

Combating SARS-CoV-2: leveraging microbicidal experiences with other emerging/re-emerging viruses

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ABSTRACT

The emergence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in Wuhan City, China, late in December 2019 is an example of an emerging zoonotic virus that threatens public health and international travel and commerce. When such a virus emerges, there is often insufficient specific information available on mechanisms of virus dissemination from animal-to-human or from person-to-person, on the level or route of infection transmissibility or of viral release in body secretions/excretions, and on the survival of virus in aerosols or on surfaces. The effectiveness of available virucidal agents and hygiene practices as interventions for disrupting the spread of infection and the associated diseases may not be clear for the emerging virus. In the present review, we suggest that approaches for infection prevention and control (IPAC) for SARS-CoV-2 and future emerging/re-emerging viruses can be invoked based on pre-existing data on microbicidal and hygiene effectiveness for related and unrelated enveloped viruses.

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INTRODUCTION

Late in December 2019, cases of pneumonia began appearing in Wuhan City, Hubei Province, China. By early January 2020, these cases were attributed to a novel coronavirus that was temporarily referred to as 2019 Novel Coronavirus (2019-nCoV) (*World Health Organization, 2020a*). This member of the *Coronaviridae* family was subsequently named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (*Gorbalenya et al., 2020*). As of August 11, 2020 (*World Health Organization, 2020c*), there have been over 19,936,210 confirmed cases globally, with 732,499 deaths (case mortality rate of 3.7%). This emerging virus, and the associated disease (COVID-19), have not only impacted public health, but also international commerce and travel. As with the Middle East respiratory syndrome coronavirus (MERS-CoV) that emerged in Saudi Arabia in 2012 and

Table 1 Characteristics of selected emerging/re-emerging viruses including SARS-CoV-2.

Virus	Family	Particle size	Lipid envelope	Genome* (segments)	Reservoir species	References
Lassa virus	<i>Arenaviridae</i>	110–130 nm	yes	±ssRNA(2)	rodent	<i>Viral Hemorrhagic Fever Consortium (2020), St. Georgiev (2009)</i>
SFTSV [†]	<i>Phenuiviridae</i>	80–100 nm	yes	–ssRNA(3)	tick	<i>Zhan et al. (2017)</i>
Hantaan virus	<i>Hantaviridae</i>	80–120 nm	yes	–ssRNA(3)	rodent	<i>Jiang et al. (2016), Brocato & Hooper (2019), Laenen et al. (2019)</i>
MERS-CoV	<i>Coronaviridae</i>	118–136 nm	yes	+ssRNA(1)	bat	<i>Otter et al. (2016), AABB (2013), Gorbalenya et al. (2020)</i>
SARS-CoV	<i>Coronaviridae</i>	80–90 nm	yes	+ssRNA(1)	bat	<i>Otter et al. (2016), AABB (2013), Gorbalenya et al. (2020)</i>
SARS-CoV-2	<i>Coronaviridae</i>	60–140 nm	yes	+ssRNA(1)	bat [‡]	<i>Munster et al. (2020), Zhou et al. (2020), Zhu et al. (2020)</i>
Ebola virus	<i>Filoviridae</i>	80 × 14000 nm	yes	–ssRNA(1)	bat	<i>St. Georgiev (2009)</i>
Influenza H5N1	<i>Orthomyxoviridae</i>	80–120 nm	yes	–ssRNA(8)	avian	<i>Cassidy et al. (2018)</i>
Nipah virus	<i>Paramyxoviridae</i>	40–1900 nm	yes	–ssRNA(1)	bat	<i>Ang, Lim & Wang (2018)</i>
EV-D68	<i>Picornaviridae</i>	~30 nm	no	+ssRNA(4)	unknown	<i>Cassidy et al. (2018), Sun, Hu & Yu (2019)</i>

Notes:

* Segments (1) equates to a non-segmented genome.

[†] Now referred to as Huaiyangshan banyangvirus.

[‡] Suspected primary host based on >90% sequence homology to bat coronaviruses (*Zhou et al., 2020*).

±, ambisense; –, negative sense; +, positive sense; ss, single-stranded.

the severe acute respiratory syndrome coronavirus (SARS-CoV) that emerged in China in early 2003, SARS-CoV-2 is considered a zoonosis, with bats suspected as the primary host species (*Table 1*) (*Zhu et al., 2020; Li et al., 2020*).

The *Coronaviridae* is just one of several families of enveloped viruses that have emerged/re-emerged in recent years (*Table 1*) (*Zhan et al., 2017; Ang, Lim & Wang, 2018; Brocato & Hooper, 2019; Laenen et al., 2019; Viral Hemorrhagic Fever Consortium, 2020*). While the list of viruses in *Table 1* is not intended to be comprehensive, it contains most of the virus families attributed to the World Health Organization (WHO) current list of disease priorities needing urgent R&D attention (*World Health Organization, 2015*) (i.e., MERS and SARS (*Coronaviridae*), Crimean Congo hemorrhagic fever (*Nairoviridae*), Rift Valley fever (*Phenuiviridae*), Ebola virus disease and Marburg virus disease (*Filoviridae*), Nipah and Hendra virus disease (*Paramyxoviridae*), and Lassa fever (*Arenaviridae*)).

To our knowledge, no one has systematically compared the characteristics of the viruses causing the diseases in the WHO current list of disease priorities needing urgent R&D attention (*World Health Organization, 2015*). There may be common characteristics that may favor sustained transmissibility or mortality and could inform infection prevention and control (IPAC) activities. This review is intended to aid the IPAC community in arriving at strategies for dealing with SARS-CoV-2, as well as future emerging/re-emerging viruses, by evaluating relevant characteristics of these viruses of concern. In particular, it is our hope that this information may be leveraged to effectively mitigate the health risks

Table 2 Transmission and mortality of emerging/re-emerging viruses including SARS-CoV-2.

Virus	Tropism for organs	Mode of transmission	Case mortality (%)	Reference
Lassa virus	Vascular system	Contact, aerosols/droplets	15–20	<i>St. Georgiev (2009), Cieslak et al. (2019)</i>
SFTSV	Vascular system	Vector (tick)	12–30	<i>Xing et al. (2016), Zhan et al. (2017)</i>
Hantaan virus	Lower respiratory, renal	Contact, aerosols/droplets	1–15	<i>Nolte et al. (1995), St. Georgiev (2009), Krüger, Schönrich & Klempa (2011), Jiang et al. (2016)</i>
MERS-CoV	Lower respiratory, GI	Contact, aerosols/droplets	34–36	<i>Cieslak et al. (2019), Weber et al. (2019), Paules, Marston & Fauci (2020), Van Doremalen, Bushmaker & Munster (2013)</i>
SARS-CoV	Lower respiratory	Contact, aerosols/droplets	15 ± 11	<i>Chan et al. (2011), Cieslak et al. (2019)</i>
SARS-CoV-2	Lower respiratory, GI	Contact, aerosols/droplets	4	<i>World Health Organization (2020c), Morawska et al. (2020), Zhang et al. (2020)</i>
Ebola virus	Vascular system	Contact, aerosols/droplets	41	<i>Fischer et al. (2015), Cieslak et al. (2019), Weber et al. (2019)</i>
Influenza H5N1	Upper respiratory	Contact, aerosols/droplets	>60	<i>United States Centers for Disease Control & Prevention (2015), Cieslak et al. (2019)</i>
Nipah virus	CNS, respiratory	Contact, ingestion	65 ± 28	<i>Ang, Lim & Wang (2018), Hassan et al. (2018)</i>
EV-D68	Respiratory, CNS	Aerosols/droplets, contact	Up to 10	<i>Oermann et al. (2015), Cassidy et al. (2018)</i>

Notes:

“Contact” refers to contact with bodily fluids or with fomites; “aerosols/droplets” equates to respiratory aerosols/large or small droplets. CNS, central nervous system; GI, gastrointestinal.

associated with SARS-CoV-2 and its associated disease (COVID-19), as well as with future emerging/re-emerging enveloped viruses.

The emerging/re-emerging viruses shown in [Table 1](#), with the exception of enterovirus D68 (EV-D68), each are relatively large, enveloped, zoonotic viruses with single-stranded RNA genomes. EV-D68, a small non-enveloped virus of the *Picornaviridae* family, is an example of a re-emerging virus from that family. While EV-D68 may also be zoonotic ([Bailey et al., 2018](#); [Fieldhouse et al., 2018](#)), a reservoir species has yet to be identified for that virus.

Aside from the characteristics described in [Table 1](#), what other commonalities exist for these emerging/re-emerging zoonotic viruses? Can we use these commonalities as the basis for proposing approaches for IPAC? In the remainder of this review, we examine various aspects of the emerging/re-emerging viruses that may be important in formulating approaches for IPAC, namely transmissibility, infectivity, viral shedding, environmental survival, and expectations regarding microbicidal efficacy for targeted hygiene practices. Our hypothesis is that, when dealing with emerging enveloped viruses, knowledge of the susceptibility of one enveloped virus to microbicides which disrupt the lipid envelope should enable one to predict which microbicides should prove efficacious for other enveloped viruses, including emerging/re-emerging viruses.

SURVEY METHODOLOGY

This literature review focused upon the WHO list of diseases of concern ([World Health Organization, 2015](#)) and our search of the literature pertaining to the various virus

Table 3 Environmental survival of emerging/re-emerging viruses including SARS-CoV-2 under ambient conditions.

Virus	Survival on surfaces	Survival in aerosols	Reference
Lassa virus	0.41 log ₁₀ /d (glass)	t _{1/2} = 0.62 h	<i>Stephenson, Larson & Dominik (1984), Sagripanti, Rom & Holland (2010)</i>
SFTSV	t _{1/2} = 0.75 h (aluminum) [†]	No data	<i>Hardestam et al. (2007)</i>
Hantaan virus	t _{1/2} = 1.0 h (aluminum)	No data	<i>Hardestam et al. (2007)</i>
MERS-CoV	t _{1/2} = 0.94 h (steel)	t _{1/2} = 27 h*	<i>Ijaz et al. (1985), Van Doremalen, Bushmaker & Munster (2013)</i>
SARS-CoV	t _{1/2} = 10 h (steel), 18 h (plastic)	At least 3 h [‡] t _{1/2} = 27 h*	<i>Ijaz et al. (1985), Chan et al. (2011), Van Doremalen et al. (2020)</i>
SARS-CoV-2	t _{1/2} = 5 min (cloth), 13–14 h (steel), 16 h (plastic), 19 h (mask), 4 h (swine skin)	At least 3 h [‡] t _{1/2} = 27 h*	<i>Ijaz et al. (1985), Chin et al. (2020), Van Doremalen et al. (2020), Harbourt et al. (2020)</i>
Ebola virus	0.68 log ₁₀ /d (glass) 0.88 log ₁₀ /d (steel)	t _{1/2} = 0.25 h	<i>Cook et al. (2015), Fischer et al. (2015), Sagripanti, Rom & Holland (2010), Piercy et al. (2010)</i>
Influenza H5N1	<1 d (glass, metal)	No data	<i>Wood et al. (2010)</i>
Nipah virus	1 h (plastic)	No data	<i>United States Environmental Protection Agency (2014)</i>
EV-D68	t _{1/2} = 0.17–0.25 h (steel) [‡]	No data	<i>Sattar et al. (1987)</i>

Notes:

* Aerosol data for human coronavirus 229E (*Ijaz et al., 1985*). Survival half-life depended on humidity and temperature. The values ranged from 3.3 h (~80% RH), 67 h (50% RH), to 27 h (30% RH).

[†] No data for SFTSV are available; the result displayed is for Crimean-Congo virus.

[‡] No data for EV-D68 are available; the result displayed is for human rhinovirus type 14 at 15–55% RH (*Sattar et al., 1987*).

[§] The authors only evaluated times up to 3 h (*Van Doremalen et al., 2020*).

characteristics considered in Tables 1–3. As such, the PubMed and Google Scholar search terms included the virus names themselves as well as terms encompassing the topics addressed in the tables. These therefore included coronaviruses, Lassa virus, SFTSV, Hantaan virus, MERS-CoV, SARS-CoV, SARS-CoV-2, Ebola virus, influenza H5N1, Nipah virus, EV-D68, particle size, reservoir species, tissue tropism, mode of transmission, transmissibility, virus shedding, minimal infectious dose, infectious dose₅₀, mortality, survival on surfaces, persistence on surfaces, stability on surfaces, survival in aerosols, persistence in aerosols, stability in aerosols, microbicidal efficacy, virucidal efficacy, disinfectant efficacy, antiseptic efficacy, emerging/re-emerging enveloped viruses, UVC susceptibility, zoonoses, and personal hygiene for SARS-CoV-2. Active search of the literature concluded as of July 31, 2020. No exclusion criteria were used. This was not intended to represent a comprehensive review of the literature addressing all of the topics covered. Rather, it represents a compilation, by the authors, of the salient information regarding the set of emerging/re-emerging viruses under evaluation that, hopefully, will enable the reader to consider possible commonalities that inform IPAC. Our bias was toward information on the viruses causing the WHO diseases of concern and SARS-CoV-2, especially, in order to render the review of most potential utility and interest to the IPAC community. This, necessarily, resulted in our paying greatest attention to articles primarily from the past 15 years and to 2020 research and review articles pertaining to SARS-CoV-2 topics.

TRANSMISSIBILITY OF EMERGING/RE-EMERGING VIRUSES

According to several authors ([Geoghegan et al., 2016](#); [Walker et al., 2018](#); [Munster et al., 2020](#)), sustained person-to-person transmission of viruses is favored by certain viral characteristics, including lack of a lipid envelope, small particle size, limited genomic segmentation, and low mortality of the associated disease. Tropism of the virus for the liver, central nervous system (CNS), or the respiratory tract, and lack of vector-borne transmission also appear to favor sustained person-to-person transmission ([Geoghegan et al., 2016](#); [Walker et al., 2018](#)). On the other hand, possession of an RNA vs. a DNA genome was not found to contribute to the likelihood of such sustained transmission ([Geoghegan et al., 2016](#); [Walker et al., 2018](#)).

It is of interest that many of the viral characteristics mentioned above that are considered predictive of sustained person-to-person transmissibility are not shared by the viruses associated with the WHO diseases of concern. Namely, all of the emerging/re-emerging diseases mentioned in the WHO list ([World Health Organization, 2015](#)) involve relatively large enveloped viruses with ssRNA genomes, many of which are segmented. Of the emerging/re-emerging viruses listed in [Table 1](#), only EV-D68 is a small, non-enveloped virus. In addition, many of the WHO viruses of concern exhibit relatively high human mortality ([Tables 1 and 2](#)). It should be noted that the mortality values found in the literature for these emerging/re-emerging viruses represent case mortality rates (i.e., number of deaths per number of confirmed cases), not true mortality rates (i.e., number of deaths per number of infected persons). True mortality rates for these viruses are not known, though are likely to be lower than the case mortality rates displayed, as all asymptomatic cases are not included in the case mortality calculation. Certain predictive factors ([Geoghegan et al., 2016](#); [Walker et al., 2018](#); [Munster et al., 2020](#)) that do seem to be shared by the emerging/re-emerging viruses in the list in [Table 1](#) include tropism for the respiratory tract or the CNS, and lack of vector-borne transmission. While most enteroviruses are less susceptible to acid and are disseminated by the fecal-oral route, EV-D68 is acid-labile and has a lower temperature optimum, reflecting its tropism for the upper respiratory tract rather than the gastrointestinal tract (i.e., EV-D68 acts more like a rhinovirus than an enterovirus) ([Sun, Hu & Yu, 2019](#)).

It is unknown if sustained person-to-person transmissibility necessarily equates to a high level of concern for an emergent zoonotic virus. For instance, there appears to be no evidence that Hendra virus (another zoonotic enveloped virus) has shown person-to-person transmission ([Paterson et al., 2011](#)), yet this virus is similar to Nipah virus in many respects and is of concern, due its high case mortality rate in humans.

As mentioned in [Table 2](#), the most common modes of transmission for the emerging/re-emerging viruses discussed in this review are contact with infected bodily secretions/excretions and contaminated fomites, especially high-touch environmental surfaces (HITES), and inhalation of respiratory droplets/aerosols containing infectious virus ([Fig. 1](#)). The intermediacy of hands in transmission through contact is emphasized in [Fig. 1](#).

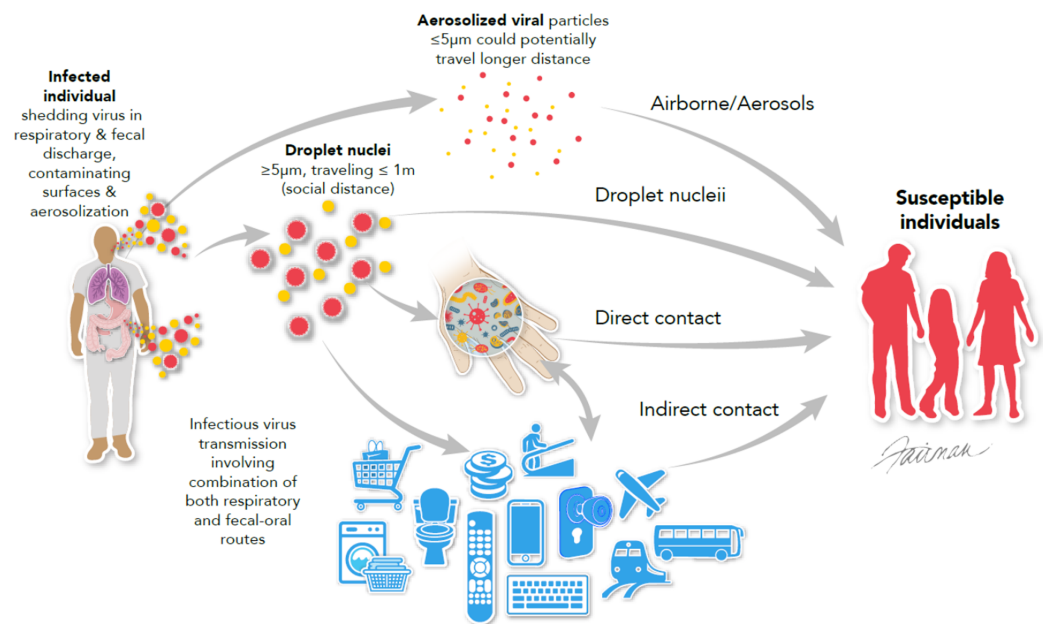


Figure 1 Modes of transmission of viruses, emphasizing multi-system infections such as SARS-CoV, MERS-CoV, and SARS-CoV-2 (modified from *Otter et al. (2016)*). © 2020, Fairman Studios, LLC. CC BY 4.0. Full-size DOI: 10.7717/peerj.9914/fig-1

The animal-to-human and person-to-person transmission of SARS-CoV-2 and associated COVID-19 disease appears to occur in a manner similar to that described for MERS-CoV and SARS-CoV. That is, the transmission of SARS-CoV-2 (*Fig. 1*) primarily involves direct inhalation of large respiratory droplets or inhalation of small airborne droplets (*Morawska et al., 2020; Patel et al., 2020; World Health Organization, 2020d*) leading predominantly to respiratory tract infections. Secondary (indirect) transmission of SARS-CoV-2 may also occur through contamination of HITES by droplets and respiratory aerosols or other patient's bodily fluids (bronchoalveolar fluid, sputum, mucus, blood, lacrimal fluid, semen, urine, or feces) (*Morawska et al., 2020; Patel et al., 2020; World Health Organization, 2020d; Wang et al., 2020*). Evidence of the role for the latter transmission pathway comes from experimental transmission studies in animal models (*Sia et al., 2020*) and by the results of investigations on the contamination of HITES with SARS-CoV-2 RNA in healthcare settings (*Jiang et al., 2020; Ong et al., 2020; Patel et al., 2020; Ye et al., 2020*).

INFECTIVITY AND VIRUS SHEDDING OF EMERGING/RE-EMERGING VIRUSES

The infectivity of a virus refers to its ability to initiate infection of a host cell with production of viral progeny. The infectious dose₅₀ (ID₅₀) is the smallest number of infectious virus particles that will lead to infection of 50% of an exposed population (*Westwood & Sattar, 1974*), and is dependent on a number of factors, such as the species, age, or race of the host, the receptor, immune and nutritional status of the host or host tissues, and the portal of entry of the virus. In the case of most viruses, only a percentage of

those infected actually develop clinical illness (*Haas, Rose & Gerba, 2014*). Those who remain asymptomatic represent subclinical cases of the infection in whom the virus may still replicate and be released into the environment. This has, in fact, been reported to occur in the case of SARS-CoV-2 (*Furukawa, Brooks & Sobel, 2020; Gandhi, Yokoe & Havlir, 2020*). IPAC may be difficult in the face of such silent disseminators (virus carriers/shedders). Exposure to as low as one infectious viral particle has a probability of causing an infection leading to disease, although that probability varies from virus to virus (*Yezli & Otter, 2011*). Typically, infectious doses are empirically derived and reported in units of 50% infective dose (ID_{50}) values that reflect the doses capable of infecting half of the subjects exposed. As prospective studies in humans of highly pathogenic viruses with potentially fatal outcomes (such as SARS-CoV-2) cannot ethically be performed, very limited data exist on the infectivity of the emerging/re-emerging viruses in [Table 1](#). Where studies have been performed using animals, extrapolations of such data to humans must be made with caution.

The estimates that have been reported for viruses listed in [Tables 1 and 2](#) are discussed below, acknowledging the unavoidable variability in literature with regard to such assessments of infectivity. It has been stated that 1–10 infectious aerosolized Ebola virus particles can cause an infection in humans (*Franz et al., 1997; Bibby et al., 2017*). A similar range has been reported for Lassa virus (*Cieslak et al., 2019*). Influenza virus infectivity values specific to the H5N1 and H7N9 strains are not available, but estimates of 100 to 1,000 infectious viral particles have been reported (*Yezli & Otter, 2011; Cieslak et al., 2019*). The human infective dose for SARS-CoV has been estimated at 16–160 plaque-forming units (*Watanabe et al., 2010*). Data on the human infectious doses for MERS-CoV, severe fever with thrombocytopenia syndrome virus (SFTSV), Nipah virus, EV-D68, and SARS-CoV-2 have not been reported. Until such data become available, it should be assumed that these emerging/re-emerging viruses, including SARS-CoV-2, have relatively low ID_{50} values.

Once infected with one of these emerging/re-emerging viruses, during the prodromal period before actual appearance of symptoms, as well as once symptoms appear, the infected individual may become a shedder of infectious particles, as mentioned above. The extent to which virus shedding might lead to dissemination of the associated disease depends upon a number of factors, including the amount of virus released (shed), the infectivity of the virus within the released matrix (droplets/aerosols, fecal/diarrheal discharge, and other excretions, including respiratory secretions), and the survival of the released viruses within such matrices once dried on HITES. Extent of virus shedding, unfortunately, is commonly measured through detection of genomic material (e.g., *Otter et al., 2016; Yezli & Otter, 2011; Hassan et al., 2018; Killerby et al., 2020; Santarpia et al., 2020a, 2020b*), rather than through use of cell-based infectivity assays, so there are only limited data available on infectious SARS-CoV-2 viral shedding (*Francis et al., 2020; Widders, Broom & Broom, 2020; Santarpia et al., 2020a, 2020b*).

As displayed in [Fig. 1](#), transmission of respiratory infections commonly involves the intermediacy of the hand. The same can be said about gastrointestinal infections (i.e., through the fecal-oral route). The coronaviruses SARS-CoV, MERS-CoV, and

SARS-CoV-2 have been reported ([Otter et al., 2016](#); [Zhang et al., 2020](#)) to be shed from patients both within respiratory and gastrointestinal secretions/excretions, therefore contaminated HITES and large and small respiratory droplets/aerosols may potentially play an important role in dissemination of SARS-CoV-2 ([Morawska et al., 2020](#)), in many cases through the intermediacy of hands ([Guo et al., 2020](#)).

VIRAL SURVIVAL ON ENVIRONMENTAL SURFACES AND IN AIR

Knowledge of the transmissibility and infectivity of emerging/re-emerging viruses enables one to assess the risk of spread of a viral disease in the case that infectious virus is shed from an infected individual and is deposited on environmental surfaces/fomites or in droplets/aerosols. Another important factor to consider when assessing risk is the survival (i.e., the continued infectivity) of these viruses on the environmental surfaces/fomites or in air in the form of droplets/aerosols.

There is much more information addressing survival of infectious viruses on environmental surfaces than in aerosols. The data that are available address a number of environmental factors of relevance ([Otter et al., 2016](#)), including the types and porosities of the surfaces, the matrices in which the viruses have been suspended prior to being deposited onto the surfaces, the temperature and relative humidity (RH), and methods used for measuring survival (e.g., \log_{10} reduction in infectivity per unit time, infectivity half-life, infectious titer after a measured duration, etc.). For [Table 3](#), the results that have been displayed focus on room temperature (ambient) conditions at relatively low and medium RH. [Table 3](#) should not, therefore, be considered to represent a comprehensive review of literature for survival of these viruses on surfaces. For a more systematic review of coronavirus survival on environmental surfaces under various conditions, see the reviews by [Otter et al. \(2016\)](#), [Kampf et al. \(2020\)](#), [Ren et al. \(2020\)](#), [Castaño et al. \(2020\)](#), and [Aboubakr, Sharafeldin & Goyal \(2020\)](#). For certain viruses (e.g., SFTSV), survival data are not yet available, so data for surrogate viruses from the same or similar families are shown in [Table 3](#).

Infectious virus survival (persistence) of SARS-CoV-2 on experimentally contaminated prototypic HITES and in air has recently been reported by [Van Doremalen et al. \(2020\)](#) and on surfaces by [Chin et al. \(2020\)](#), [Pastorino et al. \(2020\)](#), [Harbourt et al. \(2020\)](#), and [Kasloff et al. \(2020\)](#). Not all of these data are displayed in [Table 3](#). SARS-CoV-2 was found to remain infectious in aerosols for at least the 3-h period studied by [Van Doremalen et al. \(2020\)](#). The survival half-life estimated based on the limited period of observation of that study was 68 min. In experiments conducted with HCoV-229E over a 6-day observation period, the survival half-life was found to depend on RH and temperature ([Ijaz et al., 1985](#)). At 20 °C, the half-life values observed were 3.3 h (~80% RH), 67 h (50% RH), and 27 h (30% RH). A different pattern of results was obtained at low temperature (6 °C) and high RH (~80~), with the half-life increasing to 86 h, nearly 30 times that found at 20 °C and high RH. The pronounced stabilizing effect of low temperature on the survival of HCoV-229E at high RH indicates that the role of the environment on the survival of coronaviruses in air may be more complex and significant

than previously thought (Ijaz *et al.*, 1985). This likely is the case for SARS-CoV-2 as well. The survival of SARS-CoV-2 on prototypic HITES has been investigated, and survival of the virus has been reported for up to 24 h on cardboard and 2–4 days on plastic and stainless steel surfaces. Survival in the presence of an organic load was generally longer than survival in the absence of such a load (Chin *et al.*, 2020; Van Doremalen *et al.*, 2020; Kasloff *et al.*, 2020; Pastorino *et al.*, 2020; Harbourt *et al.*, 2020).

HIERARCHY OF SUSCEPTIBILITY OF PATHOGENS INCLUDING SARS-COV-2 TO MICROBICIDES

Infectious virus surviving in aerosols/droplets or on HITES represents a source for dissemination of emerging/re-emerging viruses, including SARS-CoV-2. The enveloped viruses listed in Tables 1 and 2 should be relatively susceptible to the virucidal activity of a variety of microbicides, as discussed below. Sattar (2007) previously has advanced the concept of utilizing the known knowledge of the susceptibility of human viral pathogens to chemical disinfecting agents (microbicides) (Klein & Deforest, 1983; McDonnell & Russell, 1999; Ijaz & Rubino, 2008), to predict the efficacy of such agents for inactivating emerging/re-emerging viral pathogens. This concept, referred to as a hierarchy of susceptibility to microbicides, is portrayed in Fig. 2. As shown, infectious agents can be viewed as displaying a continuum of susceptibilities to microbicides, with enveloped viruses at the bottom of this hierarchy, highlighting their relatively high susceptibilities to formulated microbicides (Klein & Deforest, 1983; McDonnell & Russell, 1999; Sattar, 2007; Ijaz & Rubino, 2008).

Among pathogens, prions are considered to be the least sensitive to microbicides, requiring highly caustic solutions for inactivation. Bacterial spores and protozoan cysts/oocysts are next on the microbicidal susceptibility spectrum. Small, non-enveloped viruses are considered to be less susceptible to microbicides, although these viruses display increased susceptibility to high pH, oxidizers such as sodium hypochlorite, activated hydrogen peroxide, alcohols, and a variety of microbicidal actives, relative to spores and protozoan cysts/oocysts. Mycobacteria, fungi, vegetative bacteria, and enveloped viruses appear to be more susceptible to certain formulated microbicides, such as alcohols, oxidizers, quaternary ammonium compounds (QAC), and phenolics (e.g., *p*-chloro-*m*-xylenol (PCMX)) (Klein & Deforest, 1983; Sattar *et al.*, 1989; McDonnell & Russell, 1999; Rabenau *et al.*, 2005; Sattar, 2007; Ijaz & Rubino, 2008; Geller, Varbanov & Duval, 2012; Maillard, Sattar & Pinto, 2013; Cook *et al.*, 2015, 2016; Cutts *et al.*, 2018, 2019, 2020; Rutala *et al.*, 2019; Weber *et al.*, 2019; Chin *et al.*, 2020; Kampf *et al.*, 2020; O'Donnell *et al.*, 2020; Senghore *et al.*, 2020; Vaughan *et al.*, 2020; Yu *et al.*, 2020). A number of commercially available formulated microbicides (antiseptic liquid, hand sanitizers, liquid hand wash, bar soap, surface cleanser, disinfectant wipe, and disinfectant spray) have been evaluated for virucidal efficacy against SARS-CoV-2 (Ijaz *et al.*, 2020), and as expected, were found to cause complete inactivation ($3.0\text{--}4.7 \log_{10}$) within the 1–5 min contact times tested.

It is of interest that the enveloped viruses are considered to be the most susceptible to a variety of formulated microbicidal actives, even more so than fungi and vegetative bacteria,

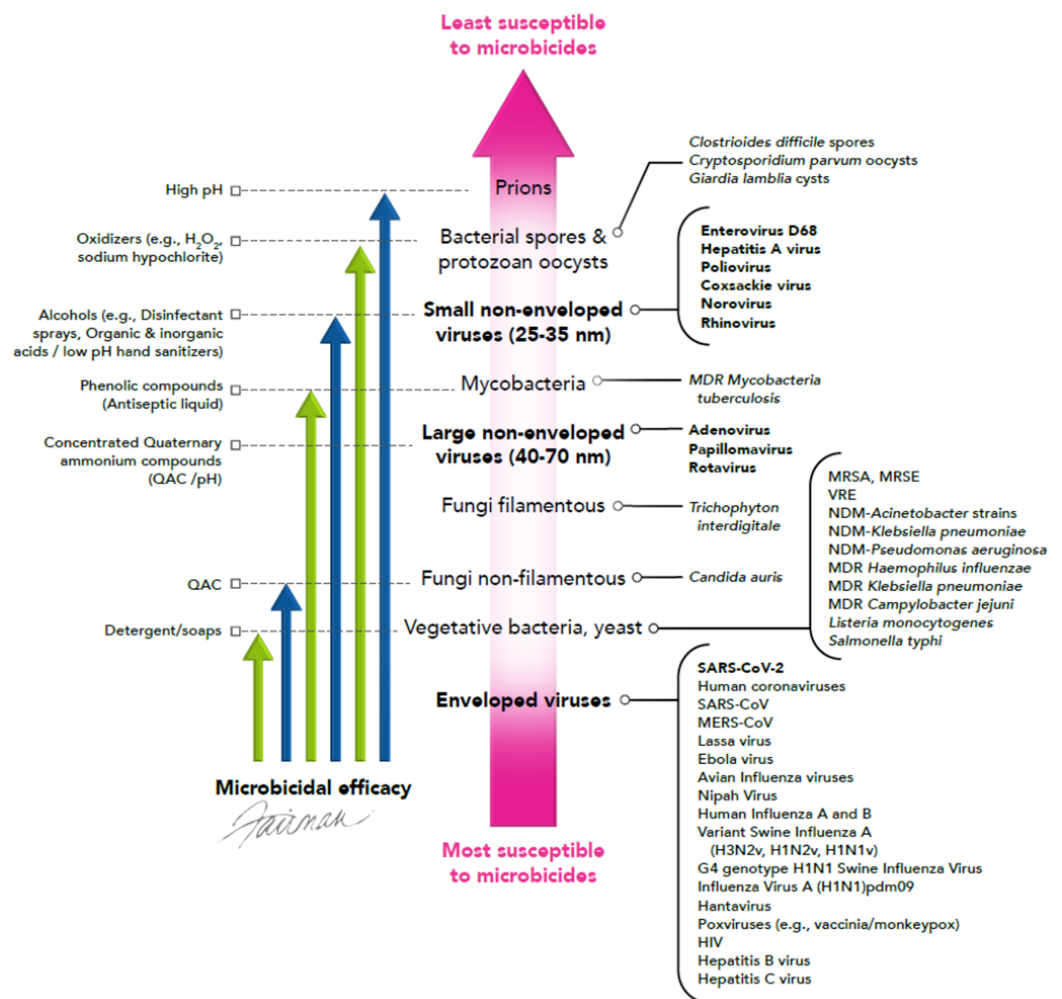


Figure 2 Hierarchy of susceptibility of pathogens to formulated microbicidal actives (adapted from Sattar (2007)). © 2020, Fairman Studios, LLC. CC BY 4.0. Full-size [DOI: 10.7717/peerj.9914/fig-2](https://doi.org/10.7717/peerj.9914/fig-2)

yeast, and mycobacteria (Fig. 2). Viral envelopes are typically derived from the host cell and are, therefore, comprised of host cell phospholipids and proteins (Fig. 3), as well as some virally inserted glycoproteins. Coronaviruses are known to obtain their lipid envelopes from the host cell endoplasmic reticulum Golgi intermediate compartment, after which the particles are transported by exocytosis via cargo vesicles (reviewed in O'Donnell et al. (2020)). The composition of the coronavirus lipid envelope, therefore, is determined by the lipid composition of the host cell endoplasmic reticulum. Since the envelopes contain lipid material, they are readily destroyed by phenolics such as PCMX, oxidizing agents such as sodium hypochlorite and activated hydrogen peroxide, QAC, alcohols, and detergents. Even mild detergents, such as soap, may inactivate enveloped viruses by denaturing the lipoproteins in the envelope. These include the SARS-CoV-2 spike proteins that interact with the human angiotensin-converting enzyme 2 receptor as a requisite event in initiating viral infection (Letko, Marzi & Munster, 2020). This makes enveloped viruses more susceptible to most of the formulated virucidal microbicides commonly used for IPAC.

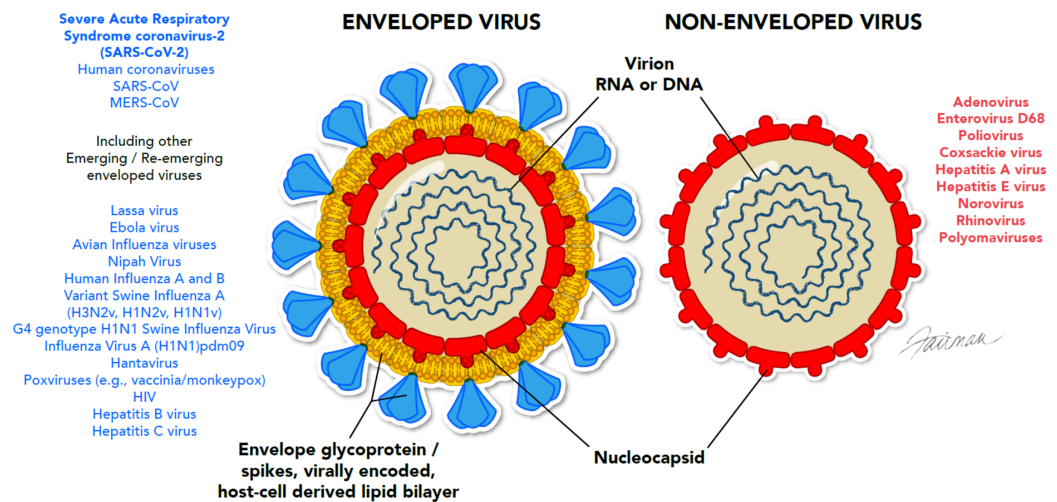


Figure 3 Ultrastructural differences between enveloped and non-enveloped viruses. Conformationally, these viral genomes may be single-or double-stranded, and segmented or non-segmented (examples are not shown in the figure). © 2020, Fairman Studios, LLC. CC BY 4.0.

Full-size DOI: 10.7717/peerj.9914/fig-3

It can be assumed as a starting point, therefore, that the enveloped emerging/re-emerging viruses listed in [Table 1](#) should be readily inactivated by a variety of formulated microbicidal actives. This assumption has, in fact, been verified by extensive empirical data ([Klein & Deforest, 1983](#); [Sattar et al., 1989](#); [McDonnell & Russell, 1999](#); [Rabenau et al., 2005](#); [Sattar, 2007](#); [Ijaz & Rubino, 2008](#); [Geller, Varbanov & Duval, 2012](#); [Cook et al., 2015, 2016](#); [Cutts et al., 2018, 2019, 2020](#); [Weber et al., 2019](#); [Chin et al., 2020](#); [Ijaz et al., 2020](#); [Kampf et al., 2020](#); [O'Donnell et al., 2020](#); [Vaughan et al., 2020](#); [Yu et al., 2020](#); [Castaño et al., 2020](#)), and has been embraced by the U.S. Environmental Protection Agency ([United States Environmental Protection Agency, 2016](#)). The data for various members of the *Coronaviridae* family, reviewed recently by [Kampf et al. \(2020\)](#), [Cimolai \(2020\)](#), and [Golin, Choi & Ghahary \(2020\)](#) support the expectation that SARS-CoV-2 and other coronaviruses of concern (e.g., MERS-CoV, SARS-CoV, mouse hepatitis virus, porcine epidemic diarrhea virus, etc.) should be readily inactivated by commonly employed and commercially available formulated microbicides, including QAC. Virucidal efficacy testing results for SARS-CoV-2 reported by [Ijaz et al. \(2020\)](#) also confirm the expectation of susceptibility of this coronavirus to a variety of microbicidal actives. In addition, a recently issued European guidance document ([European Centre for Disease Prevention & Control, 2020](#)) lists a variety of microbicidal agents that have demonstrated efficacy against a variety of human and animal coronaviruses and that, therefore, could be applied for decontamination of surfaces in non-healthcare facilities.

Aqueous solutions of the phenolic PCMX at concentrations of 0.12–0.48% by weight were shown to inactivate $>4 \log_{10}$ of infectious Ebola virus–Makona variant (EBOV/Mak) suspended in an organic load and evaluated in liquid virucidal efficacy studies ([Cutts et al., 2018; 2019](#)) or dried on a steel surface (a prototypic HITES) in a hard surface carrier virucidal efficacy study ([Cutts et al., 2018](#)). In each case, complete inactivation of $\geq 6.8 \log_{10}$

of EBOV/Mak was observed after contact times ≥ 5 min. In addition, EBOV/Mak dried on prototypic steel carriers was completely inactivated ($\geq 6.5 \log_{10}$) by aqueous solutions of 70% ethanol or 0.5% or 1% NaOCl ($\geq 0.5\%$) after contact times ≥ 2.5 min (Cook *et al.*, 2015). Disinfectant pre-soaked wipes containing, as active ingredients, either activated hydrogen peroxide or a QAC were found to have virucidal efficacy ($>5 \log_{10}$) for EBOV/Mak and vesicular stomatitis virus following as little as 5 s contact time (Cutts *et al.*, 2020).

Microbicidal formulations based on oxidizing agents, QAC, alcohols, phenolics, and aldehydes displaying virucidal efficacy for enveloped viruses and relatively less susceptible non-enveloped viruses (such as human norovirus surrogates) have been recommended for decontaminating environmental surfaces or materials used for food preparation (Zonta *et al.*, 2016; Scott, Bruning & Ijaz, 2020). The efficacy of ethanol and QAC actives for inactivating the norovirus surrogate feline calicivirus depends on how the microbicides are formulated. Factors, such as the addition of an alkaline agent, were found to increase their efficacy (Whitehead & McCue, 2010). Microbicides satisfying these requirements can be regarded as effective against emerging/re-emerging viruses, such as SARS-CoV-2. Following this logic, the U.S. EPA has invoked an Emerging Viral Pathogen Policy in the past for pandemic influenza, for the Ebola virus, and most recently, for SARS-CoV-2 (United States Environmental Protection Agency, 2020).

In the case of highly pathogenic emerging/re-emerging viruses, such as SARS-CoV-2, effective and frequent targeted hygiene using appropriate microbicides is essential for prevention of infectious virus dissemination. Practicing hygiene inappropriately and only once daily may not be sufficient, as recontamination of HITES could potentially occur, particularly under healthcare settings where SARS-CoV-2 infected patients are treated. For instance, infectious coronavirus 229E was detected on HITES (e.g., door knobs) in a university classroom in which samples were collected daily over a 1-week period (Bonny, Yezli & Lednicky, 2018). Vigilant decontamination of HITES becomes of paramount importance in high risk areas, such as intensive care units (Zhang, 2020). This is especially true when dealing with highly pathogenic viruses with relatively low human infectious doses, as is the case with many of the emerging/re-emerging viruses, and likely including SARS-CoV-2, being discussed in this review.

The enveloped emerging/re-emerging viruses listed in Table 1 display high susceptibility to inactivation by ultraviolet light at 254 nm, an inactivation approach amenable to inactivation of aerosolized viruses (Ijaz *et al.*, 2016). For instance, empirical data (Lytle & Sagripanti, 2005) for Lassa virus, Hantavirus, and Ebola virus, and for the virus families *Coronaviridae*, *Orthomyxoviridae*, *Paramyxoviridae*, *Phenuiviridae*, indicate that UV fluencies of 3–14 mJ/cm^2 should inactivate 4 \log_{10} of the enveloped viruses in Table 1. The susceptibility of coronaviruses, including HCoV-229E, SARS-CoV, and MERS-CoV, to UV irradiation has been reviewed recently (Heßling *et al.*, 2020). Characterization of the UV-C susceptibility of SARS-CoV-2 has also been evaluated (Bianco *et al.*, 2020). In that study, a fluency of 3.7 mJ/cm^2 resulted in 3 \log_{10} inactivation. These fluency values are relatively low, compared to those needed to inactivate 4 \log_{10} of the least UV-susceptible viruses, such as those of the *Adenoviridae* (98–222 mJ/cm^2) and *Polyomaviridae* (235–364 mJ/cm^2) families of non-enveloped viruses (Nims & Plavsic, 2014).

PERSONAL HYGIENE PRACTICES FOR PREVENTING INFECTIOUS VIRUS ACQUISITION

The WHO has posted a webpage entitled “Coronavirus Disease (COVID-19) advice for the public” (*World Health Organization, 2020b*). Basic protective measures against SARS-CoV-2 recommended by the WHO include: frequent hand washing with soap and water or an alcohol-based rub and maintenance of social distancing (at least 1 m; see *Fig. 1*), especially in the presence of people who are coughing, sneezing, or have a fever (*World Health Organization, 2020b*). The latter recommendation is applicable to any of the viruses listed in *Table 2*, for which transmission by respiratory aerosols/droplets is expected. Avoidance of touching eyes, nose, mouth, or other mucous membranes with hands after contact with HITES is also recommended (*World Health Organization, 2020b*). As displayed in *Fig. 1*, the hands play an important role in transfer of infectious virus from contaminated HITES to a susceptible mucous membrane, enabling virus-host interactions initiating infection. Following the appropriate hygiene practices described above can potentially help in prevention and control of emerging and re-emerging viruses, including the currently circulating SARS-CoV-2.

The U.S. CDC has posted a webpage entitled “Coronavirus 2019 (COVID-19) How to protect yourself and others” (*United States Centers for Disease Control & Prevention, 2020*). This includes a brief description of the primary modes of transmission of the virus, advice on handwashing (especially situations after which hand washing should be done), advice on social distancing, admonitions on use of face coverings, targeted hygiene of frequently touched surfaces (HITES), and self-monitoring of health.

While handwashing practices practically can be applied in developed countries, there are still some three billion people in developing countries without access to basic handwashing facilities in the home and where proper hand hygiene may not be practiced in the majority of healthcare facilities (*Mushi & Shao, 2020*). Basic IPAC practices, such as those mentioned by the WHO and by the U.S. CDC, are applicable not only to the current SARS-CoV-2 pandemic, but also to any emerging outbreaks involving enveloped viruses, which are highly susceptible to hand washing using soap and water and alcohol-based hand rubs and to surface hygiene using commonly employed household disinfectants.

DISCUSSION

As Dr. Anthony Fauci eloquently stated in 2005 (*Fauci, 2005*), “Public health officials once suggested that it might someday be possible to ‘close the book’ on the study and treatment of infectious diseases. However, it is now clear that endemic diseases as well as newly emerging ones (e.g., West Nile virus), and even deliberately disseminated infectious diseases (e.g., anthrax from bioterrorism) continue to pose a substantial threat throughout the world.” Recent experience certainly verifies these predictions. *Weber et al. (2019)* have correctly emphasized that “Preventing disease acquisition via person-to-person transmission or contact with the contaminated environment depends on rapid and appropriate institution of isolation precautions, appropriate hand hygiene, and

appropriate disinfection of medical equipment, devices, and the surface environment. Importantly, once the nature of the emerging disease is known (i.e., enveloped virus, bacteria, fungi, nonenveloped virus, mycobacteria), it is possible to determine the proper antiseptics and disinfectants, even in the absence of studies of the exact infectious agent. For example, an enveloped virus (e.g., Ebola, MERS-CoV) or vegetative bacterium (e.g., CRE) would be inactivated by any agent against nonenveloped viruses or mycobacteria.” (*Weber et al., 2019*).

It is fortunate that so many of the emerging/re-emerging viruses (examples listed in [Table 1](#) and below) are enveloped viruses. It is not clear why there are not more small, non-enveloped viruses mentioned in the WHO list of viral diseases of concern (*World Health Organization, 2015*). The small non-enveloped viruses are much less susceptible to commonly employed cleaning agents (antiseptics, detergents, microbicidal actives) and, in general, display relatively longer survival on environmental surfaces. According to theoretical modeling of sustained person-to-person transmissibility (*Geoghegan et al., 2016; Walker et al., 2018; Munster et al., 2020*), small non-enveloped viruses are predicted to be more likely to lead to sustained infections within the community. The reality is that the emerging/re-emerging viruses of concern, both in humans and in economically important animals, have more typically included enveloped viruses. Recent examples include porcine epidemic diarrhea virus, MERS-CoV, SARS-CoV and SARS-CoV-2 (*Coronaviridae*), African swine fever virus (*Asfarviridae*), Schmallenberg virus (*Peribunyaviridae*), Crimean-Congo hemorrhagic fever virus (*Nairoviridae*), Rift Valley fever virus (*Phenuiviridae*), West Nile virus and Zika virus (*Flaviviridae*), Hantaviruses (*Hantaviridae*), and Lassa viruses (*Arenaviridae*).

The fact that the emerging/re-emerging viruses are predominantly RNA viruses might be explained in part by the notion (*Jaijyan et al., 2018*) that RNA viruses can more readily adapt to the rapidly changing global and local environment due to the high error rate of the polymerases that replicate their genomes. The RNA viruses are thought, therefore, to display higher evolution rates through mutation, genomic reassortment, or recombination.

In our review of articles pertaining to SARS-CoV-2 IPAC, we have identified several knowledge gaps. These include the fact that contamination of surfaces in the vicinity of COVID-19 patients (i.e., contamination hot-spots) has primarily been described on the basis of measurement of SARS-CoV-2 RNA, and not on the basis of recovery of infectious virus using cell-based assays. The measurement of RNA does not inform as to the infection potential of the surface contamination. Similarly, articles describing the contamination of waste-water streams by SARS-CoV-2 have been based on measurement of viral RNA, not infectious virus. As a result, it is not presently known whether infectious virus is present in such waste streams and, therefore, whether the finding of viral RNA in waste water represents real risk in terms of onward dissemination of the virus. Another knowledge gap, that has already been mentioned above, is the true mortality rates for the various emerging/re-emerging viruses addressed in this review. As these viral infections are relatively deadly, empirical data on true mortality rates are lacking. For the same reason, accurate data on human MID are not generally available for these viruses. The risk of acquiring an infection of one of these viruses from a contaminated environmental

surface, over a period of time following an initial contamination event, will remain difficult to assess until such knowledge gaps have been resolved.

CONCLUSIONS

The likelihood of experiencing future emergent zoonotic viruses is high (*Morens & Fauci, 2013; Paules, Marston & Fauci, 2020*), and defining in advance appropriate approaches for limiting the spread of such viruses through IPAC is essential. We now have the sequencing tools necessary for rapidly identifying a novel virus such as SARS-CoV-2, the genetic sequence of which was determined within just over 1 week (*Zhu et al., 2020*). Provided that a novel emerging virus is found to be a member of a lipid-enveloped viral family, it should be possible to leverage IPAC experience for other enveloped viruses of concern, and thereby make predictions as to risk of viral transmission, virus survival on surfaces, and microbicidal efficacy for the virus and risk mitigation. SARS-CoV-2 is no exception in this regard.

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Author Contributions

- M. Khalid Ijaz conceived the review approach, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Syed A. Sattar analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.

- Joseph R. Rubino analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Raymond W. Nims conceived the review approach, review, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Charles P. Gerba analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.

Data Availability

The following information was supplied regarding data availability:

This is a literature review article. No new data were generated.

REFERENCES

- Aboubakr HA, Sharafeldin TA, Goyal SM. 2020.** Stability of SARS-CoV-2 and other coronaviruses in the environment and on common touch surfaces and the influence of climatic conditions: a review. *Transboundary and Emerging Diseases* **133(1510):6** DOI [10.1111/tbed.13707](https://doi.org/10.1111/tbed.13707).
- Ang BSP, Lim TCC, Wang L. 2018.** Nipah virus infection. *Journal of Clinical Microbiology* **56(6):e01875-17** DOI [10.1128/JCM.01875-17](https://doi.org/10.1128/JCM.01875-17).
- AABB. 2013.** Middle East Respiratory Syndrome Coronavirus. Available at <https://www.aabb.org/tm/eid/Documents/middle-east-respiratory-syndrome-coronavirus.pdf>.
- Bailey ES, Fieldhouse JK, Choi JY, Gray GC. 2018.** A mini review of the zoonotic threat potential of influenza viruses, coronaviruses, adenoviruses, and enteroviruses. *Frontiers in Public Health* **6:104** DOI [10.3389/fpubh.2018.00104](https://doi.org/10.3389/fpubh.2018.00104).
- Bianco A, Biasin M, Pareschi G, Cavaliere A, Cavatorta C, Fenizia C, Galli P, Lessio L, Lualdi M, Redaelli E, Saulle I, Trabattoni D, Zanutta A, Clerici M. 2020.** UV-C irradiation is highly effective in inactivating and inhibiting SARS-CoV-2 replication. *MedRxiv* DOI [10.1101/2020.06.05.20123463](https://doi.org/10.1101/2020.06.05.20123463).
- Bibby K, Fischer RJ, Casson LW, De Carvalho NA, Haas CN, Munster VJ. 2017.** Disinfection of Ebola virus in sterilized municipal wastewater. *PLOS Neglected Tropical Diseases* **11(2):e0005299** DOI [10.1371/journal.pntd.0005299](https://doi.org/10.1371/journal.pntd.0005299).
- Bonny TS, Yezli S, Lednicky JA. 2018.** Isolation and identification of human coronavirus 229E from frequently touched environmental surfaces of a university classroom that is cleaned daily. *American Journal of Infection Control* **46(1):105-107** DOI [10.1016/j.ajic.2017.07.014](https://doi.org/10.1016/j.ajic.2017.07.014).
- Brocato RL, Hooper JW. 2019.** Progress on the prevention and treatment of hantavirus disease. *Viruses* **11(7):610** DOI [10.3390/v11070610](https://doi.org/10.3390/v11070610).
- Cassidy H, Poelman R, Knoester M, Van Leer-Buter CC, Niesters HGM. 2018.** Enterovirus D68: the new polio? *Frontiers in Microbiology* **9:2677** DOI [10.3389/fmicb.2018.02677](https://doi.org/10.3389/fmicb.2018.02677).
- Castaño N, Cordts S, Jalil MK, Zhang K, Koppaka S, Bick A, Paul R, Tang SKY. 2020.** Fomite transmission and disinfection strategies for SARS-CoV-2 and related viruses. Available at <https://arxiv.org/abs/2005.11443>.
- Chan KH, Malik Peiris JS, Lam SY, Poon LLM, Yuen KY, Seto WH. 2011.** The effects of temperature and relative humidity on the viability of the SARS coronavirus. *Advances in Virology* **734690(7):1-7** DOI [10.1155/2011/734690](https://doi.org/10.1155/2011/734690).

- Chin AWH, Chu JTS, Perera MRA, Hui KPY, Yen H-L, Chan MCW, Peiris M, Poon JJM. 2020.** Stability of SARS-CoV-2 in different environmental conditions. *Lancet Microbe* **1(1)**:e10 DOI [10.1016/S2666-5247\(20\)30003-3](https://doi.org/10.1016/S2666-5247(20)30003-3).
- Cieslak TJ, Herstein JJ, Kortepeter MG, Hewlett AL. 2019.** A methodology for determining which diseases warrant care in a high-level containment care unit. *Viruses* **11(9)**:773 DOI [10.3390/v11090773](https://doi.org/10.3390/v11090773).
- Cimolai N. 2020.** Environmental and decontamination issues for human coronaviruses and their potential surrogates. *Journal of Medical Virology* **1–13(6)**:1655 DOI [10.1002/jmv.26170](https://doi.org/10.1002/jmv.26170).
- Cook BWM, Cutts TA, Nikiforuk AM, Leung A, Kobasa D, Theriault SS. 2016.** The disinfection characteristics of Ebola virus outbreak variants. *Scientific Reports* **6(1)**:38293 DOI [10.1038/srep38293](https://doi.org/10.1038/srep38293).
- Cook BWM, Cutts TA, Nikiforuk AM, Poliquin PG, Court DA, Strong JE, Theriault SS. 2015.** Evaluating environmental persistence and disinfection of Ebola virus Makona variant. *Viruses* **7(4)**:1975–1986 DOI [10.3390/v7041975](https://doi.org/10.3390/v7041975).
- Cutts TA, Ijaz MK, Nims RW, Rubino JR, Theriault SS. 2018.** Efficacy of dettol antiseptic liquid for inactivation of Ebola-Makona virus suspended in an organic load—a targeted hygiene intervention for reducing virus spread. In: *International Conference on Emerging Infectious Diseases (ICEID 2018)*, Atlanta Georgia, USA.
- Cutts TA, Ijaz MK, Nims RW, Rubino JR, Theriault SS. 2019.** Effectiveness of dettol antiseptic liquid for inactivation of Ebola virus in suspension. *Scientific Reports* **9(1)**:6590 DOI [10.1038/s41598-019-42386-5](https://doi.org/10.1038/s41598-019-42386-5).
- Cutts TA, Robertson C, Theriault SS, Nims RW, Kasloff SB, Rubino JR, Ijaz MK. 2020.** Assessing the contributions of inactivation, removal, and transfer of Ebola virus and vesicular stomatitis virus by disinfectant pre-soaked wipes. *Frontiers in Public Health* **8**:183 DOI [10.3389/fpubh.2020.00183](https://doi.org/10.3389/fpubh.2020.00183).
- European Centre for Disease Prevention and Control. 2020.** Interim guidance for environmental cleaning in non-healthcare facilities exposed to SARS-CoV-2. Available at <https://www.ecdc.europa.eu/en/publications-data/interim-guidance-environmental-cleaning-non-healthcare-facilities-exposed-2019>.
- Fauci AS. 2005.** Emerging and reemerging infectious diseases: the perpetual challenge. *Academic Medicine* **80(12)**:1079–1085 DOI [10.1097/00001888-200512000-00002](https://doi.org/10.1097/00001888-200512000-00002).
- Fieldhouse JK, Wang X, Mallinson KA, Tsao RW, Gray GC. 2018.** A systematic review of evidence that enteroviruses may be zoonotic. *Emerging Microbes & Infections* **7(1)**:164 DOI [10.1038/s41426-018-0159-1](https://doi.org/10.1038/s41426-018-0159-1).
- Fischer R, Judson S, Miazgowicz K, Bushmaker T, Prescott J, Munster VJ. 2015.** Ebola virus stability on surfaces and in fluids in simulated outbreak environments. *Emerging Infectious Diseases* **21(7)**:1243–1246 DOI [10.3201/eid2107.150253](https://doi.org/10.3201/eid2107.150253).
- Francis R, Le Bideau M, Jardot P, Grimaldier C, Raoult D, Bou Kalil JY, la Scola B. 2020.** High speed large scale automated isolation of SARS-CoV-2 from clinical samples using miniaturized co-culture with high content screening. *BioRxiv* **30**:313 DOI [10.1101/2020.05.14.097295](https://doi.org/10.1101/2020.05.14.097295).
- Franz DR, Jahrling PB, Friedlander AM, McClain DJ, Hoover DL, Bryne WR, Pavlin JA, Christopher GW, Eitzen EM Jr. 1997.** Clinical recognition and management of patients exposed to biological warfare agents. *Journal of the American Medical Association* **278(5)**:399–411 DOI [10.1001/jama.1997.03550050061035](https://doi.org/10.1001/jama.1997.03550050061035).
- Furukawa NW, Brooks JT, Sobel J. 2020.** Evidence supporting transmission of severe acute respiratory syndrome coronavirus 2 while presymptomatic or asymptomatic. *Emerging Infectious Diseases* **26(7)**:jiaa119 DOI [10.3201/eid2607.201595](https://doi.org/10.3201/eid2607.201595).

- Gandhi M, Yokoe DS, Havlir DV. 2020.** Asymptomatic transmission, the Achilles' heel of current strategies to control COVID-19. *New England Journal of Medicine* **382(22)**:2158–2160 DOI [10.1056/NEJMe2009758](https://doi.org/10.1056/NEJMe2009758).
- Geoghegan JL, Senior AM, Di Giallonardo F, Holmes EC. 2016.** Virological factors that increase transmissibility of emerging human viruses. *Proceedings of the National Academy of Sciences* **113(15)**:4170–4175 DOI [10.1073/pnas.1521582113](https://doi.org/10.1073/pnas.1521582113).
- Geller C, Varbanov M, Duval RE. 2012.** Human coronaviruses: insights into environmental resistance and its influence on the development of new antiseptic strategies. *Viruses* **4(11)**:3044–3068 DOI [10.3390/v4113044](https://doi.org/10.3390/v4113044).
- Golin AP, Choi D, Ghahary A. 2020.** Hand sanitizers: a review of ingredients, mechanisms of action, modes of delivery, and efficacy against coronaviruses. *American Journal of Infection Control* (in press) DOI [10.1016/j.ajic.2020.06.182](https://doi.org/10.1016/j.ajic.2020.06.182).
- Gorbalenya AE, Baker SC, Baric RS, De Groot RJ, Drosten C, Gulyaeva AA, Haagmans BJ, Lauber C, Leontovich AM, Neuman BW, Penzar D, Perlman S, Poon LLM, Samborskiy DV, Sidorov IA, Sola I, Ziebuhr J. 2020.** The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. *Nature Microbiology* **5(4)**:536–544 DOI [10.1038/s41564-020-0695-z](https://doi.org/10.1038/s41564-020-0695-z).
- Guo Z-D, Wang Z-Y, Zhang S-F, Li X, Li L, Li C, Cui Y, Fu R-B, Dong Y-Z, Chi X-Y, Zhang M-Y, Liu K, Cao C, Liu B, Zhang K, Gao Y-W, Lu B, Chen W. 2020.** Aerosol and surface distribution of severe acute respiratory syndrome coronavirus 2 in hospital wards, Wuhan, China, 2020. *Emerging Infectious Diseases* **26(7)**:1583–1591 DOI [10.3201/eid2607.200885](https://doi.org/10.3201/eid2607.200885).
- Haas CN, Rose JB, Gerba CP. 2014.** *Quantitative microbial risk assessment*. New York: John Wiley.
- Harbourt DE, Haddow AD, Piper AE, Bloomfield H, Kearney BJ, Fetterer D, Gibson K, Minogue T. 2020.** Modeling the stability of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on skin, currency, and clothing. *MedRxiv* DOI [10.1101/2020.07.01.20144253](https://doi.org/10.1101/2020.07.01.20144253).
- Hardestam J, Simon M, Hedlund KO, Vaheri A, Klingström J, Lundkvist Å. 2007.** Ex vivo stability of the rodent-borne Hantaan virus in comparison to that of arthropod-borne members of the *Bunyaviridae* family. *Applied and Environmental Microbiology* **73(8)**:2547–2551 DOI [10.1128/AEM.02869-06](https://doi.org/10.1128/AEM.02869-06).
- Hassan MZ, Sazzad HMS, Luby SP, Sturm-Ramirez K, Bhuiyan MU, Rahman MZ, Islam MM, Ströher U, Sultana S, Kafi MAH, Daszak P, Rahman M, Gurley ES. 2018.** Nipah virus contamination of hospital surfaces during outbreaks, Bangladesh, 2013–2014. *Emerging Infectious Diseases* **24(1)**:15–21 DOI [10.3201/eid2401.161758](https://doi.org/10.3201/eid2401.161758).
- Heßling M, Hönes K, Vatter P, Lingenfelder C. 2020.** Ultraviolet irradiation doses for coronavirus inactivation: review and analysis of coronavirus photoinactivation studies. *GMS Hygiene and Infection Control* **15**:Doc08 DOI [10.3205/dgkh000343](https://doi.org/10.3205/dgkh000343).
- Ijaz MK, Brunner AH, Sattar SA, Nair RC, Johnson-Lussenburg CM. 1985.** Survival characteristics of airborne human coronavirus. *Journal of General Virology* **66(12)**:2743–2748 DOI [10.1099/0022-1317-66-12-2743](https://doi.org/10.1099/0022-1317-66-12-2743).
- Ijaz MK, Rubino JR. 2008.** Should test methods for disinfectants use vertebrate virus dried on carriers to advance virucidal claims? *Infection Control Hospital Epidemiology* **29(2)**:192–194 DOI [10.1086/526441](https://doi.org/10.1086/526441).
- Ijaz MK, Whitehead K, Srinivasan V, McKinney J, Rubino JR, Ripley M, Jones C, Nims RW, Charlesworth B. 2020.** Microbicidal actives with virucidal efficacy against SARS-CoV-2. *American Journal of Infection Control* **48(8)**:972–973 DOI [10.1016/j.ajic.2020.05.015](https://doi.org/10.1016/j.ajic.2020.05.015).

- Ijaz MK, Zargar B, Wright K, Rubino JR, Sattar SA. 2016. Generic aspects of the airborne spread of human pathogens indoors and emerging air decontamination technologies. *American Journal of Infection Control* 44(9):S109–S120 DOI 10.1016/j.ajic.2016.06.008.
- Jaijyan DK, Liu J, Hai R, Zhu H. 2018. Emerging and reemerging human viral diseases. *Annals of Microbiology Research* 2(1):31–44.
- Jiang F-C, Jiang X-L, Wang Z-G, Meng Z-H, Shao S-F, Anderson BD, Ma N-J. 2020. Detection of severe acute respiratory syndrome coronavirus 2 RNA on surfaces in quarantine rooms. *Emerging Infectious Diseases* 26(9):2162–2164 DOI 10.3201/eid2609.201435.
- Jiang H, Du H, Wang LM, Wang PZ, Bai XF. 2016. Hemorrhagic fever with renal syndrome: pathogenesis and clinical picture. *Frontiers in Cellular and Infection Microbiology* 6:1 DOI 10.3389/fcimb.2016.00001.
- Kampf G, Todt D, Pfaender S, Steinmann E. 2020. Persistence of coronaviruses on inanimate surfaces and its inactivation with biocidal agents. *Journal of Hospital Infection* 104(3):246–251 DOI 10.1016/j.jhin.2020.01.022.
- Kasloff SB, Strong JE, Funk D, Cutts TA. 2020. Stability of SARS-CoV-2 on critical personal protective equipment. *MedRxiv* DOI 10.1101/2020.06.11.20128884.
- Killerby ME, Biggs HM, Midgley CM, Gerber SI, Watson JT. 2020. Middle East respiratory syndrome coronavirus transmission. *Emerging Infectious Diseases* 26(2):191–198 DOI 10.3201/eid2602.190697.
- Klein M, Deforest A. 1983. Principles of viral inactivation. In: Block SS, ed. *Disinfection, Sterilization, and Preservation*. Third Edition. Philadelphia: Lea and Febiger, 422–434.
- Krüger DH, Schönrich G, Klempa B. 2011. Human pathogenic hantaviruses and prevention of infection. *Human Vaccines* 7(6):685–693 DOI 10.4161/hv.7.6.15197.
- Laenen L, Vergote V, Calisher CH, Klempa B, Klingström J, Kuhn JH, Maes P. 2019. *Hantaviridae*: current classification and future perspectives. *Viruses* 11(9):788 DOI 10.3390/v11090788.
- Letko M, Marzi A, Munster V. 2020. Functional assessment of cell entry and receptor usage for SARS-CoV-2 and other lineage B betacoronaviruses. *Nature Microbiology* 5(4):562–569 DOI 10.1038/s41564-020-0688-y.
- Li W, Shi Z, Yu M, Ren W, Smith C, Epstein JH, Wang H, Crameri G, Hu Z, Zhang H, Zhang J, McEachern J, Field H, Daszak P, Eaton BT, Zhang S, Wang L-F. 2020. Bats are natural reservoirs of SARS-like coronaviruses. *Science* 310(5748):676–679 DOI 10.1126/science.1118391.
- Lytle CD, Sagripanti J-L. 2005. Predicted inactivation of viruses of relevance to biodefense by solar radiation. *Journal of Virology* 79(22):14244–14252 DOI 10.1128/JVI.79.22.14244-14252.2005.
- Maillard J-Y, Sattar SA, Pinto F. 2013. Virucidal activity of microbicides. In: Fraiese AP, Maillard J-Y, Sattar A, eds. *Russell, Hugo & Ayliffe's: Principles and Practice of Disinfection, Preservation and Sterilization*. Fifth Edition. Hoboken: Blackwell Publishing Ltd.
- McDonnell G, Russell AD. 1999. Antiseptics and disinfectants: activity, action, and resistance. *Clinical Microbiology Reviews* 12(1):147–179 DOI 10.1128/CMR.12.1.147.
- Morawska L, Tang JW, Bahnfleth W, Bluysen PM, Boerstra A, Buonanno G, Cao J, Dancer S, Floto A, Franchimon F, Haworth C, Hoegling J, Isaxon C, Jimenez JL, Kurnitski J, Li Y, Loomans M, Marks G, Marr LC, Mazzarella L, Melikov AK, Miller S, Milton DK, Nazaroff W, Nielsen PV, Noakes C, Peccia J, Querol X, Sekhar C, Seppänen O, Tanabe S, Tellier R, Tham KW, Wargocki P, Wierzbicka A, Yao M. 2020. How can airborne transmission of COVID-19 indoors be minimized? *Environment International* 142:105832 DOI 10.1016/j.envint.2020.105832.

- Morens DM, Fauci AS. 2013.** Emerging infectious diseases: threats to human health and global stability. *PLoS Pathogens* **9**(7):e1003467 DOI [10.1371/journal.ppat.1003467](https://doi.org/10.1371/journal.ppat.1003467).
- Munster VJ, Koopmans M, Van Doremalen N, Van Riel D, De Witt E. 2020.** A novel coronavirus emerging in China: key questions for impact assessment. *New England Journal of Medicine* **382**(8):692–694 DOI [10.1056/NEJMp2000929](https://doi.org/10.1056/NEJMp2000929).
- Mushi V, Shao M. 2020.** Tailoring of the ongoing water, sanitization and hygiene interventions for prevention and control of COVID-19. *Tropical Medicine and Health* **48**(1):47 DOI [10.1186/s41182-020-00236-5](https://doi.org/10.1186/s41182-020-00236-5).
- Nims R, Plavsic M. 2014.** Identification of worst-case model viruses for selected viral clearance steps. *Bioprocessing Journal* **13**(2):6–13 DOI [10.12665/J132.Nims](https://doi.org/10.12665/J132.Nims).
- Nolte KB, Feddersen RM, Foucar K, Zaki SR, Koster FT, Madar D, Merlin TL, McFeeley PJ, Umland ET, Zumwalt RE. 1995.** Hantavirus pulmonary syndrome in the United States: a pathological description of a disease caused by a new agent. *Human Pathology* **26**(1):110–120 DOI [10.1016/0046-8177\(95\)90123-X](https://doi.org/10.1016/0046-8177(95)90123-X).
- O'Donnell VB, Thomas D, Stanton R, Maillard J-Y, Murphy RC, Jones SA, Humphreys I, Wakelam MJO, Fegan C, Wise MP, Bosch A, Sattar SA. 2020.** Potential role of oral rinses targeting the viral lipid envelope in SARS-CoV-2 infection. *Function* **1**(1):1260 DOI [10.1093/function/zqaa002](https://doi.org/10.1093/function/zqaa002).
- Oermann CM, Schuster JE, Connors GP, Newland JG, Selvarangan R, Jackson MA. 2015.** Enterovirus D68: a focused review and clinical highlights from the 2014 U.S. outbreak. *Annals of the American Thoracic Society* **12**(5):775–781 DOI [10.1513/AnnalsATS.201412-592FR](https://doi.org/10.1513/AnnalsATS.201412-592FR).
- Ong SWX, Tan YK, Chia PY, Lee TH, Ng OT, Wong MSY, Marimuthu K. 2020.** Air, surface environmental, and personal protective equipment contamination by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) from a symptomatic patient. *Journal of the American Medical Association* **323**(16):1610–1611 DOI [10.1001/jama.2020.3227](https://doi.org/10.1001/jama.2020.3227).
- Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. 2016.** Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination. *Journal of Hospital Infection* **92**(3):235–250 DOI [10.1016/j.jhin.2015.08.027](https://doi.org/10.1016/j.jhin.2015.08.027).
- Pastorino B, Touret F, Gilles M, De Lamballerie X, Charr RN. 2020.** Prolonged infectivity of SARS-CoV-2 in fomites. *Emerging Infectious Diseases* **26**(9):2256–2257 DOI [10.3201/eid2609.201788](https://doi.org/10.3201/eid2609.201788).
- Patel KP, Vunnam SR, Patel PA, Krill KL, Korbitz PM, Gallagher JP, Suh JE, Vunnam RR. 2020.** Transmission of SARS-CoV-2: an update of current literature. *European Journal of Clinical Microbiology and Infectious Disease* **7**(1):11 DOI [10.1007/s10096-020-03961-1](https://doi.org/10.1007/s10096-020-03961-1).
- Paterson BJ, Mackenzie JS, Durrheim DN, Smith D. 2011.** A review of the epidemiology and surveillance of viral zoonotic encephalitis and the impact on human health in Australia. *New South Wales Public Health Bulletin* **22**(5–6):99–104 DOI [10.1071/NB10076](https://doi.org/10.1071/NB10076).
- Paules CI, Marston HD, Fauci AS. 2020.** Coronavirus infections: more than just the common cold. *Journal of the American Medical Association* **323**(8):707–708 DOI [10.1001/jama.2020.0757](https://doi.org/10.1001/jama.2020.0757).
- Piercy TJ, Smither SJ, Steward JA, Eastaugh L, Lever MS. 2010.** The survival of filoviruses in liquids, on solid substrates and in a dynamic aerosol. *Journal of Applied Microbiology* **109**(5):1531–1539.

- Rabenau HF, Cinatl J, Morgenstern B, Bauer G, Preiser W, Doerr HW. 2005. Stability and inactivation of SARS coronavirus. *Medical Microbiology and Immunology* 194(1–2):1–6 DOI 10.1007/s00430-004-0219-0.
- Ren S-Y, Wang W-B, Hao Y-G, Zhang H-R, Wang Z-C, Chen Y-L, Gao R-D. 2020. Stability and infectivity of coronaviruses in inanimate environments. *World Journal of Clinical Cases* 8(8):1391–1399 DOI 10.12998/wjcc.v8.i8.1391.
- Rutala WA, Kanamori H, Gergen MF, Sickbert-Bennett EE, Weber DJ. 2019. Susceptibility of *Candida auris* and *Candida albicans* to 21 germicides used in healthcare facilities. *Infection Control Hospital Epidemiology* 40(3):380–382 DOI 10.1017/ice.2019.1.
- Sagripanti J-L, Rom AM, Holland LE. 2010. Persistence in darkness of virulent alphaviruses, Ebola virus, and Lassa virus deposited on solid surfaces. *Archives of Virology* 155(12):2035–2039 DOI 10.1007/s00705-010-0791-0.
- Santarpia JL, Herrera VL, Rivera DN, Ratnesar-Shumate S, Reid SP, Denton PW, Martens JWS, Fang Y, Conoan N, Callahan MV, Lawler JV, Brett-Major DM, Lowe JJ. 2020a. The infectious nature of patient-generated SARS-CoV-2 aerosol. *MedRxiv* DOI 10.1101/2020.07.13.20041632.
- Santarpia JL, Rivera DN, Herrera V, Morwitzer NJ, Creager H, Santarpia GW, Crown KK, Brett-Major DM, Schnaubelt E, Broadhurst MJ, Lawler JV, Reid SP, Lowe JJ. 2020b. Aerosol and surface transmission potential of SARS-CoV-2. *MedRxiv* DOI 10.1101/2020.03.23.20039446.
- Sattar SA. 2007. Hierarchy of susceptibility of viruses to environmental surface disinfectants: a predictor of activity against new and emerging viral pathogens. *Journal of AOAC International* 90(6):1655–1658 DOI 10.1093/jaoac/90.6.1655.
- Sattar SA, Karim YG, Springthorpe VS, Johnson-Lussenburg CM. 1987. Survival of human rhinovirus type 14 dried onto nonporous inanimate surfaces: effect of relative humidity and suspending medium. *Canadian Journal of Microbiology* 33(9):802–806 DOI 10.1139/m87-136.
- Sattar SA, Springthorpe VS, Karim Y, Loro P. 1989. Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. *Epidemiology and Infection* 102(3):493–505 DOI 10.1017/S0950268800030211.
- Scott E, Bruning E, Ijaz MK. 2020. Decontamination of environmental surfaces in everyday settings. In: McDonnell G, Hansen J, eds. *Block's Disinfection, Sterilization, and Preservation*. Sixth Edition. Philadelphia: Wolters Kluwer.
- Senghore M, Diarra B, Gehre F, Otu J, Worwui A, Muhammad AK, Kwambana-Adams B, Kay GL, Sanogo M, Baya B, Orsega S, Doumbia S, Diallo S, De Jong BC, Pallen MJ, Antonio M. 2020. Evolution of *Mycobacterium tuberculosis* complex lineages and their role in an emerging threat of multidrug resistant tuberculosis in Bamako, Mali. *Scientific Reports* 10(1):327 DOI 10.1038/s41598-019-56001-0.
- Sia S-F, Yan L-M, Chin AWH, Fung K, Choy K-T, Wong AYL, Kaewpreedee P, Perera RAPM, Poon LLM, Nicholls JM, Peiris M, Yen H-L. 2020. Pathogenesis and transmission of SARS-CoV-2 in golden hamsters. *Nature* 583(7818):834–838 DOI 10.1038/s41586-020-2342-5.
- Stephenson EH, Larson EW, Dominik JW. 1984. Effect of environmental factors on aerosol-induced Lassa virus infection. *Journal of Medical Virology* 14(4):295–303 DOI 10.1002/jmv.1890140402.
- St. Georgiev V. 2009. Chapter 23: Defense against biological weapons (Biodefense). In: *National Institute of Allergy and Infectious Diseases, NIH, Infectious Disease*. Berlin: Springer.
- Sun J, Hu X-Y, Yu X-F. 2019. Current understanding of human enterovirus D68. *Viruses* 11(6):490 DOI 10.3390/v11060490.
- United States Centers for Disease Control and Prevention. 2015. Highly pathogenic Asian avian influenza A (H5N1) in people. Available at <https://www.cdc.gov/flu/avianflu/h5n1-people.htm>.

- United States Centers for Disease Control and Prevention. 2020.** Coronavirus 2019 (COVID-19) how to protect yourself and others. Available at <https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html>.
- United States Environmental Protection Agency. 2014.** Persistence of categories A and B select agents in environmental matrices. EPA/600/R-14/074. Available at https://nepis.epa.gov/Exe/ZyNET.exe/P100L8VR.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011+Thru+2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C11thru15%5CTxt%5C00000013%5CP100_L8VR.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL.
- United States Environmental Protection Agency. 2016.** Guidance to registrants: process for making claims against emerging viral pathogens not on EPA-registered disinfectant labels. Available at https://www.epa.gov/sites/production/files/2016-09/documents/emerging_viral_pathogen_program_guidance_final_8_19_16_001_0.pdf.
- United States Environmental Protection Agency. 2020.** Coronavirus cases trigger EPA rapid response. Available at <https://www.epa.gov/pesticides/coronavirus-cases-trigger-epa-rapid-response>.
- Van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, Tamin A, Harcourt JL, Thornburg NJ, Gerber SI, Lloyd-Smith JO, De Wit E, Munster VJ. 2020.** Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *New England Journal of Medicine* **382(16)**:1564–1567 DOI [10.1056/NEJMc2004973](https://doi.org/10.1056/NEJMc2004973).
- Van Doremalen N, Bushmaker T, Munster VJ. 2013.** Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. *Eurosurveillance* **18(38)**:pii+20590 DOI [10.2807/1560-7917.ES2013.18.38.20590](https://doi.org/10.2807/1560-7917.ES2013.18.38.20590).
- Vaughan A, Aarons E, Astbury J, Brooks T, Chand M, Flegg P, Hardman A, Harper N, Jarvis R, Mawdsley S, McGivern M, Morgan D, Morris G, Nixon G, O’Conner C, Palmer R, Phin N, Price DA, Russell K, Said B, Schmid ML, Vivancos R, Walsh A, Welfare W, Wilburn J, Dunning J. 2020.** Human-to-human transmission of monkeypox virus, United Kingdom, October 2018. *Emerging Infectious Diseases* **26(4)**:782–785.
- Viral Hemorrhagic Fever Consortium. 2020.** Lassa. Available at <https://vhfc.org/diseases/lassa/>.
- Walker JW, Han BA, Ott IM, Drake JM. 2018.** Transmissibility of emerging viral zoonoses. *PLOS ONE* **13(11)**:e0206926 DOI [10.1371/journal.pone.0206926](https://doi.org/10.1371/journal.pone.0206926).
- Wang W, Xu Y, Gao R, Lu R, Han K, Wu G, Tan W. 2020.** Detection of SARS-CoV-2 in different types of clinical specimens. *Journal of the American Medical Association* **323(18)**:1843–1844.
- Watanabe T, Bartrand TA, Weir MH, Omura T, Haas CN. 2010.** Development of a dose-response model for SARS coronavirus. *Risk Analysis* **30(7)**:1129–1138 DOI [10.1111/j.1539-6924.2010.01427.x](https://doi.org/10.1111/j.1539-6924.2010.01427.x).
- Weber DJ, Sickbert-Bennett EE, Kanamori H, Rutala WA. 2019.** New and emerging infectious diseases (Ebola, Middle Eastern Respiratory Syndrome coronavirus, carbapenem-resistant *Enterobacteriaceae*, *Candida auris*): focus on environmental survival and germicide susceptibility. *American Journal of Infection Control* **47**:A29–A38 DOI [10.1016/j.ajic.2019.03.004](https://doi.org/10.1016/j.ajic.2019.03.004).
- Westwood JCN, Sattar SA. 1974.** The minimal infective dose: can it establish infection? In: *International Conference on “Viruses in Water”, Mexico City, Mexico*.

- Whitehead K, McCue KA. 2010.** Virucidal efficacy of disinfectant actives against feline calicivirus, a surrogate for norovirus, in a short contact time. *American Journal of Infection Control* **38**(1):26–30 DOI [10.1016/j.ajic.2009.03.015](https://doi.org/10.1016/j.ajic.2009.03.015).
- Widders A, Broom A, Broom J. 2020.** SARS-CoV-2: the viral shedding vs. infectivity dilemma. *Infection, Disease & Health* **25**(3):210–215 DOI [10.1016/j.idh.2020.05.002](https://doi.org/10.1016/j.idh.2020.05.002).
- Wood JP, Choi YW, Chappie DJ, Rogers JV, Kaye JZ. 2010.** Environmental persistence of a highly pathogenic avian influenza (H5N1) virus. *Environmental Science and Technology* **44**(19):7515–7520 DOI [10.1021/es1016153](https://doi.org/10.1021/es1016153).
- World Health Organization. 2015.** WHO publishes list of top emerging diseases likely to cause major epidemics. Available at <https://www.who.int/medicines/ebola-treatment/WHO-list-of-top-emerging-diseases/en/>.
- World Health Organization. 2020a.** Novel coronavirus (2019-nCoV). Available at <https://www.who.int/emergencies/diseases/novel-coronavirus-2019>.
- World Health Organization. 2020b.** Coronavirus disease (COVID-19) advice for the public. Available at <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public>.
- World Health Organization. 2020c.** Coronavirus disease 2019 (COVID-19) situation report: 204. Available at https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200811-covid-19-sitrep-204.pdf?sfvrsn=1f4383dd_2.
- World Health Organization. 2020d.** Transmission of SARS-CoV-2: implications for infection prevention precautions. Available at <https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions>.
- Xing X, Guan X, Liu L, Zhan J, Jiang H, Liu L, Li G, Xiong J, Tan L, Xu J, Jiang Y, Yao X, Zhan F, Nie S. 2016.** Natural transmission model for severe fever with Thrombocytopenia Syndrome bunyavirus in villages in Hubei Province, China. *Medicine* **95**(4):e2533 DOI [10.1097/MD.0000000000002533](https://doi.org/10.1097/MD.0000000000002533).
- Ye G, Lin H, Chen S, Wang S, Zeng Z, Wang W, Zhang S, Rebmann T, Li Y, Pan Z, Yang Z, Wang Y, Wang F, Qian Z, Wang X. 2020.** Environmental contamination of SARS-CoV-2 in healthcare premises. *Journal of Infection* **81**(2):e1–e5 DOI [10.1016/j.jinf.2020.04.034](https://doi.org/10.1016/j.jinf.2020.04.034).
- Yezli S, Otter JA. 2011.** Minimum infective dose of the major human respiratory and enteric viruses transmitted through food and the environment. *Food and Environmental Microbiology* **3**:1–30.
- Yu X, Zhang L, Tong L, Zhang N, Wang H, Yang Y, Shi M, Xiao X, Zhu Y, Wang P, Ding Q, Zhang L, Qin C, Cheng G. 2020.** Broad-spectrum virucidal activity of bacterial secreted lipases against flaviviruses, SARS-CoV-2 and other enveloped viruses. *BioRxiv* DOI [10.1101/2020.05.22.109900](https://doi.org/10.1101/2020.05.22.109900).
- Zhan J, Wang Q, Cheng J, Hu B, Li J, Zhan F, Song Y, Gup D. 2017.** Current status of severe fever with thrombocytopenia syndrome virus in China. *Virologica Sinica* **32**(1):51–62 DOI [10.1007/s12250-016-3931-1](https://doi.org/10.1007/s12250-016-3931-1).
- Zhang DX. 2020.** SARS-CoV-2: air/aerosols and surfaces in laboratory and clinical settings. *Journal of Hospital Infection* **105**(3):577–579 DOI [10.1016/j.jhin.2020.05.001](https://doi.org/10.1016/j.jhin.2020.05.001).
- Zhang Y, Chen C, Zhu S, Shu C, Wang D, Song J, Zhen W, Feng Z, Wu G, Xu J, Xu W. 2020.** Notes from the field: isolation of 2019-nCoV from a stool specimen of a laboratory-confirmed case of the coronavirus disease 2019 (COVID-19). *Chinese Center for Disease Control Weekly* **2**(8):123–124.
- Zhou P, Yang X-L, Wang X-G, Hu B, Zhang W, Si H-R, Zhu Y, Li B, Huang C-L, Chen H-D, Chen J, Luo Y, Guo H, Jiang R-D, Liu M-Q, Chen Y, Shen X-R, Wang X, Zheng X-S, Zhao K, Chen Q-J, Deng F, Liu L-L, Yan B, Zhan F-X, Wang Y-Y, Xiao G-F, Shi Z-L. 2020.**

A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature* 579(7798):270–273 DOI [10.1038/s41586-020-2012-7](https://doi.org/10.1038/s41586-020-2012-7).

Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, Zhao X, Huang B, Shi W, Lu R, Niu P, Zhan F, Ma X, Wang D, Xu W, Wu G, Gao GF, Tan W, China Novel Coronavirus Investigating and Research Team. 2020. A novel coronavirus from patients with pneumonia in China, 2019. *New England Journal of Medicine* 382:727–733.

Zonta W, Mauroy A, Farnir F, Thiry E. 2016. Comparative virucidal efficacy of seven disinfectants against murine norovirus and feline calicivirus, surrogates of human norovirus. *Food and Environmental Virology* 8(1):1–12 DOI [10.1007/s12560-015-9216-2](https://doi.org/10.1007/s12560-015-9216-2).