.

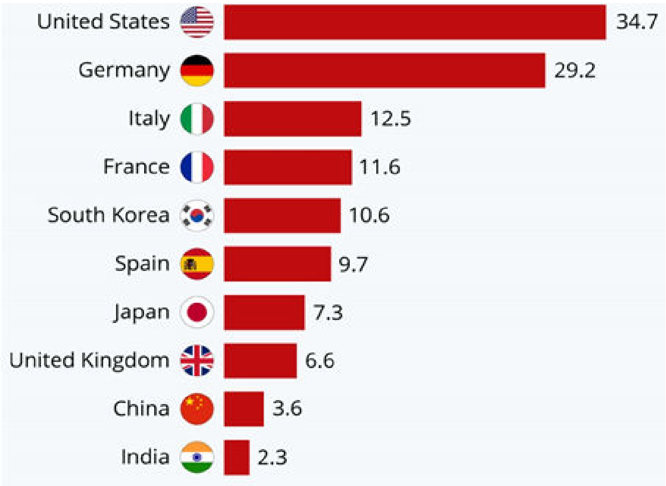

Figure 3: Critical care beds per capita availability in various countries* * Source: from statista.com dated 12 march 2020.

Argaman Ltd., from Israel has been working on Bio-Block mask. The effectiveness of their masks against the 2019-nCoV coronavirus yet to be tested. Dr. Thomas Rainey, a senior lecturer from Queensland University of Technology (QUT) with his team developed a new material for biodegradable anti-pollution masks using cellulose nanofiber. The nanocellulose was obtained from waste plant material such as sugar cane bagasse and other agricultural waste products. They reported that the material has higher breathability and ability to remove virus-size nanoparticles. This material could be used as a disposable filter cartridge in face masks. Therefore, it can be inexpensive and suitable for single-use.

Silver nanoparticles incorporated Nanocellulose

Advancement in the renewable, green nanomaterials are redefining the nanoscience and nanotechnology research era by trying to replace petroleum-based materials. Particularly, nanocellulose a most abundant natural polymer has drawn considerable interest because of its inherent properties such as low thermal expansion, high mechanical strength, high surface area, interesting optical and rheological properties and ease of surface modification. Cellulose is present in algae, bacteria, plants, and tunicates etc. The properties and extraction efforts to produce nanocellulose mainly depends on the source of the cellulose. Nanostructured cellulose obtained are of two types called as cellulose -nanocrystals (CNCs) and -nanofibrils (CNFs). CNCs (or cellulose whiskers) are needle-like crystals of size 4–25 nm in diameter and 100–1000 nm in length, and CNFs also known as cellulose nanofibrils are aggregations of elementary fibrils (made up of crystalline and amorphous parts) with micrometer length and 10–100 nm in diameter. Another kind of nanocellulose fibrils produced by Gluconacetobacter species called bacterial cellulose (BC). These BC form as bundles of nanofibrils assembly made of nanosized ribbon-shaped fibrils with70–80 nm in width producing a pellicle (membrane). These CNFs are produced using various mechanical, chemical, high intensity ultrasonication and electrospinning techniques by defibrillation of cellulose. CNFs are flexible and porous cellulosic materials and it can act as a support to immobilize metal and metal oxide nanoparticles (such as Ag, Au, Cu, Pt, TiO2 and Fe2O3). Especially, taking advantage of the bactericidal property of Ag against a wide range of bacteria, fungi and viruses, Ag nanoparticle incorporated nanocellulose has been the subject of interest for many researchers [5]. The metal nanoparticles loading, size and stability and the efficacy of antimicrobe activity depends on the nanoparticle immobilization approaches. Three types of immobilization strategies are: (i) addition of a reducing agent such as NaBH4 to the metal precursor solution with nanocellulose, (ii) use of nanocellulose as both a reducing agent and an immobilization substrate and (iii) reduction via surface-functionalized nanocellulose. Various methods of Ag nanoparticles incorporation on several types of cellulose materials were summarized in Table 1. However, still there is a scope of development in design of impressive performance nanocellulose-based nanocomposites with respect to selection of suitable nanocellulose source and environmental friendly, green synthetic methods (Table 1).

S. No	Substrate	Preparation method
1	Sub-micrometer crystalline jute cellulose (SCJC)	Ethanolic extract of M. erythrophylla bracts and NaOH solution were used for accelerating reduction of Ag ions to metallic AgNPs.
2	Polyvinyl alcohol-modified bacterial nanocellulose	In situ reduction by NaBH4 followed by UV light treatment method.
3	Bacterial cellulose (BC)-Polydopamine	Impregnation method
4	Holocellulose nanofibrils	Hydrothermal method and substrate as reducing agent for silver ions.
5	Bacterial nanocellulose (BC)	In situ reduction by NaBH4
6	Nanofibrillar cellulose (NFC)	Electrostatic adsorption
7	Crystalline nanocellulose (CNC)	Tollen's reagent / in situ reduction by glucose
8	TEMPO-oxidized CNC	In situ reduction by NaBH4
9	Crystalline nanocellulose (CNC)	Ag nanopowder, electrostatic adsorption and spin-coated methods
10	Nanofibrillar cellulose (NFC)	In situ reduction by UV irradiation

Table 1: Synthesis of antimicrobial Ag nanoparticles on various types of nanocellulose.

Conclusion

Researchers in nanoscience and nanotechnology are carrying out their social responsibility to tackle the ongoing COVID-19 global health emergency. Many start-ups, industries and academia are intensively working on design and development of nanomaterials for protective measures. More collaboration between material scientists and medical researchers are required to address the challenges in prevention, dissemination, transmission and detection of viral infections.

Nanotechnology plays a pivotal role in developing simple and rapid immunodiagnostic methods as to identify corona cases meticulously. A universal and reusable virus deactivation system for respiratory protection is need of the hour. Among various metal & metal oxide nanoparticles, silver nanoparticles have superior potential as a broad-spectrum, fast-acting, antibacterial, antifungal and antiviral agent.

In addition, knowledge exists on biodegradable materials such as nanocellulose obtained from various resources that can effectively remove particles in the range of a virus-size and easy to breathe material. So, the combination/composite of silver nanoparticles and nanocellulose materials could be a best choice for a protective nano-shield which can be used against virus. However, the properties of nanocellulose fibres are source specific and the anti-viral activity of metal nanoparticles on nanocellulose fibres are contingent on immobilization approaches. Hence further studies are required to develop Ag nanoparticle incorporated nanocellulose fibres with superior anti-viral efficiency.

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