REVIEW

Disinfection and decontamination in the context of SARS-CoV-2-specific data

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Abstract

Given the high transmissibility of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as witnessed early in the coronavirus disease 2019 (COVID-19) pandemic, concerns arose with the existing methods for virus disinfection and decontamination. The need for SARS-CoV-2-specific data stimulated considerable research in this regard. Overall, SARS-CoV-2 is practically and equally susceptible to approaches for disinfection and decontamination that have been previously found for other human or animal coronaviruses. The latter have included techniques utilizing temperature modulation, pH extremes, irradiation, and chemical treatments. These physicochemical methods are a necessary adjunct to other prevention strategies, given the environmental and patient surface ubiquity of the virus. Classic studies of disinfection have also allowed for extrapolation to the eradication of the virus on human mucosal surfaces by some chemical means. Despite considerable laboratory study, practical field assessments are generally lacking and need to be encouraged to confirm the correlation of interventions with viral eradication and infection prevention. Transparency in the constitution and use of any method or chemical is also essential to furthering practical applications.

KEYWORDS
COVID-19, decontamination, disinfection, prevention, SARS-CoV-2

1 | INTRODUCTION

The containment of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections in the current pandemic requires a comprehensive strategy including physical, immunological, and behavioral interventions. Whereas immunity from natural infection and vaccination are at the forefront of prevention strategies, protection for virus acquisition with other approaches is nevertheless imperative for comprehensive containment. Infection routes continue to be debated for their relevance and for prevention. As previously elaborated, focus on disinfection and decontamination continues to be one such critical aspect for infection control.[1] Although it may be debated whether the respiratory acquisition is practically more for risk than direct acquisition through contact, various scenarios may lend themselves to more or less risk for any given transmission mode.[2] As supported by a recent study, SARS-CoV-2 transmission is highly likely to occur through both aerosol and nonaerosol contacts.[3] Previous studies with other coronaviruses as theoretical and/or experimental surrogates have provided ample information with regard to disinfection and decontamination, but SARS-CoV-2-specific data are desirable to confirm any such extrapolations.[1] This review examines the contemporary SARS-CoV-2-specific science as it has emerged from the initiation of the current pandemic. Such an analysis is even more essential, given the projection that SARS-CoV-2 may become an endemic respiratory pathogen much like other established coronaviruses.[4]

The presence of SARS-CoV-2 on human and environmental surfaces has been determined using both culture and genetic amplification technologies. Whereas culture methods are assumed to determine biological virus integrity with the thereafter

presumption of potential transmissibility, the majority of studies that search for the surface virus have depended on the detection of viral RNA, which, in most circumstances, does not have a direct and reliable infectivity correlation. Furthermore, there is inherent laboratory-based variability in both culture and RNA detection methods that adds another layer of ambiguity for the presumptive detection of infectious virus.[5–7] Culture methods vary considerably among laboratories in terms of their stringency, and genetic amplification methods vary considerably in terms of their targets or thresholds for determination. Whereas there may be a correlation between amplification threshold values and viral quantitation, the application of the same to surface sampling is less understood, and interlaboratory variability in such applications is inherent.[8] Paton et al.[9] illustrate how virus infectivity as measured by cell culture decreases considerably on a variety of materials, while the detection of virus through RNA amplification remains relatively stable for apparent viral load. There is also the possibility that some SARS-CoV-2 variants may differ in their environmental stability.[10]

The presence of virus on a patient's skin is ubiquitous and proportionate to the respiratory burden.[11] The latter is consistent with experimental observations of SARS-CoV-2 survival on human skin.[12] Such contamination is determinable by both culture and RNA detection.[13] Post-mortem virus infectivity is also apparent.[14] These findings are practically expected, and although likely to be variable, they confirm the need for hygiene applicable to both the patient directly and the immediate environment. The potential for non-respiratory sources of virus from humans has been confirmed and will add to the potential for patient environment contamination.[2,15] One must also be cognizant of the possibility that other common infection control measures may yet allow for escape of viable virus, given that some patients may excrete beyond currently enforced quarantine periods.[16–18]

Although early studies at times proposed that SARS-CoV-2 was sparsely found in the patient environment, the ubiquity of the environmental presence of the virus in contiguity to the infected patient soon became more obvious.[1] There has been a plethora of investigations since that corroborate the common environmental presence at least of viral RNA.[19–36] These positive determinations have included caregiver garments and accessories. Flooring is often underappreciated for contamination.[32,33,36,37] Diagnostic equipment may also be a common site for virus contamination.[34] Nevertheless, there is likely to be considerable variability in the degree of environmental or protective gear soiling with virus, given the heterogeneity of home, societal, and hospital environments. Furthermore, the risk for such contamination may depend on the patient's viral load and symptom duration.[7,29] Most such viral RNA detections are not associated with cultivable virus, but the ability for viral spread through these routes must be tempered by the voluminous opportunity for the microbe to reach these surfaces if not only for the short-term infectivity that may prevail. Under experimental conditions, viable virus undergoes time-accrued inactivation that is variable but can survive for up to several hours, during which transmission can be contemplated.[7,9,38] Although there is variable

attrition for different surface materials, viral persistence for at least 4 h on many such solids must be carefully viewed in the context of infection control.[7,39,40] Apart from the presence directly on environmental surfaces, the virus may survive for long periods in a variety of fluid suspensions.[41] Some have also suggested that in a highly endemic region for COVID-19, widespread detection of virus may be possible for a large variety of public air and surfaces regardless of their constitution.[35,42] The latter study did not include an assessment for viable virus. Wastewater as a potential source or at least an indicator of disease prevalence is well studied.[43] It is reassuring that both proximal and distant wastewaters do not yield SARS-CoV-2 in culture, even though viral genome may be abundantly evident.[44,45] The latter provides some reassurance that decontamination of such fluids is not logistically required. Paper, coins, and banknote materials also allow virus survival.[46–49] It is conceivable that inactive virus RNA may remain on surfaces for many days, thus jeopardizing the understanding of infectivity.[28,37,50] Virus strain variants may not differ in survival on some surfaces.[51] The presence of environmental virus may also be a marker for eventual human transmission.[31]

The contamination of environmental and other touch surfaces with virus may occur directly or through settling from aerosol distribution. Evidence for potential aerosol distribution continues to emerge, but the consensus suggests that viral particles, as measured mainly through RNA detection, do circulate in air with variable distributions, within variable sizes of air particles, and for varied distances.[20,22,24,26,28,30,32,33,35,37,52–56] Few of these studies have examined for viable virus, but for those that had, positivity was determined, although for few samples.[25,30,33,53,55] Concerns continue to be raised for the distance in which aerosol or airborne transmission can otherwise occur.[28,30,32,33,35,54] There are also possible contributions for heating, ventilation, and air conditioning units.[52] Aerosol transmission via plumbing systems and related air traps has introduced new hypotheses of spread, although a similar hypothesis was previously entertained in the SAR-CoV-1 era.[1,57] There is no doubt that the variable definitions of aerosol or airborne spread have been complicated by semantics.[2] When considering the latter, it must be conceded that high touch surface contamination can occur regardless, and this may confuse the appreciation of routes for transmission. Nevertheless, when the latter is accounted for, airborne spread indoors continues to be found and appears to be proportionate to viral loads among patients.[26] Exhaled aerosol burden is generally associated with the infectious state.[58]

2 | INACTIVATION VIA TEMPERATURE MODULATION

Virus inactivation with extremes of heat exposure was established early and as expected.[1] Temperatures above 70°C are particularly effective. There has been considerable work since corroborating this hypothesis, and additional findings are worth considering.

In cold storage, SARS-CoV-2 is less stable at 4°C than at −20°C.[59] Over the span of ambient temperatures that are associated

with meteorological fluctuation, infectivity is prolonged whether on surfaces or in body fluids, although variably.[49,60,61] There is evident time dependency at high temperatures.[49,62–64] At 50–55°C, a 90% reduction or more in virus occurs usually within 4–9 min.[64–66] At 58–60°C, there is a marked reduction by 10–30 min.[49,62,67] Total viral inactivation is achieved at either 65°C over 10–15 min or 70°C for 5 min, and the latter has provided some safety guidance for laboratory processes.[49,68–70] Near boiling temperature inactivates virus in less than 2 min.[67]

Over the range of 24–37°C, there appears to be some fluctuation in stability for different virus strains and an association with a few specific laboratory features of viral growth.[63] For the range of 56–80°C over 10 min of exposure, stability in the viral genome has been measured, although exposure to 70°C for 30 min leads to some loss of the viral genome.[65,70] Holder pasteurization (62.5°C for 30 min) inactivates virus in milk samples.[71] The latter has the potential to aid in the mitigation of maternal–newborn transmission.[72] Pasteurized milk food products also have the same reduction potential.[73] Heat treatment of other food products abrogates virus stability as expected.[74] Exposure of N95 respirators at 70°C for 60 min sufficiently inactivates virus contamination.[75]

Virus stability with temperature variation must be considered to be variable depending on the milieu or environment. Some assessments of temperature effect have examined for viral genome only and not with live virus cultures.[76]

3 | pH VARIATIONS

As detailed previously, both extremes of hyperacidity and hyperalkalinity can have significant anticoronavirus effects.[1] pH values less than 4 or more than 11 are mostly associated with virus reduction with some variation, especially at lower pH.[65,66,73,77–79] Some variations at these extremes will also depend on ambient temperature, the presence of organic constituents, or the presence of other potential inactivating agents.[49,80]

Substances such as citric acid, lactic acid, salicylic acid, and hydrochloric acid have been used in various disinfectant or germicidal products, and all of these are reported to have some antiviral effects.[81,82] In working dilutions, efficacy may trail that of alcohol-based products or those with quaternary ammonium compounds, but the details of pH, working concentrations, temperature of use, exposure times, and product combinations, among other features, have not been explored in sufficient detail.

Several other factors modulate the antiviral activity of pH extremes. Bleach products are commonly very alkaline (undiluted 5% bleach pH~11). Other common disinfectants have pH ranges from 1 to 12. Most commercial products do not post pH values regardless of whether other content descriptions are detailed.[83] Low pH in some foods may slowly reduce viral load during prolonged refrigeration.[73]

4 | IRRADIATION METHODS

Blanket acceptance of irradiation methods for SARS-CoV-2 inactivation must be tempered by the variation in application. For example, distance of exposure, intensity of irradiation, and the presence of different surfaces affect efficacy more or less.

4.1 | Gamma irradiation

Doses of 0.5–1.65 kGy/h induced considerable reduction in viral RNA when the virus was appended to the materials of two facial respirators.[84] Complete degradation of viral RNA was achieved with ≥30 kGy.

4.2 | Nonultraviolet light exposures

Sunlight exposure may serve to decontaminate SARS-CoV-2 experimentally, but will depend on the specific virus milieu.[85] Selective use of visible light with wavelengths of 405–425 also inactivates virus in a time-dependent manner.[86–88] Chemical photosensitization enhances the effects of visible light spectra.[89–91] It is conceivable that several variations of such exposure could contribute to further practical applications.

4.3 | UV irradiation

Variable efficacy for ultraviolet (UV) irradiation exposure has long been associated with different UV wavelengths. SARS-CoV-2 is susceptible to simulated full-spectrum UV light that approaches natural environmental conditions.[92] Broad-spectrum UV may be effective for application to many material surfaces.[93,94] Although wavelengths of UV-A and UV-B have been considered as less effective, the utility of non-UV-C wavelengths remains controversial.[95–97] Combinations of UV wavelengths and temperature enhancements have also been studied.[98] There is also the potential to combine UV treatment with sensitizing agents for niche application.[99]

The exploitation of UV-C for SARS-CoV-2 inactivation has been studied intensively.[62,66,68,69,95,100–104] Although UV-C is inclusive of wavelengths spanning 200–280 nm, it has been proposed that particular wavelengths may be more efficacious.[104] Regardless, there is a dose-responsiveness, and the time to sufficient viral inactivation is dependent on the environment, temperature, distance, and timing for exposure.[102,103,105–112] It is not apparent that any particular SARS-CoV-2 strain variant is more or less resistant.[110] Differential effects can depend on surface quality and humidity.[100,103,105,106,113] Early in the pandemic, emphasis was placed on the decontamination of N95 respirators, which were in short supply.[101,104] For the latter use, variable effects of UV-C were seen on the irregular surface of these masks, but it must be acknowledged that mask layers may trap virus at different strata.[114,115] Modes of UV-C-based viral

inactivation are left to the ingenuity of design, which includes disinfection chambers and robotics.[102,105,109,114] The mechanism of action of UV-C was more correlated with viral RNA effects than those on structural protein changes.[116] Using an animal model system, aerosol transmission could be interrupted with UV-C.[117] Other measures of virus aerosol inactivation confirm the latter.[112]

5 | COATING AND IMPREGNATION BARRIERS

Apart from using disinfectants as constitutive agents in solutions to inactivate live virus from surfaces, the development of preformed surfaces that manifest antiviral effect has garnered considerable interest in the materials production industries. Additives to plastics, metals, ceramics, and other surfaces have shown antiviral efficacy to the extent that these surfaces may have inhibitory effects after initial viral deposition. Several copper-based products have especially attracted attention.[118–131] Some of the latter surfaces have included protective gear.[121,129] It is not clear how much other foreign substances may interfere with antiviral efficacy on these coated surfaces.[123] Some have chosen to apply copper together with other heavy metals.[118,124,125,130] Alternatively, the effects of copper may be augmented with other topical coadditives.[129] Silver in itself does not appear to confer considerable antiviral effects, but silver nanoparticles have had some efficacy in vitro and there is some theoretical support for its use.[125,130,132,133] Zinc oxide and titanium dioxide coatings also show antiviral activity.[134,135] Antiviral heavy metals found in nutritional supplements may have some efficacy.[136] Quaternary ammonium compound coatings have attracted study.[137,138] Both anionic polymer and surface calcium bicarbonate generate an antiviral effect based on the extremes of surface pH.[79,139] Other innovations for fabric or mask impregnation have been cited.[131,140,141]

While the aforementioned applications of disinfection are potentially attractive, little has been published on the safety and toxicity of this in these contexts. For example, direct skin contact may promote delayed-type hypersensitivity reactions among some sensitive individuals and with select exposures.

6 | PEROXIDES AND OZONATION

Building on the success of oxygen radicals in inactivating coronaviruses, several studies have assessed either hydrogen peroxide or ozonation.[127,142] Exposure to vaporized hydrogen peroxide under variable conditions leads to marked reduction of both inactive and cultivable viruses.[25,143–145] Time for complete inactivation can be prolonged depending on the circumstances. Direct gaseous ozonation is also effective on a variety of solid surfaces or for viruses in clinical samples.[146,147] A system of combined ozonation and negative ions allowed for a reduction in the amount of ozone concentration

required.[148] However, the safety of ozone technologies in practical settings has been questioned.[149]

Under experimental conditions, hydrogen peroxide in solution up to 3% achieved mild antiviral activity.[150]

7 | HALOGENS

As for other coronaviruses, neat or working dilutions of common household bleach are very effective anti-SARS-CoV-2 treatments and have been commonly touted in international infection control standards.[49,77,81] Efficacy is achieved in 1–5 min exposures. Some difference in efficacy for various chlorine agents has been proposed.[151] Topical application of povidone–iodine has also been shown to reduce viral titers.[49,152] The latter is consistent with the in vitro action of this compound against the virus.[153,154] Sustained residual effects of povidone–iodine on skin in a model system have been suggested.[152]

Environmental fogging with dilutions of hypochlorous acid has been assessed, and presumed inactivation is concentration and time dependent.[145] Chlorination of waters has attracted attention whether for wastewater treatment or for swimming pool disinfection.[155–157] Inactivation is time, pH, and concentration dependent.

8 | PHENOLICS

Variant compositions of products inclusive of chloroxylenol have been assessed.[49,77,81,82] Concentrations ranging from 0.05% to 0.12% have antiviral properties, but may not achieve comparative efficacy with alcohol-based preparations or working bleach dilutions.[77] Depending on the experiment, efficacy for high viral loads can be found in short time periods.[81] Comprehensive details of pH or other constitutive products in such formulations are often lacking.

9 | ALCOHOLS

Ethanol and propanol have been studied the most and likely due to the need for developing safe and effective hand disinfectants. Concentrations of ethanol ranging from 40% to 80% show strong antiviral properties whether for surfaces or for skin.[49,72,75,77,158–168] Exposure in vitro to 70% ethanol results in rapid reduction of virus as early as 15–30 s.[154] Concentrations less than 30%, although having some effect, are limited for the rapidity of virucidal effects.[158,162] Isopropanol has generally been assessed at 70% vol/vol unless in combinations with ethanol.[158,160,161] Time-dependent efficacy is evident.[77] Studies on model systems of skin preparations did not find residual activity after alcohol exposures.[152]

In commercial products, it is not uncommon to see ethanol or propanol combined with other potentially effective agents such as

surfactants or quaternary ammonium compounds.[81,82,142,161,167,169] It is proposed that a concomitant surfactant may enhance efficacy.[161]

10 | DETERGENTS AND SURFACTANTS

The use of these agents may have several purposes in commercial products. Apart from direct antiviral activity, chemical agents that facilitate disruption or increase the solubility of organic debris may have an additive benefit. There is a large collective of such chemicals in disinfection products.[83] These may include ready-to-use solutions, concentrates, handwashes, and soaps, among other products.

Benzalkonium chloride is commonly representative for the subcategory of quaternary ammonium products.[1,49,152,158,168] Working concentrations of the latter vary from 0.05% to 0.2%. Although there is some efficacy in short durations of treatment, large viral loads usually require several minutes of exposure or higher concentrations.[49] Some have found greater efficacy on human skin in contrast to in vitro experimental exposures.[158]

In general, these chemicals may be less effective than alcohols.[158] In fact, they may be better combined with other agents.[81,82,142] Commercial solutions or other products not uncommonly include a combination of more than one quaternary ammonium agent or a combination of quaternary ammonium agents with other surfactants.[1,81,83,142,167]

Several products listing surfactants only, such as some soaps or washing liquids, have efficacy, and the latter may complicate the understanding of active ingredients when products are being assessed.[1,49,77,82,83,161] Some studies list a single active agent when indeed a product may have several chemicals that have potential antiviral effects. The additive or synergistic combinations are also difficult to assess. One study found that varying degrees of total fatty matter in soap bars influenced virus reduction.[159] The impregnation of apparel with surfactants has also attracted attention.[163]

As previously suggested, there is better appreciation for any such products through an open designation of pH, working dilution, temperature for use, and full product constituent disclosure.[1,83] It must also be considered whether, for these products or others, there may be a residual antiviral effect that persists after application and that has the potential for prolonged prevention.[152,167]

11 | MISCELLANEOUS ANTIVIRALS

Chlorhexidine products do variably achieve anti-SARS-V-2 activity in products with concentrations ranging from 0.05% to 1%.[49,152,158,169] They appear to be less effective than alcohols and have differential action depending on the milieu.[158] Some residual antiviral activity may be possible.[152] Potassium peroxymonosulfate exerts an antiviral effect as previously demonstrated for other coronaviruses.[1,77] Coniferous tree rosin oils have been shown to exert virucidal activity in aqueous formats.[170] Formaldehyde with 4%–10% concentrations used in the laboratory is very effective.[67,77] Cold plasma exposure, as differentiated from ionizing atmospheres, has been assessed experimentally.[164] The use of a very high osmotic pressure on the virus does not appear to have any effect on survival.[66] The utility of negative ion ionizers has also been studied.[171]

12 | DISINFECTANTS AND TOPICAL MUCOSAL APPLICATION

As an extension of applying topical disinfectants, several studies have assessed various topical mucosal anti-SARS-CoV-2 agents.[150,165,169,172,173] Conceivably, such use could be of potential value for the prevention of both infection acquisition or secondary spread. For example, the focused use of these agents in dental offices to mitigate potential transmission has been considered to be useful. Extending the latter, others have conceived uses for possible treatment.[166]

Active agents in oral or nasal rinse preparations have been varied as have their carrier vehicles or other associated ingredients. Both duration of administration and sampling site affect perceptions of efficacy. Formulations including hydrogen peroxide, benzalkonium chloride, dequalinium chloride, chlorhexidine, cetylpyridinium chloride, octenidine dihydrochloride, povidone–iodine, alkaline solutions, ethanol, hexetidine, cyclodextrin, polyaminopropyl biguanide, bioflavonoids, hypochlorous acid, delmopinol, silver nanoparticles, combination surfactants, essential oils, hydroxyapatite, glycyrrhizic acid, and/or sodium fluoride have been assessed.[150,154,169,172,174–186] Efficacy during in vitro or in vivo experiments has yielded variable results. Komine et al.[175] did not find efficacy for chlorhexidine. Others found reduced efficacy for hydrogen peroxide and chlorhexidine.[150,177,179,180] Cetylpyridinium chloride in various dilutions inactivates virus, and the mechanism of action in part appears to be related to the interruption of the Spike protein/receptor complex.[150,169,186] The degree of product dilution has a considerable impact.[150,176] Methods of virucidal determination have also been variable and have included genetic amplification (reverse transcription-polymerase chain reaction [RT-PCR]), antigen detection, and viral culture. Non-culture methods may be more associated with lack of efficacy.[174] Although viral culture is often cited as the standard for virucidal activity, differences among laboratories even for this approach must be considered.[5]

Many such studies have assessed antiviral effects in a short time span for exposure and have often not provided data on sustained efficacy. Suggested applications for oral or nasal rinsing, or both, have also been variable. In vivo cellular cytotoxicity has not been consistently considered.

There are few controlled trials of efficacy. Carrouel et al.[178] showed a modest benefit of virus reduction with an oral preparation in a placebo-controlled study. The clinical implications of their findings are uncertain. Chaudhary et al.[181] also reported modest reductions in viral load, but it is noteworthy that substances containing hydrogen peroxide, chlorhexidine, or povidone–iodine fared no better than saline rinses. Meister et al.[150] found that

benzalkonium chloride had only a mild effect on virus reduction. In a randomized-controlled trial, both 1% povidone–iodine and 0.2% chlorhexidine reduced viral marker load and were superior to the use of a distilled water control.[182] In a randomized trial of a silver nanoparticle suspension for oral and nasal rinsing and prevention, some early success was reported.[184] Another study showed a reduction in oral virus with cetylpyridinium chloride, but not povidone–iodine, and yet, others have suggested value in using

povidone–iodine in a treatment format.[169,173] Ogun et al.[172] found some reductions with hexetidine- and hydrogen peroxide-containing products. Overall, and despite in vitro or in vivo efficacy, the actual contribution to practical disease prevention or reduction is not well established. Use of oral rinse products must also be tempered with the potential for continuing nasal excretion of virus and its potential consequences on infectivity. With the latter in mind, Amoah et al.[187] reported on the nonrandomized use of combined oral and nasal hydrogen peroxide lavage for prevention. The authors proposed some clinical benefit for both patients and healthcare workers. The potential for placebo-containing rinses to be associated with some viral reduction due to lavage must also be considered.[172]

13 | GENERAL CONSIDERATIONS AND CONCLUSION

In general, the findings in the considerable number of studies identified above mirror those previously found for other coronaviruses, and there have been few, if any, surprises.[1] Tables 1 and 2 provide some generalizations of method and/or product equivalency for the inactivation of SARS-CoV-2, but specific applications or product specifications may affect efficacy and must be thoroughly considered. Table 3 presents some comparative antiviral efficacies for disinfectants.

Some investigators have found value for the use of surrogate viruses such as coliphages or non-SARS-CoV-2 coronaviruses in comparative assessments and given the desire to use less pathogenic microbes during experimentation.[65,81,92,138–140] Despite the evolving literature on this topic to date, there is a dearth of focused publications on field trials. The latter could include both virucidal efficacy and human prevention assessments. Lesho et al.[23] have provided some insight into the relative benefits of different disinfection and decontamination methods in situ. Zhang et al.[188] reported on the detection of virus with genetic amplification from hospital rooms that accommodated patients with active SARS-CoV-2 infection. It is noteworthy that the combination of terminal chemical

TABLE 1 Extrapolations for SARS-CoV-2 inactivation where different stringencies are required

Low- to intermediate-level inactivation
Alcohols
Halogens—chlorine, iodine
Phenolics
Peroxide solutions
Quaternary ammonium compounds
Surfactants (in combination with other active agents)
High-level inactivation
Aldehydes
Heat—pasteurization
Ozonation
pH extremes
Sterilization
Heat
Gamma irradiation
UV-C (with or without sensitizing agents)

Note: Uses are tempered by specific materials that will tolerate the physicochemical inactivation method. Uses are also tempered by the anticipated viral loads.

Abbreviations: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; UV, ultraviolet.

TABLE 2 Comparative efficacies of SARS-CoV-2 inactivation methods in solution

More efficacy		Lesser efficacy
⟵——————————————⟶		
Alcohols, high concentration	Quaternary ammonium	Surfactants
Bleach (chlorine)	Phenolics	Chlorhexidine
Aldehydes	Alcohols, low concentration	
	Povidone-iodine	
	Hydrogen peroxide	

Note: Commercial products should be considered for their multicomponent contents and variable pH.

Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

TABLE 3 Comparative efficacies of disinfectants against SARS-CoV-2

Agent	Agent dilution	Experimental milieu	Exposure time	Starting viral load	Virus reduction	Comments	Reference
Alcohols							
Ethanol							
	70%	Solution	5 min	7.8 log	Complete		[49]
	75%	Solution	1 min	6.5 log	≥1.83 log	Determination limited by toxicity	[77]
			5 min	6.5 log	>2.00 log		
	70%	Solution	15 s	?	4 log		[154]
			30 s	?	>4 log		
			60 s	?	>4 log		
			5 min	?	>4 log		
	40%–80%	Solution	5–60 s	?	>4.5 log		[158]
	70%	Polyvinylchloride-coated disc	1 min	Variable	5–7 log		[161]
	>30%	Solution	3 min	7 log	6 log		[162]
Isopropanol							
	70%	Solution	5–60 s	?	>4.5 log		[158]
	70%	Polyvinylchloride-coated disc	1 min	Variable	5–7 log		[161]
Mixed ethanol/isopropranol							
	35%/35%	Polyvinylchloride-coated disc	1 min	Variable	5–6 log		[161]
Aldehydes							
Formaldehyde							
	2%	Solution	15 min	>5 log	Complete		[67]
	10%	Solution	1 min	6.5 log	Complete	Determination limited by toxicity	[77]
Paraformaldehyde							
	4%	Glass slides	?	6.5 log	Complete		[77]
Halogens							
Hypochlorite							
	10%	Solution	1 min	6.5 log	≥3.25 log	Determination limited by toxicity	[77]
			5 min	6.5 log	≥3.25 log	Determination limited by toxicity	
	8 ppm	Solution	10 s-3 min	6–7 log	2–3 log		[151]
	80 ppm	Solution	10 s-3 min	6–7 log	4–5 log		

Agent	Agent dilution	Experimental milieu	Exposure time	Starting viral load	Virus reduction	Comments	Reference
	1 mg/L	Solution	≥8 min	5 log	4–5 log		156
Free chlorine							
	1.5 ppm	Solution	30 s	4 log	>3 log		157
Povidone–iodine							
	7.5%	Solution	5 min	7.8 log	Complete		49
	0.05%	Solution	30 s	6 log	<1 log		150
	0.1%	Solution	30 s	6 log	<1 log		
	0.5%	Solution	30 s	6 log	<1 log		
	>0.5 mg/ml	Solution	30 s-5 min	6 log/ml	99%		153
	0.1%	Solution	20 min	?	>97.0%		186
Peroxides							
Hydrogen peroxide							
	0.5%	Solution	30 s	6 log	<1 log		150
	1%	Solution	30 s	6 log	<1 log		
	2%	Solution	30 s	6 log	<1 log		
	3%	Solution	30 s	6 log	<1 log		
Quaternary ammonium (cationic)							
Benzalkonium chloride							
	0.1%	Solution	5 min	7.8 log	Complete		49
	0.025%	Solution	30 s	6 log	1 log		150
	0.05%	Solution	30 s.	6 log	3 log		
	0.075%	Solution	30 s	6 log	>3.7 log		
	0.1%	Solution	30 s	6 log	>3.7 log		
	0.05%	Solution	5–60 s	?	1.3–2.2 log		158
	0.2%	Solution	5–60 s	?	1.8–3.0 log		
Cetylpyridium chloride							
	0.025%	Solution	30 s	6 log	<1 log		150
	0.05%	Solution	30 s	6 log	<2 log		
	0.075%	Solution	30 s	6 log	<3 log		
	0.1%	Solution	30 s	6 log	>2.7 log		
	0.05%	Solution	60 min	?	>97.0%		186
	0.1%	Solution	20 min	?	>97.0%		
	0.3%	Solution	20 min	?	>97.0%		
Dequalinium chloride							
	0.025%	Solution	30 s	6 log	<1 log		150
	0.05%	Solution	30 s	6 log	<1 log		
	0.075%	Solution	30 s	6 log	<1 log		
	0.1%	Solution	30s	6 log	<1 log		

(Continues)

TABLE 3 (Continued)

Agent	Agent dilution	Experimental milieu	Exposure time	Starting viral load	Virus reduction	Comments	Reference
Other							
Chlorhexidine							
	0.05%	Solution	5 min	7.8 log	Complete		49
	0.1%	Solution	30 s	6 log	<1 log		150
	0.125%	Solution	30 s	6 log	<1 log		
	0.2%	Solution	30 s	6 log	<1 log		
	0.5%	Solution	30 s	6 log	<1 log		
	0.2%	Solution	5–60 s	?	0.3–0.6 log		158
	1%	Solution	5–60 s	?	1–1.8 log		
Chloroxylenol							
	0.05%	Solution	5 min	7.8 log	Complete		49
	0.12%	Solution	5 min	6 log	6 log		81
	0.12%	On glass	5 min	6 log	6 log		

Note: Direct comparisons are complicated by variations in methods between studies. Studies in which multiple component disinfectants are studies are not detailed.

Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

disinfection and UV exposure was not associated with considerable reduction in the virus target, and there was some variation depending on the surface sampled. While somewhat sobering in terms of the findings, one must remember that such virus detection does not necessarily correlate with live virus detection. In order to be reassured about the practical applications of disinfection and decontamination, more such field trials will be required.

Many variables could affect efficacy including different viral loads, contact times, predisinfection cleaning, patient volume and contiguity, frequency of application, and the specific environment, among others. There is also the confounding variability in the products themselves, as discussed above. Some surfaces may inactivate cleaning agents. Live virus determinations better suit the need to assess for infection potential. The need to simultaneously eradicate other microbial pathogens, especially nosocomial pathogens, may also complicate the necessary treatments.[189] Again, direct real-life experiences with standard protocols would be desirable.

There is also the potential for environmental disinfection and decontamination to present hazardous exposures. Chemical agents may persist after application. There needs to be due regard for their potential flammable, caustic, corrosive, and/or allergenic nature. As the COVID-19 pandemic continues and as there has been increasing use of consumer products for disinfection and sanitization, there are more reports of toxic exposures.[190] The latter adds to the potential for direct skin toxicity or irritation.[191]

In making laboratory assessments transferable to clinically useful prevention, it may not necessarily be that all-or-none eradications of virus are required. It cannot be assumed that all eradications must

have the same equivalency as any detailed gold standard, given the lack of direct clinical assessments. The continuing COVID-19 pandemic offers considerable opportunity for future studies. With the current knowledge at hand, an abundance of caution should be exercised in the interim and in the context of necessary and inevitable practical limitations.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are neither available nor created for this review paper.

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