

REVIEW

Physicochemical susceptibility of SARS-CoV-2 to disinfection and physical approach of prophylaxis

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Abstract

The transmission control of the newly emerged severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the most effective strategy by the absence of its specified vaccine or drug. Although the aerosol mediated transmission of SARS-CoV-2 has been confirmed, the physicochemical treatment of the biotic and abiotic objects is still the most promising approach in its infection control. The front line of the most effective disinfecting compounds on SARS-CoV-2 implies to be sodium hypochlorite, ethanol, hydrogen peroxide, quaternary ammonium compounds, and phenolic compounds, respectively. However, widely used compounds of alkyldimethylbenzylammonium chloride (benzalkonium chloride) biguanides (chlorhexidine) have not shown the multitude load reduction in less than 10 minutes. The susceptibility of SARS-CoV-2 to physical treatment follows the pattern of heat, acidity, and UV radiation. Rather all of the mentioned physical or chemical treatments, target the envelope proteins of the coronavirus mainly by impairing its entry to host cells. The anti-SARS-CoV-2 activity of combinatorial physicochemical treatments or evaluation of new chemical entities or physical treatments such as microwave irradiation still needs to be explored. Therefore, the development of a reliable decontamination protocol for SARS-CoV-2 demands revealing its stability pattern study vs a spectrum of single and combinatorial physicochemical parameters.

KEYWORDS

antiseptics, anti-viral, biocides, biosafety, coronavirus, disinfection, sanitization, SARS-CoV-2

1 | INTRODUCTION

Over the past two decades, Severe Acute Respiratory Syndrome (SARS-CoV-1), Middle East Respiratory Syndrome (MERS-CoV), and recently SARS-CoV-2 coronaviruses have been for the causative agents of three epidemics around the world. The fourth epidemic of

the human Coronavirus (H-CoVs), SARS-CoV-2, led to a pandemic with 1 152 604 death in 213 countries till August 31, 2020¹ with an overall mortality rate of 6.8% and up to 14.8% in elderly patients.²

Since the emergence of the new human coronavirus in the Wuhan at the end of December 2019, the focus of worldwide research is channeled to confine the effective ways to limit the outbreak of the virus till its effective drug and vaccination are developed. Although maintaining the conventional hygiene protocols is the approach in prophylaxis of all infections including the recent coronavirus outbreak, the most effective cleaning and disinfection practices of

Abbreviations: CDC, Centers for Disease Control and Prevention; EPA, Environmental Protection Agency; HCl, hydrochloric acid; H-CoV, human coronavirus; MERS, Middle East Respiratory Syndrome; RT, room temperature; SARS, Severe Acute Respiratory Syndrome coronavirus; SARS-CoV-2, Corona Virus Disease 2019; UV, ultraviolet.

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skin and surfaces are preferred to be followed in the clinic and society.³ Confining the spread of the virus can minimize the risk of human infection and the environmental toxicity associated with long-term usage of disinfectants in the upcoming months of lacking the vaccine or drugs of SARS-CoV-2.

Since the beginning of the pandemic, several reports have been published on disinfectants affecting coronaviruses, and a systematic review on the physicochemical susceptibility of the SARS-CoV-2 was targeted in this review. In this paper, in addition to summarizing the available information in the field of disinfectants and physical treatments on SARS-CoV-1, MERS-CoV, and SARS-CoV-2, a hierarchical categorization is presented based on the effective contact time and the virus titer reduction. This classification appears to be useful in selecting effective disinfectants for effective prophylaxis of virus dissemination.

This study summarizes the effectiveness of the physical and chemical agents in reducing the stability and infection of human coronavirus published so far to recommend a balanced prophylaxis protocol for SARS-COV-2.

2 | BIOLOGICAL CHARACTERISTICS OF THE CORONAVIRUS

Coronaviruses are classified in the subfamily *Orthocoronavirinae* from the family *Coronaviridae*, in the order *Nidovirales* as ssRNA enveloped virus.⁴

Although most of the H-CoVs) cause typically mild respiratory tract infections and the common cold in humans, the nonhuman adapted forms (SARS-CoV, MERS-CoV, SARS-CoV-2) are pathogenic.⁵ A high tropism to the respiratory tract cells is observed by SARS-CoV-2, which leads to severe sometimes irreversible lung injury by colonization in these cells and eventually acute respiratory syndrome. Binding to specific receptor (the angiotensin-converting enzyme 2) together with proteolytic activation of spike protein in the presence of endosomal low pH is among the important factors that allow the attachment of the SARS-CoV-2 fusion peptide into target cell membranes. Therefore, the coating structures involved in attachment and entry in the initial stage of infection are the pivotal targets of antiviral drug discovery efforts for SARS-CoV-2.⁶

3 | TRANSMISSION OF SARS-COV-2

The causative agent of SARS-CoV-2 seems to be spreading sustainably to all countries soon. It has been found that there is a direct relationship between population density in public places, transportation, and SARS-CoV-2 distribution pattern. The indirect SARS-CoV-2 transmission occurs through the release of the virus from an infected person to the skin or surfaces, and eventually to the next person's mucous membranes (eyes, nose, or mouth).⁷ Furthermore, a study in China demonstrates coherency between the SARS-CoV-2 contagion rate and the type of vehicle used for transportation by 68.72% and

11.85% of infection transmission when trafficking by train and car, respectively.⁸ The main way of coronaviruses spread is a person-to-person transmission with the incubation times between 1 and 14 days, which occurs in direct and indirect contacts or via respiratory droplets.⁹ Based on previous evidence, the transmission of H-CoVs and presumably SARS-CoV-2 is influenced by parameters such as flow and density of the population, immunity of the human host, climate variations like high temperature and higher relative, or absolute humidity.^{10,11} Investigation of globally meteorological conditions also indicates that calm, cold, dry, and overcast conditions can be favorable to the SARA-CoV-2 transmission.¹⁰

4 | PERSISTENCE OF CORONAVIRUS TO PHYSICAL ENVIRONMENTAL PARAMETERS

Due to the high genetic similarity of SARS-CoV-2 with SARS-CoV-1 and MERS-CoV,¹² physical treatments for other members of its own family are expected to have a similar effect on SARS-CoV-2. Although, it is generally deduced that coronavirus strains have a limited tolerance and survival capacity on dry surfaces. Nevertheless, some studies confirmed that the strains with high pathogenicity, SARS-CoV-1, SARS-CoV-2, and MERS-CoV remain infectious in drought conditions ranging from 2 hours to 28 days dependent on the type of surfaces and relative humidity (RH) on different nonbiologic materials at room temperature (RT).^{13,14}

In principle, H-CoVs have the potential to retain their infectivity in various environmental reservoirs like surface water and untreated water, food materials, sewage and in general, on a wide range of biological and nonbiological materials, including many types of smooth and porous materials such as metals, woven, paper, ceramic, wood, glass, formica, tiles tissue, and feathers.¹⁵ A new investigation reported that the SARS-CoV-2 can remain viable on paper and tissue paper, air, copper, cloth and wood, cardboard, and plastic for up to 30 minutes, 3, 4, 24, and 72 hours, respectively.^{14,16} By contrast, SARS-CoV-2 is more stable on smooth surfaces such as plastics and stainless steel (for 4 days) and Banknote (for 2 days). Notably, SARS-CoV-2 can be infective on the inner and outer layer of face mask up to 4 and 7 days, respectively.¹⁴

In addition to the intrinsic nature of the surfaces some other critical factors including, strain variations, imposed titer, temperature, pH, irradiation, and humidity influence the persistence and survival of H-CoVs.¹³ In general, H-CoVs are more resistant to ambient humidity and acidity than to heat treatment and UV radiation (Figure 1). The decrease in temperature coupled with the increase in RH support the coronavirus infectivity for a longer time.¹⁷ Although, the survival of this viral group, and especially SARS-CoV-2, generally decreases at temperatures of 30°C to 40°C, they can remain viable and infective for up to 28 days at temperatures around 4°C to 20°C.¹⁸ The HCoV-229E persists significantly longer in 50% RH compared to the 30% humidity at RT. Also, the reported survival times for SARS-CoV-1 vary between 1 day (80%-95% RH at 33°C) and 28 days (40%-50% RH at RT).¹⁹ Similarly, Bu et al reported that SARS-CoV-2 can maintain its

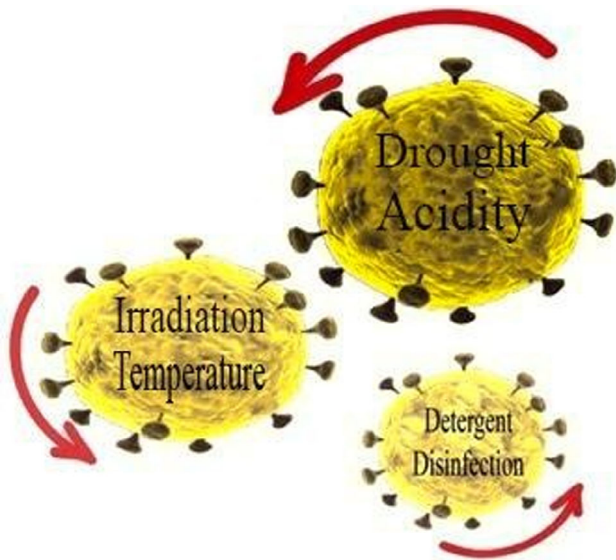


FIGURE 1 Stability trend of the virus exposed to physicochemical stress is indicated by fading the color intensity of the virus. As shown, the detergents and disinfectants are the most detrimental treatments for SARS-CoV-2. In contrast, exposure to physical treatment has less efficiency in reducing the viral infectivity. Many members of the coronavirus can survive for 7 to 28 days at the low relative humidity (20%-40%) and dry conditions at room temperature (20°C-21°C). They are also resistant to a wide range of pH changes (3-12). While, increasing the temperature to 75°C reduces the viral load to $\geq 5 \log_{10}$ in less than 10 minutes. The viral particles of SARS-CoV-2 become undetectable in less than 10 minutes at 4016 $\mu\text{W}/\text{cm}^2$ of UV radiation⁴⁴

transmissibility and infectivity from 13°C to 19°C in humidity of 50% to 80% for 1 to 7 days dependent on the material of virus-infected surfaces.²⁰ Recently, chin et al showed that only a 0.7 \log_{10} reduction of virus infectious titer was observed after 14 days incubation at 4°C.¹⁴

5 | UNIVERSAL ANTIVIRAL DISINFECTANTS

During the varied wave of H-CoVs irruption within the recent decade, some universal guidelines have been published by WHO, CDC, and other authorities as recommendations of disinfection procedures for the management of coronavirus. European Standard (NF EN 14476 + A1) is one of the commonly implemented valid suspension protocols for assessment of virucidal activity that is routinely applied to measure the effectiveness of antiseptic and disinfectant products on enveloped and nonenveloped viruses. Based on this universal standard, the detectable titer reduction of an active compound on coronavirus must be at least four logarithmic titer reductions.²¹

The main antiviral targets of skin and surface disinfectants are the three-dimensional macromolecule structures of the virus, capsid proteins degradation, and genomic segmentation. These functional impairments are dependent on the type of disinfectant and their

specific chemical change mechanism.²² Although little information is available about SARS-CoV-2 behavior in the presence of virucidal compounds, it is assumed that it should be prone to disinfectants-antiseptics with proven activity on other members of the *Coronaviridae* or enveloped viruses.

5.1 | Skin disinfection of the coronavirus

The skin contamination may occur by direct contact with patient secretions or indirectly from contact with the high-touch surfaces that have become contaminated with dispersed droplets. The exact surviving time of H-CoVs on human skin is still not specifically determined but it can stay long enough to spread from person to person.²³ There is a limited study on the virucidal antiseptics of SARS-CoV-2 and most available data only origin SARS-CoV-1 and H-CoV 229E (Table 1).

The denaturing and coagulation effect of alcohols on proteins makes them effective against a wide range of bacteria and viruses. As investigated in numerous studies, alcohols have demonstrated immediate, significant inhibitory effects against the majority of enveloped and nonenveloped viruses including the members of coronaviruses family.³³ Alcohol-based hand sanitizers are widely considered to be effective to reduce or eliminate infectious microorganism, bacterial/viral load. Common alcoholic disinfectants such as ethanol, isopropanol, and n-propanol are applied in the form of hand rub rinses, gels, and foams. It has been confirmed that ethyl alcohol diminishes the infectivity of coronavirus at concentrations of 78% to 95% within 30 seconds contact time by greater than 4.0 \log_{10} .²⁶ Additionally, WHO reports that alcohol-based formulations (80% ethanol or 75% 2-propanol) have completely inactivated SARS-CoV-1 and MERS-CoV in suspension tests after 30 seconds of exposure time.²⁵ Moreover, a recent study has shown that >30% concentrations of ethanol and isopropanol were effective in inactivating SARS-CoV-2 within 30 seconds.²⁸ Among the compounds based on halogens, povidone-iodine (PVP-I) is widely available for medical and personal use. Based on the data obtained by quantitative assay, this compound shown rapid and effective virucidal activity against SARSCoV-2 corresponding to $\geq 4 \log_{10}$ reduction of virus titer, within 30 seconds of contact in all concentrations of 0.45%, 1%, 7.5%, and 10%.³¹ Undoubtedly, the use of these compounds as antiseptics can augment health and hygiene measures to limit the COVID-19 separating in the community.

5.2 | Surface inactivation of the coronavirus using chemical reagents

Among all conventional prophylaxis approaches, using surface disinfectants is one of the effective approaches for reducing the risk of exposure to SARS-CoV-2; although, its airborne nature is plausible. Therefore, one of the most drastic approaches that interrupt the coronaviruses and in particular, SARS-CoV-2 infection, is the tailored,

TABLE 1 The concentrations of antiseptic agents required to inactivate the human coronavirus (H-CoV) on skin

Category	Compound	Tested concentration	H-CoV strain	Required contact time	Log reduction rate	References	
Alcohol based compounds	2-propanol	100%	SARS-CoV-1	30 s	≥ 3.3	24	
		75%	SARS-CoV-1/ MERS-CoV	30 s	≥4.0	25	
		70%	SARS-CoV-1	30 s	≥ 3.30	24	
	Ethanol	95%	SARS-CoV-1	30 s	≥5.50	26	
		85%					
		80%	SARS-CoV-1			≥4.30	
			MERS-CoV			> 4.0	25
		78%	SARS-CoV-1			≥ 5.0	24
		70%	H-CoV229E	1 min		3.9	27
			SARS-CoV-2	5 mins		Undetectable	19
	2-propanol + 1-propanol	45% + 30%	SARS-CoV-1	30 s	≥ 2.8	24	
					≥4.3	26	
	Isopropanol + glycerol + hydrogen peroxide	75% + 1.45% + 0.125%	SARS-CoV-1/ MERS-CoV	30 s		Undetectable	25
Ethanol + glycerol + hydrogen peroxide	85% + 1.45% + 0.125%						
Isopropanol + glycerol + hydrogen peroxide	75% + 0.725% + 0.125%	SARA-CoV-2	30 s		≥5.9	28	
Ethanol + glycerol + hydrogen peroxide	85% + 0.725% + 0.125%						
Halogens	Povidone iodine (PVP-I)	0.23%	SARS-CoV-1, MER-oV	15 s	≥4.4	29	
		2.3% to 7.5%	H-CoV 229E/ MERS-CoV	15 s to 1 min dependent on concentration	> 3.0 to >5.0 dependent on concentration	30	
		7.5%	SARS-CoV-2	5 mins	Undetectable	19	
				30 s	≥4.0	31	
	10%		30 s	≥4.0			
Biguanide based compounds	Chlorhexidine gluconate + ethanol	0.1% + 70%	H-CoV 229E	1 min	≥ 3	30	
	Chlorhexidine gluconate + cetrimide + ethanol	0.05% + 0.5% + 70%	H-CoV 229E	1 min	≥ 3		
	Chlorhexidine	0.05%	SARS-CoV-2	5 mins	Undetectable	14	
Calixarenic derived compounds	Tetra-para-sulfonato-calix[33]arene (C[33]S)	0.1%	H-CoV 229E	5 mins	3	32	
	1,3-bis(bithiazolyl)-tetra-para-sulfonato-calix[33]arene (C[33]S-BTZ)						

Note: Test strains include Middle East Respiratory Syndrome (MERS-CoV), Severe Acute Respiratory Syndrome (SARS-CoV-1), and Severe Acute Respiratory Syndrome (SARS-CoV-2) H-CoV 229E.

suitable, and periodical disinfection of contaminated surfaces and equipment.

Although it is shown that enveloped viruses are in general more sensitive to the disinfectants than the nonenveloped viruses, coronavirus exhibit resistance to some conventional chemical disinfectants.³⁴ The human coronaviruses, including HCoV-229E and SARS-CoV-1, as well as several animal coronaviruses (e.g., mouse hepatitis virus and

transmissible gastroenteritis virus of pigs), have been used as coronavirus models to investigate and determine the activity of chemical disinfectants. As a result, among the candidates of formulated disinfectants against coronaviruses, just some of them have received the Environmental Protection Agency (EPA) confirmation.³⁵

In general, biocidal agents can be categorized in the nine groups including, acids, alcohols, oxidizing agents, aldehydes, phenols, alkalis,

biguanides, halogens, and quaternary ammonium compounds, among which, hydrogen peroxide, alcohols, sodium hypochlorite, benzalkonium chloride, or biguanides are commonly used to disinfect the virus exposed suspected area, mainly in healthcare settings.³⁶ The virucidal activities of different disinfectants based on the so far investigations are summarized in Table 2. Some widely used disinfectants such as sodium hypochlorite and hydrogen peroxide show a significant activity on the H-CoVs. Hydrogen peroxide as the most available compound is an effective surface disinfectant at a concentration of 0.5% by exhibiting more than 4.0 log₁₀ in viral titer. Sodium hypochlorite at concentrations of 0.1 to 0.5% and glutaraldehyde at the concentration of 2% have shown also significant viral titer reduction with >3.0 log₁₀.¹⁴ Nevertheless, in the case of chlorine-derived compounds, regardless of their dose-dependent effect on the H-CoVs, their toxicity and detrimental effect on the ecosystems during this huge worldwide consumption must be considered.

5.3 | Surface inactivation of the coronavirus by physical treatments

Unlike many enveloped viruses that are sensitive to most of the physicochemical changes, less susceptibility of H-CoVs to these changes has been demonstrated in some studies.⁴² The majority of the physical treatments similar to chemical interventions agents inactivate the viruses via denaturation of its structural proteins and interference with the virus and host cell-effective interaction.²²

A thermal disinfection program can be variable from 60°C, 65°C or 80°C, for 30, 15 and 1 minute, respectively. All of these schedules were efficacious to decrease the infectivity of H-CoVs up to four logarithmic reductions.⁴³ Two H-CoVs, SARS-CoV-1 and MERS-CoV, can be completely inactivated at 65°C and 75°C after 15 minutes, respectively.^{44,45} It is confirmed that inactivation of SARS-CoV-2 can be achieved after 5 minutes with the incubation temperature increased to 70°C.⁴⁶

The N protein of SARS-CoV-1 is substantially denatured at 55°C treatment for 10 minutes.⁴³ Also, it is suggested that extreme pH conditions can probably change the infectious nature of the viral particles and indirectly affect the attachment and fusion process of spike proteins to cell membranes. The alkaline (pH > 12) and acidic (pH < 3) conditions can cause the inactivation of SARS-CoV-1 at 37°C while the viral articles remain infectious in pH range of 5 to 9. The optimum UV range for uppermost disinfection efficacy is between 245 and 285 nm. The complete deactivation effect of UV irradiation for a 6 minutes is reported for SARS-CoV-1 at 60 minutes at >90 μW/cm².^{19,41} As a similar susceptibility is assumed for SARS-CoV-2, it is recommended to use the UV radiation treatment in the compatible area to confine the environmental discharge of the chemical disinfectants (Table 3).

6 | CONCLUSIONS

The highly infectious nature of SARS-CoV-2 has triggered an urge to investigating its susceptibility, transmissibility, and persistence, to

reveal the most precise preventive measures against this new deadly virus. The stability duration of the virus on the surface is influenced by the physical parameters and can extend up to 28 days at RT under 20% to 40% RH. Despite their eventual inactivation by the time, the chemical interventions are required to neutralize their infectious capability before being transmitted to the next host in these days' duration.

Based on studies conducted till August 2020, the effective ingredients to H-CoVs titer reduction can be graded based on Figure 2. As the schematic figure reflects, among the antiseptic compounds, alcohol-based formulas can be considered as the most effective solutions. The solutions sodium hypochlorite 0.2% and hydrogen peroxide 0.5% are the most efficient and cost-effective compounds for the purpose of abiotic disinfection in household and healthcare. Nevertheless, the interval usage of all these compounds is recommended by WHO and CDC protocols,⁵³ as their unprincipled and excessive consumption, in addition to skin and respiratory damage, can cause the loss of the individual's normal flora and, as a result, subsequent diseases by opportunistic viral and bacterial agents.⁵⁴

The effectiveness of the single antiseptic and biocide agents is often interpreted based on the intensity of the logarithmic load reduction and the time required for inactivation. However, some critical parameters should be considered such as the presence of organic materials namely the presence of interfering agents in antiseptic formulae such as the moisturizers or glycerin. Additionally, the protocol of disinfection for sample shipment and decontamination of SARS-CoV-2 samples in case of spilling needs to be published by the authorities.

The average of D90 values (UV energy that inactivates 90% of the exposed virus) for different strains of coronaviruses is 308 J/m². Although this dose has not yet been determined for SARS-CoV-2, similar stability is expected. The surface cleaning precedent to the disinfectants such as sodium hypochlorite 0.2% and hydrogen peroxide 0.5%, followed by UV-irradiation, is assumed to completely inactivate this group of infectious viruses including SARS-CoV-2. In addition, physical stress of acidic pH created by many of the EPA-approved chemical antiviral reagents can have a synergistic effect with chemical reagents on inactivation of viral particles.⁵⁵ In contrary, the acidity condition may lead to neutralization of the antiviral compound or even the production of toxic byproducts.

As described in case of most viruses, the major inactivation mechanism by heat treatment is the denaturation of surface glycoproteins of enveloped viruses. As a result, host cell receptor-detecting structures are out of reach by the virus, which reduce its infectivity. This magnified survival rate at low temperature may explain the winter propagation of coronaviruses and also the tropism of the virus to the respiratory system. Breathing cold air in winter may diminish the lung temperatures up to 5°C.⁵⁶ Since the bronchus is fully saturated with water vapor, these conditions provide an appropriate situation for coronaviruses viability and infection development. According to a recent study, it is demonstrated that SARS-CoV-2 can be detected in aerosols for up to 3 hours. This implies that treatments targeting airborne transmissions such as

TABLE 2 The concentration of chemical disinfectant agents that inactivate the human coronavirus (H-CoV) on surface and tools

Category	Compound	Tested concentration	H-CoV strain	Required contact time	Log reduction rate	Reference
Halogens	Benzalkonium chloride	0.04%	HCoV- 229E	1 min	< 3.0	30
		0.1%	SARS-CoV-2	5 mins	Undetectable	14
	Chloramine T	0.3%	HCoV- 229E	1 min	≥ 3	30
	Sodium hypochlorite	0.1% -0.5%	HCoV -229E	1 min	≥ 3	
		0.05-0.1%	SARS-CoV-1	5 mins	≥ 3	37
	Sodium hypochlorite + potassium bromide	0.05% to 0.1%	HCoV 229E	1 min	≥ 3	37
Sodium hypochlorite 5%	1:45	SARS-CoV-2	5 mins	Undetectable	14	
	1:99					
Aldehyde based compounds	Glutaraldehyde	0.5% to 2.5%	SARS-CoV-1, HCoV 229E	2 mins to 4 mins	> 4.0	26,38
	Formaldehyde	0.7% to 1%	SARS-CoV-1	2 mins to 24 h dependent on concentration	> 3.0 to >4.0 dependent on exposure time	24
	Glucoprotamin	26%	SARS-CoV-1	2 mins	≥ 1.68	
Oxidizing agents	Hydrogen peroxide	0.5%	H-CoV 229E	1 min	> 4.0	39
Quaternary ammonium compounds	<i>n</i> -alkyl-dimethylbenzyl chloride + HCl	0.04 + pH 7.00	H-CoV 229E	1 min	≥ 3.0	30
	<i>n</i> -alkyl-dimethylbenzyl chloride + ethanol	0.04% + 70%	H-CoV 229E	1 min	≥ 3.0	
	<i>n</i> -alkyl-dimethylbenzyl chloride + sodium metasilicate	0.04% + 0.5%	HCoV 229E	1 min	≥ 3.0	
	Alkyl dimethyl benzyl ammonium chloride	0.077%	SARS-CoV-2	5 mins	≥4.1	40
		0.19%	SARS-CoV-2	2 mins	≥3.5	
	Alkyl dimethyl benzyl ammonium saccharinate + ethanol	0.083% + 50%	SARS-CoV-2	2 mins	≥4.6	
Phenolic compounds	<i>o</i> -phenylphenol + <i>o</i> -benzyl-chlorophenol + <i>p</i> -tert-amyphenol + SDS	0.02% + 0.03% + 0.01% + 0.60%	HCoV 229E	1 min	≥ 3.0	30
	<i>o</i> -phenylphenol + <i>o</i> -benzyl-chlorophenol + <i>p</i> -tert-amyphenol + ethanol	0.02% + 0.03% + 0.01% + 70.0%	HCoV 229E	1 min	≥ 3.0	
	Sodium <i>o</i> -benzyl- <i>p</i> -chlorophenate + Sodium dodecyl sulfate	0.50% + 0.60%	HCoV 229E	1 min	≥ 3.0	
Household detergent	Lauryl ether sulfate, alkyl polyglycosides, and coco-fatty acid diethanolamide	0.5%	SARS-CoV-1	5 mins	> 3.0	41

Note: The viral strains include Severe Acute Respiratory Syndrome (SARS-CoV-1), Severe Acute Respiratory Syndrome 2 (SARS-CoV-2), Middle East Respiratory Syndrome (MERS-CoV), and Human coronavirus strain 229E (HCoV-229E).

using UV radiation or the ozone gas must be more emphasized in parallel to the disinfection regimes.¹⁶

7 | FUTURE DIRECTIONS

The experimental data on sensitivity of SARS-CoV-2 to physical and chemical environmental parameters should be accumulated by the

follow-up studies to allow us to make precise designation of prevention methods. Up until now, the biosafety level 2 (BSL2) is acceptable for nonpropagative diagnostic research on SARS-CoV-2 while handling high concentration, propagation, or working on infected animals with coronavirus demands the requirements of Biosafety Level 3 (BSL3). Even this level of required core care and biosafety rules may be subjected to some changes by more upcoming data on transmission by aerosol and its susceptibility to chemical disinfection.

TABLE 3 Effect of physical treatments including heat, acidity, UV and humidity conditions on the stability of Human coronavirus strain Middle East Respiratory Syndrome (MERS), Severe Acute Respiratory Syndrome (SARS-CoV-1), and Severe Acute Respiratory Syndrome 2 (SARS-CoV-2)

Coronavirus strain	SARS-CoV-1	MERS-CoV	SARS-CoV-2
Heat (°C)	Complete inactivation time by exposure to heat		
56	90 mins ⁴¹	30 mins ⁴⁷	30 mins ⁴⁸
60	90 mins ²⁴	ND	60 mins ⁴⁸
65	60 mins ²⁴	15 mins ⁴⁷	ND
70	60 mins ⁴⁴	ND	ND
75	30 mins ³⁷	ND	ND
92	ND	ND	15 mins ⁴⁸
pH	Stability/inactivation by exposure to extreme pH		
≤5	Inactive ⁴⁴	Inactive ⁴⁹	Stable ⁵⁰
7	Stable ⁴⁴	Stable ⁴⁹	Stable ⁵⁰
9	Stable ⁴⁴	Stable ⁴⁹	Stable ⁵⁰
≥12	Inactive ⁴⁴	Inactive ⁴⁹	ND
UV-C (nm)	Complete inactivation time by exposure to irradiation		
365	60 mins at >90 μW/cm ²⁴⁴	ND	ND
254	6 mins at 4016 μW/cm ²⁴⁴	5 mins ⁵¹	9 mins ⁵²
Relative humidity (%)	Stability time at room temperature		
40-50	28 days ¹⁹	2 days ⁴⁹	ND
60-70	ND	ND	2-7 days ¹⁷
80-90	1 day ¹⁹	8 h ⁴⁹	ND
> 95	1 day ¹⁹	ND	ND

Abbreviation: ND, not determined.

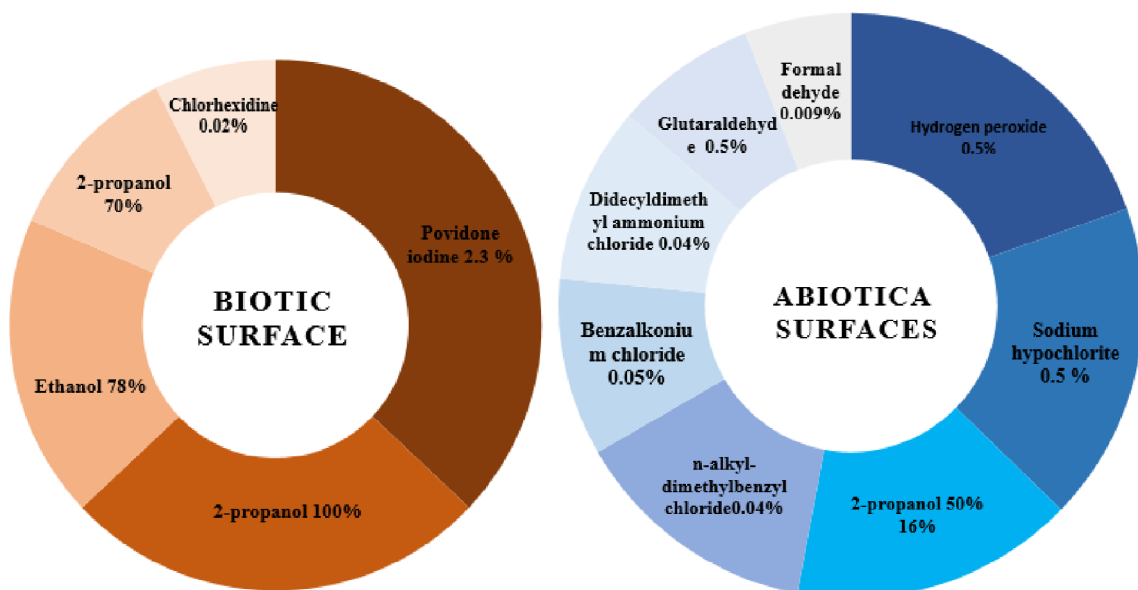


FIGURE 2 Hierarchy of the virucidal efficacy of the pure chemical compounds on H-CoV. Left: Antiseptics agents (on skin) and Right: Biocides (on abiotic surface and tools)

In forthcoming studies, the prioritization must be allotted to the survival time of the virus, which dramatically influences the probabilistic of the transmission. In contrast, the load reduction is more correlated to the high mass of the virus, which is not the case in most of the accidental spread and contamination of the virus specially from nonsymptomatic carriers.

The application of chemical disinfectants is the fastest and most efficient and irreversible treatment for attenuating the growth of the pandemic so far. One of the open fields of research is the investigation of a combination of the chemical disinfectant and obtaining the least effect concentrations. Moreover, the antiviral activity of the nanomaterial or natural compounds on the inactivation of the

SARS-CoV-2 may also deliver some new potential effective compounds. The power unit and time necessary to inactivate the virus by microwave radiation or ozone vapor are also demanding to be described.

Furthermore, in such a massive worldwide usage of the disinfectants, the vast discharge and waste of these chemicals to the environment must have also be foreseen. At least, two types of studies can ameliorate this massive scale of chemical waste concern. The lines of studies that can diminish the required concentration or replace them with less toxic alternatives or the ones that introduce the decontamination and neutralization of these chemicals in discharged waste to the nature.

ACKNOWLEDGMENT

Authors would like to thank the support of Science and Technology Park of the University of Tehran (UTSTP). Funding is not applicable for the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest for the content of the paper.

AUTHOR CONTRIBUTION

Data collection and writing original draft: Fatemeh Saadatpour. Conceptualization, data collection, review, and editing: Fatemeh Mohammadipannah.

All authors have read and approved the final version of the manuscript.

The corresponding author had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

The authors declare that this manuscript is an accurate and transparent comparative overview of the published literature on the subject.

DATA AVAILABILITY STATEMENT

All the data reported in this manuscript are derived from published articles.

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How to cite this article: Saadatpour F, Mohammadipناه F. Physicochemical susceptibility of SARS-CoV-2 to disinfection and physical approach of prophylaxis. *Health Sci Rep*. 2020;3:e213. <https://doi.org/10.1002/hsr2.213>