

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Review

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

G. Kampf^{a,*}, D. Todt^b, S. Pfaender^b, E. Steinmann^b^a *University Medicine Greifswald, Institute for Hygiene and Environmental Medicine, Ferdinand-Sauerbruch-Straße, 17475 Greifswald, Germany*^b *Department of Molecular and Medical Virology, Ruhr University Bochum, Universitätsstrasse 50, 44801 Bochum, Germany*

ARTICLE INFO

Article history:

Received 31 January 2020

Accepted 31 January 2020

Available online xxx

Keywords:

Coronavirus

Persistence

Inanimate surfaces

Chemical inactivation

Biocidal agents

Disinfection

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.

© 2020 The Healthcare Infection Society. Published by Elsevier Ltd. All rights reserved.

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

* Corresponding author.

E-mail address: guenter.kampf@uni-greifswald.de (G. Kampf).

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 ≥ 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 | ≥ 28 d | [22] |
| | | | | 20°C | 3–28 d | |
| | MHV | Unknown | 10^6 | 40°C | 4–96 h | |
| | | | | 4°C | ≥ 28 d | [22] |
| 20°C | | | | 4–28 d | | |
| Aluminium | HCoV | Strain 229E | 10^3 | 40°C | 4–96 h | |
| | HCoV | Strains 229E and OC43 | 5×10^3 | 21°C | 5 d | [23] |
| Metal | SARS-CoV | Strain P9 | 10^5 | 21°C | 2–8 h | [24] |
| Wood | SARS-CoV | Strain P9 | 10^5 | RT | 5 d | [25] |
| Paper | SARS-CoV | Strain P9 | 10^5 | RT | 4 d | [25] |
| | SARS-CoV | Strain GVU6109 | 10^5 | RT | 4–5 d | [25] |
| Glass | SARS-CoV | Strain P9 | 10^6 | RT | 24 h | [26] |
| | | | 10^5 | | 3 h | |
| | HCoV | Strain 229E | 10^4 | | < 5 min | |
| | HCoV | Strain 229E | 10^5 | RT | 4 d | [25] |
| Plastic | SARS-CoV | Strain HKU39849 | 10^3 | 21°C | 5 d | [23] |
| | MERS-CoV | Isolate HCoV-EMC/2012 | 10^5 | 22°–25°C | ≤ 5 d | [27] |
| PVC | SARS-CoV | Strain P9 | 10^5 | 20°C | 48 h | [21] |
| | | | 10^5 | 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] |
| Silicon rubber | HCoV | Strain 229E | 10^3 | 21°C | 5 d | [23] |
| Surgical glove (latex) | HCoV | Strains 229E and OC43 | 10^3 | 21°C | 5 d | [23] |
| Disposable gown | SARS-CoV | Strain GVU6109 | 5×10^3 | 21°C | ≤ 8 h | [24] |
| | | | 10^6 | RT | 2 d | [26] |
| | | | 10^5 | | 24 h | |
| Ceramic | HCoV | Strain 229E | 10^4 | | 1 h | |
| | | | 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 | ≥ 5.5 | [29] |
| | 85% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 5.5 | [29] |
| | 80% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 4.3 | [29] |
| | 80% | MERS-CoV | Strain EMC | 30 s | > 4.0 | [14] |
| | 78% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 5.0 | [28] |
| | 70% | MHV | Strains MHV-2 and MHV-N | 10 min | > 3.9 | [30] |
| 2-Propanol | 70% | CCV | Strain I-71 | 10 min | > 3.3 | [30] |
| | 100% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 3.3 | [28] |
| | 75% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 4.0 | [14] |
| | 75% | MERS-CoV | Strain EMC | 30 s | ≥ 4.0 | [14] |
| | 70% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 3.3 | [28] |
| | 50% | MHV | Strains MHV-2 and MHV-N | 10 min | > 3.7 | [30] |
| 2-Propanol and 1-propanol | 50% | CCV | Strain I-71 | 10 min | > 3.7 | [30] |
| | 45% and 30% | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 4.3 | [29] |
| Benzalkonium chloride | | SARS-CoV | Isolate FFM-1 | 30 s | ≥ 2.8 | [28] |
| | 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] |
| Didecylmethyl ammonium chloride | 0.05% | CCV | Strain I-71 | 10 min | > 3.7 | [30] |
| | 0.00175% | CCV | Strain S378 | 3 d | 3.0 | [32] |
| | 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 | ≥ 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] |
| Hydrogen peroxide | 0.001% | CCV | Strain I-71 | 10 min | 0.9 | [30] |
| | 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] |
| Glutaraldehyde | 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 | ≥ 4.4 | [38] |
| 0.23% | MERS-CoV | Isolate HCoV-EMC/2012 | 15 s | ≥ 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] |
| | 2% | 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 log₁₀ 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 log₁₀. Concentrations of 0.1–0.5% sodium hypochlorite and 2% glutardialdehyde were also quite effective with > 3.0 log₁₀ reduction in viral titre. In contrast, 0.04% benzalkonium chloride, 0.06% sodium hypochlorite and 0.55% ortho-phthalaldehyde 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.

Funding Sources

None.

References

- [1] WHO. Coronavirus Disease 2019 (COVID-19). WHO; 2020. Situation Report 23.
- [2] de Wit E, van Doremalen N, Falzarano D, Munster VJ. SARS and MERS: recent insights into emerging coronaviruses. *Nat Rev Microbiol* 2016;14:523–34.
- [3] Chan JF, Yuan S, Kok KH, To KK, Chu H, Yang J, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet* 2020. [https://doi.org/10.1016/s0140-6736\(20\)30154-9](https://doi.org/10.1016/s0140-6736(20)30154-9).
- [4] Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination. *J Hosp Infect* 2016;92:235–50.
- [5] Dowell SF, Simmerman JM, Erdman DD, Wu JS, Chaovavanich A, Javadi M, et al. Severe acute respiratory syndrome coronavirus on hospital surfaces. *Clin Infect Dis* 2004;39:652–7.
- [6] Geller C, Varbanov M, Duval RE. Human coronaviruses: insights into environmental resistance and its influence on the development of new antiseptic strategies. *Viruses* 2012;4:3044–68.
- [7] Kampf G. Antiseptic stewardship: biocide resistance and clinical implications. Cham: Springer International Publishing; 2018.
- [8] Ijaz MK, Brunner AH, Sattar SA, Nair RC, Johnson-Lussenburg CM. Survival characteristics of airborne human coronavirus 229E. *J Gen Virol* 1985;66(Pt 12):2743–8.
- [9] Bean B, Moore BM, Sterner B, Peterson LR, Gerding DN, Balfour HH. Survival of influenza viruses on environmental surfaces. *J Infect Dis* 1982;146:47–51.

- [10] Ansari SA, Springthorpe VS, Sattar SA, Rivard S, Rahman M. Potential role of hands in the spread of respiratory viral infections: studies with human parainfluenza virus 3 and rhinovirus 14. *J Clin Microbiol* 1991;29:2115–9.
- [11] Kwok YL, Gralton J, McLaws ML. Face touching: a frequent habit that has implications for hand hygiene. *Am J Infect Contr* 2015;43:112–4.
- [12] WHO. Infection prevention and control during health care when novel coronavirus (nCoV) infection is suspected. WHO; 2020. Interim guidance. 25 January 2020.
- [13] WHO. Annex G. Use of disinfectants: alcohol and bleach. Infection prevention and control of epidemic-and pandemic-prone acute respiratory infections in health care. Geneva: WHO; 2014. p. 65–6.
- [14] Siddharta A, Pfaender S, Vielle NJ, Dijkman R, Friesland M, Becker B, et al. Virucidal Activity of World Health Organization-Recommended Formulations Against Enveloped Viruses, Including Zika, Ebola, and Emerging Coronaviruses. *J Infect Dis* 2017;215:902–6.
- [15] Yen MY, Lu YC, Huang PH, Chen CM, Chen YC, Lin YE. Quantitative evaluation of infection control models in the prevention of nosocomial transmission of SARS virus to healthcare workers: implication to nosocomial viral infection control for healthcare workers. *Scand J Infect Dis* 2010;42:510–5.
- [16] Alshammari M, Reynolds KA, Verhoughstraete M, O'Rourke MK. Comparison of perceived and observed hand hygiene compliance in healthcare workers in MERS-CoV endemic regions. *Healthcare (Basel, Switzerland)* 2018;6:122.
- [17] Al-Tawfiq JA, Abdrababnabi R, Taher A, Mathew S, Rahman KA. Infection control influence of Middle East respiratory syndrome coronavirus: A hospital-based analysis. *Am J Infect Contr* 2019;47:431–4.
- [18] Wong TW, Tam WW. Handwashing practice and the use of personal protective equipment among medical students after the SARS epidemic in Hong Kong. *Am J Infect Contr* 2005;33:580–6.
- [19] Wiboonchutikul S, Manosuthi W, Likanonsakul S, Sangsajja C, Kongsanan P, Nitiyanontakij R, et al. Lack of transmission among healthcare workers in contact with a case of Middle East respiratory syndrome coronavirus infection in Thailand. *Antimicrob Resist Infect Contr* 2016;5:21.
- [20] Ki HK, Han SK, Son JS, Park SO. Risk of transmission via medical employees and importance of routine infection-prevention policy in a nosocomial outbreak of Middle East respiratory syndrome (MERS): a descriptive analysis from a tertiary care hospital in South Korea. *BMC Pulm Med* 2019;19:190.
- [21] van Doremalen N, Bushmaker T, Munster VJ. Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *Euro Surveill* 2013;18.
- [22] Casanova LM, Jeon S, Rutala WA, Weber DJ, Sobsey MD. Effects of air temperature and relative humidity on coronavirus survival on surfaces. *Appl Environ Microbiol* 2010;76:2712–7.
- [23] Warnes SL, Little ZR, Keevil CW. Human Coronavirus 229E Remains Infectious on Common Touch Surface Materials. *mBio* 2015;6:e01697–15.
- [24] Sizun J, Yu MW, Talbot PJ. Survival of human coronaviruses 229E and OC43 in suspension and after drying on surfaces: a possible source of hospital-acquired infections. *J Hosp Infect* 2000;46:55–60.
- [25] Duan SM, Zhao XS, Wen RF, Huang JJ, Pi GH, Zhang SX, et al. Stability of SARS coronavirus in human specimens and environment and its sensitivity to heating and UV irradiation. *Biomed Environ Sci* 2003;16:246–55.
- [26] Lai MY, Cheng PK, Lim WW. Survival of severe acute respiratory syndrome coronavirus. *Clin Infect Dis* 2005;41:e67–71.
- [27] Chan KH, Peiris JS, Lam SY, Poon LL, Yuen KY, Seto WH. The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. *Adv Virol* 2011;734690.
- [28] Rabenau HF, Cinatl J, Morgenstern B, Bauer G, Preiser W, Doerr HW. Stability and inactivation of SARS coronavirus. *Med Microbiol Immunol* 2005;194:1–6.
- [29] Rabenau HF, Kampf G, Cinatl J, Doerr HW. Efficacy of various disinfectants against SARS coronavirus. *J Hosp Infect* 2005;61:107–11.
- [30] Saknimit M, Inatsuki I, Sugiyama Y, Yagami K. Virucidal efficacy of physico-chemical treatments against coronaviruses and parvoviruses of laboratory animals. *Jikken Dobutsu Exp Anim* 1988;37:341–5.
- [31] Wood A, Payne D. The action of three antiseptics/disinfectants against enveloped and non-enveloped viruses. *J Hosp Infect* 1998;38:283–95.
- [32] Pratelli A. Action of disinfectants on canine coronavirus replication in vitro. *Zoonoses Publ Health* 2007;54:383–6.
- [33] Dellanno C, Vega Q, Boesenberg D. The antiviral action of common household disinfectants and antiseptics against murine hepatitis virus, a potential surrogate for SARS coronavirus. *Am J Infect Contr* 2009;37:649–52.
- [34] Omidbakhsh N, Sattar SA. Broad-spectrum microbicidal activity, toxicologic assessment, and materials compatibility of a new generation of accelerated hydrogen peroxide-based environmental surface disinfectant. *Am J Infect Contr* 2006;34:251–7.
- [35] Pratelli A. Canine coronavirus inactivation with physical and chemical agents. *Vet J (London, England : 1997)* 2008;177:71–9.
- [36] Kariwa H, Fujii N, Takashima I. Inactivation of SARS coronavirus by means of povidone-iodine, physical conditions and chemical reagents. *Dermatol (Basel, Switzerland)* 2006;212(Suppl 1):119–23.
- [37] Eggers M, Eickmann M, Zorn J. Rapid and Effective Virucidal Activity of Povidone-Iodine Products Against Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and Modified Vaccinia Virus Ankara (MVA). *Infect Dis Ther* 2015;4:491–501.
- [38] Eggers M, Koburger-Janssen T, Eickmann M, Zorn J. In Vitro Bactericidal and Virucidal Efficacy of Povidone-Iodine Gargle/Mouthwash Against Respiratory and Oral Tract Pathogens. *Infect Dis Ther* 2018;7:249–59.
- [39] Hulkower RL, Casanova LM, Rutala WA, Weber DJ, Sobsey MD. Inactivation of surrogate coronaviruses on hard surfaces by health care germicides. *Am J Infect Contr* 2011;39:401–7.
- [40] Sattar SA, Springthorpe VS, Karim Y, Loro P. Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. *Epidemiol Infect* 1989;102:493–505.
- [41] Goyal SM, Chander Y, Yezli S, Otter JA. Evaluating the virucidal efficacy of hydrogen peroxide vapour. *J Hosp Infect* 2014;86:255–9.