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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 and July 2020 to reflect new findings and provide additional information about the virus that may be relevant to the public health response. As new evidence and new interpretations evolve, this document will continue to be updated.

SARS-CoV-2 genomics

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, suggesting it is evolving more slowly in response to selective pressure.^{1,2} Monitoring genomic variants can help inform how the disease is spreading geographically.³⁻⁷ The dominant variants have shifted over the course of the pandemic, with the first wave in Europe being associated with a variant that emerged in February 2020 and became the most dominant form globally (e.g., D614G).^{3,8} During the summer of 2020, two new variants emerged in Spain accounting for the majority of sequences now measured in Europe (e.g., 20A.EU1 and 20A.EU2).⁹ Genomic sequencing identified that these variants spread across Europe during a period of quarantine-free travel between many countries, highlighting a potential impact of relaxing travel restrictions.

Research is ongoing to understand how the evolution of the virus in different geographies is affecting transmissibility and severity of disease.³⁻⁷ Genomic surveillance data¹⁰ and conventional epidemiological techniques such as contact tracing are being used in tandem to trace the origin of outbreaks, identify clusters, and understand distribution in target populations (e.g., children and the elderly). Relating genomic variants to health and epidemiological data can help to inform the public health response, vaccine development and the design of therapies.^{1,4} Genomic sequencing and

surveillance has also been proposed as a means of tracing the links between animal hosts and humans as part of efforts to prevent future pandemics.¹¹ *See more on zoonotic transmission below.*

Symptoms and severity of disease

Symptoms

Symptoms of COVID-19 can include cough, fever, shortness of breath, tiredness, sore throat, body aches, chills, and headache. Some people may also experience loss of smell or taste, nausea, vomiting or diarrhea. In some severe cases the disease can result in lethal pneumonia.¹²⁻¹⁴ Among children, abdominal symptoms and skin changes or rash may be more commonly reported.¹² The severity of disease and range of symptoms can vary from person to person, with some people experiencing no symptoms or very mild symptoms.¹⁵ 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.^{16,17} 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-19.¹⁸⁻²⁰ Some groups may also be disproportionately affected by COVID-19 as a result of existing health inequities related to socioeconomic factors.²¹

As of November 1, 2020, about 8% of persons with COVID-19 in Canada have required hospitalization, of whom about 20% required admission to intensive care and 5% required mechanical ventilation.²² This is a reduction in the proportion of cases requiring hospitalization or admission to ICU compared to earlier in the pandemic.¹⁵ 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.²³ Patients with a higher viral load appear to experience more severe symptoms and shed more virus over a longer timeframe than mild cases²⁴ and a higher viral load has been found to be associated with a higher rate of mortality rate among COVID-19 patients.²⁵

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. 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.²⁶ Persistent symptoms may include fatigue, cough, breathing difficulties, headache, joint pain. Some people have also suffered damage to the heart muscle, scarring of the alveoli, endocrinological and metabolic dysfunction, psychiatric problems with cognitive deficits, strokes, and seizures.²⁷

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.^{22,28} 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 October 24, 2020 was reported as about 4.6%, with the highest case fatality rates recorded in Quebec (6.2%), Ontario (4.5%), Nova Scotia (5.9%), and BC (2%). No deaths have been recorded in P.E.I. or the Territories at the time of writing.^{22,29}

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.³⁰⁻³⁴ As of November 1, 2020, 13.1% of COVID-19 cases in Canada were persons 19 years of age and younger, accounting for just over 30,000 cases.²² Of these, there were 227 hospitalizations, 47 admissions to ICU and 2 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).³⁵⁻³⁷ 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.³³ 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.³⁸⁻⁴¹ Children who do experience more severe symptoms have a shorter hospital stay, decreased requirement for mechanical ventilation and decreased mortality compared to adults.³⁸

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. 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.⁴² 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 1.4-2.5⁴³ with subsequent research estimating the mean R_0 at 3.28.⁴⁴ 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.⁴⁵ 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.⁴⁶ 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.⁴⁷ Since mid-August, the R_t has shown a slight upward trend and has remained > 1 , reflecting increases in cases in some regions of the country. The R_t varies between and within provinces and territories.

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.¹⁶ The virus replicates predominantly in the tissues of the upper respiratory tract.⁴⁸ 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.⁴⁹⁻⁵² Most transmission appears to be due to exposure to the respiratory droplets and aerosols of an infected person.⁵³⁻⁶⁰ Other routes (e.g., fomites) may be possible but are not considered to be major routes of transmission.

Respiratory droplets and aerosols

Respiratory emissions can range in size, with **large droplets** typically referring to those above 5-10 µm in diameter, and small droplets or aerosols referring to those below 5-10 µm diameter. Forceful respiratory actions such as coughing and sneezing can produce a burst of droplets that range in size and could include both large droplets and aerosols that present an exposure risk in close proximity to 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.⁶¹⁻⁶³ A susceptible person is more likely to encounter large droplets that have not fallen to the ground, or concentrated bursts of aerosols when in close proximity to the emitter.^{64,65} 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.^{60,66-68} 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.⁶⁹

The majority of respiratory emissions produced by less forceful respiratory activities such as breathing, speaking, singing, shouting, heavy breathing or laughing are aerosols < 5 µm. Transmission via **respiratory aerosols** may be an important route of transmission.^{64,70-74} Aerosols can remain suspended in air for longer than large droplets and be transported over larger distances by ambient air currents.^{53,70,75} 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.^{55,76,77} 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.^{50,65,78} 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.^{79,80}

- 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](#), and [Shared laundry facilities](#).
- See more from the NCCEH on [Masks](#), [Physical barriers](#), and [Ventilation](#)

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 can 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.^{76,81-83} 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.^{76,81-88} Survival time on copper, aluminum, and zinc is low (a few hours).^{76,83} 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.^{81,89-91} 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.⁹² 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.^{45,93-98}

- 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](#))

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.^{99,100} Several studies have identified the presence of SARS-CoV-2 RNA in feces but only a few have identified viable virus.¹⁰⁰⁻¹⁰⁴ Viral RNA has also been detected in the toilets of COVID-19 patients but to date viable virus has not been detected.⁵⁷⁻⁵⁹ 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 a low-income area, also in Guangzhou, China, but neither outbreak could be definitive that fecal-oral transmission had occurred.^{105,106}

- See more from the NCCEH on [Public washrooms in the time of COVID-19](#)

Infectious dose

The dose of SARS-CoV-2 required to cause an infection is still unknown.¹⁰⁷ 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.¹⁰⁸ Infection may occur due to a short but intense dose of infectious virus or following prolonged or repeated exposure to a smaller dose. Initial evidence from animal studies suggests that the minimum infectious dose varies by species but may be slightly higher than SARS-CoV-1 and lower than Middle East Respiratory Syndrome (MERS), e.g., approximately a few hundred viral particles.^{61,63,109-112} No human studies have been completed at the time of writing to establish infectious dose, but human challenge trials are due to begin in the UK in 2021 to determine the minimum dose needed to cause infection.¹¹³ Animal studies have indicated that infectious dose and subsequent distribution of the virus in the host may vary by the route of infection.^{107,114} 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).^{115,116}

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.^{107,117} 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.^{107,118-120} 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.¹²¹ Mink farms in Spain, Sweden, Italy, and the US have also been affected by COVID-19 outbreaks.¹²² 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.¹²³ Continued identification and surveillance of cases of zoonotic transmission is ongoing around the world to understand transmission pathways and the risk to humans.

Period of infectiousness

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.^{107,124} The mean incubation period (time between exposure to the virus and the appearance of symptoms) has been estimated to be around five days,^{125,126} with modelling indicating a range of about two to 11 days (2.5th and 97.5th percentiles).^{127,128}

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.^{51,129-134} Pre-symptomatic persons can potentially infect others one to about three days before symptom onset.^{124,133} For asymptomatic spread, the period of transmission is still being investigated.^{135,136} 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.^{137,138} 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.¹³² 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.¹³⁹ 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.^{51,134,140,141}

Symptomatic transmission

Current evidence suggests that while peak infectiousness occurs slightly before symptom onset, most transmission occurs during the symptomatic phase.¹⁴⁰ 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.^{142,143} 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.^{48,128,144,145} In a limited number of severe to critical cases, infectious virus has been detected for > 30 days.¹⁴⁴ 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.^{136,142} Median viral loads have been found to be between 10⁴ and 10⁶ copies per mL of respiratory fluid with an average emitter releasing about 10⁶ copies per ml, but levels up to 10¹¹ copies per mL have been detected in some cases.^{48,142,143,146} 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.¹⁴⁷ 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 small number of people are responsible for a large numbers of infections.¹⁴⁸⁻¹⁵⁰

Persons who have been infected with COVID-19 may continue to shed virus beyond the period of infectiousness and after symptoms have resolved.^{48,128,145} Persistent shedding of viral RNA may be responsible for some patients testing positive again after an apparent negative RNA test.^{145,151}

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.¹⁵²

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.^{81,153,154} 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.⁸⁵ 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.¹⁵⁵

Humidity

Humidity may influence viral transmission by affecting how droplets move and their rate of decay and can influence susceptibility of individuals to infection.¹⁵⁶ 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 deposited droplets remain viable. In contrast, warm dry environments could enhance evaporation of droplets, resulting in a greater number of aerosols being dispersed.¹⁵⁷ 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.^{153,156} 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.^{158,159} 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.¹⁵⁶

- See more from the NCCHEH 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,^{160,161} 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.¹⁶² 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.¹⁶³⁻¹⁶⁶ UV irradiation has also been proposed as a decontamination method for personal protective equipment (PPE) contaminated by SARS-CoV-2.^{91,167,168} Initial results suggest that UV treatment may be more effective on smooth surfaces such as steel as compared to fabrics or porous materials.¹⁶⁹ The use of UV-C for disinfection carries some risk, as UV-C can be harmful to human skin

and eyes. 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](#).

The information provided in this *Introduction to SARS-CoV-2* 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. 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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