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Green Materials Sterilization Solutions

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Synonyms

Biodegradable solutions; Green nanomaterials; Sterilization solutions

Definition

Nowadays, green nanomaterials are a related and interdisciplinary subject that has appeared as a fast-expanding research area. This is an effective approach that focuses on developing clean, safe, and environmentally friendly procedures. Due to their tiny size, high surface-to-volume ratio, and greater reactivity compared to their bulk counterparts, they have certain unique features, and these traits may help the system perform better. At this time, the whole world is involved with the COVID-19, and everyone must use cleaning and disinfecting products capable of eliminating SARS-CoV-2. Therefore, this represents a big problem for people and environmental health. Specific compounds in sterilizing solutions may lead to irritation or toxicity (e.g., skin and eye irritation). In laboratory experiments, alkylphenol ethoxylates, a common surfactant component in cleansers, were shown to act as an "endocrine disrupter," bringing severe reproductive implications. Some common surfactants disintegrate slowly or break down into more persistent, hazardous, and bioaccumulative compounds, causing a threat to aquatic life. Phosphorus- and nitrogen-containing ingredients can promote nutrient overloading in water bodies, resulting in poor water quality. As a result, it appears that using biodegradable green nanomaterials is an excellent option in this regard. Some green nanomaterials and biodegradable solutions, which are nontoxic and noncarcinogenic, have a high ability to kill viruses and bacteria. These materials, such as hydrogen peroxide, ethyl alcohol (ethanol), citric acid, L-lactic acid, caprylic acid (octanoic acid), and thymol, are environmentally friendly and biodegradable. In this way, while improving the

C. Baskar et al. (eds.), *Encyclopedia of Green Materials*,
https://doi.org/10.1007/978-981-16-4921-9_81-1

efficiency of the product, its safety can be significantly increased.

Introduction

The presence of viruses shows profound impacts on the path of life of the planet, even though they themselves biologically are not considered an alive organisms. They have a part of alive types, while they have nonliving characters. They have an astonishingly simple structure. For example, the prototypical Ebola virus (*Zaire ebolavirus*) can dramatically infect people with just seven proteins (Choi and Croyle 2013; Sullivan et al. 2003). More complex and superviruses have genes, but they can have metabolic proteins. Because the viruses could be replicated through co-opting the molecular machinery in a living cell, their harnessing process has vital importance (Moniruzzaman et al. 2020). Green nanomaterials are promising options that have recently reviewed broad applications in recent biological and biomedical trials. This chapter focused on clarifying their usage in sterilization solutions as antiviral materials.

Carbon-Based Nanomaterials (CBNs)

Antiviral sterilizing compounds could be categorized into two main subgroups based on their mechanism of action: (1) virus inhibitors that usually act in the cellular phase and (2) immunomodulating materials (Smith et al. 1980). Antiviral materials need a mechanism to inhibit a specific cell cycle of a virus from harnessing the viral replication process. As viral replication mainly depends on the host cell's metabolism as viruses are obligate intercellular parasites, valuable antivirals can disrupt viral-specific functions or at least obstruct virus-directed functions as opposed to the host cell. Because of that, the viral replication cycle leans to the metabolism of host cells. Designing antiviral drugs can easily interrupt the viral cycle and functions. Based on this fact, types of such antiviral medications have been limited, and just the existing types work based on (i) their blocking effect on host cells through imposed alterations on the conformation of capsids on the viral surface, (ii) manipulation of the viral genome during an uncoating process, and (iii) interdiction of virus penetrating. A vital principle in achieving antiviral activity is the ability to reach an inhibitory effect on the direct attachment of the virus to host cells or limiting their entry path. According to recent reports, some types of antiviral drugs stop the integration process between the virus genome and host cells. Other types disrupt the coating process. Finally, the cell-to-cell enzymatic inhibitory process could be used for harnessing viruses (Bennett et al. 2019; Chono et al. 2010). Ever-raising viral infections could be controlled by multi-drug package consisting of antibiotics, antimicrobials (Liu et al. 2008), ammonium-based materials (Jia and Xu 2001), and peptoid families (Chongsiriwatana et al. 2008). In this respect, carbon-based nanomaterials (CBNs), as one of the most famous green materials with proven antimicrobial properties (Henriques et al. 2018), could conquer viral resistance due to some combined physicochemical mechanisms. For example, graphene (G) could be related to disruption of peptidoglycan membrane in bacteria or virus structure through an electron transfer process and imposing stress known to oxidative stress caused by membrane deformation process (Zou et al. 2016). Although many other metal and metal oxide nanomaterials (e.g., silver, copper, titanium, or zinc) were reported for their similar properties, the toxicity is their unsolved challenge that restricts their long-term application as drugs or antiviral or antimicrobial agents. For these reasons, CBNs could be introduced as highly potent candidates as next-generation materials for antiviral applications due to their outstanding physical and chemical properties such as high specific surface area and biocompatibility.

Green CBNs could be categorized in fullerene, carbon dots, graphene, and derivatives that the different antiviral activity mechanism was reported.

Fullerenes

Fullerenes, an allotrope of CBN that benefit from anti-radical and antioxidant properties (see Fig. 1), can be used as a hydrophilic drug (Innocenzi and Stagi 2020; Gacem et al. 2020). Reports on the antiviral properties of fullerenes were initiated in 1993 to find effective drugs against HIV-1 infections.135 One study revealed that a bis (mono-

succinimide) conjugate of p,p′-bis(2-aminoethyl)-diphenyl-fullerene provides an inhibiting effect on HIV-1 and HIV-2. In 1997, fullerene-based drugs presented an antiviral property against single-stranded RNA SARS-CoV-2, M-MuLV, and SIV viruses (Nacsa et al. 1997).

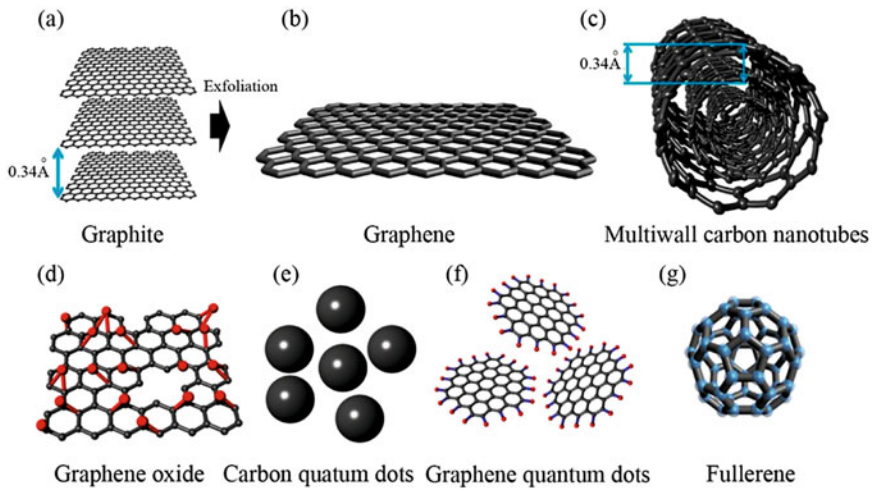
From the mechanistic view of the point, fullerenes could inhibit entry of virus by alteration in viral shape and, as a consequence, block the replication process (Innocenzi and Stagi 2020). Some studies revealed that C60-fullerene provides antiviral activity against HIV-1 and HIV-2 by well-fit attachment on the active site of the virus (Friedman et al. 1993). Antiviral activity of a C60/PVP conjugate (known as the membranotropic agent) on the SARS-CoV-2 virus could be explained by attachment of C60/PVP to the lipid component in membranes of the virus (Sirotkin et al. 2006). Attachment of C60/PVP to the glycoprotein spikes of virus in "brush" forms destroyed their integrity and function through breaking effect on the structure of lipoprotein envelopes.

Carbon Dots (CDs)

CDs known as 0D carbon quantum particles (see Fig. 1) are other families of the CBNs with particle diameter size of about ~10 nm and are one of the greenest cost-effective materials that provide environmentally friendly and inert compounds (Ruiz-Hitzky et al. 2020). They represent a high specific surface area and could be dispersed in aqueous media, making them appropriate for sterilizing solutions due to their stable dispersibility. The application of CDs in broad fields of science and medicine was reported in recent decades, especially in biosensing, bioimaging, (electro) catalysis, etc. (Lim et al. 2015). Functional CDs were recently introduced as candidates for an antiviral agent (e.g., CDs with 4-aminophenyl boronic acid functional groups) against coronavirus (HCoV). Another CD-based green material is benzoxazine functionalized carbon dots (BZM-CDs) that show outstanding antiviral impact against the Japanese encephalitis virus (JEV) (Huang et al. 2019).

Graphene (G)

Graphene and graphene oxide (GO) as 2D allotropes of CBNs (see Fig. 1) could be applied for detecting and capturing the process of various viruses (Song et al. 2015). Among them, carbon nanofibers (CNFs) represented the greatest antiviral activity that their incorporated forms conjugated into alginate were examined for

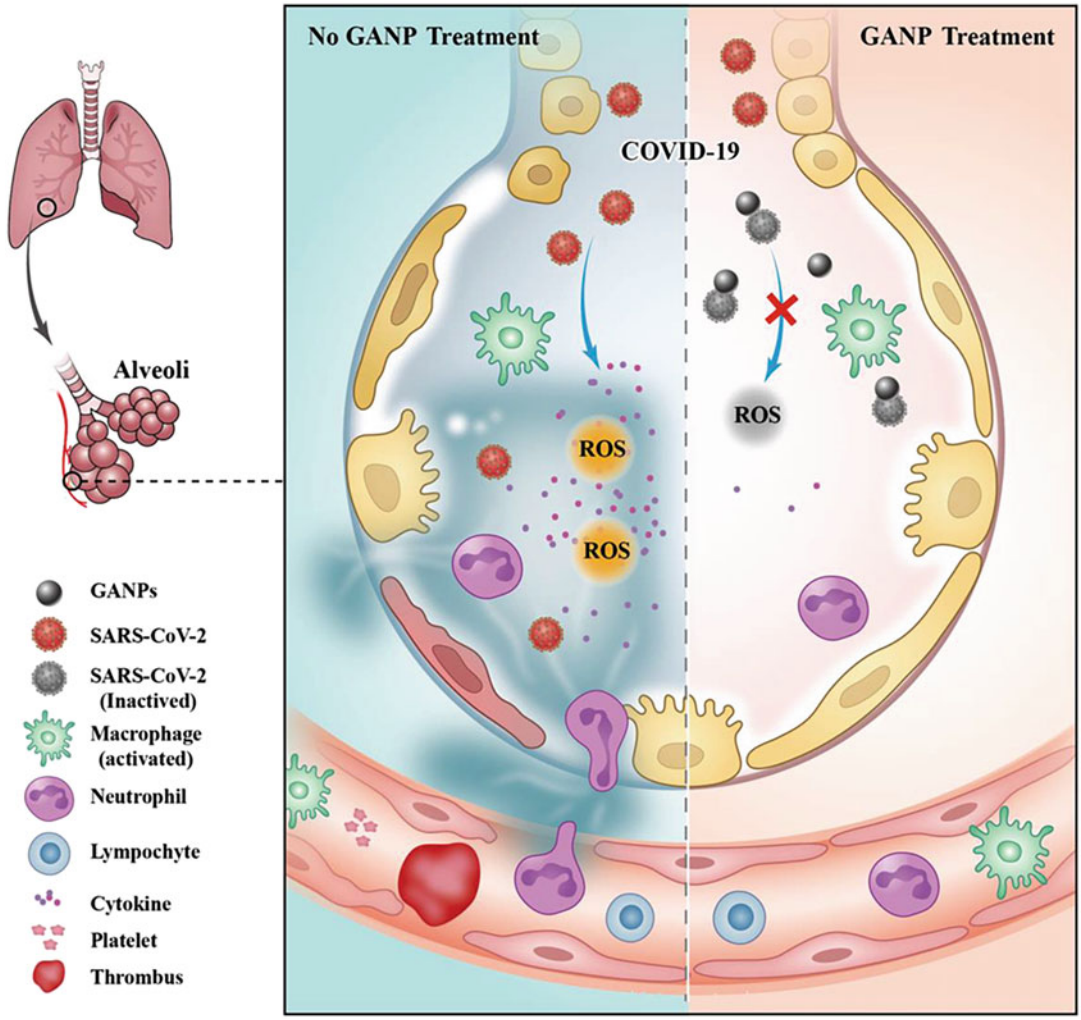


Green Materials Sterilization Solutions, Fig. 1 CBN molecular structures which showed potential ability as antiviral agents, especially against single-stranded RNA viruses: (**a**) layered structure of graphite; (**b**) G, single layers of graphite are known to G; (**c**) multiwall carbon nanotubes, tubelike sheets of G; (**d**) GO, the surface of G could be oxidized in chemical, physical, and other methods to obtain GO; (**e**) CDs are like amorphous carbon but very smaller in size; (**f**) graphene quantum dots are also similar to G but smaller in size in three dimensions; (**g**) fullerene, a sheet of G in spherical shape (Nguyen et al. 2019)

SARS-CoV-2. The impact of stable dispersibility raising from hydrophilicity of these materials is a key point for their antiviral activity. Combining antiviral metal nanoparticles such as silver (AgNPs) with GO has been reported as a promising method for fighting feline coronavirus (FCoV). 66 In recent years, aliphatic chain-functionalized G materials were introduced as inhibitory agents against FCoV and SARS-CoV-2 viruses due to their stable dispersibility and impact on the replication process, which proved the potential capability of CBNs as antiviral agents and their usage in sterilizing solutions (Donskyi et al. 2021).

Glycyrrhizic Acid Nanoparticles

The antiviral impact of glycyrrhizic acid nanoparticles (GANPs) and their anti-inflammatory effect against infections of SARS-CoV-2 were considered by Shan et al. (Ruiz-Hitzky et al. 2020). Their finding, low toxicity under in vitro and in vivo conditions, was one of the main characteristics of these green antiviral materials. Biocompatibility and good accumulation of GANPs in infected zones of the lungs and livers are other advantages of these types of nanoparticles through the treatment process (see Fig. 2).



Green Materials Sterilization Solutions, Fig. 2 Illustration of treating pathway of GANPs for COVID-19 infections (Zhao et al. 2021)

Polymers

This part will introduce the polymer materials as one of the greenest types for antiviral applications and their possibility of using sterilization solutions and drugs.

Natural

The first types of polymeric antiviral materials that were developed for harnessing the activity of HIV were natural and green polymers consisting of polysaccharides. In 1987, the sulfated polysaccharide polymers and also dextran sulfate-based materials showed an inhibitory effect on HIV. After that, efforts revealed that sulfated polysaccharide polymers use an interfering mechanism for effective interaction with gp120 glycoprotein on HIV spikes and stimulating for CD4+ antigen receptor of the T cells in the immune system. The exact mechanism of this process remained under debate, but some main mechanisms have been identified up to now. For example, a fusion occurs between virus and cell by V3 loop of gp120 glycoprotein with Tat protein of HIV-1. Another mechanism is the blocking effect of the virus through a reverse transcription (Takemoto and Liebhaber 1961; Takemoto and Fabisch 1964).

Dendrimer

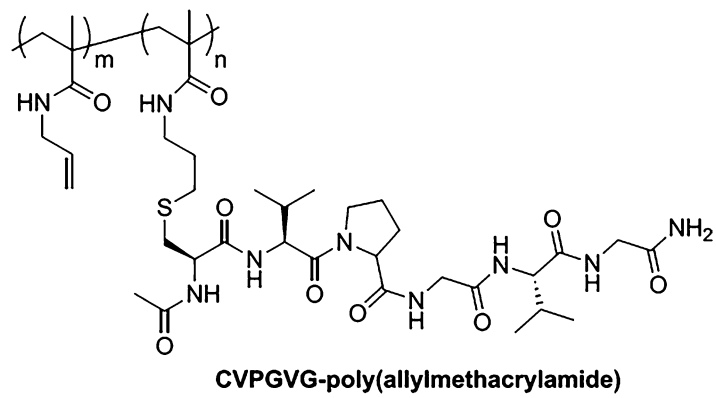
Wide dendrimers have been utilized to develop antiviral green materials, and typically, they have found antiviral applications against HIV. For instance, Han and coworkers developed families of polylysine-based dendrimers that included sulfated cellobiose at their end, functional groups. The presence of sulfated oligosaccharides in dendrimer structures provides biological activities under the condition that the cytotoxicity of materials remains in low values and an outstanding antiviral activity could be obtained against HIV. From the mechanical aspect, these polymers could alter the membrane of the virus and run the oxidative pathways in intraviral media.

Biomimetics

The anti-replicative design for antiviral application was reported by using biomimetic polymers. For example, Yahi and coworkers developed a series of the synthetic polypeptide for mimicking the structure of the V3 loop that provides a blocking effect on the fusion process of HIV-infected cells with $CD4^+$ immune cells. Similar polymers were designed by Klok et al. that have a polyvalent peptide-structured conjugates that represented an outstanding mimicking of the CDR H3 loop (see Fig. 3) (Singha et al. 2011). Interaction between IgG1 b12 antibody and $CD4^+$ could be mimicked for inhibiting HIV.

Hard Nanomaterials (HNMs)

Ever-rising families of HNMs were developed for use as antiviral sterilizing agents that provide various approaches for application consisting of (1) ability in preventing viral entry, (2) harnessing interactions with host cells, and (3) stimulating the



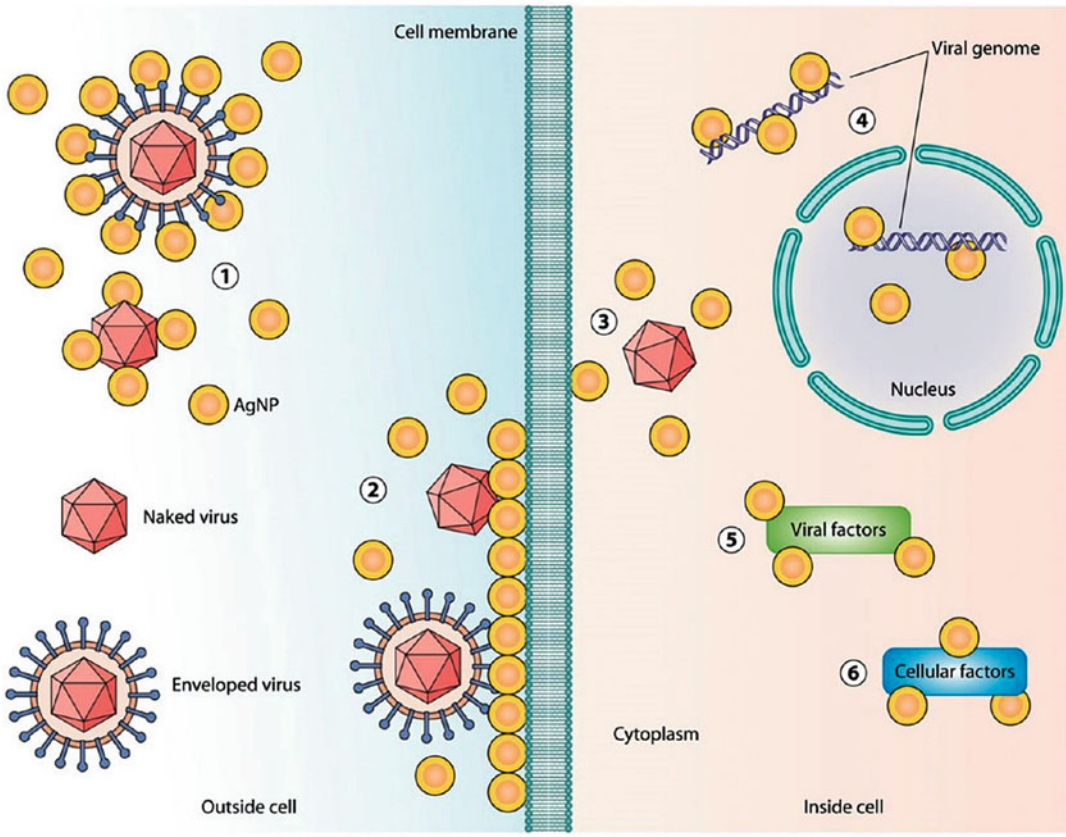
Green Materials Sterilization Solutions, Fig. 3 A synthetic peptide CVPGVG was conjugated to the poly(allyl methacrylamide) polymer (Bianculli et al. 2020)

immune system. The HNMs consisting of noble metal and their oxide forms can deactivate the virus system by running a dysregulation revolutionary process as a homeostasis path in the capsid structures. Moreover, their ability in interfacial functionalizing makes it possible for these particles to mimic the host cells and/or increase the efficiency of infected cell targeting (Reina et al. 2020).

Silver Nanoparticles (AgNPs)

Many reports demonstrated that AgNPs provide an ability to control and prevent viral diseases under the condition that the antiviral effect mechanism remains under debate.

Meanwhile, there are many mechanical theories about this issue consisting of the following: (1) AgNPs can disrupt the virus entering into the intracellular media of host cells; (2) inhibit the virus binding to the receptor of the host cell and ending infecting process of targeted cells; (3) might be able to bind to the viral spikes and act as inhibitory agent in interaction that could be formed between virus and membrane of cell receptors (Fig. 4); and (4) inactivate the virus during denaturation process of proteins that are in surface spike containing cysteine molecules and also methionine residues (Rai et al. 2016; Elechiguerra et al. 2005).



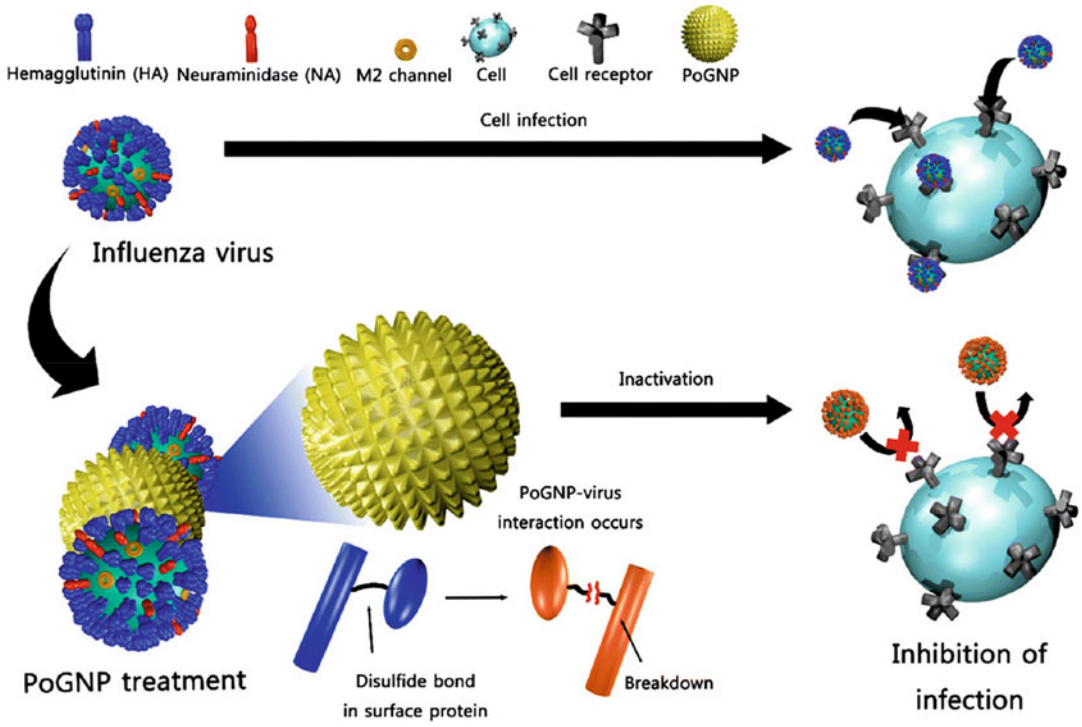
Green Materials Sterilization Solutions, Fig. 4 Mechanism of antiviral activity and pathways for AgNPs. (1) Interaction between AgNPs and viral envelope on proteins of viral surface; (2) interaction between AgNPs and cell membranes through a blocking process of viral penetration into host cells; (3) Intracellular pathways blocking by AgNPs after viral entry; (4) interact with genomes of the virus; (5) AgNPs interaction with necessary factors that are urgent and play a critical role in the replication process of the virus; and (6) AgNPs interaction with necessary factors that are urgent and play a critical role in cellular factors (Rai et al. 2016)

Gold Nanoparticles

From a comparative view of the point between AgNPs and AuNPs, reports revealed a tendency to use AuNPs in vivo and clinical trials instead of AgNPs because of reduced toxicity and biocompatibility on healthy cells. Indeed, AuNPs have passed their morality for successfully inhibiting viral entrance into intracellular media of host cells. AuNPs could have undergone interactions with hemagglutinin (HA), and Au atoms might be potentially oxidized by a disulfide bond (see Fig. 5). The presence of Au atoms in the microenvironment of glycoproteins also causes an impeding effect on the membrane fusion process to the host cells. Therefore, targeting HA by AuNPs has been accepted as a promising strategy in clinical therapy in neuraminidase and matrix protein 2. In the cases of highly infective pandemic viruses that we observe, a fast mutation and evolution in the proteineous structure of spikes and the ability to harness the virus ever-rising cycle are vital, and using AuNPs will be promising (Thompson et al. 2004). For example, such methods were utilized for fighting against influenza viruses such as H1N1, HCV, and herpes viruses (Kim et al. 2020). Many studies attributed that the antiviral and sterilizing effect of AuNPs depends on the specific surface area of NPs. Consequently, all factors that intervene in surface area amounts will be vital. For example, morphology, size, and symmetry of particles play a role in presenting antiviral properties.

Reactive Oxygen Species Generating Materials

Generating oxidative species by nanomaterials could be accounted as determinative characteristics as an antiviral material. Slow release of active herbs such as ions and/or clusters substantially enhances the antiviral ability of these materials.



Green Materials Sterilization Solutions, Fig. 5 Schematic representation for the mechanism of inactivation in virus influenza A (IAV) in the presence of porous AuNP (PoGNP). Interactions between PoGNP and IAV and viral spikes make it possible to form disulfide bonds (Kim et al. 2020)

Copper (Cu)

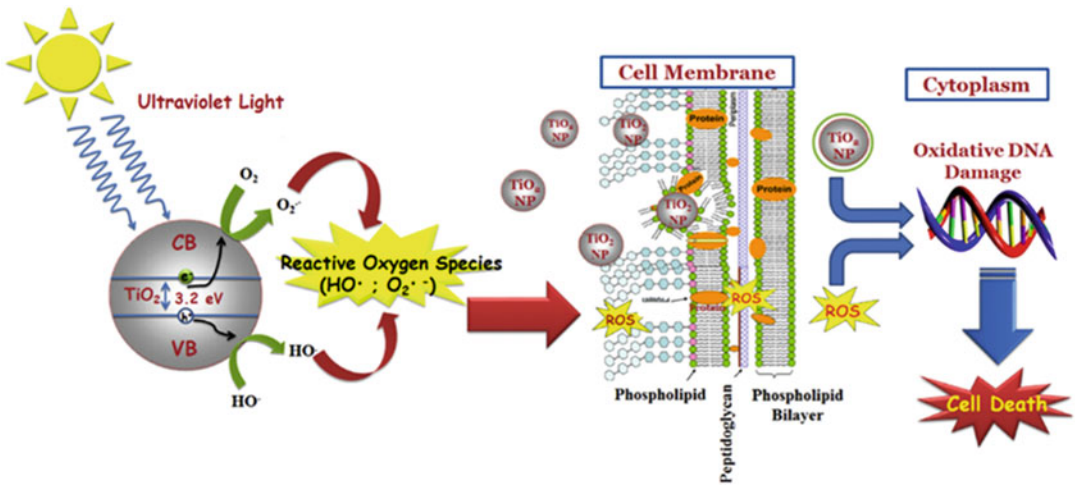
From a mechanistic view of the issue, the presence of such HNMs could generate Cu or Fe ions that potentially catalyze the pathways in Fenton reactions that cause the blocking of proteinaceous capsids and, as consequences, foment on antiviral properties and also sterilizing impact on solutions or agents. For example, Cu ions released from sulfate- or iodide-based nanoparticles could be utilized for reaching antiviral properties to harnessing wide types of (non)enveloped hepatitis A.55, influenza (Noyce et al. 2007), and herpes viruses (Betanzos-Cabrera et al. 2004). Such ions foment the formation of hydroxyl radicals as highly active radical species that provide antiviral properties (Shionoiri et al. 2012). 56 The Cu-based nanoparticles represent advantages consisting of generating reactive oxygen species (ROS) in homeostasis path into healthy cells to tune the toxicity for viruses.

Zinc (Zn)

The zinc salt-based NPs also have been proposed for antimicrobial application in clinical trials (Khattar et al. 2007). ZnO nanoparticles (ZnONPs) were utilized for remediation of HSV-2 infections prepared in tetrapod-like morphology. Based on results, interestingly, they showed an outstanding ability for mimicking the host cell surface that interacts with HS groups of capsids. Moreover, the photocatalytic properties of these HNMs were reported so far and well-documented, and they inferred that these particles could generate ROS for destroying viruses under visible and UV light conditions (Antoine et al. 2012). These results were validated under in vivo conditions for therapeutic applications. Cu^{+} ions' ability in the generation of ROS compared to other types of HNMs raises the speculations about the toxicity of these nanoparticles. The cytotoxicity of ions depends on the functionalization degree modulated by the surface. From other aspects of the issue, these nanomaterials could be utilized for applications in sterilizing solution industry as antiviral agents in their formulations instead of surfactant-based sterilizing materials. The considerations revealed that the antiviral efficiency of copper oxide nanoparticles against the H1N1 influenza virus (Fujimori et al. 2012) can fight against SARS-CoV-2 by applying in sterilizing solutions and may be applied for upgrading next-generation mask textiles.

Titanium Dioxide (TiO_2)

Biological and biomedical applications of TiO_2 nanoparticles are well-known for researchers and have attracted focal research interests in their photocatalytic capabilities in the inactivation of bacteria and viruses (see Fig. 6). The mechanism



Green Materials Sterilization Solutions, Fig. 6 The photocatalytic activity of TiO_2 nanoparticles causes a reactive oxygen species and, consequently, imposes a disturbance in the structure of lipid membranes and alters genetic information. Such changes result in an antiviral activity that causes viral death under light irradiation conditions (Halbus et al. 2017)

of this remarkable feature could be explained by light absorption and the ability of electron/hole separation that makes it possible to oxidize organic compounds by interaction with highly active species like superoxides. These hydroxyl-based radicals have been regenerated in the valence band (VB) of TiO_2. Some recent studies considered the photoinactivation mechanisms of TiO_2 against microbes in solution (Halbus et al. 2017). Akhtar and coworkers fabricated TiO_2 colloidal nanoparticles through a sonochemical method and revealed the antiviral activity of TiO_2 (Halbus et al. 2017).

Boronic Acid-Based Nanomaterials

Although HIV-1 can be effectively suppressed by using a combination of antiviral agents consisting of antiretroviral therapy (cART) and ART drugs, side effects of these drugs are still unavoidable and limit their extensive clinical trials.

Therefore, many researchers worldwide have still focused on promising therapeutic agents that provide better interaction between immunodeficiency virus (HIV) and drug agents. Recent findings showed that the boron-containing materials could be appropriate and considerable candidates for such biomedical applications. The biological apps of boron materials are well documented and reviewed for drug design and for pharmaceutical drugs especially, but organic derivatives of these compounds such as polymers and other types of nanoparticles can provide antiviral inhibitory effects (Aung et al. 2021).

Conclusion

The back history of human life has shown that the spread of various infective viruses has been inevitable in the future by the ever-increasing pandemic of H1N1 flu, HIV, and SARS viruses. In recent years, the pandemic of the hazardous virus, SARS-CoV-2, globally changed daily life and altered scientists' short-time research perspectives worldwide. This context tries to gather together antiviral materials from various spectra of organic and inorganic types to consider the mechanical aspects of how the replication cycle of this virus could be harnessed and how this material could be utilized in sterilization solutions to enhance their quality. These materials that could be categorized in green types due to their green sources and their environmentally friendly properties have been subdivided in several cases. Carbon-based nanomaterials, hard nanomaterials, and organic and polymeric compounds use different mechanisms for harnessing coronavirus. Moreover, most of them showed this capability to apply in sterilization solutions instead of conventional surfactant types based on their dispersibility degree and their stability in dispersed forms. Therefore, this context provided a brief and comprehensive clarification about antiviral sterilizing materials for solutions against the SARS-CoV-2 virus.

Cross-References

- ▶ Antimicrobial and Antiviral Properties of Herbal Green Materials
- ▶ Green Dentistry
- ▶ Green Nanomaterials for Drug Delivery
- ▶ Herbal Green Nanomaterials and Their Applications

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