Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Colloid & Interface Science

The viability of SARS-CoV-2 on solid surfaces

Mohsen Hosseini[a], Saeed Behzadinasab[a], Zachary Benmamoun and William A. Ducker

Abstract

The COVID-19 pandemic had a major impact on life in 2020 and 2021. One method of transmission occurs when the causative virus, SARS-CoV-2, contaminates solids. Understanding and controlling the interaction with solids is thus potentially important for limiting the spread of the disease. We review work that describes the prevalence of the virus on common objects, the longevity of the virus on solids, and surface coatings that are designed to inactivate the virus. Engineered coatings have already succeeded in producing a large reduction in viral infectivity from surfaces. We also review work describing inactivation on facemasks and clothing and discuss probable mechanisms of inactivation of the virus at surfaces.

Addresses

Dept. of Chemical Engineering and Center for Soft Matter and Biological Physics, Virginia Tech, VA, 24061, USA

Corresponding author: Ducker, William A. (wducker@vt.edu)
[a] These authors contribute equally to this article.

Current Opinion in Colloid & Interface Science 2021, **55**:101481

This review comes from a themed issue on **Hot Topic: COVID-19**

Edited by **Reinhard Miller** and **Libero Liggieri**

For complete overview about the section, refer Hot Topic: COVID-19

https://doi.org/10.1016/j.cocis.2021.101481

Keywords

COVID-19, SARS-CoV-2, Surface, Coating, Solid, Coronavirus.

Introduction

Severe acute respiratory coronavirus-2 (SARS-CoV-2) is the virus that causes COVID-19 and has been responsible for more than 100 million cases and 2 million deaths as of February 2021 (COVID-19 Dashboard by the Center for Systems Science and Engineering at Johns Hopkins University, https://coronavirus.jhu.edu/map.html). SARS-CoV-2 is transmitted through infected respiratory droplets and aerosols generated by a diseased person [1,2]. Respiratory droplets and aerosols can be generated when a person sneezes, coughs, speaks, or breathes [3]. An individual is infected by the virus through nasal or oral inhalation of the infected droplets or aerosols and then attachment of the virus to the epithelial membrane [2]. The pathway to infection is not fully understood but is thought to be via inhalation of either respiratory droplets or aerosolized virus (WHO Transmission of SARS-CoV-2: implications for infection prevention precautions, https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions). For this reason, health officials have advised that individuals should avoid poorly ventilated public places [4], wear a mask in public places, and increase distance between other individuals [3,5].

The possibility of infection via solid surfaces has also been considered. In this scenario, a droplet that contains virus lands on and contaminates an inanimate object. The contaminated object is called a fomite. The next user touches the fomite, and the virus is transferred from the fomite to the user's hand. Infection can occur if the person then touches their nose, mouth, eyes, or ears (Figure 1). A preprint (Behzadinasab et al., medRxiv doi: 10.1101/2021.04.24.21256044) confirmed that SARS-CoV-2 can be transferred from fomites to artificial skin.

A study on Golden Hamsters showed that the virus can be indirectly transmitted through fomites [6], but we are unaware of a study directly showing fomite transmission in humans. The WHO not only states that "fomite transmission is considered a likely mode of transmission for SARS-CoV-2" (WHO Transmission of SARS-CoV-2: implications for infection prevention precautions. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions), but also notes that "People who come into contact with potentially infectious surfaces often also have close contact with the infectious person, making the distinction between respiratory droplet and fomite transmission difficult to discern" (WHO Transmission of SARS-CoV-2: implications for infection prevention precautions. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions). Modeling of outbreaks suggests that transmission via fomites may contribute up to 25% of deaths during periods of lockdown [7].

Infection via fomites depends on the longevity of SARS-CoV-2 on a solid because an infectious dose clearly must survive until following users contact the solid. The longevity of SARS-CoV-2 depends on the solid material,

(AlN) microparticles (average size = ~0.5–2 μm) *in vivo*. They added 15 w/w% of each powder to PBS, in addition to adding SARS-CoV-2 suspension that contained 2×10^5 $TCID_{50}$. After slow rotation of the two suspensions for 1 or 10 min, the microparticles were separated by centrifugation and filtration with 0.2 μL filter. Subsequently, the supernatant was used to determine the inactivation of the virus by the $TCID_{50}$ method. The authors reported 100% viral reduction with only 1 min of virus exposure to either Si_3N_4, Cu, or AlN.

A related pre-print by Lehman et al. (Lehman et al., bioRxiv: 10.1101/2020.08.29.271015) also reported that in vivo Si_3N_4 can inactivate the virus. The researchers incubated similar-size particles of Si_3N_4 to Pezzotti et al.'s study [54] with a viral culture that contained 2×10^4 PFU/mL. They employed Si_3N_4 concentration from 5 up to 20 w/v%. To provide contact between the virus and active particles, the suspension was vortexed for 30 s, followed by slow rotation using a tube revolver from 1 to 10 min. The results depended on both concentration and incubation duration, as one might expect: with 1 min incubation, the virus was reduced 85% and 98% when using 5% Si_3N_4 and 20% Si_3N_4, respectively. Longer incubation periods led to increased inactivation of the virus. The authors showed that ~91% and 99.6% reduction of SARA-CoV-2 can be achieved when 5% Si_3N_4 and 20% Si_3N_4 are utilized, respectively.

Other methods for inactivating SARS-CoV-2 at surfaces

SARS-CoV-2 can be inactivated by other methods, such as light-activated coatings [62], ultraviolet (UV) light [63–65], atmospheric cold plasma [12], heat treatment [66], and ozone [67].

Micochova et al. [62] evaluated the efficacy of TiO_2 and TiO_2–Ag coatings on lowering the infectivity of SARS-CoV-2 while a surface is illuminated with light. They described that radicals are initiated by photons on the TiO_2 surface and that these radicals inactivate the virus. A spray gun was used to coat TiO_2 or TiO_2–Ag on ceramic tiles. Micochova et al. showed that the percentage of the infected SARS-CoV-2 after 1 h was only 15% on the illuminated coating compared to 80% on polystyrene. They also reported that the introduction of silver into their coatings did not improve the antiviral activity.

Inagaki et al. [64] reported a dramatic reduction in SARS-CoV-2 viability by utilizing a deep UV-emitting diode (DUV-LED) with a wavelength of 280 ± 5 nm. They placed 150 μL of 2×10^4 PFU/mL virus stock on a petri dish (the material was not described) and irradiated it for various times (intensity of 3.75 mW/cm^2 from a 2 cm height). This resulted in 87.4% (1s), 99.9% (10s), and >99.9% (20 s) reduction in infection titer of SARS-CoV-2 compared to control (i.e., no UV irradiation). These results are impressive; however, the UV wavelength that the researchers used is on the boundary of the UV-C region (UV–C wavelength = 100–280 nm), and UV-C light is known to be harmful to humans. This may limit application to situations where humans are not present or protected by shielding. Additionally, Inagaki et al. used a low concentration of virus (only 2×10^4 PFU/mL); however, in the publication by Heilingloh et al. [63] a 5×10^6 TCID50/mL viral stock was employed.

Heilingloh et al. [63] compared the ability of UV-A versus UV-C lights for the inactivation of SARS-CoV-2. UV-A has a wavelength of 320–400 nm while UV-C wavelength is between 100 and 280 nm. The researchers added 600 μL of 5×10^6 TCID50/mL virus stock (i.e. much more concentration than Inagaki et al.) in well plates and fixed the UV lamp at a distance of 3 cm (UV–C and UV-A intensities of 1940 and 540 mW/cm^2, respectively). UV-C irradiation resulted in complete inactivation of virus in 9 min, while UV-A light was much less impactful. The authors noted that the required UV dose for complete inactivation of virus is 1048 mJ/cm^2. Additionally, they investigated the effect of combined UV-A and UV-C light combined, and, as one might expect, by this method SARS-CoV-2 was inactivated the fastest. This resulted in 100% reduction in virus viability within 3 min.

Chen et al. [12] reported that cold atmospheric plasma can rapidly inactivate SARS-CoV-2 on solids. They used argon plasma (flow rate: 6.4 L/min, distance from surface: 15 mm, discharge voltage of 16.8–16.6 kV [peak–peak] at 12.9 kHz frequency) and achieved complete inactivation of virus in less than 180 s. The surfaces they tested were plastic, metal, cardboard, a football, a basketball, and a baseball. The researchers did not specify which type of plastic, metal, cardboard, and so on they used. Chen et al. also investigated similar goal using helium-fed argon with a flow rate of 16.5 L/min (distance from surface: 15 mm, discharge voltage of 16.8–16.6 kV [peak–peak] at 12.7 kHz frequency) and found that it is much less effective for inactivation of SARS-CoV-2. They were not able to reach complete inactivation of the virus in 5 min on plastic or metal. The researchers noted the surface that was Ar-plasma–treated reached a high of 32 °C, while that treated with He-plasma reached 29 °C. The results by Chen et al. [12] are significant.

Thermal treatment is also highly effective. For example, Daeschler et al. [66] used heat to disinfect personal protective equipment (PPE). They used high temperature to inactivate SARS-CoV-2 virus on four models of commercial N95 masks. The researchers incubated 5 μL of 7.8 log units $TCID_{50}$/mL virus stock on both unprocessed and 10 times heat processed N95 masks and