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Chemical disinfectants of COVID-19: an overview

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ABSTRACT

The outbreak of coronavirus (COVID-19) has led to a broad use of chemical disinfectants in order to sterilize public spaces and prevent contamination. This paper surveys the chemicals that are effective in deactivating the virus and their mode of action. It presents the different chemical classes of disinfectants and identifies the chemical features of these compounds that pertain to their biocidal activity, relevant to surface/water disinfection.

Key words | coronavirus, COVID-19, disinfectants, novel coronavirus 2019, SARS-CoV-2, sterilization

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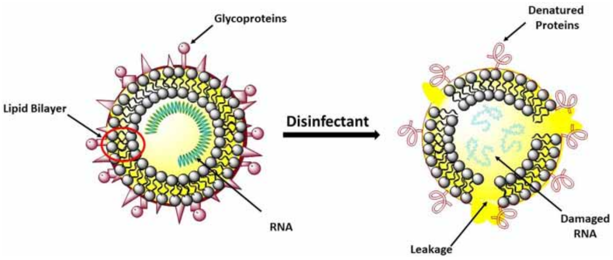
HIGHLIGHTS

- The article is a mini-review of the types and modes of action of chemical disinfectants against coronavirus.
- The article is very timely in providing information on the types of chemicals approved by health agencies for sterilizing surfaces and public areas.

GRAPHICAL ABSTRACT



INTRODUCTION

The recent widespread of coronavirus (SARS-CoV-2) worldwide stimulated a mass effort by governments, local authorities, and public health institutes to conduct disinfection campaigns of public facilities and community-shared spaces (Kannan *et al.* 2020; Zhu *et al.* 2020). A recent study has shown that COVID-19 virus can survive on infected surfaces up to 9 days and it remains infective, which increases its spread among the public (Kampf *et al.* 2020). Thus, in order to minimize the chances of infection, public health agencies (such as WHO) has encouraged and recommended that individuals maintain high levels of personal hygiene by frequently washing their hands with soap for a minimum of 20 s or by using disinfectants that can deactivate and kill the virus and eliminate its infectivity. Multi-user items (for example, shopping carts, elevators buttons, doors knobs, etc.) are considered areas of high risk for transmitting the virus

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and, thus, require continuous sterilization with effective biocidal agents (Kampf *et al.* 2020).

Disinfectants and antiseptics are used extensively to sterilize surfaces and spaces. An area or a device is considered sterilized when the disinfectant completely kills and removes microbial infecting agents (Springthorpe & Sattar 1990). The ability of a disinfectant to deactivate a microbe depends on the mode of action of the chemical, the molecular structure of the pathogen's surface, and the intracellular vulnerability (Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019). This paper surveys the classes of chemical disinfectants used for sterilizing surfaces and medical devices that can be contaminated by COVID-19 virus. A general description of the mode of action for each class of these chemicals as related to the virus is also presented.

STRUCTURAL FEATURES OF CORONAVIRUS

The coronavirus has a spherical shape with a diameter of 120 nm on average. The virus envelope is a lipid bilayer which is varnished with glycoproteins (projecting outside as 'spikes') and transmembrane proteins (Figure 1; Kannan *et al.* 2020; Zhu *et al.* 2020). These proteins enable the virus's attachment to the cell surface and its entry inside the infected cells. The lipid membrane engulfs the genetic RNA code of the virus which is then replicated inside the cell. The structural integrity of the virus's membrane, the defined topology and tertiary structure of membrane proteins, and the conserved structure and activity of the virion genome are all critical factors for the infectivity of the virus. Thus, any significant damage or disruption of these entities renders the virus inactive and prevents its infectivity (Figure 1).

CHEMICAL DISINFECTANTS AND THEIR EFFECTS ON THE VIRUS

Alcohols

Ethanol and isopropanol are the main alcohols used as disinfectants for a broad spectrum of bacteria, viruses, and fungi. The biocidal activity of these alcohols is dependent on their concentration and hydroaffinity. The optimal concentration for antimicrobial activity is at 60–80% of alcohol where ethanol is superior to isopropanol against hydrophilic viruses, such as rotavirus, human immunodeficiency virus (HIV), and coronaviruses, while isopropanol is more active against lipophilic viruses, such poliovirus and hepatitis A virus (HAV) (Wood & Payne 1998; McDonnell & Russell 1999; Dellanno *et al.* 2009; Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019). Ethanol and isopropanol are capable of destroying coronavirus at 70–90% concentrations within

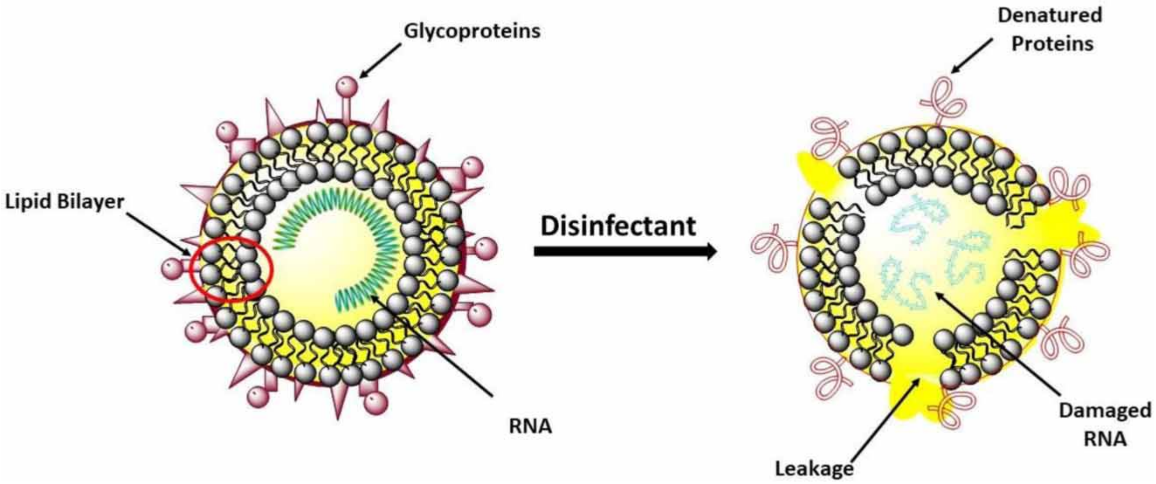

Figure 1 | Schematic representation of coronavirus and the effect of disinfectants on its structural components.

30 s (Warnes *et al.* 2015; Kampf *et al.* 2020). It is believed that the alcohol causes membrane damage and denaturing of virus's proteins in addition to damaging the RNA. The strong ability of these alcohols to form hydrogen bonding and their amphoteric nature allow them to disrupt the tertiary structure of proteins by disrupting the intramolecular hydrogen bonds within the structure.

Oxidizing agents

Peroxide-based disinfectants, such as hydrogen peroxide and peroxyacetic acid, target the oxidation of thiol groups and disulfide bonds of proteins and denature them (McDonnell & Russell 1999). Hydrogen peroxide is virucidal at 1–3% concentrations and it can deactivate SARS-CoV within a minute; it is even more potent in the gas phase (Herzog *et al.* 2012; Goyal *et al.* 2014). The peroxyacetic acid is more active than hydrogen peroxide against a broad spectrum of pathogens and at lower concentrations (~0.3%); thus, it is frequently used to disinfect medical devices (McDonnell & Russell 1999; Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019). Both peroxy compounds produce hydroxyl radicals that attack different parts of the virus including lipid membrane, proteins, and nucleic acids (Knotzer *et al.* 2015; Yamaguchi *et al.* 2016).

Phenol-based disinfectants

These chemicals that are usually based on substituted phenols and bisphenols where the hydrogen atom on the aromatic ring is replaced by an alkyl group or a halogen (Figure 2; McDonnell & Russell 1999). The high potency of these compounds granted them a major role in the disinfection of hospitals (Addie *et al.* 2015). Phenol derivatives can deactivate viruses, such as HIV, and other hydrophilic viruses within minutes at a concentration range of 0.5–5%. These compounds deactivate pathogens by inducing membrane damage which leads to leakage of intracellular components and denaturing of proteins.

Quaternary ammonium compounds

Quaternary ammonium compounds (QACs) are effective disinfectants that are used widely (Rabenau *et al.* 2005a; Addie *et al.* 2015; Sozzi *et al.* 2019; Kampf *et al.* 2020). These compounds are organic-based salts in which the cation is an amino group with four organic substituents on the nitrogen atom and the anion is either a halide or a sulfate (Figure 2). The variation of the substituents on the amino group between combination of alkyl chains, aryl groups, and/or heterocycles provides these compounds with a wide range of activity and adaptability. Generally, one of the substituents is a long alkyl chain, while the other three are smaller in size. Such a structure facilitates the formation of micelles which leads to their biocidal activity through the disintegration (lysing) of the pathogens' membranes and, hence, the loss of their structural integrity. One group of the QACs family that is widely used as a biocidal agent is the alkyldimethylbenzylammonium chloride where structural variations are associated with the length of the alkyl group. These are active against coronaviruses at less than 1% concentration and within an exposure time of a minute or less (Saknimit *et al.* 1988; Pratelli 2008; Kampf *et al.* 2020). Another group of these QACs, which gained attention as disinfectants, is the one where the N-atom has two alkyl substituents of the same structure. The popularity of these dialkyl quaternaries is due to their ability to retain biocidal activity in the presence of anionic residues and hard water (Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019).

Chlorine-releasing agents

Household bleach is one of the most used domestic disinfectants due to its availability, low cost, low toxicity, and a wide range of biocidal activity. The active chemical of bleach is sodium hypochlorite which is usually present at a concentration range of 3–6%. At low pH (4–7), the hypochlorite anion gets protonated and exists in equilibrium with hypochlorous acid, which will be the predominant species (Dellanno *et al.* 2009; Addie *et al.* 2015; Kampf *et al.* 2020). It is believed that the acid is the active biocidal agent due to its permeability of membranes and strong oxidizing ability which damages the lipids of the membrane and the nucleic acids. As the pH of the solution increases, the hypochlorite ion becomes predominant and the biocidal activity decreases (McDonnell & Russell 1999; Tarka *et al.* 2016).

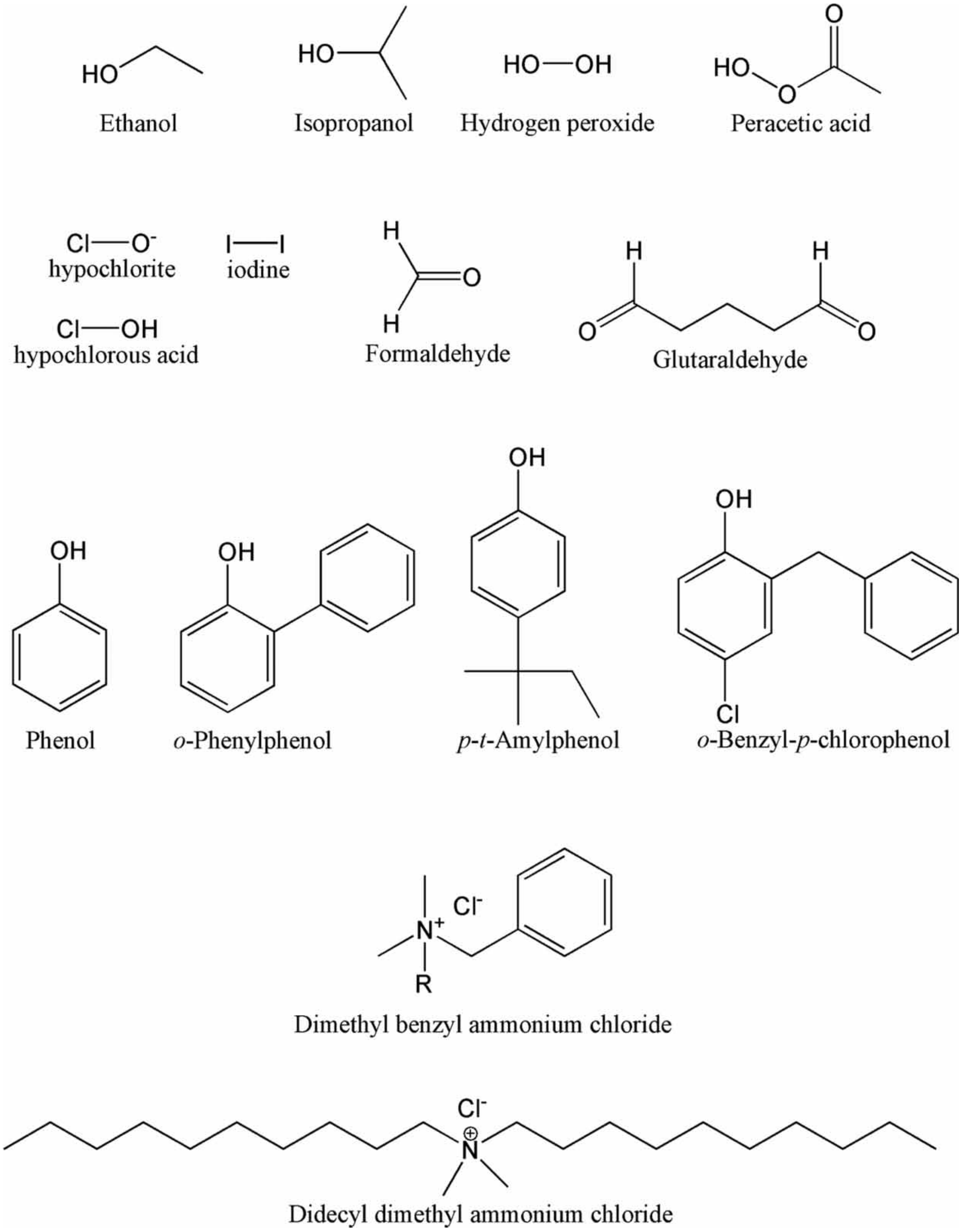

Figure 2 | Structural formula of frequently used disinfectants.

Formaldehyde and glutaraldehyde

Both compounds are considering high-level disinfectants for medical devices and surgical equipment (Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019). The use of formaldehyde is limited, however, as compared to glutaraldehyde, due to its strong odor and fumes and because it is listed by OSHA as a possible carcinogen (McDonnell & Russell 1999; Rutala, W., Weber, D. & Healthcare Infection Control Practices Advisory Committee 2019; Tarka *et al.* 2016). These aldehydes disinfect bacteria and viruses by alkylating their proteins and nucleic acids and they are active against coronavirus at a concentration range 0.5–3% within 2 min of exposure (Rabenau *et al.* 2005a, 2005b; Kariwa *et al.* 2006).

Iodine-releasing agents

Iodophores are iodine-releasing agents formed from a complex of iodine with a solubilizing agent in aqueous solutions since iodine alone is not stable in water. For example, povidone-iodine has been long used as an antiseptic on skin and tissues for a broad spectrum of bacteria (Wood & Payne 1998; Kariwa *et al.* 2006; Eggers *et al.* 2015, 2018a, 2018b). The released elemental iodine is able to penetrate the membrane and attack proteins at the sulfuryl and disulfide bonds in addition to damaging the nucleic acids. Studies have shown that povidone-iodine is able to deactivate SARS-CoV in suspension within seconds at a concentration of 1% or less (Kariwa *et al.* 2006; Eggers *et al.* 2015, 2018a).

CONCLUSION

A variety of chemical disinfectants are widely available and they provide an effective tool against SARS-CoV viruses on surfaces or in water. Several of these disinfectants are household chemicals, such as alcohols and hypochlorite solutions, are inexpensive, have low toxicity, easy to use, and have shown excellent biocidal activity within a very short time. Other more specialized chemicals are used in medical facilities for thorough sterilization of medical devices and hard-to-reach surfaces.

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DISCLOSURE

This paper represents the opinions of the author and does not mean to represent the position or opinions of the American University of Sharjah.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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