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Review

Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents

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SUMMARY

Currently, the emergence of a novel human coronavirus, SARS-CoV-2, has become a global health concern causing severe respiratory tract infections in humans. Human-to-human transmissions have been described with incubation times between 2-10 days, facilitating its spread via droplets, contaminated hands or surfaces. We therefore reviewed the literature on all available information about the persistence of human and veterinary coronaviruses on inanimate surfaces as well as inactivation strategies with biocidal agents used for chemical disinfection, e.g. in healthcare facilities. The analysis of 22 studies reveals that human coronaviruses such as Severe Acute Respiratory Syndrome (SARS) coronavirus, Middle East Respiratory Syndrome (MERS) coronavirus or endemic human coronaviruses (HCoV) can persist on inanimate surfaces like metal, glass or plastic for up to 9 days, but can be efficiently inactivated by surface disinfection procedures with 62–71% ethanol, 0.5% hydrogen peroxide or 0.1% sodium hypochlorite within 1 minute. Other biocidal agents such as 0.05–0.2% benzalkonium chloride or 0.02% chlorhexidine digluconate are less effective. As no specific therapies are available for SARS-CoV-2, early containment and prevention of further spread will be crucial to stop the ongoing outbreak and to control this novel infectious thread.

Introduction

A novel coronavirus (SARS-CoV-2) has recently emerged from China with a total of 45171 confirmed cases of pneumonia (as of February 12, 2020) [1]. Together with Severe Acute Respiratory Syndrome (SARS) coronavirus and Middle East Respiratory Syndrome (MERS) coronavirus [2], this is the third highly pathogenic human coronavirus that has emerged in the last two decades. Person-to-person transmission has been described both in hospital and family settings [3]. It is therefore of utmost importance to prevent any further spread in the public and healthcare settings. Transmission of coronaviruses from contaminated dry surfaces has been postulated including self-inoculation of mucous membranes of the nose, eyes or mouth [4,5], emphasizing the importance of a detailed understanding of coronavirus persistence on inanimate surfaces [6]. Various types of biocidal agents such as hydrogen peroxide, alcohols, sodium hypochlorite or benzalkonium chloride are used worldwide for disinfection, mainly in healthcare settings [7]. The aim of the review was therefore to summarize all available data on the persistence of all coronaviruses including emerging SARS-CoV and MERS-CoV as well as veterinary coronaviruses such as transmissible gastroenteritis virus (TGEV), mouse hepatitis virus (MHV) and canine coronavirus (CCV) on different types of

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inanimate surfaces and on the efficacy of commonly used biocidal agents used in surface disinfectants against coronaviruses.

Method

A Medline search has been done on January 28, 2020. The following terms were used, always in combination with "coronavirus", "TGEV", "MHV" or "CCV": survival surface (88 / 10 / 25 / 0 hits), persistence surface (47 / 1 / 32 / 0 hits), persistence hand (8 / 0 / 3 / 0 hits), survival hand (22 / 0 / 3 / 1 hits), survival skin (8 / 0 / 0 / 1 hits), persistence skin (1 / 0 / 0 / 1 hit), virucidal (23 / 3 / 3 / 1 hits), chemical inactivation (33 / 0 / 6 / 1), suspension test (18 / 0 / 0 / 0 hits) and carrier test (17 / 4 / 0 / 0 hits). Publications were included and results were extracted given they provided original data on coronaviruses on persistence (surfaces, materials) and inactivation by biocidal agents used for disinfection (suspension tests, carrier tests, fumigation studies). Data with commercial products based on various different types of biocidal agents were excluded. Reviews were not included, but screened for any information within the scope of this review.

Results

Persistence of coronavirus on inanimate surfaces

Most data were described with the endemic human coronavirus strain (HCoV-) 229E. On different types of materials it can remain infectious for from 2 hours up to 9 days. A higher temperature such as 30°C or 40°C reduced the duration of persistence of highly pathogenic MERS-CoV, TGEV and MHV. However, at 4°C persistence of TGEV and MHV can be increased to $\geq$ 28 days. Few comparative data obtained with SARS-CoV indicate that persistence was longer with higher inocula (Table I). In addition it was shown at room temperature that HCoV-229E persists better at 50% compared to 30% relative humidity [8].

Inactivation of coronaviruses by biocidal agents in suspension tests

Ethanol (78–95%), 2-propanol (70–100%), the combination of 45% 2-propanol with 30% 1-propanol, glutardialdehyde (0.5–2.5%), formaldehyde (0.7–1%) and povidone iodine

Table I
Persistence of coronaviruses on different types of inanimate surfaces

Type of surface	Virus	Strain / isolate	Inoculum (viral titer)	Temperature	Persistence	Reference
Steel	MERS-CoV	Isolate HCoV-EMC/2012	10^5	20°C	48 h	[21]
				30°C	8–24 h	
	TGEV	Unknown	10^6	4°C	$\geq$ 28 d	[22]
				20°C	3–28 d	
				40°C	4–96 h	
	MHV	Unknown	10^6	4°C	$\geq$ 28 d	[22]
				20°C	4–28 d	
				40°C	4–96 h	
	HCoV	Strain 229E	10^3	21°C	5 d	[23]
Aluminium	HCoV	Strains 229E and OC43	5 x 10^3	21°C	2–8 h	[24]
Metal	SARS-CoV	Strain P9	10^5	RT	5 d	[25]
Wood	SARS-CoV	Strain P9	10^5	RT	4 d	[25]
Paper	SARS-CoV	Strain P9	10^5	RT	4–5 d	[25]
	SARS-CoV	Strain GVU6109	10^6	RT	24 h	[26]
			10^5		3 h	
			10^4		$<$ 5 min	
Glass	SARS-CoV	Strain P9	10^5	RT	4 d	[25]
	HCoV	Strain 229E	10^3	21°C	5 d	[23]
Plastic	SARS-CoV	Strain HKU39849	10^5	22°-25°C	$\leq$ 5 d	[27]
	MERS-CoV	Isolate HCoV-EMC/2012	10^5	20°C	48 h	[21]
				30°C	8–24 h	
	SARS-CoV	Strain P9	10^5	RT	4 d	[25]
	SARS-CoV	Strain FFM1	10^7	RT	6–9 d	[28]
	HCoV	Strain 229E	10^7	RT	2–6 d	[28]
PVC	HCoV	Strain 229E	10^3	21°C	5 d	[23]
Silicon rubber	HCoV	Strain 229E	10^3	21°C	5 d	[23]
Surgical glove (latex)	HCoV	Strains 229E and OC43	5 x 10^3	21°C	$\leq$ 8 h	[24]
Disposable gown	SARS-CoV	Strain GVU6109	10^6	RT	2 d	[26]
			10^5		24 h	
			10^4		1 h	
Ceramic	HCoV	Strain 229E	10^3	21°C	5 d	[23]
Teflon	HCoV	Strain 229E	10^3	21°C	5 d	[23]

MERS = Middle East Respiratory Syndrome; HCoV = human coronavirus; TGEV = transmissible gastroenteritis virus; MHV = mouse hepatitis virus; SARS = Severe Acute Respiratory Syndrome; RT = room temperature.

Table II
Inactivation of coronaviruses by different types of biocidal agents in suspension tests

Biocidal agent	Concentration	Virus	Strain / isolate	Exposure time	Reduction of viral infectivity (log_{10})	Reference
Ethanol	95%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 5.5	[29]
	85%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 5.5	[29]
	80%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 4.3	[29]
	80%	MERS-CoV	Strain EMC	30 s	$>$ 4.0	[14]
	78%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 5.0	[28]
	70%	MHV	Strains MHV-2 and MHV-N	10 min	$>$ 3.9	[30]
	70%	CCV	Strain I-71	10 min	$>$ 3.3	[30]
2-Propanol	100%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 3.3	[28]
	75%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 4.0	[14]
	75%	MERS-CoV	Strain EMC	30 s	$\geq$ 4.0	[14]
	70%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 3.3	[28]
	50%	MHV	Strains MHV-2 and MHV-N	10 min	$>$ 3.7	[30]
	50%	CCV	Strain I-71	10 min	$>$ 3.7	[30]
2-Propanol and 1-propanol	45% and 30%	SARS-CoV	Isolate FFM-1	30 s	$\geq$ 4.3	[29]
		SARS-CoV	Isolate FFM-1	30 s	$\geq$ 2.8	[28]
Benzalkonium chloride	0.2%	HCoV	ATCC VR-759 (strain OC43)	10 min	0.0	[31]
	0.05%	MHV	Strains MHV-2 and MHV-N	10 min	$>$ 3.7	[30]
	0.05%	CCV	Strain I-71	10 min	$>$ 3.7	[30]
	0.00175%	CCV	Strain S378	3 d	3.0	[32]
Didecyldimethyl ammonium chloride	0.0025%	CCV	Strain S378	3 d	$>$ 4.0	[32]
Chlorhexidine digluconate	0.02%	MHV	Strains MHV-2 and MHV-N	10 min	0.7–0.8	[30]
	0.02%	CCV	Strain I-71	10 min	0.3	[30]
Sodium hypochlorite	0.21%	MHV	Strain MHV-1	30 s	$\geq$ 4.0	[33]
	0.01%	MHV	Strains MHV-2 and MHV-N	10 min	2.3–2.8	[30]
	0.01%	CCV	Strain I-71	10 min	1.1	[30]
	0.001%	MHV	Strains MHV-2 and MHV-N	10 min	0.3–0.6	[30]
	0.001%	CCV	Strain I-71	10 min	0.9	[30]
Hydrogen peroxide	0.5%	HCoV	Strain 229E	1 min	$>$ 4.0	[34]
Formaldehyde	1%	SARS-CoV	Isolate FFM-1	2 min	$>$ 3.0	[28]
	0.7%	SARS-CoV	Isolate FFM-1	2 min	$>$ 3.0	[28]
	0.7%	MHV		10 min	$>$ 3.5	[30]
	0.7%	CCV	Strain I-71	10 min	$>$ 3.7	[30]
	0.009%	CCV		24 h	$>$ 4.0	[35]
Glutardialdehyde	2.5%	SARS-CoV	Hanoi strain	5 min	$>$ 4.0	[36]
	0.5%	SARS-CoV	Isolate FFM-1	2 min	$>$ 4.0	[28]
Povidone iodine	7.5%	MERS-CoV	Isolate HCoV-EMC/2012	15 s	4.6	[37]
	4%	MERS-CoV	Isolate HCoV-EMC/2012	15 s	5.0	[37]
	1%	SARS-CoV	Hanoi strain	1 min	$>$ 4.0	[36]
	1%	MERS-CoV	Isolate HCoV-EMC/2012	15 s	4.3	[37]
	0.47%	SARS-CoV	Hanoi strain	1 min	3.8	[36]
	0.25%	SARS-CoV	Hanoi strain	1 min	$>$ 4.0	[36]
	0.23%	SARS-CoV	Hanoi strain	1 min	$>$ 4.0	[36]
	0.23%	SARS-CoV	Isolate FFM-1	15 s	$\geq$ 4.4	[38]
	0.23%	MERS-CoV	Isolate HCoV-EMC/2012	15 s	$\geq$ 4.4	[38]

SARS = Severe Acute Respiratory Syndrome; MERS = Middle East Respiratory Syndrome; MHV = mouse hepatitis virus; CCV = canine coronavirus; HCoV = human coronavirus.

Table III
Inactivation of coronaviruses by different types of biocidal agents in carrier tests

Biocidal agent	Concentration	Virus	Strain / isolate	Volume / material	Organic load	Exposure time	Reduction of viral infectivity (log_{10})	Reference
Ethanol	71%	TGEV	Unknown	50 µl / stainless steel	None	1 min	3.5	[39]
	71%	MHV	Unknown	50 µl / stainless steel	None	1 min	2.0	[39]
	70%	TGEV	Unknown	50 µl / stainless steel	None	1 min	3.2	[39]
	70%	MHV	Unknown	50 µl / stainless steel	None	1 min	3.9	[39]
	70%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	> 3.0	[40]
	62%	TGEV	Unknown	50 µl / stainless steel	None	1 min	4.0	[39]
	62%	MHV	Unknown	50 µl / stainless steel	None	1 min	2.7	[39]
Benzalkoniumchloride	0.04%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	< 3.0	[40]
Sodium hypochlorite	0.5%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	> 3.0	[40]
	0.1%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	> 3.0	[40]
	0.06%	TGEV	Unknown	50 µl / stainless steel	None	1 min	0.4	[39]
	0.06%	MHV	Unknown	50 µl / stainless steel	None	1 min	0.6	[39]
	0.01%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	< 3.0	[40]
Glutardialdehyde	2%	HCoV	Strain 229E	20 µl / stainless steel	5% serum	1 min	> 3.0	[40]
Ortho-phtalaldehyde	0.55%	TGEV	Unknown	50 µl / stainless steel	None	1 min	2.3	[39]
	0.55%	MHV	Unknown	50 µl / stainless steel	None	1 min	1.7	[39]
Hydrogen peroxide	Vapor of unknown concentration	TGEV	Purdue strain type 1	20 µl / stainless steel	None	2–3 h	4.9–5.3*	[41]

TGEV = transmissible gastroenteritis virus; MHV = mouse hepatitis virus; HCoV = human coronavirus; *depending on the volume of injected hydrogen peroxide.

(0.23–7.5%) readily inactivated coronavirus infectivity by approximately 4 $\log_{10}$ or more. (Table II). Sodium hypochlorite required a minimal concentration of at least 0.21% to be effective. Hydrogen peroxide was effective with a concentration of 0.5% and an incubation time of 1 min. Data obtained with benzalkonium chloride at reasonable contact times were conflicting. Within 10 min a concentration of 0.2% revealed no efficacy against coronavirus whereas a concentration of 0.05% was quite effective. 0.02% chlorhexidine digluconate was basically ineffective (Table II).

Inactivation of coronaviruses by biocidal agents in carrier tests

Ethanol at concentrations between 62% and 71% reduced coronavirus infectivity within 1 min exposure time by 2.0–4.0 $\log_{10}$. Concentrations of 0.1–0.5% sodium hypochlorite and 2% glutardialdehyde were also quite effective with $> 3.0 \log_{10}$ reduction in viral titre. In contrast, 0.04% benzalkonium chloride, 0.06% sodium hypochlorite and 0.55% ortho-phtalaldehyde were less effective (Table III).

Discussion

Human coronaviruses can remain infectious on inanimate surfaces at room temperature for up to 9 days. At a temperature of 30°C or more the duration of persistence is shorter. Veterinary coronaviruses have been shown to persist even longer for 28 d. Contamination of frequent touch surfaces in healthcare settings are therefore a potential source of viral transmission. Data on the transmissibility of coronaviruses from contaminated surfaces to hands were not found. However, it could be shown with influenza A virus that a contact of 5 s can transfer 31.6% of the viral load to the hands [9]. The transfer efficiency was lower (1.5%) with parainfluenza virus 3 and a 5 s contact between the surface and the hands [10]. In an observational study, it was described that students touch their face with their own hands on average 23 times per h, with contact mostly to the skin (56%), followed by mouth (36%), nose (31%) and eyes (31%) [11]. Although the viral load of coronaviruses on inanimate surfaces is not known during an outbreak situation it seem plausible to reduce the viral load on surfaces by disinfection, especially of frequently touched surfaces in the immediate patient surrounding where the highest viral load can be expected. The WHO recommends "to ensure that environmental cleaning and disinfection procedures are followed consistently and correctly. Thoroughly cleaning environmental surfaces with water and detergent and applying commonly used hospital-level disinfectants (such as sodium hypochlorite) are effective and sufficient procedures." [12] The typical use of bleach is at a dilution of 1:100 of 5% sodium hypochlorite resulting in a final concentration of 0.05% [13]. Our summarized data with coronaviruses suggest that a concentration of 0.1% is effective in 1 min (Table III). That is why it seems appropriate to recommend a dilution 1:50 of standard bleach in the coronavirus setting. For the disinfection of small surfaces ethanol (62–71%; carrier tests) revealed a similar efficacy against coronavirus. A concentration of 70% ethanol is also recommended by the WHO for disinfecting small surfaces [13].

No data were found to describe the frequency of hands becoming contaminated with coronavirus, or the viral load on hands either, after patient contact or after touching contaminated surfaces. The WHO recommends to preferably apply alcohol-based hand rubs for the decontamination of hands, e.g. after removing gloves. Two WHO recommended formulations (based on 80% ethanol or 75% 2-propanol) have been evaluated in suspension tests against SARS-CoV and MERS-CoV, and both were described to be very effective [14]. No in vitro data were found on the efficacy of hand washing against coronavirus contaminations on hands. In Taiwan, however, it was described that installing hand wash stations in the emergency department was the only infection control measure which was significantly associated with the protection from healthcare workers from acquiring the SARS-CoV, indicating that hand hygiene can have a protective effect [15]. Compliance with hand hygiene can be significantly higher in an outbreak situation but is likely to remain an obstacle especially among physicians [16–18]. Transmission in healthcare settings can be successfully prevented when appropriate measures are consistently performed [19,20].

Conclusions

Human coronaviruses can remain infectious on inanimate surfaces for up to 9 days. Surface disinfection with 0.1% sodium hypochlorite or 62–71% ethanol significantly reduces coronavirus infectivity on surfaces within 1 min exposure time. We expect a similar effect against the SARS-CoV-2.

Conflict of interest statement
None declared.

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