Role of Nanoparticles in COVID-19 Management

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SUMMARY

The COVID-19 epidemic has globally influenced every significant facet of our societies. SARSCov-2 can withstand severe environmental conditions for up to 72 hours, which may be a factor in the virus's quick dissemination. As a result, efficient containment measures like sanitization, therapy, and vaccination are essential. An alternative to stop the COVID-19 virus from spreading is nanotechnology, especially in high-risk settings like public spaces and healthcare facilities. Nanoparticles can be obtained from metals as well as from plants. The phytochemical metabolites embodying extracts function as reducing agents to form nanoparticles, and such plant-based nanoparticles have diverse applications in nanomedicines. Regardless of the biological makeup, physiology, or drug-resistant characteristics of various diseases, including viruses, nanotechnology-based solutions effectively block them. Although there are different licensed nanotechnology-based antiviral medications, this chapter emphasizes various nanoparticles and their antiviral role against SARS-Cov-2 (COVID-19). Nanoparticles exhibit antimicrobial properties to limit the bacteria and fungi that might contaminate healthcare-related facilities. Therefore, nanoparticles can eliminate the virus and lower the risk of secondary microbial infections in COVID-19 patients. And lastly, affordable, simple-to-synthesize antiviral nanomaterials may lessen COVID-19's impact on harsh environments and impoverished nations. This chapter is about the antiviral activity of nanoparticles with special emphasis on COVID-19.

INTRODUCTION

Globally, infectious diseases represent the most significant risk to human existence, except for immense natural disasters or man-made nuclear conflicts. Throughout history, infectious diseases have been a persistent burden on humanity, serving as a significant contributor to illness and death over the course of many centuries (Baker et al., 2022). Moreover, these diseases have played a crucial role in shaping the evolution of the human species. In the developing world, they continue to represent the primary factor contributing to early mortality. Nevertheless, contemporary society has developed a significant level of complacency towards the potential dangers of infectious diseases. This complacency may be mainly attributed to the widespread availability and improved accessibility of hygiene and sanitization practices and the development and utilization of vaccinations and antibiotics. Despite the unwarranted complacency and the illusory feeling of safety, epidemiological specialists and sentinel groups worldwide have consistently issued numerous warning signs, which have frequently been disregarded, regarding our global susceptibility to infectious diseases and their wide-ranging and unrestricted consequences. The requirement of possessing a passport does not constrain microorganisms, nor do they

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comprehend artificial geopolitical boundaries. Moreover, the situation is exacerbated by the processes of globalization and climate change. The recent outbreaks of viral diseases, including severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Ebola, and H1N1 (Hemagglutinin type1 and Neuraminidase type 1, have significantly heightened global recognition of the substantial risk that viral infections continue to present to the entirety of humankind (Lombardi et al., 2021). Nevertheless, these concerns were frequently fleeting and quickly disregarded after the subsequent outbreaks appeared to be managed, leading to our lack of preparedness despite our firm belief and expectation that another epidemic or pandemic would inevitably occur. Indeed, the anticipated period of waiting was relatively short. As of the beginning of 2020, the human population is currently grappling with a pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), leading to the development of coronavirus illness, commonly called COVID-19 (Malla et al., 2020). Various antiviral drugs have been used to treat COVID-19 patients but their efficacy has declined because of resistance development and alternative drugs like nanoparticles are under consideration. The current chapter enlightens the nanoparticles, and their antiviral activity in pre-clinical and clinical studies with special reference to COVID-19.

THE SARS-2 (COVID-19) VIRUS PANDEMIC

The SARS-CoV-2, positive-stranded large-size RNA virus, possesses a nucleocapsid and exhibits a structural resemblance to SARS-CoV-1—the diameter of SARS-CoV-2 ranges from 80 to 140 nm (Cascella et al., 2020). The zoonotic coronavirus has emerged as a significant contributor to the rise of respiratory illnesses, exhibiting a rapid global spread that has impacted a substantial portion of the worldwide population. This unprecedented occurrence has led to unforeseen transformations in healthcare systems, the global economy, and societal interactions on a worldwide scale. The global economic burden of this infectious disease is projected to reach trillions of dollars. However, accurately estimating the actual cost remains challenging (Apostol, 2020). The practical implementation of measures aimed at mitigating the expansion of the phenomenon necessitates the active engagement and involvement of the entire societal framework. Furthermore, it requires the formulation and execution of novel approaches to social, occupational, and healthcare policies. Various strategies have been employed to mitigate the spread of COVID-19, encompassing initiatives targeting individual hygiene behaviors and community-based interventions like social distance and quarantine measures. The recommended public health interventions to minimize the impact of this pandemic include (1) effective implementation of stay-at-home measures, (2) rapid testing for COVID-19, and (3) an effective healthcare response. The final aspect considers safeguarding healthcare professionals by providing measures to avoid nosocomial infections, encompassing the availability of suitable personal protective equipment (PPE) and effective sanitization protocols. The implementation of appropriate sanitization protocols is of utmost importance. A recent study found that the presence of SARS-CoV-2 on plastic and stainless-steel surfaces can be identified for up to 72 hours. However, no viable SARS-CoV-2 was observed on copper surfaces after 4 hours following application (Van Doremalen et al., 2020). The copper-based deactivation of a virus is not surprising, as it is widely acknowledged that metal nanoparticles can render viral particles inactive. Therefore, it is plausible that nanotechnology could offer an alternate approach to surface sanitization by utilizing antibacterial and antiviral nanoparticles.

ANTIVIRAL NANOPARTICLES AND THEIR STATUS

The nanomaterial idea encompasses various definitions. In a broad sense, nanomaterials can be defined as entities that exist as individual structures or composites, with dimensions falling inside the nanometric scale, often less than 100 nm in at least one of their three dimensions. The physicochemical characteristics of materials undergo notable changes when they are inside the nanometric range, often known as the nanoscale. These changes contrast with the properties observed at larger sizes since they are influenced by quantum effects, leading to the emergence of new properties (Initiative and Initiative, 2018). Nanomaterials have garnered growing attention due to their unique or enhanced physicochemical features, including increased durability, conductivity, biocompatibility, chemical reactivity, and negligible toxicity (Brydson and Hammond, 2005). Nanomaterials possess a chemical makeup that may encompass both organic and inorganic components, and they can exist in many forms, such as singular, composites, or matrix. Nanoparticles are found in numerous recognized commodities, including electronics, healthcare and wellness, and surface coatings, including paints, consumables, and textiles, among numerous other sectors (Vance et al., 2015). Furthermore, the field of medicine has witnessed an increasing interest in applying nanotechnology. The utilization of nanotechnology in medicine, commonly referred to as nanomedicine, has gained significant attention and recognition in recent years. Nanomaterials have found extensive utilization in several healthcare-related domains, encompassing sanitization, diagnostics, imaging modalities, wound management, wearable technologies, anticancer treatments, pharmaceuticals, medication administration, vaccinations, diagnostic methodologies, and implantation procedures, among other uses. Nanomaterials have been extensively investigated in pharmaceutical research for their potential in developing antiviral and antibacterial medications. These materials have demonstrated promising properties in effectively combating various pathogenic microbes. Multiple nanomaterials can exhibit antiviral properties. The nanomaterials under consideration exhibit a chemical composition that can be classified as either organic or inorganic, namely metal-based. These materials often possess a spheroid or polyandric shape with an aspect ratio close to Their size typically falls within the range of 1 to 50 nm, and they are commonly formulated as free particles in suspension, enabling their active behavior. Antiviral nanomaterials generally have smaller dimensions than those of viral particles, including the SARS-CoV-2 viral particle (Cascella et al., 2020).

PRECLINICAL STUDIES: ANTIVIRAL PROPERTIES OF NANOPARTICLES

Numerous studies have investigated the efficacy of nanomaterials in combating various viral families, as evidenced by a comprehensive range of scholarly publications. Research conducted in vitro has demonstrated the ability of silver nanoparticles (AgNPs) to effectively neutralize various types of viruses, including HIV-1 (Elechiguerra et al., 2005), monkeypox virus (Rogers et al., 2008), hepatitis B (Lu et al., 2008), Tacaribe virus (Speshock et al., 2010), and the Rift Valley fever virus (Borrego et al., 2016). Additionally, it has been observed that silver nanoparticles (AgNPs) exhibit antiviral properties against influenza viruses such as H3N2 (Xiang et al., 2013) and H1N1 (Mori et al., 2013). The existing body of literature indicates that nanomaterials have the potential to effectively neutralize SARS-CoV-2 virus particles based on their demonstrated efficacy in suppressing other viruses belonging to the Coronaviridae family (Chen et al., 2016). Additionally, some other nanomaterials have shown antiviral properties against respiratory syndrome-causing viruses. The inhibitory effects of titanium oxide nanoparticles on the H9N2 virus have been demonstrated (Cui et al., 2010). Additionally, the inactivation of the H1N1 virus has been observed using carbon fullerene liposomes (Ji et al., 2008). Furthermore, the influenza A virus can be effectively inactivated by a complex consisting of peptides and nanoparticles (Lauster et al., 2017). According to a study, it has been observed that the Zika virus can be rendered inactive through the application of ivermectin-nanoparticle complexes (Surnar et al., 2019). Hence, it has been shown that nanomaterials can cause various viruses to become inactive, irrespective of their structural composition and strain (Chan, 2020). Furthermore, several studies have documented the role of nanoparticles in detecting, inhibiting viral activity, and eliciting immune response by targeting viruses belonging to various families, as shown in Tab 1. In mouse models, several nanomaterials have demonstrated efficacy in inhibiting the respiratory syncytial virus (Morris et al., 2019), HIV (Kovarova et al., 2015), influenza virus (Donovan et al., 2000), human papillomavirus, herpes simplex virus, lentivirus, and dengue virus (Cagno et al., 2018). Furthermore, antiviral nanomaterials have demonstrated antiviral efficacy in several in vivo models viz; dog for canine distemper virus (Bogdanchikova et al., 2016), chicken for Newcastle disease virus (Nazaktabar et al., 2017), and shrimp for white spot syndrome virus (Ufaz et al., 2018).

ANTIVIRAL MECHANISMS OF ACTION

Preclinical trials have demonstrated the mechanisms by which interactions between viruses and nanoparticles result in either direct or indirect antiviral effects. Nanomaterials exhibiting indirect activity do not possess inherent virus-inhibiting properties. Instead, they serve to enhance the efficacy of antiviral treatments by facilitating transport (Herzog et al., 2009), promoting stability (Alconcel et al., 2011), and augmenting bioavailability (Donalisio et al., 2018), among other functions. In addition, it has been observed that nanomaterials can elicit an immunological response, leading to the development of both short-term and long-term immunity (Seto and Yuen, 2016). The silver nanoparticles (AgNPs) can bind with HIV receptors, thereby decreasing the infectivity of the virus (Lara et al., 2010). The researchers proposed that silver nanoparticles (AgNPs) exhibit binding affinity towards the gp120 glycoprotein knobs, impeding the virus-cell interaction process, as seen by their in vivo findings. In a recent study, Morris et al. (2019) proposed that silver nanoparticles (AgNPs) could bind to the virus's surface glycoproteins, thereby impeding the fusion process and diminishing its capacity to adhere to host cells (Morris et al., 2019). Furthermore, Cagno et al. (2018) demonstrated in their study that applying organic ligand-coated gold and iron oxide nanoparticles can disrupt the ultrastructure of several viruses (Cagno et al., 2018). This disruption causes the viral particle to break down, reducing viral activity for both enveloped and naked viruses. Kim and colleagues (2018) have provided evidence that nanomaterials can inhibit the expression of viral genes. Their study revealed that the in vivo delivery of anti-CCR5 siRNA/LFA-1 I-tsNPs effectively suppressed gene expression solely in leukocytes for around 10 days, hence offering protection against HIV infection (Kim et al., 2018). Cojocaru et al. (2020) conducted a comprehensive review that elucidated the various methods by which nanomaterials might effectively neutralize DNA and RNA viruses (Cojocaru et al., 2020). Furthermore, they may demonstrate diminished toxicity in comparison to non-nanostructured materials.

THE CLINICAL STUDIES AND AVAILABLE NANOPARTICLE-BASED PRODUCTS

There is ongoing clinical research on some antiviral nanomedicines, while others have already received approval and are already accessible for commercial usage. Several recent reviews provide an overview of the present state of antiviral

Tab 1. Nanoparticles and their mode of action against different viruses.

Chemical Nature	Characterization technique	Size (nm)	Application	Virus	References
Gold (Au-NPs)	TEM	2, 14	Sialic-acid-functionalized, Multivalent, Antiviral activity	Influenza A (H1N1)	Papp et al., 2010
	SEM	2-50	Detection of nucleic acid (RNA) in clinical cases	Hepatitis C	Shawky et al., 2010
	SEM	10, 20, 40	Immunoconjugate used for detection	Hepatitis C	Gopinath et al., 2013
	DLS, UV-Vis spectroscopy	12.92	Form cationic complexes with siRNA; Anti-viral activity	Dengue	Paul et al., 2014
	DLS, TEM, UV–Vis spectrophotometry	12	Immuno-potent as conjugate with matrix 2 protein and CpG	Influenza A	Tao et al., 2014
	DLS, TEM	13	Anti- hemagglutinin monoclonal antibody based Immunosensor in colorimetric assay	Influenza A	Liu et al., 2015
	TEM, Filter-based multimode microplate reader	35	Used in modified ELISA and antiviral	Influenza A (H1N1)	Ahmed et al., 2016
	TEM, UV–Vis spectroscopy	N/A	Peptide nucleic acids nanoparticle; Immunosensor in colorimetric assay	BVD virus	Askaravi et al., 2017
	SEM, TEM	30	Immunosensor for antigen coupled with Horseradish peroxidase	Hepatitis B	Alizadeh et al., 2017
	N/A	15	Probe for ultrasensitive detection of viral core	Hepatitis C	Yin et al., 2017
	N/A	11, 15, 19	Nucleic acid sensor for ultrasensitive virus detection	Hepatitis B	Zengin et al., 2017
	SEM, XRD, AFM	5-20	SiO_2 encapsulated; Anti-viral	Adeno	Lysenko et al., 2018
	CLSM	18	Immuno-potent along with antigen for enhanced adaptive immune response	Influenza	Wang et al., 2018
	DLS, TEM	19	A potential way to detect virus with 1 pmol/µL detection limit	MERS-Corona	Kim et al., 2019
	TEM, DLS	40, 100	Immuno-potent to in duce IgG response as an adjuvant with S protein	SARS-Corona	Sekimukai et al., 2019
Silver (Ag-NPs)	N/A	30-50	Antiviral activity	HIV-1	Lara et al., 2010
	TEM	10	Antiviral activity	Influenza A (H1N1)	Xiang et al., 2011
	TEM	11.4	Antiviral activity	Ad3	Chen et al., 2013
	TEM, UV–Vis spectrophotometry	7-20	Antiviral activity (viral replication)	HSV; HP-influenza3	Gaikwad et al., 2013
	TEM, SEM	3.5, 6.5, 12.9	Antiviral activity	Influenza A (H1N1)	Mori et al., 2013
	High resolution (HR) TEM, Field emission (FE) SEM	5-25	Antiviral activity (Ag- Graphene)	Feline Corona; IBDV	Chen et al., 2016
	TEM, FE-SEM, UV-Vis Spectroscopy	4-9	Antiviral activity (electrochemical synthesis)	Polio and non-enveloped	Huy et al., 2017
	TEM, SEM	13, 33, 46	Antiviral activity	HSV2	Orłowski et al., 2018
	TEM	33	Antiviral activity (Mucoadhesive hydrogel)	HSV-1&2	Szymańska et al., 2018
Silica (Si-NPs)	TEM, DLS	150-200	Viral entry inhibitor (by viral binding)	HSV	Lee et al., 2016
	TEM, SEM	200	Antigen carrier for vaccine (with HMS)	PCV2	Guo et al., 2012
	FTIR, TGA, FE-SEM	50-70	Fluorescence based immunoassay for detection	HIV	Chunduri et al., 2017
Iron Oxide (IO-NPs)	TEM, XRD	60, 90, 120	Magentism-based separation and detection with MALDI-TOF MS	Influenza A	Chou et al., 2011
	Malvern's zetasizer-ZS90	101, 103, 105	Magnetism-based nano-sensor for detection	Zika	Shelby et al., 2017
	FTIR, HR-TEM, XRD, DLS-zeta	10-15	Viral growth inhibitor	Influenza H1N1 pandemic eastern and Indian strains	Kumar et al., 2019
Zinc Oxide (ZnO-NPs)	SEM	200 to 1000	Antiviral activity	HSV2	Antoine et al., 2012
	TEM, ICP-MS, FE-SEM, XRD	20-50	Antiviral activity	Influenza A (H1N1)	Ghaffari et al., 2019
Graphene oxide (GO-NPs)	Raman and UV-Vis spectroscopy	127.7nm	Antiviral activity (Curcumin functionalized)	RSV	Yang et al., 2017
	High resolution (HR) TEM, Field emission (FE) SEM	5-25	Antiviral activity (Ag- Graphene composite)	Feline Corona; IBDV	Chen et al., 2016
Titanium Dioxide (TiO_2-NPs	EM	4-10	Antiviral activity	Influenza	Mazurkova et al., 2010
Ceria NPs	TEM	6	Immuno-potent (aqueous solution)	Influenza	Zholobak et al., 2016
Selenium (Se-NPs)	EDX, TEM, XPS, FTIR	82	Antiviral activity (Zanamivir modified)	Influenza A (H1N1)	Lin et al., 2017

properties of nanomedicines, encompassing preclinical and clinical trials and those that have already received approval. In their study, Lembo et al. (2018) conducted comprehensive research on enhancing antiviral drug efficacy using nanotechnology-based formulations (Lembo et al., 2018). They elucidate the various benefits offered by distinct nanomaterials.

On a related note, Sato and Yuen (2016) provide valuable insights into the current progress of multiple therapeutic interventions targeting the hepatitis B virus (HBV), which are currently going through clinical trials (Seto and Yuen, 2016). Lastly, Singh et al. (2017) present a comprehensive view of research conducted on nanoparticles for treating viral infections, encompassing preclinical investigations, clinical trials, and the subsequent commercialization of these interventions (Singh et al., 2017). Two examples of nanotechnology-based products that have received approval from the Food and Drug Administration (FDA) are Inflexal V©, which is a virosomal anti-influenza vaccine (Herzog et al., 2009), and Pegasys©, which is a pegylated IFN alpha 2a anti-Hepatitis [HBV and HVC (Ventola, 2017)].

NANOPARTICLES AND COVID-19

As previously said, nanoparticles are presently employed in several commercially accessible commodities, including cosmetics and healthcare applications. The Nanowerk databases (Vazquez-Munoz and Lopez-Ribot, 2020) provide a comprehensive and current compilation of goods that may be referenced for specific information. The diverse array of physical and chemical characteristics exhibited by nanomaterials confers several benefits in addressing the SARS-Cov-2 virus, encompassing the mitigation of its transmission and the potential for future therapeutic interventions. The stability and reactivity of antiviral nanoparticles are enhanced when they are immobilized onto a support, leading to an increase in the surface area of the support. Nanoparticles are commonly utilized in a variety of applications, including filters, personal protective equipment (PPE), packaging, and medical textiles, where they are typically absorbed by textiles (Emam et al., 2013) and polymers (Massella et al., 2019). Nanomaterial suspensions have demonstrated utility in various domains, including but not limited to sanitization, coatings, and medicinal applications. In conclusion, several nanomaterials have the potential to serve as effective agents for nanocarrier systems, diagnostic applications, and detection methodologies. Personal Protective Equipment (PPE) refers to individuals' specialized gear or clothing to protect themselves from potential hazards or risks in various environments. Extensive research has been conducted on using textiles embedded with nanoparticles, owing to their ability to enhance the physicochemical characteristics of fabrics. These improvements include but are not limited to fire retardancy, self-cleaning capabilities, antibacterial qualities, and UV protection (Yetisen et al., 2016). Fibers that include metallic nanoparticles have antibacterial 8 and antiviral characteristics (Suryaprabha & Sethuraman, 2017). The application of nanotechnology in the development of protective clothing, specifically focusing on PPE viz; lab coats, facemasks, and aprons has been evaluated. This assessment was prompted by nanoparticles' unique characteristics of fabric materials (Paul, 2019). Recently, there has been a significant surge in the utilization of nanoparticles in the textile industry. The global consumption of silver nanoparticles alone has reached over 35 tons (Syafiuddin et al., 2017). The investigation of wearable smart fabrics and electronics for sensing purposes, specifically focusing on health-related applications, has been extensively examined, as elucidated by Libertino et al. (2018) In particular, the early identification of infections has garnered significant attention (Libertino, Plutino & Rosace 2018). According to Jayathilaka et al. (2019), wearables and textiles can also be utilized for drug delivery purposes (Jayathilaka et al., 2019). Nanomaterial-based surface coating. Nanomaterials-based coatings are being utilized in many applications, with a range of products readily accessible. These products primarily consist of metallic components, including silver, bismuth, copper, or titanium (Sim et al., 2021). Furthermore, it has been observed that nanostructured surfaces could diminish the adhesion of infections effectively. Moreover, the nanoscale topographical arrangement of these surfaces can potentially disturb the structural integrity of pathogens (Elbourne, Crawford, and Ivanova, 2017). Nanomaterials have the potential to be incorporated into paints or coatings used in various applications, including medical apparatus, walls, and frequently touched surfaces like doorknobs and handrails. In research conducted by Rai et al. (2020) several nanocoating are discussed concerning their possible application in public spaces to mitigate the presence of diseases (Rai et al., 2020). Currently, disinfectants containing silver salts are employed, as silver is considered a safe agent for the goal of sanitization (Ku, Walraven & Lee 2018). Implementing nanotechnology-based solutions for sanitization purposes in hospitals and other healthcare-related institutions can potentially reduce the viral load on frequently touched surfaces, prolonging their virus-free state. It includes the effective elimination of the SARS-CoV-2 virus. Metallic nanoparticles have been suggested as a potential solution due to the observed decrease in survivability of the SARS-CoV2 virus on metallic surfaces, specifically copper (Van Doremalen et al., 2020).

Nanomaterials possess several applications, including their potential to enhance the efficacy of air filtration systems deployed in healthcare institutions or other environments reliant on recirculated air. Devices enhanced by nanotechnology can potentially mitigate the transmission of viral particles. For instance, air filters and water treatment methods can be improved to eliminate infections and viruses effectively (Pedroza-Herrera et al., 2020). Moreover, extensive research has been conducted on the application of nanotechnology in producing wound dressings (VazquezMunoz & Lopez-Ribot, 2020). It is primarily attributed to their capacity to provide protection against infections and enhance the rate of wound healing. Potential future applications could encompass the advancement of enhanced detection kits, as this has emerged as a prominent requirement within existing efforts to mitigate and monitor the virus's dissemination. Hameed et al. (2018) provide a comprehensive overview in their latest review, elucidating nanotechnology's significance in In addition to pathogen detection, new advancements have been made in the field of nanotechnology-based innovative packaging with the aim of pathogen prevention (Zhong et al., 2020). While the studies conducted by Hameed et al. (2018) and Zhong et al. (2020) primarily examine the applications of food-related interventions, it is worth noting that similar interventions can also be applied in the clinical domain. Specifically, microbial secondary infections pose a significant yet often overlooked risk in healthcare settings. The ongoing COVID-19 epidemic has given rise to other health issues that extend beyond primary sickness, including the underappreciated risk of secondary infections that can manifest themselves concurrently with or after the administration of therapeutic interventions for COVID-19, owing to the strain imposed on the healthcare system by the viral pathogen. Furthermore, it is not uncommon for individuals diagnosed with COVID-19 to experience consequences related to acute organ injury and secondary infection (Luo et al., 2020), which may potentially be caused by microbial agents. In a recent study conducted by Rawson et al., an extensive analysis of existing literature was undertaken to examine the occurrence of microbial co-infections among individuals afflicted with various strains of coronaviruses. Despite the relatively low rate of co-infection, estimated at 8%, it was determined that these co-infections nevertheless provide a significant risk for patients suffering from COVID-19 (Rawson et al., 2020). One significant concern related to microbial infections is the emergence of drug resistance, resulting in ineffective treatment modalities for these disorders. Numerous global health 10 organizations emphasize that the emergence of multidrug-resistant microorganisms poses a pressing and critical menace, resulting in a significant number of fatalities and incurring immeasurable financial implications. The latest publication from the Centers for Disease Control and Prevention (CDC), titled "Antibiotic Resistance Threats in the United States," provides a comprehensive inventory of therapeutically relevant microbial infections and elucidates the various issues that arise due to the emergence of medication resistance (CDC, 2019). Biofilms provide a protective environment for microbial pathogens, enabling their survival despite rigorous sanitization methods and adverse conditions. Biofilms facilitate the persistent colonization of health-related infrastructures by microbial diseases. Antimicrobial nanoparticles, known as nano antibiotics, have emerged as a promising alternative for combating infections. Nano antibiotics exhibit a broad spectrum of antibacterial action against bacteria (Vazquez-Muñoz et al., 2019), protozoa (Kurvet et al., 2017), and fungi (Lara et al., 2020). Extensive research has been conducted on metallic nanoparticles due to their inherent antibacterial capabilities (Frei et al., 2020). These nanoparticles exhibit antimicrobial activity independent of the antibiotic susceptibility of microorganisms (Lara et al., 2020). Furthermore, it has been suggested by Vazquez-Munoz et al. (2019) that nanomaterials can augment the effectiveness of existing antimicrobial medications (Vazquez-Muñoz et al., 2019). Their recent study outlined a possible interaction mechanism between silver nanoparticles (AgNPs) and antibiotics, resulting in synergistic outcomes (Vazquez-Munoz & Lopez-Ribot, 2020). In addition, the application of nanoparticles has been found to effectively decrease the formation of microbial biofilms, hence mitigating the potential for secondary microbial infections (Lara et al., 2020). Another benefit is the wide range of techniques available for synthesizing. Specific methods can be readily replicated in non-specialized facilities, even in challenging conditions (Vazquez-Munoz & Lopez-Ribot, 2020).

CONCLUSION

Antiviral nanomaterials offer a potential solution for mitigating the transmission of COVID-19, given their demonstrated efficacy against several viral pathogens. According to existing knowledge, it is possible to utilize nanomaterials in the immediate or near future to mitigate the transmission of the SARS-Cov-2 virus. This can be achieved through the application of antiviral sanitizers, the integration of nanotechnology into personal protective equipment and medical instruments, as well as the development of nanotechnology-enhanced fabrics for widespread use 11 in face masks. Nanotechnology-based sanitizers exhibit robust and wide-ranging antiviral and antibacterial properties, enhancing safety in healthcare institutions and public areas. Concerning forthcoming applications, nanoparticles have the potential to be employed in the development of detection kits, vaccinations, and therapeutic interventions. At present, the efficacy of antiviral nanotechnology-based pharmaceuticals in therapeutic applications has been demonstrated, and it is anticipated that their utilization will be further extended as additional study findings emerge. In addition, nanomaterials exhibit a diverse spectrum of functionality and can potentially augment some pharmaceuticals' antibacterial efficacy. In conclusion, the use of protocols that prioritize the development of antibacterial and antiviral nanomaterials with characteristics such as ease of use, quick synthesis, and cost-effectiveness has yielded very effective nanomaterials capable of mitigating the transmission of viruses and germs. Using cost-effective nanotechnology can enhance sanitization techniques to combat COVID-19 in underdeveloped nations where sophisticated materials are constrained. Furthermore, nanoparticles that are simple to synthesize can be employed in challenging environments, including medical mobile units, rural healthcare institutions, and heavily trafficked public locations.

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