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The Basics of SARS-CoV-2 Transmission

(Previously *An Introduction to SARS-CoV-2*)
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The emergence of a novel coronavirus in late 2019, identified as SARS-CoV-2, has resulted in a global pandemic accompanied by an unprecedented public health response. This brief review of the properties of SARS-CoV-2 and how it is transmitted outlines some of the evidence that currently forms the basis of the evolving public health response. This document has been updated from previous versions published in April, July, and November 2020 (previously titled "*An introduction to SARS-CoV-2*), and January and March 2021 to reflect new findings and provide additional information about the virus that may be relevant to the public health response. The evidence presented below is based on current knowledge on dominant variants known to be circulating. As new evidence and new interpretations evolve, this document will continue to be updated.

SARS-CoV-2 genomics and emerging variants

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the coronavirus responsible for the illness COVID-19. Coronaviruses are genetically distinct from viruses that cause influenza. They are enveloped, single-stranded RNA viruses whose surface is covered by a halo of protein spikes, or "corona." Other coronaviruses that have caused significant and lethal outbreaks in the past 20 years include SARS-CoV-1 and MERS-CoV that caused SARS and Middle East respiratory syndrome (MERS), respectively. Phylogenetic (evolutionary) analysis has helped to establish that SARS-CoV-2 emerged in the human population in November 2019. Since then, continued analysis of the genome in COVID-19 cases from around the world has identified small mutations that can be used to track the evolution of the virus.

The rate of mutation observed for SARS-CoV-2 is significantly lower than influenza, but similar to other coronaviruses.[1-3] Thousands of mutations in the SARS-CoV-2 genome have emerged over the course of the pandemic, with the dominant variants shifting over time. Monitoring has been ongoing to inform how variants are spreading geographically and whether emerging variants are a cause for concern.[4-8] The variants that are cause for most concern may:

- spread more quickly,
- evade natural or vaccine-related immunity,
- cause more severe disease,
- evade detection by available tests, or
- are less responsive to treatment.[9]

At the time of writing, three variants of concern, which all emerged in the latter half of 2020 and commonly referred to as B.1.1.7, B.1.351 and P.1. are being closely monitored by public health officials around the world.[10]

The B1.1.7 lineage, initially detected in the UK in the late summer of 2020 has become dominant in the UK, and is widespread in much of Europe and the US. As of March 16, 2021 close to 4000 cases had been detected in Canada.[11] B.1.1.7 is more transmissible than previously circulating variants and there is evidence of an increased rate of mortality.[12,13] The increased transmissibility is believed to be due to mutations to the receptor binding domain of the spike protein that makes it attach more readily to host cells.[10,14,15] There is also emerging evidence that persons infected with the variant may carry a higher viral load and are infectious for longer.[16-18] The deletion or replacement of certain genes in B.1.1.7 are believed to be responsible for the failure of certain types of test kits in detecting positive cases.

The B.1.351 lineage, initially detected in South Africa at the beginning of October 2020, has become dominant in that country and has also been found in other countries.[19,20] As of March 16, 2021, 238 cases had been detected in Canada.[11] Similar to B.1.17, B.1.351 shares a mutation (N501Y) that is thought to confer greater transmissibility compared to previously circulating variants.[21,22] Further study is needed to understand whether the variant causes more severe disease or increased mortality, but B.1.351 appears to be more resistant to neutralization by antibodies, inferring that natural or vaccine induced immunity may be less effective against this variant.[23,24] A recent study found that immunization with the Pfizer and Moderna mRNA vaccines confers less immunity against B.1.351 compared to earlier variants. B.1.351 does not share the gene deletions of B1.1.7 and therefore seems to be more readily detected by most tests.[10]

The P.1 lineage, first reported in Brazil in December 2020, and soon after identified in Brazilian travellers in Japan, has spread rapidly throughout South America and has been detected in Europe, the UK, the US, Canada and elsewhere. As of March 16, 2021, 71 cases had been detected in Canada.[11] P.1 also shares the N501Y mutation with B.1.17 and B.1.351 that is thought to confer greater transmissibility and P.1. also shares a mutation (E484K) with B.1.351 that is thought to be associated with evading natural or vaccine induced immunity.[9,24,25] Further study is needed to assess the impact on disease severity and mortality.

Two other variants of concern have been identified in the US (B.1.427 and B.1.429), which are estimated to be about 20% more transmissible compared to previous variants. There area also three variants of interest (B.1.526, B.1.525 and P.2) being monitored for signs they may become variants of concern.[9]

Research is ongoing to understand how the evolution of the virus in different geographies is affecting transmissibility, severity of disease, ability to evade detection, or vaccine-induced immunity, or susceptibility to therapeutic treatment.[3-8,14] Relating genomic variants to health and epidemiological data can help to inform the public health response, vaccine development and the design of therapies.[1,5] The potential for increased transmissibility emphasizes the need for increased compliance with existing public health measures such as mask-wearing, physical distancing and limits to social gatherings.

Symptoms and severity of disease

Symptoms

The most frequently reported symptoms of COVID-19 can include new or worsening cough, fever or temperature ≥ 38°C, shortness of breath or difficulty breathing, fatigue or weakness, loss of appetite and loss of smell and/or taste.[26] Less frequently reported symptoms can include sore throat, body aches, dizziness, headache, nausea, vomiting or diarrhea. In some severe cases, the disease can result in lethal pneumonia.[26-28] Among children, the reported symptoms are similar to those of adults but may be less severe, and abdominal symptoms and skin changes or rash may be more commonly reported.[27]

The severity of disease and range of symptoms can vary from person to person, with some people experiencing no symptoms or very mild symptoms.[26,28] Some more serious manifestations of illness may be due to an immune response to SARS-CoV-2 rather than due to infection. In some patients an intense immune response results in a hyper-inflammatory reaction that can result in more severe outcomes.[29,30] The elderly, the obese, smokers, and immunosuppressed persons and those with pre-existing conditions including diabetes, hypertension, heart disease, or cancer are at the greatest risk of requiring hospitalization or dying from COVID-19.[31-33] Persons with conditions that involve multiple comorbidities, such as Down syndrome, may be at heightened risk of COVID-19 related hospitalization or death.[34] Some groups may also be disproportionately affected by COVID-19 as a result of existing health inequities related to socioeconomic factors.[35]

As of March 9, 2021, about 7.7% of persons with COVID-19 in Canada have required hospitalization, of whom about 17.6% required admission to intensive care and 3.2% required mechanical ventilation.[11] This is a reduction in the proportion of cases requiring hospitalization or admission to ICU compared to earlier in the pandemic. Research is ongoing to help explain the relationship between the viral load (the quantity of viral particles per unit of bodily fluid in the infected person) and severity of disease.[36] Patients with a higher viral load appear to experience more severe symptoms and shed more virus over a longer timeframe than mild cases[37] and a higher viral load has been found to be associated with a higher rate of mortality among COVID-19 patients.[38]

Duration of illness and long-term sequelae

The duration of illness ranges from about two weeks for mild cases to between three and six weeks in severe to critical cases. Long-term symptoms (sequelae) that persist beyond six weeks have been observed in some patients, with some referring to this as “long Covid”.[39] Age, chronic health conditions and obesity have been found to be significant predictors of persistent symptoms and those who have been hospitalized may experience symptoms for longer.[40,41] Persistent symptoms may include fatigue, cough, breathing difficulties, headache, joint pain, and many of the other common symptoms listed earlier, with the majority of those suffering long-term symptoms experiencing more than one.[40,42] Some people have also suffered damage to the heart muscle, scarring of the alveoli, endocrinological and metabolic dysfunction, neurological effects, strokes, and seizures. [41,43,44]

Case fatality

The case fatality rate for COVID-19 differs around the world and across Canada and relates in part to case identification and to local epidemiology. Not all cases are identified so incidence of diseases may be underestimated and the associated fatality rate overestimated. The case fatality rate for Canada as of March 16, 2021 was reported as about 2.5%, with most cases (67.6%) and fatalities (78.7%) occurring in Ontario and Quebec. The highest case fatality rates have been recorded in Nova Scotia (3.9%), Quebec (3.5%), Manitoba (2.8%) and Ontario (2.2%).[11] No deaths have been recorded in P.E.I. or the Northwest Territories at the time of writing and only one in each of Nunavut and the Yukon.

COVID-19 in children

COVID-19 is less prevalent in children as compared to adults and children infected with SARS-CoV-2 experience less severe symptoms.[45-49] Evidence also suggests that children may be more likely to be asymptomatic compared to infected adults, but further study is needed to understand transmission pathways in children.[50] As of March 16, 2021, 17.1% of COVID-19 cases in Canada were persons 19 years of age and younger, accounting for just under 153,000 cases.[11] Of these, there were 767 hospitalizations, 113 admissions to ICU and 6 deaths in this age group. Case data for various provinces indicate that the incidence of COVID-19 cases in children under 10 is lower than that of teens (11-19).[51-53] Children under one year of age and with underlying conditions may experience more severe illness than other children, but the case fatality rate for children is much lower than for adults.[48] In very rare cases, children with COVID-19 have developed pediatric multisystem inflammatory syndrome in children (MIS-C), which can include symptoms of fever and inflammation, and can affect cardiac, renal, respiratory hematologic, gastrointestinal, dermatologic, or neurological systems.[54-57] Children who do experience more severe symptoms have shorter hospital stays, decreased requirement for mechanical ventilation, and decreased mortality compared to adults.[54]

Transmission dynamics

Rate of transmission

The basic reproduction number for a contagious disease, or the R_0 value, estimated at the beginning of an outbreak, indicates the number of secondary cases that can be infected by a primary case in a population with no underlying immunity, vaccine, or preventive measures. Where R_0 is greater than 1, the number of infected persons is likely to increase. Over time, the effective reproductive number (R_t) changes as more people are infected and public health measures are implemented to contain the spread. Factors such as the emergence of new variants with different levels of transmissibility can affect the R_t. The goal of public health interventions is to bring the R_t below 1, which would indicate that the outbreak intensity is declining and will eventually die out.[58] Monitoring the change in R_t can help to evaluate the effectiveness of public health measures.

For SARS-CoV-2 the preliminary World Health Organization estimate of R_0 was 1.4-2.5[59] with subsequent research estimating the mean R_0 at 3.28.[60] This suggests that every primary case at the beginning of the outbreak could potentially infect about three others. The R_t is an average and can vary depending on the location and patterns of local transmission over time.[61,62] The rate of transmission can also change with mutations in the genome and may be higher for emerging variants.[61] Estimates of R_t can not easily account for secondary cases that are asymptomatic unless these cases have been detected in the population through widespread testing.[63] The R_t for Canada near the beginning of the pandemic in March 2020 was estimated to be > 2. Following widespread public health measures to prevent transmission, the R_t dropped to < 1 from about the end of April to late June 2020, followed by fluctuations above and below 1, up to the end of July, with an upward trend from mid-August into the autumn, with the R_t remaining above 1.[64] As of March 16, 2021, the R_t was stable or decreasing in most provinces and territories, with the exception of Alberta and Manitoba, where there are indications it is likely increasing.[65]

Routes of transmission

SARS-CoV-2 is thought to infect a host cell by binding to ACE-2 receptors that are present on tissues throughout the body including in epithelial cells of the airway, lungs, intestines, kidneys, and blood vessels, etc.[29] The virus replicates predominantly in the tissues of the upper respiratory tract.[66] SARS-CoV-2 is primarily transmitted via prolonged close contact with an infected person. The vast majority of COVID-19 outbreaks have taken place indoors and are most often associated with close contacts in the home environment, or other indoor spaces where there is a high density of people and an extended period of contact.[67-70] Most transmission appears to be due to exposure to the respiratory droplets and aerosols of an infected person.[71-78] Other routes (e.g., fomites) may be possible but are not considered to be major routes of transmission.

Transmission via respiratory emissions

Forceful respiratory actions such as coughing, and sneezing can produce a burst of droplets and aerosols that range in size and could present an exposure risk when near an infected person. Evidence from animal studies has shown that transmission due to close contact is likely to be more efficient than indirect transmission over longer distances.[79-81] A susceptible person is more likely to encounter large droplets (e.g., > 5-10 µm in diameter) that have not fallen to the ground, or concentrated bursts of aerosols when in close proximity to the emitter.[82,83] Large droplets are thought to travel less than 1 m before dropping to the ground, leading to the 2 m physical distancing practice that has been adopted for limiting the spread in the general public.[78,84-86] Current evidence has shown that measures to protect against the spread of respiratory droplets, namely physical distancing and mask wearing, have led to a reduction in cases.[87,88]

Respiratory emissions produced by less forceful respiratory activities such as heavy breathing, speaking, singing, shouting, or laughing are mostly aerosols < 5 µm in diameter. Transmission via respiratory aerosols may be an important route of transmission.[82,89-93] Aerosols can remain suspended in air for longer than large droplets and be transported over larger distances by ambient air currents.[71,89,94] Under experimental conditions, SARS-CoV-2 has been found to remain viable when airborne over short distances for several hours and in field studies, viable virus has been isolated from air samples at distances greater than two metres from a COVID-19 patient.[73,95,96] Transmission via respiratory aerosols could be occurring in settings where they accumulate in poorly ventilated indoor environments where there is a high density of people, and extended duration of contact, allowing for transmission beyond 2 m to occur.[68,83,97] Control measures for this type of transmission may rely heavily on reducing crowding, reducing the duration of interactions in indoor spaces, and ensuring good ventilation.[98,99]

- See more from the NCCEH on transmission risks in different settings including Indoor spaces, Outdoor spaces, Multi-unit residential buildings, Choir or Performing arts settings, Encampments, Shared laundry facilities, Outdoor dining, Outdoor urban spaces, and Carpools.
- See more from the NCCEH on measures for reducing transmission risks including Masks, Face shields, Physical barriers, Air cleaning technologies, Ventilation and CO_2 sensors

Transmission via contact with surfaces

Contact with contaminated surfaces (fomites) followed by touching of the eyes, mouth or nose is another possible mode of SARS-CoV-2 transmission, although it is not considered to be the main route. Fomites can become contaminated by deposition of droplets, aerosols, sputum, or feces, either directly or by cross-contamination by touching an object with contaminated hands. Surfaces that are frequently touched by many people (high-touch surfaces), such as door handles, or faucets may be more important in fomite transmission compared to objects or surfaces that are only touched incidentally and less frequently.

The risk of transmission through contact with fomites is not well understood and could depend on the initial concentration of viable virus, its viability on a specific surface over time, and the quantity of virus transferred through touching of the eyes, mouth, or nose. Several studies have measured the persistence of SARS-CoV-2 on common surfaces under experimental conditions.[95,100-102] The virus appears to remain viable for longer periods (one to seven days or more) on smooth hard surfaces such as stainless steel, hard plastic, glass, and ceramics and for shorter periods (several hours to two days) on porous materials such as paper, cardboard, and textiles, although viability may be dependent on other factors such as temperature.[95,100-107] Survival time on copper, aluminum, and zinc is low (a few hours).[95,102] Experimental study of the persistence on skin found that SARS-CoV-2 remained stable on swine skin for up to 96 h at room temperature (22°C),[104] whereas a study using human skin found that viable virus was only detected for up to 10 h at room temperature (25°C).[108] There are fewer studies that have detected viable virus in real-world settings, where variation in environmental conditions such as temperature, ultraviolet radiation, and humidity can all affect viability.[100,109-111] Observational studies have detected viral RNA on a wide range of surfaces in settings where persons with COVID-19 have been present, such as hospitals or quarantine rooms.[112] Most of these studies did not attempt to culture virus, so it is not known whether viral detections represented sources of viable virus in many cases. Hand hygiene and routine cleaning and disinfection of surfaces reduces the likelihood of contact transmission.[113-119]

- See more from the NCCEH on Hand sanitizers, Cleaning and disinfection of household surfaces, Air and surface disinfection measures, use of Disinfectants and sanitizers in food premises, and Nanomaterials as disinfectants, Disinfectant chemical exposures and health effects

Transmission via feces

SARS-CoV-2 is shed via feces. Patients with more severe COVID-19 have higher concentrations of SARS-CoV-2 in their stool and viral particles can be detected in stool long after respiratory samples test negative.[120,121] Several studies have identified the presence of SARS-CoV-2 RNA in feces, but only a few have identified viable virus.[121-125] Viral RNA has also been detected in the toilets of COVID-19 patients but to date viable virus has not been detected.[75-77] There is little evidence to suggest that transmission via the fecal-oral pathway (e.g., passing in fecal particles from one person to the mouth, or fecal contamination of food) is significant in the current pandemic. Fecal aerosol transmission is implicated in a COVID-19 cluster in a high-rise in Guangzhou, China and exposure to sewage is implicated in an outbreak in an urban community with poor sanitation services, also in Guangzhou, China, but neither investigation could be definitive that fecal-oral transmission had occurred.[126,127] Transmission through bathroom vents was also implied in a cluster of 10 cases in an apartment building in Seoul, South Korea, although it is not possible to conclude that transmission was associated with fecal aerosols.[128]

- See more from the NCCEH on Public washrooms in the time of COVID-19 and Wastewater based epidemiology

Zoonotic transmission

Like SARS and MERS, the SARS-CoV-2 virus is thought to have originated in bats, but may have had an intermediate mammalian host prior to transfer to humans, although the source of introduction into humans is still unknown.[129,130] Experimental studies have shown that several mammal species including ferrets, cats, and dogs, can become infected with SARS-CoV-2, and the virus has been detected in some companion animals, zoo animals, and farmed mink.[130-133] Evidence of transmission of SARS-CoV-2 from animals to humans is scarce. Transmission of SARS-CoV-2 from humans to animals and back to humans has been reported on mink farms in the Netherlands and Denmark, resulting in widespread culling of farmed mink.[134] Mink farms in Spain, Sweden, Italy, Canada, and the US have also been affected by COVID-19 outbreaks.[135] Between June and November 2020, 214 cases of COVID-19 in humans in Denmark were found to be associated with farmed mink. Twelve of these cases, identified on November 5, were found to have a unique variant with a decreased sensitivity to neutralizing antibodies in humans, resulting in the planned culling of the entire mink population of Denmark, to prevent further spread of the variant to humans.[136] In December 2020, a COVID-19 outbreak was declared at a mink farm in B.C., with seventeen human cases associated with the outbreak. Subsequent genetic analysis indicated that the virus had been transmitted from humans to animals, but not from animals back to humans.[137,138] Continued identification and surveillance of cases of zoonotic transmission is ongoing around the world to understand transmission pathways and the risk to humans.

- See more from the NCCEH on [SARS-CoV-2 and mink]

Other routes of transmission

To date there is no evidence to suggest that are there are primary routes of transmission other than those discussed above. Conjunctival transmission through the eyes or tears and vertical transmission (from a mother to a fetus) may occur but are likely to be uncommon.[139-141] Food-borne transmission, sexual transmission, and transmission via other bodily fluids including blood, urine, breast milk, are unlikely to be occurring.[130,142,143]

Infectious dose

While the precise dose of SARS-CoV-2 required to cause an infection is still unknown, findings from animals studies and modelling experiments have narrowed estimates of a median dose to between about 10 and 1000 viral particles.[130] This suggests that the minimum infectious dose may be slightly higher than SARS-CoV-1 and lower than Middle East Respiratory Syndrome (MERS), e.g., approximately a few hundred viral particles.[79,81,144-147] Human challenge trials are due to begin in the UK in 2021 to determine the minimum dose needed to cause infection.[148] The efficiency of viral transmission during exposure can be affected by the number of infectious viral particles inhaled and the duration of exposure for a secondary case. Infection may occur due to a short but intense dose of infectious virus or following prolonged or repeated exposure to a smaller dose. Modeling by Goyal et al. reported that exposure to an infected person with a viral load of $< 10^5$ SARS-CoV-2 RNA copies is unlikely to result in transmission, compared to exposure to a person shedding $> 10^7$ SARS-CoV-2 RNA copies, which is much more likely to result in infection.[149] Increasing the viral load and the number of people an infected person has contact with, is likely to result in greater secondary transmission. Exposure to a higher dose can result from both the intensity and duration of contact with an infected person.[150] Animal studies have indicated that infectious dose and subsequent distribution of the virus in the host may vary by the route of infection.[130,139] There is also some evidence to suggest that severity of disease may be influenced by the magnitude of the inoculum (e.g., the number of infectious particles a person is exposed to via respiratory droplets, aerosols, or contact with fomites).[150-152]

Timing of transmission

An infected person can transmit the virus to others both before they show any symptoms (pre-symptomatic) and when they are symptomatic. Peak infectiousness is thought to occur about one day before symptom onset.[130,153] The mean incubation period (time between exposure to the virus and the appearance of symptoms) has been estimated to be around five days,[154,155] with modelling indicating a range of about two to 11 days (2.5th and 97.5th percentiles).[156,157]

Pre-symptomatic and asymptomatic transmission

The occurrence of pre-symptomatic transmission (during the incubation phase of an infected person) and asymptomatic transmission (transmission via an infected person who never displays symptoms) has been recorded throughout the pandemic in various locations around the world.[69,158-163] Pre-symptomatic persons can potentially infect others one to about three days before symptom onset.[153,162] For asymptomatic spread, the period of transmission is still being investigated.[164,165] The precise incidence of pre-symptomatic and asymptomatic transmission and overall importance to the spread of the virus is still unknown but could be significant, with recent modelling by Johannsen et al. (2020) estimating that at least 50% of transmission could be from infected persons without symptoms.[166-168]

Persons who are not symptomatic may be less likely to transmit the virus via large respiratory droplets due to the absence of coughing and sneezing.[161] Other routes of transmission, such as via smaller respiratory aerosols released during breathing, speaking, laughing or singing, may be more important for pre-symptomatic or asymptomatic transmission.[88] Current evidence suggests that asymptomatic transmission is more likely to occur following prolonged close contact, such as in family settings where there may be exposure during shared meals, talking, and contact with shared common objects and surfaces.[69,163,169,170]

Symptomatic transmission

Current evidence suggests that while peak infectiousness occurs slightly before symptom onset, most transmission occurs during the symptomatic phase.[169] The viral load has been measured to be highest soon after symptom onset in the early stages of the disease, when level of transmission may also be highest, and decreases about one week following the peak.[29,171,172] Symptomatic persons could be transmitting the virus to others for days to several weeks after symptom onset, although most cases are not infectious beyond eight to ten days after symptom onset.[66,157,173-176] In a limited number of severe to critical cases, infectious virus has been detected for > 30 days.[173] As infection progresses, the quantity of virus contained in droplets and aerosols expelled by an infected person will vary by the viral load in various parts of the respiratory tract and the stage of the disease. In the early stages of the disease viral load is found to be higher in sputum than in the throat.[165,171] Median viral loads have been found to be between 10^4 and 10^6 copies per mL of respiratory fluid with an average emitter releasing about 10^6 copies per ml, but levels up to 10^{11} copies per mL have been detected in some cases.[66,171,172,177,178] Infected super-emitters who release a greater number of respiratory droplets could present a greater risk for transmitting the virus to others, particularly if they also carry a high viral load.[179] Genomic sequencing has helped to identify that SARS-CoV-2 tends to spread in clusters rather than in a steady manner, and increasing evidence indicates that a few people can infect many others.[61,180,181]

Persons who have been infected with COVID-19 may continue to shed virus beyond the period of infectiousness and after symptoms have resolved.[66,157,174] Persistent shedding of viral RNA may be responsible for some patients testing positive again after an apparent negative RNA test.[174,182] Reinfection with SARS-CoV-2 is possible, and genomic analysis has been used to distinguish between persistent shedding due to the original infection, and the presence of a new infection, which has occurred in a small number of cases.[183,184]

Sensitivity of SARS-CoV-2 to environmental factors

Research is ongoing to understand how environmental conditions affect the persistence of SARS-CoV-2, with various studies investigating the effect of different levels of temperature, humidity, and ultraviolet light and combinations of different conditions.

Temperature

Experiments have found that high temperatures are more effective for deactivating the SARS-CoV-2 virus, and the virus is more persistent at colder temperatures. Experiments using viral suspension found minimal reduction over 14 days at 4°C, but detected no viable particles after four days at 22°C, within one day at 37° C, less than 30 minutes at 56°C and less than five minutes at 70°C.[100,185,186] Studies of persistence of SARS-CoV-2 on various surfaces (skin, currency and clothing) also found that the virus remained stable for much longer at 4°C compared to experiments at 22°C and 37°C.[104] A study of persistence of SARS-CoV-2 in milk found that pasteurization temperatures of 56°C and 63°C for 30 minutes resulted in no viable virus. At colder temperatures no reduction was detected after 48 hours stored at 4°C, and only a minimal reduction after 48 hours stored at -30°C.[187]

Humidity

Humidity may influence viral transmission by affecting how droplets move and their rate of decay, and can influence susceptibility of individuals to infection.[188] Humid conditions can reduce evaporation of liquid contained in respiratory droplets, reducing aerosolization and allowing droplets to fall to the ground or settle on surfaces more readily. This could potentially increase the risk of fomite transmission if virus in deposited droplets remains viable. In contrast, warm dry environments could enhance evaporation of droplets, resulting in a greater number of aerosols being dispersed.[189] Aerosol transmission may be more likely in very dry environments compared to very humid ones.[190] Humidity may also affect the persistence of the virus, as demonstrated with other coronaviruses, with decreased viability as temperature and humidity increases and potential to remain infectious for longer under cool, dry conditions.[185,188] This has been demonstrated in experimental studies of SARS-CoV-2 in aerosols and on surfaces but the effect may also vary depending on the UV index, with the importance of temperature and humidity decreasing as the UV index increases.[191,192] Humidity can affect the susceptibility of respiratory systems to viral infection, with dry conditions reducing the effectiveness of the mucosal lining of the respiratory tract to prevent infection.[188]

- See more from the NCCEH on humidity in High humidity environments and the risk of COVID-19 transmission

Light/Ultraviolet (UV) irradiation

UV irradiation has been shown to reduce viral loads for respiratory viruses, including SARS-CoV-1 in clinical and other controlled settings.[193,194] Germicidal effects can occur between 200-320 nm, which covers the range of UV produced by natural sunlight (UV-B, 280-320 nm) and UV produced by lamps for specific applications (UV-C, below 280 nm) Solar UV-B has been shown to provide a disinfectant effect under a high UV-index over a sustained period.[195] Disinfection using UV-C is more efficient than UV-B, and UV-C has been shown to be effective for inactivation of double-stranded, enveloped RNA viruses.[196-199] UV irradiation has also been proposed as a decontamination method for personal protective equipment (PPE) contaminated by SARS-CoV-2.[111,200,201] Initial results suggest that UV treatment may be more effective on smooth surfaces such as steel as compared to fabrics or porous materials.[202] The use of UV-C for disinfection carries some risk, as exposure to UV-C can be harmful to human skin and eyes.[203] Further study is needed to determine the optimum dose needed for inactivation of SARS-CoV-2, and how UV-C could be safely applied in public settings.

- See more from the NCCEH on UV disinfection in COVID-19 in indoor environments – Air and surface disinfection measures and Air cleaning technologies for indoor spaces

The information provided in this *Basics of SARS-CoV-2 Transmission* is based on current understanding and interpretations of the literature at the time of writing. There are still many knowledge gaps in understanding aspects of transmission and progression of the disease that continue to be researched, including the impact of emerging variants on transmission patterns. As new evidence and interpretations emerge, this document will be updated. Additional COVID-19 related resources to support environmental health can be found on our Environmental Health Resources for the COVID-19 Pandemic topic page.

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