



A systematic review of emerging human coronavirus (SARS-CoV-2) outbreak: focus on disinfection methods, environmental survival, and control and prevention strategies

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Abstract

Recently, an outbreak of a novel human coronavirus which is referred to as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (COVID-19) by the World Health Organization (WHO) was identified in Wuhan, China. To help combat the pandemic, a systematic review (SR) was performed to collect all available studies concerning inactivation methods, environmental survival, and control and prevention strategies. A comprehensive literature survey yielded 42 eligible studies which included in the SR. The results confirmed that the WHO recommended two alcohol-based hand rub formulations (ethanol 70–95% and 2-propanol 70–100%) had an efficient virucidal activity in less than 60 s by more and equal 4 log₁₀ (≥ 99.99) approximately and could be used for disinfection in public health and health-care facilities. The findings indicated that SARS-CoV-1 and SARS-CoV-2 can survive under different environmental conditions between 4 and 72 h approximately. The results also demonstrate that temperature and relative humidity are important factors in the survival of SARS-CoV-2. The main strategies recommended by the WHO to avoid contracting SARS-CoV-2 are hand washing several times in the day and maintaining social distancing with others. It is important to note that the more studies require addressing, the more possible airborne transmission due to the survival of SARS-CoV-2 in aerosols for 3 h approximately. We hope that the results of the present SR can help researchers, health decision-makers, policy-makers, and people for understanding and taking the proper behavior to control and prevent further spread of SARS-CoV-2.

Highlights

- A SR was performed to collect all available studies on inactivation methods, environmental survival, and control and prevention strategies.
- A comprehensive literature survey yielded 42 eligible studies which included in SR.
- Results show that the WHO recommended two alcohol-based hand rub formulations had an efficient virucidal activity in less than 60 s.
- SARS-CoV-1 and SARS-CoV-2 can survive under different environmental conditions between 4 and 72 h.
- The main strategies recommended by the WHO are hand washing several times in the day and maintaining social distancing with others.

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Introduction

Coronaviruses (CoVs) belong to the family of Coronaviridae that includes four genera: alpha coronavirus (α -CoV), beta coronavirus (β -CoV), gamma coronavirus (γ -CoV), and delta coronavirus (δ -CoV) (Yin and Wunderink 2018). Alpha- and β -CoVs can infect mammals, and two others can infect birds as well as mammals. Seven CoVs have been known to infect human so far. Four of them, HCoV-229E, HCoV-OC43, HCoV-NL63, and HCoV-HKU1, lead to the self-limited upper respiratory tract infection (Chang et al. 2020). Middle East respiratory syndrome-coronavirus (MERS-CoV) and severe acute respiratory syndrome coronavirus 1 (SARS-CoV-1) both cause lower respiratory tract infection and lead to severe respiratory syndrome (Ding et al. 2003).

During the last few months, an outbreak of pneumonia with unknown origin and etiology was identified in Wuhan city, the most populous city in central China with a population more than 11 million, at Hubei province on 31 December 2019. It was acknowledged that the outbreak resulted from a novel coronavirus (CoV); first, it was named as the 2019-nCoV2 and recently referred to as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and its related disease is now entitled CoV disease 2019 (COVID-19) by the WHO (Peng et al. 2020; Sohrabi et al. 2020).

During the last two decades, in addition to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (emerged in 2003 in China) and Middle East respiratory syndrome-Coronavirus (MERS-CoV) (was first emerged in September 2012 and as of September 2019 in Saudi Arabia), this is the third high pathogenic HCoV with a pandemic spread and now has a total of 2,626,321 confirmed cases with pneumonia and 181,938 deaths worldwide (as of April 24, 2020) ((WHO, 2020b, Al-Rabiaah et al. 2020).

This virus has several properties that make it difficult to deal with these properties including non-particular aspects of the disease, long incubation period, infectivity even before symptoms appearing in the incubation duration, contagious nature of this virus infection even in asymptomatic infected people, and extended disease period and transmission. More so, recovery might start about the 2nd or 3rd week following infection (Singhal 2020). On 30 January 2020, responding to the rapid growth of this viral outbreak and confirmed human-to-human contagion, the WHO stated a public health emergency of international concern (Peng et al. 2020).

As there is no approved treatment for this viral infection, prevention is essential (Singhal 2020; Smatti et al. 2018). The environment conditions play an important role in the spread of the infectious virus; also, the control of virus infections is an issue of major concern and a great challenge. Introducing

optimized disinfection methods is vital to prevent and minimize the infection spread (Abreu et al. 2013). Through recent decades, requirements as to the antimicrobial activities of disinfectants in the medical setting have been appointed based on various criterions. In addition, guidelines have been prepared to recommend people and hospitals to fully clear and disinfect environmental and medical instrument surfaces on a regular basis (Pitten et al. 2003; Carling et al. 2008). In the current SARS-CoV-2 pandemic, identification of the chemical and/or physical disinfectant that interrupts the virus transmission routes including human-to-human, spreads via respiratory droplets, and contaminated hands or surfaces are of utmost importance. Therefore, the present SR attempts to provide sufficient information and strategies for viral inactivation (disinfection) methods and determine the virus survival in different environmental conditions and control and prevention strategies.

Methods

A comprehensive search was conducted on all the available papers from literature reporting on disinfection (inactivation), environmental survival, and control and prevention strategies with a focus on HCoV. We followed the Cochrane Reviewer's Handbook and PRISMA (Preferred Reporting Items for SR and Meta-analysis) guidelines for writing of the protocol of the present SR (<http://www.prisma-statement.org/Extensions/InDevelopment.aspx>) (Mohamoud et al. 2013; Noorimotlagh et al. 2020).

Information sources and search strategy

To identify different disinfectants and environmental survival associated with HCoV as well as control and prevention methods of this novel virus, a comprehensive search was systematically carried out between 1990 and 2020. The last systematic search was conducted on April 24, 2020. Main database of the Elsevier Bibliographic Database (Scopus), Institute for Scientific Information (ISI) Web Science, Google Scholar, PubMed (MEDLINE), World Health Organization (WHO, <https://www.who.int/>), and American Centers for Disease Control and Prevention (CDC, <https://www.cdc.gov/>) were used to search using free text words, MeSH (Medical Subject Headings), and their possible combination. Therefore, we searched in aforementioned databases with proper keywords: ("Coronaviruses" OR "CoV" OR "Human Coronaviruses" OR "HCoV" OR "nCoV" OR "Novel Coronaviruses" OR "2019 Novel Coronavirus" OR "Covid-19" OR "2019-nCoV" OR "

Severe Acute Respiratory Syndrome- Coronaviruses-2” OR “SARS-COV-2”) AND (“Disinfectant” OR “Disinfection” OR “Chemical Inactivation” OR “Physical Inactivation” OR “Germicide Susceptibility”) AND (“Environmental Resistance” OR “Environmental Stability” OR “Environmental Persistence” OR “Inanimate surfaces” OR “Persistence Skin” OR “Persistence Surface” OR “Persistence Hand” OR “Survival Skin” OR “Survival Hand”) AND (“Prevention Methods” OR “Infection Prevention and Control” OR “Environmental Survival”), as illustrated in Fig. 1.

Included/excluded criteria for reviewed studies

This study was systematically considered and collated articles into the following: (a) original articles, (b) studies published in English, (c) available electronic version (online), and (e) articles focusing on disinfections, environmental survival, and control and prevention strategies of HCoV. The excluded criteria for this SR were review articles, book review, guidelines, book chapters, duplicate articles, short communications, conference documents, oral presentation, and comments.

Data extraction

In the present work, M.SA and ZN systematically investigated title-abstract and full text to avoid bias. Then, information such as first author’s name, publication year, country, type of coronavirus, strain/isolate, disinfectant/concentration, phase of disinfection, exposure time, reduction of viral infectivity (log₁₀), humidity, temperature, media, survival time (days), infection control strategies, and main finding was extracted.

Results

In the present SR after the study eligibility, a total of 42 studies were identified among 86 hints which collected during the initial bibliographic search in the four international databases based on our inclusion/exclusion criteria. The details of search procedure conducted to obtained eligible studies are shown in Fig. 1. Then, all included studies were analyzed in-depth and categorized separately according to inactivation (disinfection) methods, capability to survive in different environmental conditions, and control and prevention strategies. The main results of all the 42 included studies in different parts of the study (i.e., disinfection methods, environmental survival, and control and prevention strategies) were summarized in brief in Tables 1, 2, and 3, respectively.

Among all reviewed and included studies, 20 studies were categorized in the category of inactivation (disinfection) methods (Bedell et al. 2016; Dellanno et al. 2009; Eggers et al. 2015; Eggers et al. 2018; Emmoth et al. 2011; Feldmann et al. 2019; Goyal et al. 2014; Hindawi et al. 2018; Hulkower et al. 2011; Kariwa et al. 2006; Leclercq et al. 2014; Pratelli 2007; Pratelli 2008; Rabenau et al. 2005a, b; Saknimit et al. 1988; Sattar et al. 1989; Siddhartha et al. 2017; Tyan et al. 2018; Wood and Payne 1998). As can be seen in Table 1, the different types of disinfection (inactivation) methods including physical and chemical types of disinfectants were presented and their efficacies were reviewed. Briefly, chemical disinfectant compounds such as ethanol, 2-propanol, and povidone iodine in different concentrations show the high efficacy in the inactivation of coronaviruses in a short time.

Among the included studies, 12 eligible studies were focused on the environmental survival of coronaviruses

Fig. 1 Summary of a standard four-step protocol for literature review

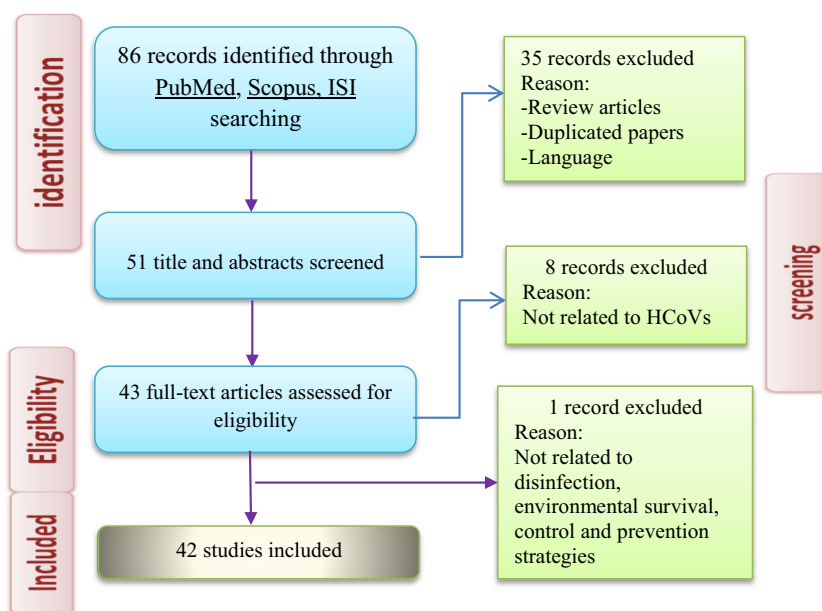


Table 1 Main summary of characteristic of included studies

Study ID	Country	Virus	Disinfection methods		Environmental survival	Control and prevention
			Chemical	Physical		
(Rabenau et al. 2005b)	Germany	SARS-CoV-1	✓	-	-	-
(Rabenau et al. 2005a)	Germany	SARS-CoV-1	✓	✓	-	-
(Goyal et al. 2014)	USA	TGEV	✓	-	-	-
(Saknimit et al. 1988)	Japan	CCA, MHV	✓	-	-	-
(Tyan et al. 2018)	USA	HCoV	✓	-	-	-
(Wood and Payne 1998)	UK	HCoV	✓	-	-	-
(Dellanno et al. 2009)	USA	MHV	✓	-	-	-
(Siddharta et al. 2017)	Germany	MERS-CoV, SARS-CoV-1	✓	-	-	-
(Sattar et al. 1989)	Canada	HCoV	✓	-	-	-
(Emmoth et al. 2011)	Sweden	FCoV	✓	-	-	-
(Feldmann et al. 2019)	USA	SARS-CoV-1	-	✓	-	-
(Hindawi et al. 2018)	Saudi Arabia	MERS-CoV	-	✓	-	-
(Bedell et al. 2016)	USA	MHV, MERS-CoV	-	✓	-	-
(Leclercq et al. 2014)	France	MERS-CoV	-	✓	-	-
(Hulkower et al. 2011)	USA	MHV and TGEV	✓	-	-	-
(Pratelli 2007)	Italy	CCoV	✓	-	-	-
(Pratelli 2008)	Italy	CCoV	✓	-	-	-
(Kariwa et al. 2006)	Japan	SARS-CoV-1	✓	-	-	-
(Eggers et al. 2015)	Germany	MERS-CoV	✓	-	-	-
(Eggers et al. 2018)	Germany	MERS-CoV, SARS-CoV	✓	-	-	-
(Wames et al. 2015)	UK	HCoV-229E	-	-	✓	-
(Lai et al. 2005)	China	SARS-CoV-1	-	-	✓	-
(Wang et al. 2005)	China	SARS-CoV-1	-	-	✓	-
(Rabenau et al. 2005a)	Germany	SARS 229E	-	-	✓	-
(Sizun et al. 2000)	Canada	HCoV-229E and HCoV-OC43	-	-	✓	-
(Prussin et al. 2018)	USA	Phi6	-	-	✓	-
(Pyankov et al. 2018)	Russia	MERS-CoV	-	-	✓	-
(Casanova et al. 2010)	Carolina	SARS-CoV-1	-	-	✓	-
(Chan et al. 2011)	China	SARS-CoV-1	-	-	✓	-
(Van Doremalen et al. 2013)	USA	MERS-CoV	-	-	✓	-
(Duan et al. 2003)	China	SARS-CoV-1	-	-	✓	-
(Van Doremalen et al. 2020)	USA	SARS-CoV-1 and SARS-CoV-2	-	-	✓	-
(Huh 2020)	Korea	SARS-CoV-2	-	-	-	✓
(Rabaan et al. 2017)	Saudi Arabia	MERS-CoV	-	-	-	✓

Table 1 (continued)

Study ID	Country	Virus	Disinfection methods		Environmental survival	Control and prevention
			Chemical	Physical		
(Sikkema et al. 2017)	Egypt	MERS-CoV	-	-	-	✓
(El Bushra et al. 2017)	Saudi Arabia	MERS-CoV	-	-	-	✓
(Al-Tawfiq et al. 2019)	Saudi Arabia	MERS-CoV	-	-	-	✓
(Wiboonchutikul et al. 2016)	Thailand	MERS-CoV	-	-	-	✓
(Wong and Wai-San Tam 2005)	Hong Kong	SARS-CoV-1	-	-	-	✓
(Ki et al. 2019)	Korea	MERS-CoV	-	-	-	✓
(Koul et al. 2018)	India	HCoV-229E and HCoV-OC43	-	-	-	✓
(Butt et al. 2016)	Saudi Arabia	MERS-CoV	-	-	-	✓

(Casanova et al. 2010; Duan et al. 2003; Sizun et al. 2000; Van Doremalen et al. 2020; Van Doremalen et al. 2013; Wang et al. 2005; Warnes et al. 2015; Chan et al. 2011; Lai et al. 2005; Prussin et al. 2018; Pyankov et al. 2018; Rabenau et al. 2005a). According to the results of the included studies in Table 2, the SARS-CoV-2 susceptibility on surfaces of different materials at 4–5 °C, 20–22 °C, and 30–40 °C is approximately > 28 days, 3–9 days, and a few hours, respectively. The survival of the SARS-CoV-1 and SARS-CoV-2 in five environmental conditions (aerosols, stainless steel, plastic, cardboard, and copper) was also reported. Both viruses demonstrated survival between 3 and 72 h on these surfaces.

Among the included studies, 10 eligible studies were focused on the IPC of coronaviruses (Ki et al. 2019; Koul et al. 2018; Rabaan et al. 2017; Sikkema et al. 2017; El Bushra et al. 2017; Butt et al. 2016; Wiboonchutikul et al. 2016; Wong and Wai-San Tam 2005; Al-Tawfiq et al. 2019; Huh 2020). According to finding of the included studies, the SARS-CoV-2 can be easily spread via two main ways in human-to-human transmission: (1) respiratory droplet and (2) direct and indirect contact with aerosol infected surfaces. Therefore, the main recommendations were presented in the following sections.

Discussion

The novel human coronavirus which is named as SARS-CoV-2 (COVID-19) by the WHO, recently emerged from Wuhan city, China. After a short time, COVID-19 is spreading rapidly in approximately all developed and developing countries worldwide. Considering the rapid spreading and pandemic situation, the WHO assigned a global level of SARS-CoV-2 risk assessment that was very high ((WHO 2020a, c). The officials of the WHO reported that human-to-human transmission is the main route to spread the virus. The study reported that SARS-CoV-2 had a high stability in a favorable environment, but maybe is susceptible to the standard inactivation compounds (disinfection methods) (Chin et al. 2020). Therefore, identification of effective inactivation materials and/or disinfection methods is utmost importance. In the present up-to-date SR, we searched all the available evidence published on inactivation (disinfection) methods, and finally, 42 eligible studies were included in our study and reviewed in-depth to determine the favorable and standard disinfectants.

Disinfection methods applied to inactivation of coronavirus

Considering the results of the included studies, different chemical disinfectant compounds such as Sterillium Rub/Gel containing ethanol with different concentration (78, 80, 85,

Table 2 The efficiency of different type of disinfectant agents in order to inactivation of coronaviruses

Study ID	Virus	Strain/isolate	Disinfectant/concentration	Phase of disinfection	Exposure time	Reduction of viral infectivity (log ₁₀)										
(Rabenau et al. 2005b)	SARS-CoV-1	Isolate FFM-1	Sterillium Rub (80% ethanol)	Suspension test	30 s	≥ 4.25										
			Sterillium Gel (85% ethanol)			≥ 5.5										
			Sterillium Virugard (95% ethanol)			≥ 5.5										
			Sterillium (45% iso-propanol, 30% n-propanol)			≥ 4.25										
			2-propanol (100% and 70%)			≥ 3.31										
			Desderman N (78% ethanol, 0.2% 2-biphenylol)			≥ 5.01										
			Sterillium (45% 2-propanol, 30% 1-propanol)			≥ 2.78										
			Formaldehyde (0.7% and 1.0%)			≥ 3.01										
			Glutaraldehyde (0.5%)			≥ 4.01										
			Incidin plus (2%) (26% glucoprotamin)			≥ 1.68										
(Rabenau et al. 2005a)	SARS-CoV-1	Isolate FFM-1	Temperature (4 °C)	Suspension test	30 min	0										
			Temperature (56 °C)			≥ 5.01										
			Temperature (60 °C)			≥ 5.01										
			Hydrogen peroxide vapor (HPV) at three different volumes: 25, 27, and 33 mL			> 4.94–5.28										
			2-propanol 70%			> 3.3										
			2-propanol 50%			> 3.7										
			Formaldehyde, 0.7%			> 3.7										
			Benzalkonium chloride 0.05%			> 3.7										
			Chlorhexidine digluconate 0.02%			0.3										
			Sodium hypochlorite, 0.01%			1.1										
(Goyal et al. 2014), USA	TGEV	Purdue strain, type 1	Sodium hypochlorite, 0.001%	Surface carrier test/20 µL on stainless steel	2–3 h	0.9										
			Sodium hypochlorite, 0.01%			> 3.9										
			Sodium hypochlorite, 0.001%			> 3.7										
			Ethanol 70%			> 3.7										
			Benzalkonium chloride 0.05%			> 3.5										
			Formaldehyde, 0.7%			> 3.7										
			2-propanol 50%			> 3.7										
			Chlorhexidine digluconate 0.02%			0.7–0.8										
			Sodium hypochlorite, 0.01%			2.3–2.8										
			Sodium hypochlorite, 0.001%			0.3–0.6										
(Saknimit et al. 1988)	CCA	Strain I-71	Sodium hypochlorite, 0.5%	Suspension test	10 min	≥ 4.50										
			Benzalkonium chloride, 0.2%			0.0										
			Household bleach: sodium hypochlorite, 0.21%			≥ 4.40										
			Alcohol-based hand rubs (ethanol 80%)			> 4.0										
			Alcohol-based hand rubs (2-propanol 75%)			≥ 4.0										
			(Tyan et al. 2018)			HCoV	Strain 229E (ATCC VR-740)	Household bleach: sodium hypochlorite, 0.21%	Suspension test	10 min	≥ 4.40					
								Alcohol-based hand rubs (ethanol 80%)			> 4.0					
								Alcohol-based hand rubs (2-propanol 75%)			≥ 4.0					
								(Wood and Payne 1998)			HCoV	ATCC VR-759 (strain OC43)	Household bleach: sodium hypochlorite, 0.21%	Suspension test	10 min	≥ 4.40
													Alcohol-based hand rubs (ethanol 80%)			> 4.0
Alcohol-based hand rubs (2-propanol 75%)	≥ 4.0															
(DeIanno et al. 2009)	MHV	Strain MHV-1		Household bleach: sodium hypochlorite, 0.21%	Suspension test								10 min			≥ 4.40
				Alcohol-based hand rubs (ethanol 80%)												> 4.0
				Alcohol-based hand rubs (2-propanol 75%)												≥ 4.0
				(Siddharta et al. 2017)												MERS-CoV
			Alcohol-based hand rubs (ethanol 80%)			> 4.0										
			Alcohol-based hand rubs (2-propanol 75%)			≥ 4.0										

Table 2 (continued)

Study ID	Virus	Strain/isolate	Disinfectant/concentration	Phase of disinfection	Exposure time	Reduction of viral infectivity (log ₁₀)
(Sattar et al. 1989)	SARS-CoV-1 HCoV	Isolate FFM-1 Strain 229E	Alcohol-based hand rubs (2-propanol 75%) Ethanol 70% Benzalkoniumchloride, 0.04% Sodium hypochlorite, 0.5% Sodium hypochlorite, 0.1% Sodium hypochlorite, 0.01% Glutaraldehyde, 2%	Surface carrier test/20 µL on stainless steel	60 s	≥ 4.0 > 3.0 < 3.0 > 3.0 > 3.0 < 3.0 > 3.0
(Emmtho et al. 2011)	FCoV	Strain DF2 (ATCC VR-2004)	Ammonia disinfection at 25% NH ₃ in Hatchery Waste	Suspension test	1 s	> 5.0
(Feldmann et al. 2019)	SARS-CoV-1	Strain Tor 2	Gamma irradiation using a cobalt-60 source at 1 Mrad	Suspension test	5 s	> 4.0
(Hindawi et al. 2018)	MERS-CoV	MERS-CoV/Hu/Taif/SA/2015	Disinfection of virus in human plasma by amotosalen and Ultraviolet A	Suspension test	-	> 4.67
(Bedell et al. 2016)	MHV	Strain A59	The multiple-emitter, automated, continuous, whole-room UV-C disinfection system	Surface disinfection	5 min 10 min 5 min 10 min	2.71 6.11 5.91 -
(Leclercq et al. 2014)	MERS-CoV	Hu/France-FRA2_130569/2013 (FRA2)	Heat inactivation in three ranges Temperature 25 °C Temperature 56 °C Temperature 65 °C	Suspension test	- 2 h 25 min 1 min 1 min	- 0 4.0 4.0 0.62 and 0.35 1.33 and 2.03
(Hulkower et al. 2011)	MHV and TGEV	-	Chlorine bleach (6% sodium hypochlorite) Vesphene Ilse (9.09% O-phenylphenol, 7.66% P-tertiary amyl phenol) Cidex-OPA (0.55% Ortho phthalaldehyde) 70% ethanol	Carrier surfaces	1 min	1.71 and 2.27 3.92 and 3.19 2.66 and 4.04 1.98 and 3.51
(Pratelli 2007)	CCoV	Strain S378	Purell hand sanitizer (62% Ethanol) Clorox anywhere hand sanitizing spray (71% ethanol) Benzalkonium chloride, 0.00175% DDA, 0.0025%	Suspension test	3 days	3.0 > 4.0
(Pratelli 2008)	CCoV	Strain S378	Formaldehyde, 0.009% Glutaraldehyde, 2.5% PVP-I, 1% PVP-I, 0.47% PVP-I, 0.25% PVP-I, 0.23%	Suspension test Suspension test	24 h 5 min 1 min	> 4.0 > 4.0 > 4.0 3.8 > 4.0 > 4.0
(Kariwa et al. 2006)	SARS-CoV-1	Hanoi strain		Suspension test	1 min	> 4.0

Table 2 (continued)

Study ID	Virus	Strain/isolate	Disinfectant/concentration	Phase of disinfection	Exposure time	Reduction of viral infectivity (\log_{10})
(Eggers et al. 2015)	MERS-CoV	Isolate HCoV-EMC/2012	PVP-I, 7.5% PVP-I, 4.0% PVP-I, 1.0%	Suspension test	15 s	4.6 5.0 4.3
(Eggers et al. 2018)	MERS-CoV SARS-CoV-1	Isolate HCoV-EMC/2012 Isolate FFM-1	PVP-I, 0.23%	Suspension test	15 s	≥ 4.4

TGEV, transmissible gastroenteritis coronavirus of pigs (*TGEV*, a severe acute respiratory syndrome coronavirus [*SARS-CoV*] surrogate); *CCV*, canine coronavirus; *MHV*, mouse hepatitis virus; *HCoV*, human coronavirus; *FCoV*, feline coronavirus; *PVP-I*, povidone iodine; *DDA*, didecyl-dimethyl-ammonium chloride

and 95%), 2-propanol (concentration of 70, 75, 100%) Sterillium (45% iso-propanol, 30% n-propanol), ammonia disinfection at 25% NH_3 in hatchery waste, didecyl-dimethyl-ammonium chloride (DDA) (with concentration of 0.0025%), Sterillium (45% iso-propanol, 30% n-propanol), glutaraldehyde (0.5%), and povidone iodine (PVP-I) (with concentration of 1, 0.47, 0.25, 0.23, 7.5, 4.0, 1.0, and 0.23%) could readily inactivated different coronavirus strain infectivity in less than 60 s by approximately more and equal 4 \log_{10} (≥ 99.99) in a suspension test. The hydrogen peroxide vapor (HPV) as a gas-phase disinfectant required a 2–3-h contact time to inactivate the coronavirus. Only household bleach with a minimal concentration of sodium hypochlorite of 0.21% was effective in inactivating the virus in 30 s. On the other hand, sodium hypochlorite 0.5% required more contact time to inactivate the virus (10 min). Disinfectants such as formaldehyde (0.009%) and glutaraldehyde (2.5%) also required more contact time for destruction of coronavirus. It is previously suggested that a \log_{10} viral reduction of more than 3 is a benchmark for efficient virucidal activity for coronaviruses on surfaces (Sattar 2004; Chinn and Sehulster 2003; Hulkower et al. 2011); therefore, these chemical disinfectants could meet this benchmark to inactivate coronaviruses. In addition to chemical disinfectant, in the present SR, the reviewed studies reported that the efficiency of physical disinfectant including temperature (56 °C, 60 °C), gamma irradiation using a cobalt-60 source at 1 Mrad, and disinfection of virus in human plasma by amotosalen and ultraviolet A were in effective for inactivating coronavirus in a short contact time. One study reported the multiple-emitter, automated, continuous, whole-room UV-C disinfection system for surface disinfection in 5- and 10-min contact time with more than 99.999% efficiency.

In the recent guideline published by the WHO, it is recommended to ensure that environmental cleaning and disinfection procedures are followed consistently and correctly. Completely cleaning environmental surfaces with water and suitable detergent and application of commonly used hospital level disinfectants such as sodium hypochlorite are effective and sufficient procedures ((WHO) 2020b). In addition to our data in the present SR, the WHO also recommended a concentration of 70% ethanol for disinfection of small surfaces ((WHO) 2014).

The WHO recommended two alcohol-based hand rubs for disinfection of hands. The formulations of the recommended hand rubs of the WHO were ethanol with 80% concentration or 2-propanol with 75% concentration and were reported to be very effective in inactivation of SARS-CoV-1 and MERS-CoV in suspension test (Siddharta et al. 2017). It is previously reported that in the human disease-control programs, chemical disinfectants have been widely used to prevent viral infectious diseases.

Table 3 Study characteristics about persistence of human coronaviruses on different types of inanimate surfaces

Study ID	Virus	Humidity	Temperature (T)	Media	Survival time (days)	Results
(Wames et al. 2015)	HCoV-229E	30–40%	21 °C	PTFE, PVC, ceramic tiles, gas, silicone rubber, stainless steel	PTFE: at least 5 PVC: at least 5 Ceramic tiles: at least 5 Glass: at least 5 Stainless steel: at least 5 Silicon rubber: 3	Copper alloy surfaces could be employed in communal areas and at any mass gatherings to help reduce transmission of respiratory viruses from contaminated surfaces and protect the public health
(Lai et al. 2005)	SARS-CoV-1	----	4 °C 20 °C	Stool, respiratory specimens, laboratory request form, impervious disposable gown, cotton non-disposable gown	Diarrheal stool samples: 4 in alkaline pH Respiratory specimens: 5 at 20 °C Respiratory specimens: 21 at 4 °C	The risk of infection via contact with droplet-contaminated paper is small. Absorbent material, such as cotton, is preferred to non-absorbent material for personal protective clothing for routine patient care
(Wang et al. 2005)	SARS-CoV-1	----	4 °C 20 °C	Feces, urine, water	At 20 °C: Hospital wastewater: 2 Domestic sewage: 2 Dechlorinated tap water: 2 Feces: 3 PBS: 14 Urine: 17 At 4 °C: Wastewater: 14 Feces or urine: at least 17	The effect of high T in summertime, and stick control and management, except animal-to-human transmission or cross infection within labs, there is little possibility for another outbreak caused by SARS-CoV from environmental sources
(Rabenu et al. 2005a)	HCoV-229E	----	21 °C 25 °C	Suspension and dry state	<i>In suspension</i> : HCoV-229E: gradually inactivated SARS-CoV-1: up to 9 <i>In dry state</i> : HCoV-229E: 1 SARS-CoV-1: 6 <i>After drying</i> : HCoV-229E: 3 h HCoV-OC43: 1 h or less	Thermal inactivation of SARS-CoV at 56 °C and 60 °C is highly effective. In the presence of protein (20%), infectivity was only reduced by less than 2 log ₁₀ at 56 °C after 30 min (and also after 60 min)
(Sizun et al. 2000)	HCoV-229E and HCoV-OC43	55–70%	21 °C	Suspension and dried surfaces (aluminum, latex surgical gloves, sponges)	High survived: RH > 85% Low survived: RH < 60% A significant decrease: at Mid-range RHs (~ 60 to 85%) The loss of infectivity related to AH: Less than 22 g/m ³ ; less than 2 times More than 22 g/m ³ ; greater than 6 times	Virus survived in saline solution for as long as 6 days but less in culture medium, with or without added cells
(Prussin et al. 2018)	Phi6	23%, 33%, 43%, 61%, 75%, 85%, 98%,	14 °C 19 °C 25 °C 37 °C	Droplets and aerosols		RH is the most important factor in controlling virus infectivity in droplets At a fixed RH of 75%: infectivity was very sensitive to T, decreasing 2 orders of magnitude between 19 and 25 °C
(Pyankov et al. 2018)	MERS-CoV	24–79%	25 °C 38 °C	1) Common office environment (25 °C and 79% RH) 2) Climatic conditions of the Middle Eastern region (38 °C and 24% RH)	At 25 °C: Relatively high survival, with more than 63.5% of virus remaining infectious in the air 60 min after aerosolization At 38 °C:	Even at hot and dry climatic conditions relevant to the Middle Eastern region, the strain is able to survive for quite long time periods and could potentially spread resulting from respiratory transmission. Virus decay was much stronger for hot and dry air scenario with only 4.7% survival over 60 min procedures

Table 3 (continued)

Study ID	Virus	Humidity	Temperature (T)	Media	Survival time (days)	Results
(Casanova et al. 2010)	SARS-CoV-1	20–80%	4 °C 20 °C 40 °C	Stainless steel	Much more efficient inactivation with only 4.7% active virus 60 min after aerosolization At 4 °C: 28 At 20 °C: 5 Viruses were inactivated more rapidly at 40 °C than at 20 °C At 20 °C: 48 h At 30 °C: 8–24 h	The relationship between inactivation and RH was not monotonic, and there was greater survival or a greater protective effect at low RH (20%) and high RH (80%) than at moderate RH (50%) MERS-CoV was more stable at low T/low humidity conditions
(Van Doremalen et al. 2013)	MERS-CoV	30–80%	30 °C	Plastic and steel		
(Duan et al. 2003)	SARS-CoV-1	----	21–23 °C	Metal, wood board, paper	Metal: 5 Wood board: 4 Paper: 4–5 < 5	The SARS survival ability in environments seems to be relatively strong
(Chan et al. 2011)	SARS-CoV-1	40–50%	22–25 °C	Plastic		Virus viability was rapidly lost at higher T and RH
(Van Doremalen et al. 2020)	SARS-CoV-2 SARS-CoV-1	40%	21–23 °C	Aerosols and various surfaces (plastic, stainless steel, copper, and cardboard)	Plastic: 72 h Stainless steel: 72 h Aerosol: 3 h	SARS-CoV-2 was more stable on plastic and stainless steel than on copper and cardboard The stability of SARS-CoV-2 was similar to that of SARS-CoV-1 under the experimental circumstances tested



Fig. 2 Persistence of human CoVs on various surfaces according to results of included studies

Survival of SARS-CoV-2 in different environmental conditions

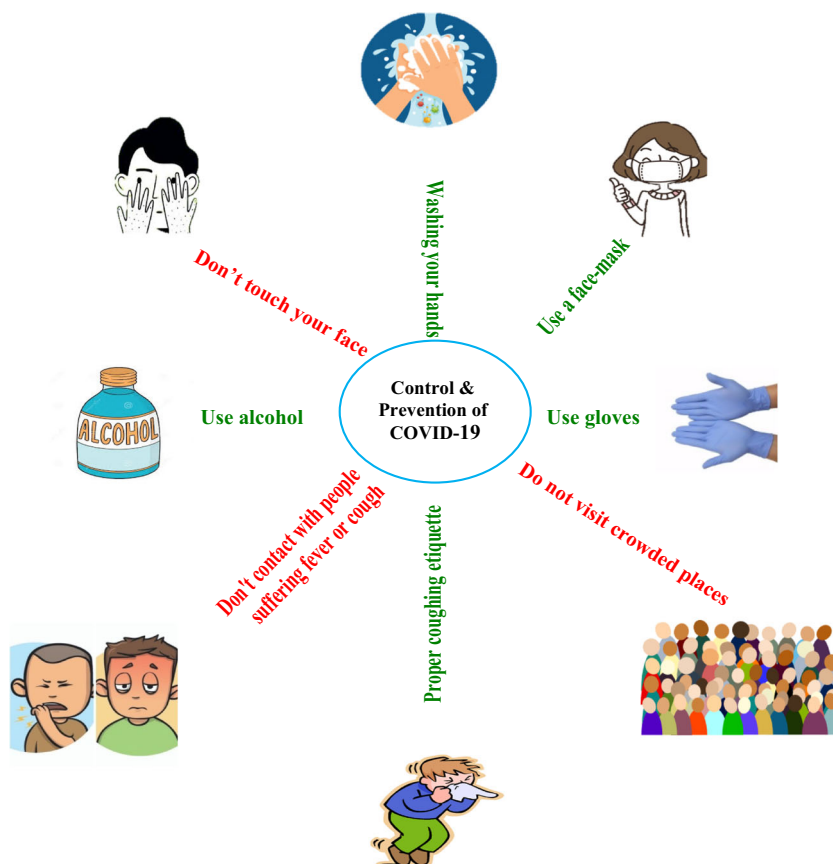
The present study is the first SR on SARS-CoV-2 survival on different media and control-prevention strategies. During MERS-CoV, SARS-CoV-1, and SARS-CoV-2 outbreaks, the survival time of SARS-CoV-2 on different environmental conditions is a concern for people, health-care workers, and the related-health agencies due to infection control measures. Various media including water/wastewater, air, and different surfaces in the places with high load of virus were usually contaminated to the virus by direct and indirect transmission mechanism. The main results of the reviewed studies in this SR were summarized in Table 3.

Our study investigated the effect of different environmental parameters like temperature, absolute humidity (AH), relative humidity (RH), and their combinations on virus survival in various environmental conditions including droplets, aerosols,

suspension and dried states, feces (stool), urine, water, wastewater, respiratory specimens, laboratory request form, aluminum, sterile latex surgical gloves, sterile sponges, impervious disposable gown, cotton non-disposable gown, polytetrafluoroethylene (Teflon; PTFE), polyvinyl chloride (PVC), ceramic tiles, gas, silicone rubber, plastic, wood, paper, cardboard, copper, and stainless steel.

On the basis of the results of included studies, virus survival in respiratory fluid droplet depends on controlling the temperature and RH. Thus, disease transmission via droplets is inhibited by increasing both temperature and RH in buildings like hospitals, schools, university, offices, and homes. It should be noticed that the relationship between RH, temperature, and SARS-CoV-2 inactivation especially SARS-CoV-2 is still complex, and more research is needed to know these effects on level of physiological (Rabenau et al. 2005a; Sizun et al. 2000; Prussin et al. 2018; Chin et al. 2020; Van Doremalen et al. 2013).

Fig. 3 Summary of IPC recommendations obtained from the findings of included studies



Several studies have reported that the SARS-CoV-2 susceptibility on surfaces of different materials at 4–5 °C, 20–22 °C (room temperature), and 30–40 °C is approximately > 28 days, 3–9 days, and a few hours, respectively (Fig. 2). SARS-CoV-1 can survive in respiratory specimens at 20 °C for 5 days and at 4 °C for 21 days and able to survive in diarrheal stool samples for 4 days. The reviewed results show that the SARS-CoV-2 remains infectious for several days and few hours in suspensions and after drying, respectively (Van Doremalen et al. 2013; Prussin et al. 2018; Rabenau et al. 2005a; Sizun et al. 2000; Wang et al. 2005; Warnes et al. 2015; Lai et al. 2005; Pyankov et al. 2018; Casanova et al. 2010; Chin et al. 2020; Duan et al. 2003). van Doremalen and colleagues' study was designed specifically to compare the survival of the SARS-CoV-1 and SARS-CoV-2 in five environmental conditions (aerosols, stainless steel, plastic, cardboard, and copper). Both viruses were more stable on plastic and stainless steel (72 h) than on copper and cardboard (4–8 h). The half-life of SARS-CoV-1 and SARS-CoV-2 were similar in aerosols (3 h) (Van Doremalen et al. 2020).

Infection prevention and control recommendations

Different reports (WHO ((WHO), W. H. O 2020d; (WHO), W. H. O 2020e), Centers for Disease Control and Prevention (CDC), governments and hospitals) and several studies

included in this SR show that SARS-CoV-2 can be easily spread via two main ways in human-to-human transmission: (1) respiratory droplet and (2) direct and indirect contact with aerosol-infected surfaces. These databases are recommended guidelines for IPC for emergency responses to outbreaks of respiratory viruses. Recommended strategies play an essential role in preventing the infection transmission (Ki et al. 2019, Koul et al. 2018, Butt et al. 2016, Rabaan et al. 2017, Sikkema et al. 2017, El Bushra et al. 2017, (WHO) 2014, 2020a, Al-Tawfiq et al. 2019, Wong and Wai-San Tam 2005, Wiboonchutikul et al. 2016, (CDC) 2020, Huh 2020). Some of the most important recommendations to consider for IPC include the following (Fig. 3):

- Maintaining social distance (1–1.5 m) between people in indoor “red zones”
- The use of alcohol-based disinfectant (adequate hand hygiene) or hot water and soap for cleaning hands for 30 s or longer after contact with infected person fluids and before eating
- The use of disposable gloves, shoe cover, and long-sleeved gowns in contact with the infected person's body fluids or feces
- The use of surgical/N95 masks, eyeglasses, and face shield for covering the mouth, the nose, the eye, and the face in confronting with a person with SARS-CoV-2 in the same room

- Do not touch the face (mouth, eyes, or nose) with your hands
- Appropriate coughing or sneezing etiquette (respiratory hygiene) with a tissue, medical mask, or flexed elbow or a sleeve
- Do not eat or drink in the ward
- The use of disposable or plastic covers for inanimate objects like keyboard, pens, and pagers
- The use of alcohol-based detergents for cleaning of equipment and different surfaces
- Take a shower immediately when direct contact with infected person fluids or respiratory droplets
- The isolation of persons (the use of separate room) with specific diagnosis for at least 14 days until the symptoms of the disease (fever, coughing, or sneezing) are over
- Health education via different methods of communication
- Vaccination
- Management of health-care worker exposures
- Do not visit crowded places
- Proper ventilation of the buildings in time of aerosol generating
- Try to minimize work time and stay at home until end outbreak
- Avoid being exposed to the SARS-CoV-2 virus is the best way to prevent illness

Conclusions

The results of the present SR reveal that SARS-CoV-2 can survive in the range of a few hours up to 28 days in the different environmental conditions depending on the temperature and relative humidity. The results of reviewed studies confirmed that two alcohol-based hand rub formulations recommended by the WHO (such as ethanol with 78, 80, 85, and 95% concentration and 2-propanol with concentration of 70, 75, and 100%) had an efficient virucidal activity in less than 60 s by approximately $\geq 4 \log_{10}$ (≥ 99.99) in suspension test and could be used for disinfecting the public health and health-care facilities. The main virus transmission routes are human-to-human transmission, spreads via respiratory droplets, and contaminated hands or surfaces. We hope that the results of the present SR can help to researchers, health decision-makers, policy-makers, and people for having the proper behavior to control and prevent further spread of SARS-CoV-2.

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Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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