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SARS-CoV-2 transmission: Findings and proposed terminology

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The appendices to this document are only available in French version.

Glossary

Aerosols: Particles suspended in the air whose movements are governed mainly by their size, generally less than 100 μm (conventionally called droplets when larger than 5 μm). These particles are potentially inhalable and can be classified according to the anatomical sites where they deposit in the respiratory tract:

- Nasopharyngeal particles, deposit in the nose or throat, ≤ 100 μm
- Tracheobronchial particles, deposit in the bronchi, ≤ 15 μm
- Alveolar particles, reach the pulmonary alveoli, ≤ 5 μm, conventionally referred to as droplet nuclei

Bioaerosols: Aerosols that contain biological material

Culturable: The ability of microorganisms such as viruses to reproduce on appropriate cell cultures under suitable conditions. The fact that a virus is culturable does not mean it is infectious.

Droplets: Previously defined as particles typically larger than 5 μm. Now included in the definition adopted for aerosols.

Drops: Particles larger than 100 μm that can deposit directly on the mucous membranes of the nose, mouth, or eyes and on surfaces or objects, depending on their ballistic trajectory (therefore not inhalable).

Infectivity: The ability of a pathogen (such as a virus) to transmit to, survive in, and multiply in a host.

Particle: A small portion of solid or liquid matter.

Transmission: The process by which a pathogen passes from a source to a host in such a way as to cause an infection in the host.

Tropism: The propensity of an infectious or parasitic agent to target a specific organ, tissue, or cell type.

Key Findings

As the SARS-CoV-2 virus drives a worldwide pandemic, our scientific understanding of how it is transmitted is constantly evolving. There is an ongoing debate on various aspects of this process, particularly aerosol transmission. In part, this debate reflects a lack of consensus on the definitions of the terms used to describe the transmission of infectious agents via the respiratory tract.

This text presents a review of the scientific literature focused on the aerosol mode of transmission, but also includes information about other modes of transmission. Authored by a multidisciplinary team, the report seeks to inform the decision-making process of public health authorities, teams of experts, ministerial policymakers, and health and social services facility managers.

Until now, infection prevention and control recommendations have been based on a dichotomous approach, i.e., infection transmission via droplets vs. airborne routes. Yet, the growing body of knowledge on the dynamic aspects of aerosols is paving the way for an approach that suggests transmission is dependent on a continuum of particles ranging in size from drops to aerosols.

The following findings emerge from this multidisciplinary analysis of experimental and epidemiological data:

- SARS-CoV-2 is transmitted primarily when people are in close contact (within 2 meters) for more than 15 minutes.
- The available experimental and epidemiological data support short-range transmission by aerosols, i.e. within 2 meters.
- The risk of SARS-CoV-2 transmission increases in closed, crowded, and poorly ventilated spaces and with prolonged exposure. The data indicate that close contact transmission remains the main route involved. However, the data also suggest that aerosol transmission over longer distances could occur. The maximum distance is uncertain, but is unlikely to exceed a few meters.
- The presence of SARS-CoV-2 RNA and infectious virus in the air does not systematically imply airborne transmission, unlike with tuberculosis. At present, there is no direct evidence unequivocally demonstrating airborne transmission of SARS-CoV-2.

SARS-CoV-2 transmission can be limited by implementing prevention and protection measures in the community, workplaces, and healthcare settings. These measures include:

- Contact restrictions
- Physical distancing
- Mask wearing
- Physical barriers
- Respiratory hygiene and etiquette
- Hand hygiene
- Adequate ventilation
- Environmental cleaning and disinfection
- Application of routine practices and additional infection prevention and control (IPC) precautions in healthcare settings

The information and findings presented in this report will be updated regularly as our knowledge of SARS-CoV-2 transmission evolves.

Summary

Institut national de santé publique du Québec (INSPQ) teams reviewed the scientific literature on SARS-CoV-2 transmission to produce a body of scientific knowledge designed to inform the decision-making process of public health authorities, teams of experts, ministerial policymakers, and health and social services facility managers. The main objective of this document is to describe the SARS-CoV-2 transmission process by addressing the aerosol transmission aspect in greater detail.

The report includes a description of the terminology used, a section on aerosol dynamics, including dispersion, inhalation potential, microbial load, and infectivity, and a summary of the positions held by various public health organizations on SARS-CoV-2 transmission. An overall description of SARS-CoV-2 transmission is presented. The literature review focuses on the scientific data related to aerosol transmission of SARS-CoV-2.

Recommendations for the prevention and control of infections associated with the droplet and airborne modes of transmission have thus far been based on an approach which, although dichotomous, has proven effective in preventing and controlling the transmission of infections such as influenza and tuberculosis. However, SARS-CoV-2 requires an approach that better reflects the growing body of knowledge about the dynamic aspects of aerosols and that suggests transmission is dependent on a continuum of particles of varying size.

Methodology

The findings reported in this document derive from two short literature reviews conducted by the nosocomial infection and environmental health teams at INSPQ. They bring a transdisciplinary perspective to the report.

The nosocomial infection team surveyed current knowledge on SARS-CoV-2 transmission via aerosols by reviewing scientific publications and pre-publications available as of September 15, 2020.

The review was carried out by consulting bibliographic databases (Medline, Embase, via the Ovid search engine) using keywords related to airborne transmission in the context of COVID-19, as well as the COVID-19 scientific watch produced by INSPQ.

Meanwhile, the environmental health team reviewed the literature on the presence of SARS-CoV-2 in the air, its viability in the environment, and modes of COVID-19 transmission (both aerosol and fomite).

An Inoreader search in combination with a snowball strategy was used to compile the studies on this subject. The same strategy was employed for studies of COVID-19 outbreaks where long-range or fomite-borne infections were suspected. The teams reviewed articles published in French and English through September 30, 2020, and included articles on aerosols and fomites published since then. They also assessed non-peer-reviewed articles available on medRxiv.

Furthermore, a non-systematic review of scientific and gray literature was conducted to document the terminology related to aerosols and identify various organizations' positions with regards to COVID-19 modes of transmission.

This document was subject to an internal consultation involving teams of experts working on COVID-19 at INSPQ (environmental health, occupational health, nosocomial infection, population measures, case management and contacts), as well as external experts: the Comité sur les infections nosocomiales du Québec (CINQ) and the COVID occupational health working group (SAT-COVID).

Definitions

Once the terminology review was completed, a model adapted from Roy and Milton (2004) and used in Québec's occupational health field was chosen to facilitate the adoption of a transdisciplinary terminology at INSPQ. INSPQ's position regarding SARS-CoV-2 transmission and the findings described herein is based on the following definitions:

Term	Definition
Aerosols	Particles suspended in the air whose movements are governed mainly by their size, generally less than 100 µm (conventionally called droplets if larger than 5 µm). These particles are potentially inhalable and can be classified according to the anatomical sites where they deposit in the respiratory tract: ▶ Nasopharyngeal particles, deposit in the nose or throat, ≤ 100 µm ▶ Tracheobronchial particles, deposit in the bronchi, ≤ 15 µm ▶ Alveolar particles, reach the pulmonary alveoli, ≤ 5 µm
Droplets:	Formerly defined as particles typically larger than 5 µm. Now included in the definition adopted for aerosols.
Drops	Particles larger than 100 µm that can deposit directly on the mucous membranes of the nose, mouth, or eyes and on surfaces or objects, depending on their ballistic trajectory (therefore not inhalable).

The findings below emerge from this multidisciplinary analysis of the available experimental and epidemiological data, guided by the above definitions:

- SARS-CoV-2 is transmitted primarily when people are in close contact (less than 2 meters) for an extended period (over 15 minutes).
- The risk of SARS-CoV-2 transmission increases in closed, crowded, and poorly ventilated spaces and with prolonged exposure.
- The available experimental and epidemiological data support short-range (within 2 meters) transmission by aerosols.
- The data indicate that under specific conditions, such as in closed, crowded, and poorly ventilated spaces and with prolonged exposure (over 15 minutes), close contact transmission (less than 2 meters) is the main route involved. The data also suggest that aerosol transmission over longer distances could occur. The maximum distance is uncertain, but is unlikely to be more than a few meters.
- The presence of SARS-CoV-2 RNA and live virus in the air does not systematically imply airborne transmission, unlike with tuberculosis.[1] At present, there is no direct evidence unequivocally demonstrating airborne transmission of SARS-CoV-2.

[1] Obligatory airborne transmission concerns infections naturally transmitted only by aerosols that may travel very long distances (several meters) and that deposit in the lower respiratory tract, without invasive intervention. With this mode of transmission, a host can be infected without having to be in close proximity to the source person or even present in the same room at the same time (e.g., measles). Preferential airborne transmission concerns infections naturally transmitted by more than one mode of transmission, but for which the principal mode of transmission is airborne, as described above (e.g., chickenpox). Opportunistic airborne transmission includes infections that are usually transmitted by other modes, but which can also be spread by fine aerosolized particles under specific conditions, e.g., during aerosol-generating medical procedures (AGMP) (INSPQ, 2009).

These findings may be revised as new evidence becomes available. The lack of common definitions for the terminology associated with aerosols and the methodological limitations of existing studies drive home the need for more high-quality investigations that will clarify specific parameters, particularly the SARS-CoV-2 infecting dose and aerosol transmission over a long distance.

This rapid synthesis of the state of knowledge concerning SARS-CoV-2 transmission provides a scientific foundation experts can refer to as they revise or confirm recommendations specific to their fields. They will continue to collaborate to ensure that their recommendations are consistent and that differences or nuances between fields are clearly indicated.

All efforts should now focus on implementing a series of prevention and protection measures to limit SARS-CoV-2 transmission in the community, the workplace, and healthcare settings.

1 Introduction

With over sixty million COVID-19 cases reported worldwide, our understanding of SARS-CoV-2 has steadily deepened. Yet there is an ongoing debate over aspects of the virus's modes of transmission. Teams at Institut national de santé publique du Québec (INSPQ) (infectious diseases, nosocomial infections, occupational health and environmental health) reviewed the scientific literature on SARS-CoV-2 transmission to produce a body of scientific knowledge that could inform the decision-making process of public health authorities, teams of experts, ministerial policymakers, and health and social services facility managers.

The main objective of this report is to provide information on the SARS-CoV-2 transmission process, but primarily on the aerosol mode of transmission. After describing the methodology, we review the terminology used to describe the modes by which infectious agents transmit via the airways and put forth a proposal. Next, we discuss aerosol dynamics and summarize the positions of various public health and regulatory bodies regarding SARS-CoV-2 transmission, before providing an overview of the SARS-CoV-2 transmission process. The results and a discussion on viral transmission by aerosols and methodological limitations follow. Lastly, we present findings that reflect a concerted, multidisciplinary position on SARS-CoV-2. These findings can be translated by experts into specific recommendations and measures to be implemented.

The information presented in this document will be updated regularly as our knowledge of SARS-CoV-2 transmission evolves.

2 Methodology

This narrative review stems from two short literature reviews conducted by the nosocomial infection and environmental health teams at INSPQ. The studies selected allowed the teams to explore the overall process of SARS-CoV-2 transmission and, more specifically, to draw conclusions concerning aerosol-based transmission.

The nosocomial infection team surveyed the current knowledge of SARS-CoV-2 aerosol-based transmission by reviewing scientific publications and pre-publications available as of September 15, 2020. This review involved searching bibliographic databases (Medline, Embase, via the Ovid search engine) with keywords related to aerosol-based transmission in the context of COVID-19, as well as the COVID-19 scientific watch produced by INSPQ. The information obtained derived primarily from experimental models, as well as observational and epidemiological data. More details are provided in Appendix I (available in the French version of this paper).

The environmental health team reviewed the literature on airborne SARS-CoV-2, the viability of viruses in the environment, and COVID-19 modes of transmission. An Inoreader search in combination with a snowball strategy was used to compile the studies on this subject. The same strategy was employed for studies of COVID-19 outbreaks where long-range and fomite-borne infections were suspected. The teams reviewed articles published in French and English through September 30, 2020, but also included articles on aerosols and fomites published since then. They also evaluated non-peer-reviewed articles available on medRxiv. Further information on fomite transmission can be found in Appendix II (available in the French version of this paper).

At the same time, the teams conducted a non-systematic review of the scientific and gray literature produced by leading authorities in order to propose a terminology adapted to aerosol dynamics and review the positions of various organizations on COVID-19 transmission. For other factors studied (aerosol dynamics, contagiousness, infectious dose), studies were not systematically compiled.

This document was subject to internal consultations with INSPQ teams that deal with COVID-19 (environmental health, occupational health, nosocomial infection, population measures, case management and contacts), as well as with external experts: the Comité sur les infections nosocomiales du Québec (CINQ) and the COVID occupational health working group (SAT-COVID).

3 Terminology Related to Modes of Transmission for Respiratory Tract Infectious Agents

Prior to discussing SARS-CoV-2 transmission, we must first survey the terminology used to describe airway transmission of infectious agents. Debate over this terminology has been ongoing since the start of the pandemic. The scientific disciplines that study aerosol dynamics have been increasingly confronted with the lack of consensus on this issue. On the one hand, experts in infection prevention and control (IPC) and public health have traditionally used the term "aerosols"[2] to refer to very small respirable particles that can be carried through the air over long distances, as opposed to "droplets", which refer to larger diameter particles that settle more quickly. On the other hand, industrial hygiene experts define aerosols as particles that remain suspended in the air. They classify them by the anatomical sites where they deposit in the respiratory tract, among other things. Table 1 summarizes a wide range of definitions proposed for these terms by various organizations and in scientific articles.

In short, the scientific community's lack of consensus on the definitions for droplets and aerosols has fueled an ongoing semantic and scientific debate. While recognizing these concepts are evolving, we believe this is an opportune moment to reposition them in the context of a process that is dynamic and not dichotomous. After completing the terminology review, we selected a model adapted from Roy and Milton (2004) by the Public Health Agency of Canada (2017) and employed in Québec's occupational health field to facilitate the adoption of a transdisciplinary terminology at INSPQ. The definitions below guided our analysis of the experimental and epidemiological data selected for review.

Aerosols: Particles suspended in the air whose movements are governed mainly by size; generally smaller than 100 µm (conventionally called droplets if larger than 5 µm). These particles are potentially inhalable and can be classified according to the anatomical sites where they deposit in the respiratory tract:

- Nasopharyngeal particles, deposit in the nose or throat, ≤ 100 µm
- Tracheobronchial particles, deposit in the bronchi, ≤ 15 µm
- Alveolar particles, reach the pulmonary alveoli, ≤ 5 µm **Droplets:** Formerly defined as particles, typically larger than 5 µm in size and now included in the definition adopted for aerosols

Drops: Particles larger than 100 µm in size that can deposit directly on the mucous membranes of the nose, mouth, or eyes and on surfaces or objects, depending on their ballistic trajectory (therefore not inhalable).

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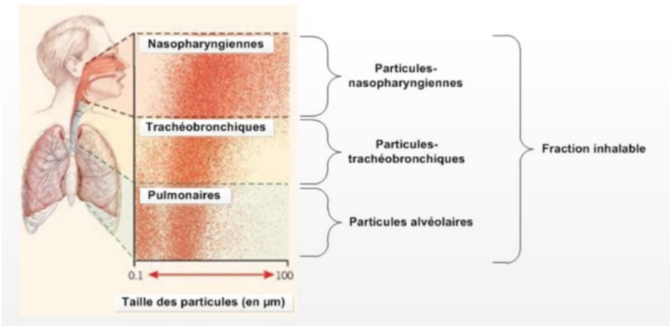
2 The term bioaerosols is also used and is defined as a particle suspended in the air upon which living or dead organic matter is found. A bioaerosol is considered infectious if it contains a biological agent capable of causing infection.

Table 1 Summary of definitions according to different organizations and scientific articles

Organization/scientific article and date	Definition/Characteristic		
	Droplets	**Aerosols**	**Droplet nuclei**
World Health Organization (WHO)	▸ Particles from 5 to 10 µm	▸ Particles smaller than 5 µm	▸ Particles smaller than 5 µm
Centers for Disease Control and Prevention (CDC)	▸ Particle diameter exceeds 5 µm	▸ Droplet nuclei or small particles that can remain suspended in the air and be inhaled	▸ Resulting from the desiccation of suspended droplets ▸ Diameter less than or equal to 5 µm
Public Health Agency of Canada (PHAC)	▸ Particle size exceeds 10 µm	▸ Solid or liquid particles suspended in the air ▸ Movements governed mainly by particle size, which is larger than 10 µm	▸ Airborne particles resulting from a droplet from which most of the liquid has evaporated ▸ Remain suspended in the air
INSPQ (up to now)	▸ Particles greater or equal to 5 µm in size that can be projected as far as two metres ▸ Do not remain suspended in the air ▸ May deposit on the mucous membranes of the eyes, nose, or mouth of the exposed person, as well as on nearby surfaces	▸ Particles that remain suspended in the air for long periods and over long distances (droplet nuclei < 5 µm)	
Institute of Medecine (2011)	▸ Respirable particles: diameter ≤ 10 µm that can be inhaled and penetrate into the alveoli, but can also deposit throughout the respiratory tract (equivalent to droplet nuclei) ▸ Inhalable particles: diameter from 10 µm to ≤ 100 µm that deposit in the upper respiratory tract		
Roy and Milton (2004)	▸ Ballistic drops: particles larger than 100 µm ▸ Inhalable particles: ≤ 100 µm that deposit in the nose or throat ▸ Thoracic particles: ≤ 10 µm and up to 15 µm that deposit in the bronchi ▸ Respirable particles: from 2.5 to 5 µm that can reach the pulmonary alveoli		
Tellier (2006)	Particles 5 µm in size that can remain suspended in the air at a height of 1.5 metres or more for up to 30 minutes		
Marr *et al.*, 2019	The time a particle remains suspended in the air depends not only on its aerodynamic diameter but also on its composition and the ambient conditions		

Figure 1 **Airways regions where particles of varying sizes deposit (adapted from Roy and Milton (2004) by PHAC, 2017)**



In short, aerosols are mainly generated when the infected source coughs, sneezes, speaks, or breathes. Their size is not static, as discussed in the next section.

4 Aerosol Dynamics

The behaviour of the aerosols presented in this section falls on a continuum not specific to SARS-CoV-2. As mentioned above, the term "aerosols" applies to any particle 100 µm or smaller that is emitted by the respiratory tract and is potentially inhalable. These particles consist mainly of water and can rapidly decrease in size as they dry out or break up after exiting the airways (Marr *et al*., 2019). In fact, particles emitted by the respiratory tract may decrease in size by up to 80% seconds after emission (Marr et al., 2019). A 10 µm particle exiting the nose or mouth can rapidly transform into a smaller particle before reaching the ground and may therefore remain suspended in the air for a longer period. The precise impact of this on the pathogens within these particles is unknown.

The suspension half-life in the air is variable and depends, among other things, on the particle's aerodynamic diameter. A particle with an aerodynamic diameter of 5 µm will remain suspended in the air for about 62 minutes before settling from a height of 3 meters to the ground. The suspension times are 17 minutes, 4 minutes et 10 seconds, respectively, for particles of 10, 20 et 100 µm for the same distance (Tellier, 2006). These estimates are based on data obtained in the laboratory and with the help of mathematical models. They depend primarily on gravitational force and air friction, per the suspended particles' aerodynamic parameters. Under real-life conditions, these figures will vary with air movement.

4.1 Dispersion

Particles smaller than 10 µm can disperse throughout a sick person's room and even beyond because they can remain suspended in the air for many minutes, if not for several hours, while spreading or being re-suspended by air movements (like particles containing tuberculosis or measles pathogens). Particles measuring 10 to 50 µm can travel beyond two meters, depending on the force of expulsion by the patient during aerosol-generating medical procedures (AGMP) and on the ambient conditions (Dionne *et al*., unpublished results). Particles in the 50 to 100 µm range do not travel more than two meters from their expulsion source. However, as mentioned above, these large liquid particles can dry up very rapidly upon contact with ambient air, decrease in size, and achieve a higher dispersal potential while retaining potentially infectious material.

4.2 Deposition efficiency of inhalable particles

A number of studies have estimated particle depositions in the respiratory tract (Brown *et al*., 2013, Oberdörster *et al*. 2005, Vincent, 2005). Despite some variance between these studies, the results are similar from one model to another. They show that only particles 10 µm or smaller deposit in the alveoli. The upper respiratory tract filters out particles larger than 10 µm. Vincent (2005) reported that deposition efficiency in the respiratory tract varies according to particle size. For people who breathe through their nose, particles with an aerodynamic diameter over 5 µm tend to deposit in the upper respiratory tract. In contrast, few particles in the 0.1 to 1 µm range deposit in the alveoli. Particles from 5 µm to around 12 µm in size deposit in the tracheobronchial tree with an efficiency exceeding 20% (Vincent, 2005).

4.3 Microbial load and infectivity

A particle's size and aerodynamic diameter are important because they determine its potential to be inhaled. These factors also influence the amount and viability of viruses present on different size particles.

In human studies, some influenza A strains (detected using the nucleic acid amplification test, or NAAT) were more present in particles under 5 µm in size (Milton *et al*., 2013, Nguyen-Van-Tam *et al*. 2020). A study of infected people showed that 7% of aerosols over 5 µm exhibited positive NAAT results for influenza A and that this proportion rose to 16% for aerosols 5 µm or smaller in size (Nguyen- Van-Tam *et al*. 2020). In a study of particles emitted when infected people coughed, influenza virus as measured by NAAT was found in 35% of particles over 4 µm in size, 23% of particles between 1 and 4 µm, and 42% of particles 1 µm or smaller contained (Lindsley *et al*., 2010).

In ferrets, again for influenza, the number of culturable viruses was about five times higher in particles larger than 4.7 µm compared with smaller particles (Gustin *et al*., 2011). The proportion of infected ferrets increased with particle size, with 10 out of 12 ferrets infected by particles smaller than 15.3 µm, 6 out of 12 infected by particles smaller than 7.9 µm, and 4 out of 12 ferrets infected by particles under 4.7 µm. Note that although most of the particles emitted by ferrets were smaller than 1.5 µm (77%), the majority of the virus was found on particles 4 µm or larger (Zhou *et al*., 2018). This experiment was reproduced in part by a Québec team that demonstrated ferrets could be infected via an airborne route only by particles larger than 1.7 µm (Turgeon et al., 2019).

In a study of viruses infecting pigs, only viruses contained in particles larger than 2.1 µm were found to be culturable (Alonso *et al*., 2015).

The significant variability observed in the above data points to the complex nature of aerosols and the lack of details concerning the exact size of infectious particles. However, the data appear to indicate that very small particles are less infectious. Note that studies in humans were conducted using NAAT but did not provide information on infectious potential, while animal studies reported data based on cultured viruses.

5 Positions of Various Public Health and Regulatory Bodies on SARS-CoV-2 Transmission

INSPQ also examined the SARS-CoV-2 modes of transmission reported by various recognized organizations.

The Centers for Disease Control and Prevention (CDC) stated that although long-range SARS-CoV-2 transmission by aerosols may occur under certain conditions, i.e., in inadequately ventilated indoor settings where there is prolonged exposure, the primary transmission route is via close and prolonged contact between infected and susceptible individuals. Their view is shared by the World Health Organization (WHO), France's High Council of Public Health (HCSP), the Government of the United Kingdom, the National COVID-19 Science Task Force in Switzerland, the State of Victoria in Australia, Toronto Public Health, the National Collaborating Center in Environmental Health (NCCEH), and Health Canada. Conditions conducive to long-range aerosol-based transmission include confined spaces with high occupant density and favourable environmental conditions (temperature and humidity), or spaces where activities such as singing or physical exercise occur.

Some organizations have issued engineering guidelines for buildings related to SARS-CoV-2 aerosol-based transmission. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) states in a paper on infectious aerosols that there is a sufficient risk of airborne SARS-Cov-2 transmission to warrant control measures via modifications to heating, ventilation, and air-conditioning systems. The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) issued recommendations for operating ventilation, heating, and air conditioning systems so as to prevent SARS-Cov-2 transmission. They assert there is evidence for long-range SARS-Cov-2 aerosol-based transmission and that it is now a recognized route, but indicate that the relative importance of different modes of transmission remains to be determined. The American Conference of Governmental Industrial Hygienists (ACGIH), in a report on ventilation in industrial settings during the COVID-19 pandemic, states that disease transmission is likely to occur via the inhalation of infectious particles suspended in the air over long periods or dispersed by indoor air currents.

6 SARS-Cov-2 Transmission Process

Drawing on current knowledge, we can portray the SARS-CoV-2 transmission process by summarizing a set of closely linked and complex relationships between the source of the infectious agent (the microorganism), the host, and the environment. Note that not all exposures result in infection.

6.1 Emitter

When infected and contagious persons breathe, talk, cough, sneeze or sing, they emit varying amounts of different size particles. As mentioned above, a number of studies found viral RNA in these particles, indicating that airways shed SARS-CoV-2 virus (Chia *et al*., 2020; Guo et al., 2020; Lei *et al*., 2020; Liu *et al*., 2020; Razzini *et al*., 2020; J. Zhou *et al*., 2020). Though rarely detected in culture, a few studies also identified viral RNA in stools (Cheung et al*.,* 2020), confirming the virus's presence in the gastrointestinal tract. However, the available data indicate the virus may not be as viable, and there are no reported cases of oral-fecal transmission.

Viral shedding

The amount of virus shed varies with disease stage. A meta-analysis suggests that SARS-CoV-2 viral loads in the upper respiratory tract peak with the onset of symptoms and for about a week after but then gradually drop in subsequent weeks (Walsh *et al*. 2020). The amount of virus shed by the respiratory tract appears to be associated with periods where the disease is most contagious, i.e., close to the onset of symptoms (Cheng *and al*., 2020) and in the two days prior to their appearance (INSPQ, 2020). However, the exact correlation between viral shedding (as measured by NAAT diagnostic tests) and contagiousness is unclear.

Contagiousness

Both asymptomatic and pre-symptomatic people are contagious. The exact relationship between particle size and SARS-CoV-2 infectivity is not well understood. Animal studies indicate that infectivity appears to increase with particle size (see 4.3). Although the smallest particles more easily reach the alveoli, current data is insufficient to correlate this finding with increased infectivity.

6.2 Transmitter

The largest particles, those over 100 µm (drops), can deposit directly in the mucous membranes of the nose, mouth, and eyes. At close range, they can also deposit on surfaces or objects and contribute to transmission through direct contact (for example, by shaking hands) or indirect contact via fomites[3] (e.g., by touching a doorknob), the latter being of less importance. Aerosols of varying size (under 100 µm) travel per their aerodynamic diameters (maximum distance not specified, but probably a few meters).

Environmental parameters that influence transmission

As with other respiratory infections, the transmission of SARS-Cov-2 is affected by environmental factors such as temperature, humidity, ultraviolet (UV) rays, and the virus's survival in the environment. High temperatures and UV radiation promote viral inactivation, but the effect of humidity is less straightforward.[4]

6.3 Recipient

Below we discuss some of the many factors that influence the development of the SARS-CoV-2 infection in individuals.

3 Appendix II to the French version of this paper presents a short literature review on fomite transmission. Appendices are available in the French version only.

4 Consult this COVID-19 document for more information (French version only): Environnement intérieur, at https://www.inspq.qc.ca/publications/2992-environnement-interieur-qr-covid19

Host

Host receptivity is required for an infection to develop. Therefore, an exposed person's immune status is a critical factor in the development of an infection after exposure. Since this is a new virus, non-vaccinated populations not previously exposed are considered vulnerable. The host's age and co-morbidities impact disease severity.

Tropism

An infectious agent's tropism is defined as the preferred entry point(s) (target tissues or cells) it uses to infect a host. It is well known that coronaviruses must first bind to angiotensin-converting enzyme 2 (ACE2) receptors in order to enter the host cells and replicate. However, there is a higher concentration of ACE2 receptors in the nasal mucosa cells, which is why the nasopharyngeal mucosa may constitute an initial site for an infection. Researchers have shown that SARS-CoV-2 binds to ACE2 receptors with 10 to 20 times more affinity than does SARS-CoV-1 on account of its surface (S) protein (the spike protein) that promotes such binding.

As a result, the largest viral loads in the initial disease stage are found in the upper respiratory tract (nasopharynx and oropharynx). It also appears the virus is less likely to colonize the distal bronchioles and alveoli (Zhang *et al*., 2020).

Using a digital simulation, Basu (2020) calculated the percentage of particles of different sizes that deposit in the nasopharynx (other sites were not studied):

- 43% were 10 to 14 µm particles
- 24% were larger particles (15 to 19 µm)
- 23% were 2.5 to 9 µm particles

Recall that, according to the Roy and Milton (2004) model, aerosols ranging from 15 to 100 µm in size deposit in the nasopharynx (see Section 2.1).

Infectious dose

The fact that viable virus particles are present in the air around infected individuals does not necessarily mean the particles are contagious. A sufficient quantity of virus (infectious dose) must be transmitted and inhaled within a short period for a person to become infected. One or a few viral particles does not usually suffice. The SARS-CoV-2 virus dose needed to infect a human is unknown and may vary from person to person. However, aerosols of different sizes may contribute to the COVID-19 infectious dose. Utilizing data reported by Bao *et al*. (2020), the US Department of Homeland Security (DHS 2020) reported that mice became infected after aerosol (<5.7 µm) exposure to between 630 and 756 culturable viral particles (PFU). According to a narrative review published by the US Department of Homeland Security (DHS, 2020), it would probably take less than 1000 PFU to infect a human. That said, however, there is much uncertainty regarding estimates of the infectious dose for humans due to the absence of human studies.

The number of viruses shed may have some connection to the infectious dose. In theory, when the required infectious dose is low, the disease will be more easily transmitted. The number of viruses transmitted will correlate with exposure time to the person shedding virus. A lower infectious dose means it takes less exposure time to a given viral concentration for the disease to transmit. However, there are many unknowns, such as the particle size needed for a virus to remain intact and retain its replication capacity (and how aerosols of different sizes contribute to transmission.

Exposure time and contact proximity

Exposure time appears to be a significant but not absolute variable. A case-controlled study in Thailand investigated SARS-Cov-2 transmission risk factors and showed that the proportion of contact incidents that resulted in cases rose rapidly with contact duration. For contacts of 15 minutes or less within a distance of one meter, 5 (2.5% of cases) developed SARS-CoV-2. This proportion rose to 7% for contacts lasting 15–60 minutes, and to 90% for contacts exceeding 60 minutes. The proportions also rose steeply with closer contacts; over two-thirds of the contact incidents that evolved into cases were due to direct physical contact. The proportions were very different for contact incidents that did not develop into cases. The adjusted odds ratios were 0.15 (95% CI 0.04-0.63) for those with no contact compared to those with direct physical contact and 0.24 (95% CI 0.07-0.90) for those within one meter for less than 15 minutes compared to those within one meter for over an hour (Doung-Ngern *et al*., 2020).

Reproduction rate

According to a literature review of peer-reviewed studies, the SARS-CoV-2 reproduction rate prior to implementation of control measures was between 2.3 and 2.6 (Biggerstaff *et al*. 2020). In comparison, the influenza reproduction rate during the 2009 pandemic was about 1.7, and the SARS-CoV-1 reproduction rate was 2.4 (Petersen *et al*., 2020). The reproduction rate is associated with virus contagiousness and not solely with transmission mode.

7 Short Literature Review on Aerosol Transmission - Results and Discussion

Despite the methodological limitations of most studies, which we will look at later on, specific findings emerge from the transdisciplinary analysis of the available experimental and epidemiological data. These findings will need to be re-assessed as new data becomes available.

7.1 Epidemiological and experimental data on aerosol transmission

A number of published epidemiological studies suggest that long-range aerosol-based transmission is possible. These studies do not share a uniform concept of distance, but we opted for a distance greater than two meters for this review. To unequivocally demonstrate aerosol-based transmission beyond two meters, investigators must also ensure subjects have not had any close contacts or any indirect contacts through an object or the environment (to eliminate the possibility of fomite transmission, for example). Such a demonstration is feasible, but the conditions required to observe it during a community outbreak rarely exist. One successful example was a measles study where researchers were able to demonstrate that transmission took place over a distance of several meters with no intermediary object between an infected person and spectators in a stadium (Ehresmann *et al*., 1995).

The authors of several studies have attempted to detect the virus in the air around people infected with SARS-CoV-2 (see review by Birgand *et al*., 2020). The studies reviewed by Birgand *et al*. employed various virus sampling methods. Some methods were suitable for measuring the number of virus particles in the air, but not necessarily their infectious potential. The authors of the studies cited in this literature review reported that the concentration of viral RNA in aerosols was very low in the vicinity of patients placed in isolation rooms with mechanical ventilation. Higher viral RNA concentrations were detected in the air in bathrooms, public areas, and staff rooms. Even so, the presence of viral RNA confirmed in air samples does not mean that SARS-CoV-2 retains its infectivity. The authors of five of these studies also tried culturing viruses from samples collected near infected patients (Santarpia *et al*., 2020A, Lednicky *et al*., 2020, Zhou *et al*., 2020, Santarpia *et al*., 2020B, Binder *et al*., 2020), succeeding in two cases. In the first of these two studies, viruses were cultured on 4 µm or smaller particles from samples taken at the foot of patients' beds (Santarpia *et al*., 2020A). It is possible these patients emitted these particles in their vicinity, but after settling, they became re-suspended. In the second study (Lednicky *et al*., 2020), viable virus particles were isolated from air samples taken at a distance of 2 to 4.8 meters from two patients. The SARS-CoV-2 strain genome sequence isolated from the material collected in these air samples was identical to that isolated from the nasopharyngeal swab of a patient with an active infection. The authors did not specify if patients had moved around during the experiment. So it is possible the sample contained particles emitted at less than two meters.

Three other authors failed to collect live virus (Zhou *et al*., 2020, Santarpia *et al*., 2020B, Binder *et al*., 2020). There are a number of explanations for this. In the study by Zhou *et al*. (2020), the sampler drew air in at a very high rate (300 litres per minute), which could have affected virus survival. The virus was also detected by NAAT in the air in low quantities with cycle threshold values (calculated viral loads) exceeding 30 (indicating the presence of viral particles, viable or not, in low amounts). The point is pertinent, given that cycle threshold levels correlate with viral amounts. Indeed, 34.3 is the lowest cycle threshold observed for a successful culture of SARS-CoV-2 with the technique used in the study (Walsh *et al*. 2020).

7.2 Epidemiological studies of outbreaks and superspreader events

The study by *Lu et al*. (2020) in a restaurant in China has often been cited as demonstrating the possibility of long-range transmission by aerosols. Another study along these lines, but not peer-reviewed, analyzed possible long-range aerosol-based transmission from person to person in much greater detail (Li *et al*., 2020). In the latter case, the authors used surveillance video data to assess whether people had been in close contact and their exposure times. They also used tracer gases to estimate aerosol dispersion in the room. Their video and tracer gas data revealed that diners seated at the index case's table were quite active, often getting up during the meal, unlike diners at adjacent tables where secondary cases were identified. There was no interaction between diners at the different tables. Although six of the contacts who developed the disease were within two meters of the index case, three other contacts were more than two meters away (2.4, 3.6, and 4.6 meters). The tracer gas analyses strongly suggested that, due to the seating arrangement and the airflow caused by the air conditioning, all three tables were similarly exposed to particles emitted from the index case for more than 53 minutes. It should be noted that there was no viral transmission to persons seated at other tables, nor to the restaurant staff. Tracer gas analyses also showed that the aerosol concentrations emitted by the index subject would have been lower elsewhere in the restaurant. It is possible that in this instance the particular type of airflow caused by the air conditioners, the lack of ventilation, the limited space, the index case's activities, and the prolonged exposure time in a remote corner of the restaurant led to aerosol-based transmission at a distance beyond two meters. It would appear that the peculiar draft conditions in this section of the restaurant could have exposed diners seated more than two meters away to conditions similar to those experienced by diners nearer the index case.

The study by Shen *et al*. (2020) also suggests that aerosol-based transmission can occur over long distances. This study focused on an outbreak in a bus and in a Buddhist temple in China's Zhejiang Province. The comparisons involved exposed bus passengers who attended a temple event and event participants who were not on the bus. A total of 300 people attended the temple event, 68 of them passengers on the bus. All bus passengers were from the same district. The bus had a ventilation system set to reheat and recirculate mode. Participants at the temple mingled in a large crowd and no one wore a mask. A meal was served, with 10 people at each round table. The meal lasted 15 to 30 minutes. The bus passengers were not seated together for the meal and were randomly distributed throughout the group. The index case reportedly began developing symptoms the evening after returning home. A total of 24 of the 68 passengers on the bus (excluding the index case) developed an infection. Of the other individuals in attendance at the temple ceremony, 7 were diagnosed with COVID-19, all of whom reported having been in close contact with the index case. The authors concluded that airborne transmission via recirculated air likely contributed to the outbreak in the bus. However, the study had significant limitations that call into question the scope of this conclusion. First, the authors wrote that all the bus cases were infected due to contact with the index case. However, the secondary cases reportedly developed symptoms between 2 and 24 days later, with 16 confirmed cases out 32 having been declared 10 days or more after the index case and another 6 cases 15 days or more after the index case. It is therefore likely that a significant number of secondary cases that occurred well after the index case were infected through tertiary rather than secondary transmission chains. We cannot know if the index case had prolonged close contact with everyone on the bus, although that is possible. It also cannot be ruled out that transmission occurred via indirect contact with the contaminated environment (via fomites) or that others on the bus were contagious at the same time as the index case.

A Dutch study reported on an outbreak in a nursing home (de Man *et al*., 2020). The authors described a situation where 17 out of 21 residents in a nursing home ward were diagnosed with COVID-19 using NAAT. Subsequently, 17 out of 34 healthcare workers were diagnosed with COVID-19. Healthcare workers at the facility were required to wear surgical masks only when providing patient care. The residents were in single rooms but could move about and spend part of the day in common rooms without wearing masks. In the ward, the ventilation system operated in such a way that outside air was mixed with inside air only when carbon dioxide levels exceeded 1000 ppm. Otherwise, the air circulated without filtration. Two air conditioning units also circulated the air. SARS-CoV-2 RNA was detected in the air conditioning units and in three of the ward's ventilation cabinets. The authors gave three reasons to explain why the data indicate the outbreak was caused by long-range aerosol-based transmission: 1) the outbreak among patients and staff was very rapid, even though staff members wore surgical masks when around patients, 2) the outbreak occurred in a ward with an unfiltered air recirculation system where the virus was detected in the ventilation system, and 3) the outbreak happened at a time when community transmission in the surrounding area was low. The residents apparently did not wear masks, were mobile, and socialized together. The authors did not analyze the ventilation settings or when the ventilation unit was turned on or off. The staff did not wear masks when they were not with patients, so there was a very real possibility of close contact transmission between staff members. Also, the chronology of staff infections did not match that of resident infections. The residents were affected first and the staff later on. These data suggest that transmission may have occurred due to close contact.

Another study, Park *et al*. (2020), is sometimes cited as demonstrating long-range aerosol-based viral transmission at a South Korean call centre. The investigation involved 922 employees working in commercial offices, 203 apartment residents, and 20 visitors. Of the 1,143 people tested for COVID-19, 97 (8.5%) came back positive. Ninety-four of them worked on the 11th floor, where there were 216 employees (a 43.5% attack rate). Most of the employees on the 11th-floor call centre worked on the same side of the building. The household member secondary attack rate among symptomatic patients was 16.2%, with 34 confirmed cases. The first case identified worked in an office on the 10th floor and allegedly never visited the 11th floor. He reportedly showed symptoms on February 22. The article provides no information on how the first two cases could have been linked. The second case, a call centre employee who worked on the 11th floor, developed symptoms on February 25. The researchers were unable to trace this case to another cluster or an imported case. Despite the considerable interactions between workers on different floors of the building and in the elevators and lobby, the spread of COVID-19 was limited almost exclusively to the 11th floor. Given that COVID-19 transmission was confined to this floor, the researchers point out that interaction (or contact) duration was likely the main factor in the spread of SARS-CoV-2. However, the study does not address the type of transmission that led to the outbreak. The authors hypothesize that the duration of exposure may have been a key factor since most cases were on the same floor and in close proximity. No mention was made of the environmental conditions at the call centre (including ventilation).

A study from China, cited as demonstrating long-range transmission, investigated a shopping centre outbreak (Cai *et al*., 2020). The index case reported to the hospital on January 20, 2020, after 11 days of fever and headaches. On January 21, this patient and a co-worker tested positive for SARS-CoV-2. On January 22, the shopping centre where the index case worked was closed. By January 28, 7 co-workers on the 7th floor and 10 customers had been diagnosed with COVID-19. The 6 co-workers who shared the same office as the index case were also diagnosed with COVID-19. Six other cases working on four different shopping centre floors were also diagnosed. These workers reportedly had no direct contact with the workers on the 7th floor, but the 10 customers had apparently had direct contact with these cases. The authors did not define what constituted direct contact. The average incubation period for the cases was 7 days and ranged from 1 to 17 days. A person believed to have been the source of the infection had reportedly returned from Wuhan on December 18, 2019. On January 15, 2020, she experienced a fever for the first time. She was tested on January 30, and her result came back positive. Given that in a number of the cases, no contacts with any other case could be traced, the authors postulated that long-range transmission in the shopping centre (by either aerosols or by fomites) might have led to the outbreak among workers who were not in direct contact with the 7th-floor cohort. This interpretation is highly speculative because, for the workers who developed COVID-19, no information was provided on possible contacts, including remote contacts. The authors suggested that transmission could have occurred in the elevators, restrooms, or dining areas, but this does not constitute proof of long-range transmission.

Another frequently cited example of aerosol transmission concerns an outbreak stemming from a choir practice involving 61 people the state of Washington in the United States. After a 150-minute practice, 87% of the choir members developed symptoms compatible with COVID-19 within 12 days, and 54% tested positive (Hamner *et al*., 2020). One person who tested positive was reportedly symptomatic at the time of the practice, although the authors could not rule out the possibility that other people may have transmitted COVID-19 to this group of singers. There were no social distancing or protective measures taken during the practice. In this context, transmission by close contact and by aerosols within two meters probably explains the vast majority of cases.

A German study claiming to demonstrate long-range aerosol-based transmission in a meat processing plant was published, but not peer-reviewed (Günther *et al*. 2020). The study calculated infection risks based on where employees worked at the facility and the spatial relations within their work teams in order to identify contacts or a potential source. They employed statistical tests with no epidemiological investigation. The results indicated that 4 out of the 6,289 employees were positive in the days preceding the investigation but were considered to be unrelated cases. Two people considered to have had insignificant contact with a case continued to work until day four, at which time they tested positive by NAAT. Eight days later, 140 workers on the same shift were tested, and 18 were positive. In the days that followed, 11 new cases were detected by NAAT. The outbreak continued, with more than 110 new cases identified. The following month, more than 1,400 employees tested positive. The investigators genotyped viruses from the first two cases, as well as the 20 cases that followed. The genotyping indicated that only one of these two cases was the source of the other 20 cases. The authors found that being positioned within 8 meters of the index case on the production line strongly correlated with transmission of the index case virus. It should be noted that one of the workers, who worked within a meter of the index case, had no fixed station. Also worth noting is that a number of these cases were agency workers, which means they may have also worked elsewhere. Other employees shared apartments and travelled together in vans to get to work. The researchers compiled data from the company but apparently did not talk to the cases directly and, therefore, could not assess if they had been in close contact with the index case at other times or with other cases—a significant limitation of this study.

A Slovenian study by Brlek *et al*. (2020) also raised the possibility of indirect transmission at a squash court. The study covered an outbreak of 5 cases at a time when there was little community transmission in Slovenia. However, the two pairs of players who followed the index case pair had spoken together outside the court, which suggests they knew each other. Workers at the sports centre were questioned, and none reported symptoms. Apart from aerosol-based transmission or indirect contact with the contaminated environment (fomites), the only plausible alternative is that another individual at the centre was infectious but likely asymptomatic. This person would not have been responsible for the index case or the partner, but could have explained transmission to the other cases. Given the varying incubation times, it is also quite possible that all the cases contracted the virus from the same source. This study shows the difficulty in using an epidemiological investigation to distinguish between close contact transmission and long-range aerosol-based transmission.

Another study focused on risk factors present during superspreader events in closed indoor settings (nightclub, boxing stadium, and an office). This case-control study, conducted in Thailand, included 211 cases and 839 controls (Doung-Ngern *et al*., 2020). The authors reported that 98% of the contacts who contracted SARS-CoV-2 had been within one meter of the index case. The rest had stayed more than one meter away, but the exact distance and contact time were not specified. In total, 2.5% of the observed COVID-19 cases were associated with contacts of less than 15 minutes and within one meter. This proportion increased to 7% for contacts of between 15 and 60 minutes, and 90% for contacts of over 60 minutes. The study suggests that almost all SARS-CoV-2 transmission cases during a so-called superspreader event are associated with a close contact period of 15 minutes or longer.

The majority of SARS-CoV-2 infections appear to be transmitted by a small number of people. In a study of case contacts, 80% of the infections were caused by 8.9% of the individuals (Bi *et al*., 2020). In another case-contact study, 19% of the cases produced 80% of the secondary infections (Adam *et al*., 2020). A modelling study came to similar conclusions: about 10% of the cases resulted in 80% of the secondary infections, often in the context of superspreader events (Endo *et al*., 2020). Significant one- time transmission events have been documented in the literature, even for events lasting an hour (Prakash, 2020). Significant transmission situations also seem to arise where index cases are mildly symptomatic or asymptomatic (Prakash, 2020). The incidence of so-called COVID-19 superspreader events decreases with the implementation of certain public health measures. For example, in Tianjin, China, before control measures were implemented, the over-dispersion parameter *k*[5] was 0.14, while after measures were implemented, the *k* increased to 0.77 (Zhang *et al*., 2020). Thus, it would appear superspreader events are less likely following the implementation of public health measures, including a ban on special events with many people in attendance.

These studies, taken together, indicate a very high transmission risk in situations where one or more contagious individuals enter a closed, crowded space where it is impossible to remain two meters apart. These situations sometimes lead to superspreader events. Such events are often presented as evidence of airborne transmission, but even though they demonstrate the explosive potential of SARS-CoV-2 transmission and the virus's high level of contagiousness under certain circumstances, they do not necessarily demonstrate long-range transmission. To validate the long-range transmission route, future studies must convincingly demonstrate this phenomenon.

7.3 Experimental data on aerosol transmission in animals

Three animal studies examining airborne SARS-Cov-2 transmission present interesting results. Experiments with ferrets (Richard *et al*., 2020) and mice (Bao *et al*., 2020) reported that these animals were infected at close range (10 cm or less) via ambient air. Bao *et al*. (2020) showed that direct and indirect contact between mice led to a greater number of infections than airborne contact between mice in two cages separated by a steel grid. This study, like the one conducted by Richard *et al*. (2020), was unable to assess whether the virus could be transmitted over a greater distance by the airborne route. Nonetheless, in a non-peer-reviewed study, Kutter *et al*. (2020) recently reported airborne SARS-CoV-2 transmission over a distance of one meter in two out of four donor-recipient ferret pairs, confirmed by a serological response in the recipient animals. These studies seem to indicate that virus is present and infectious in airborne viral particles, but the experiments were not designed to determine which particle sizes contain virus.

7.4 Findings

The epidemiological and experimental studies discussed above give rise to several observations, which will have to be reviewed as new evidence emerges:

- SARS-CoV-2 is transmitted primarily when people are in close contact (less than 2 meters) for an extended period (over 15 minutes).
- The risk of SARS-CoV-2 transmission increases in closed, crowded and poorly ventilated spaces where there is prolonged exposure.
- The available experimental and epidemiological data argue for short-range (within 2 meters) transmission by aerosols.

[5] A statistical method that makes it possible to estimate the dispersion of secondary cases from primary cases. The lower the value, the greater the number of secondary cases generated by a small number of primary cases.

- The data indicate that under specific conditions, such as in closed, crowded, and poorly ventilated spaces and with prolonged exposure (over 15 minutes), close contact transmission (less than 2 meters) remains the main route involved. The data also suggest that aerosol transmission over longer distances could occur. The maximum distance is uncertain, but is unlikely to exceed a few meters.
- The presence of SARS-CoV-2 RNA and live virus in the air does not systematically imply airborne transmission, unlike with tuberculosis.[6] At present, there is no direct evidence unequivocally demonstrating airborne transmission of SARS-CoV-2.

7.5 Methodological limitations

This narrative review primarily sought to provide information on SARS-Cov-2 transmission by aerosols, based on two short literature reviews. As such, some studies may have been overlooked.

Generally speaking, interpretation of the results and conclusions of the studies analyzed must be tempered with caution due to the potential for biases that often crop up. Current knowledge is hampered by a lack of robust data and quality studies. Methodological problems limit the validity and generality of the results, particularly with respect to the following:

- Studies must elucidate transmission chains to demonstrate fomite or aerosol-based transmission, including significant contacts (close or distant). Without this information, it is impossible to demonstrate that transmission has taken place by one route or another. Unfortunately, very few published studies on this topic performed this essential type of analysis.
- Studies examining the virus's presence in aerosols are often lacking details about the research design or are insufficiently robust. Sometimes the absence of controls for confounding variables (the presence of patients, mask-wearing, ventilation systems, etc.) can impact the likelihood of aerosol detection.
- Air sampling techniques are of little help in detecting the virus's presence and confirming its viability.
- Comparisons with viruses other than SARS-CoV-2 in animals or community settings cannot easily be extrapolated to healthcare settings.
- Some of the studies were not peer-reviewed.

[6] Obligatory airborne transmission concerns infections naturally transmitted only by aerosols that may travel very long distances (several meters) and that deposit in the lower respiratory tract, without invasive intervention. With this mode of transmission, a host can be infected without having to be in close proximity to the source person or even present in the same room at the same time (e.g., measles). Preferential airborne transmission concerns infections naturally transmitted by more than one mode of transmission, but for which the principal mode of transmission is airborne, as described above (e.g., chickenpox). Opportunistic airborne transmission includes infections that are usually transmitted by other modes, but which can also be spread by fine aerosolized particles under specific conditions, e.g., during aerosol-generating medical procedures (AGMP) (INSPQ, 2009).

8 Conclusions

The scientific community's understanding of SARS-Cov-2 transmission is handicapped by the absence of a common terminology in the fields involved in the study of aerosols. SARS-CoV-2 is transmitted primarily when people are in close contact (less than 2 meters) for an extended period (over 15 minutes). In accordance with the definitions proposed here—under certain specific conditions, such as crowded, inadequately-ventilated spaces where there is prolonged exposure (so-called superspreader events)—the scientific data indicate that close contact transmission (less than 2 meters) is involved and also suggest that long-range aerosol-based transmission (maximum distance not specified, but probably no more than a few meters) may take place.

This is an opportune time to develop a new paradigm for COVID-19 transmission modes that more accurately reflects the role of aerosol dynamics in the respiratory infection transmission process. The new paradigm will inform an array of experts who seek, among other things, to address issues related to applying IPC measures in healthcare settings and in other settings.

In the meantime, there must be a concerted effort to implement prevention and protection measures to limit SARS-CoV-2 transmission in the community, the workplace, and healthcare settings. Actions to be implemented include:

- Contact restrictions and physical distancing
- Respiratory hygiene and etiquette
- Hand hygiene
- Adequate ventilation
- Mask wearing
- Environmental cleaning and disinfection
- Application of routine practices and additional infection prevention and control precautions (IPC) in healthcare settings

Our knowledge of SARS-CoV-2 is continually evolving. More studies are needed, especially to clarify the infectious dose, long-range transmission, and the role of other transmission routes that have been the subject of little if any research (e.g., transmission by fecal aerosolization). The findings presented in this document will be re-assessed as new data emerges.

References

Adam, D.C., Wu P., Wong, J.Y., *et al*. (2020). Clustering and superspreading potential of SARS-CoV-2 infections in Hong Kong. *Nat Med* https://doi.org/10.1038/s41591-020-1092-0

Agence de santé publique du Canada. (2017). *Pratiques de base et précautions additionnelles visant à prévenir la transmission des infections dans les milieux de soins.* https://www.canada.ca/fr/sante-publique/services/publications/maladies-et-affections/pratiques-de-base-precautions-infections-aux-soins-de-sante.html

Alonso, C., Raynor, P.C., Davies, P.R., Torremorell, M. (2015, août). Concentration, Size Distribution, and Infectivity of Airborne Particles Carrying Swine Viruses. *PLoS One*. 19;10(8):e0135675. doi : 10.1371/journal.pone.0135675.

Bao (2020). Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 via Close Contact and Respiratory Droplets Among Human Angiotensin- Converting Enzyme 2 Mice. *The Journal of Infectious Diseases*. DOI: 10.1093/infdis/jiaa28

Basu, S. (2020, 27 juillet). Computational characterization of inhaled droplet transport in the upper airway leading to SARS-CoV-2 infection. *medRxiv*. 20162362; doi: https://doi.org/10.1101/2020.07.27.20162362

Bi, Q., Wu, Y., Mei, S., Ye, C., Zou, X. et al. (2020, 20 août). Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. *Lancet Infect Dis*. (8):911-919. doi: 10.1016/S1473-3099(20)30287-5. Epub 2020 Apr 27. Erratum in: Lancet Infect Dis. 2020 Jul;20(7):e148.

Biggerstaff, M., Cowling, B.J., Cucunubá, Z.M., Dinh, L., Ferguson, N.M. et al. (2020, 11 septembre). WHO COVID-19 Modelling Parameters Group. Early Insights from Statistical and Mathematical Modeling of Key Epidemiologic Parameters of COVID-19. *Emerg Infect Dis*. 26 (11). doi: 10.3201/eid2611.201074.

Binder, R.A., Alarja, N.A., Robie, E.R., Kochek, K.E., Xiu, L. et al. (2020, 1er décembre) Environmental and Aerosolized Severe Acute Respiratory Syndrome Coronavirus 2 Among Hospitalized Coronavirus Disease 2019 Patients, *The Journal of Infectious Diseases*, Volume 222, Issue 11, Pages 1798-1806 https://doi.org/10.1093/infdis/jiaa575

Birgand, G., Peiffer-Smadja, N., Fournier, S., Kerneis, S., Lescure, F.X. et al. (2020, 9 septembre) Airborne contamination of COVID-19 in hospitals: a scoping review of the current evidence. *medRxiv*. 20191213; doi: https://doi.org/10.1101/2020.09.09.20191213

Brlek, A., Vidovič, Š., Vuzem, S., Turk, K., Simonović, Z. (2020, mars). Possible indirect transmission of COVID-19 at a squash court, Slovenia, March 2020: case report. *Epidemiology and Infection* 148, e120, 1–3. https://doi.org/10.1017/S0950268820001326

Brown, J.S., Gordon, T., Price, O., Asgharian, B. (2013, 10 avril) Thoracic and respirable particle definitions for human health risk assessment. *Particle and Fibre Toxicology* doi:10.1186/1743-8977-10-12

Bryukov *et al*. (2020). Increasing Temperature and Relative Humidity Accelerates Inactivation of SARS-CoV-2 on Surfaces. *MSphere*. 5(4):e00441-20. doi : 10.1128/mSphere.00441-20

Cai, J., Sun, W., Huang, J., Gamber, M., Wu, J. *et al*. (2020, juin). Early Release - Indirect Virus Transmission in Cluster of COVID-19 Cases, Wenzhou, China, 2020 - Volume 26, Number 6—*Emerging Infectious Diseases journal - CDC*. 10.3201/eid2606.200412

Centers for disease control and prevention (CDC) (2007). *Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings* Last update: July 2019 https://www.cdc.gov/infectioncontrol/guidelines/isolation/index.html

Centers for disease control and prevention (CDC). Scientific Brief: SARS-CoV-2 and Potential Airborne Transmission. Mise à jour le 5 octobre 2020. https://www.cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html. Consulté le 11 octobre 2020.

Centers for disease control and prevention (CDC). (2020). *How COVID-19 Spreads*. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html

Cheng, H., Jian, S., Liu, D. *et al*. Contact Tracing Assessment of COVID-19 Transmission Dynamics in Taiwan and Risk at Different Exposure Periods Before and After Symptom Onset. *JAMA Intern Med.* 2020;180(9):1156–1163. doi:10.1001/jamainternmed.2020.2020

Colaneri, M., Seminari, E., Novati, S., Asperges, E., Biscarini, S. et al.. Severe acute respiratory syndrome coronavirus 2 RNA contamination of inanimate surfaces and virus viability in a health care emergency unit. Clinical Microbiology and Infection 26 (2020). https://doi.org/10.1016/j.cmi.2020.05.009

D'accolti, M., Soffritti, I., Passaro, A., Zuliani, G., Antonioli, P., *et al*. (2020). SARS-CoV-2 RNA contamination on surfaces of a COVID-19 ward in a hospital of Northern Italy: what risk of transmission? *European Review for Medical and Pharmacological Sciences*, 24, 9202-9207. 10.26355/eurrev_202009_22872

de Man, P., Paltansing, S., Ong, DSY., Vaessen, N., van Nielen, G. et al. Outbreak of COVID-19 in a nursing home associated with aerosol transmission as a result of inadequate ventilation [published online ahead of print, 2020 Aug 28]. *Clin Infect Dis*. 2020 ; ciaa1270. doi : 10.1093/cid/ciaa1270

DHS Science and Technology (2020, 6 octobre) *Master Question List for COVID-19 (caused by SARS-CoV-2)* https://www.dhs.gov/sites/default/files/publications/mql_sars-cov-2_-_cleared_for_public_release_20201006.pdf

Dietz, L., Horve, P.F., Coil, D.A., Fretz, M., Eisen, J.A. *et al*. 2020). 2019 Novel Coronavirus (COVID-19) Pandemic: Built Environment Considerations To Reduce Transmission. *MSystems*, *5*(2). 10.1128/mSystems.00245-20

Ding, Z., Qian, H., Xu, B., Huang, Y., Miao, T. et al. (2020). Toilets dominate environmental detection of severe acute respiratory syndrome coronavirus 2 in a hospital. *Science of The Total Environment*, 141710. https://doi.org/10.1016/j.scitotenv.2020.141710

Dionne, M. (2019). *Analyse des risques reliés à l'exposition des travailleurs* [document inédit]. Institut national de santé publique du Québec.

Döhla, M., Wilbring, G., Schulte, B., Kümmerer, B.M., Diegmann, C. *et al*. (2020). SARS-CoV-2 in environmental samples of quarantined households. *medRxiv*. https://doi.org/10.1101/2020.05.28.20114041

Doung-Ngern, P., Suphanchaimat, R., Panjangampatthana, A., Janekrongtham, C., Ruampoom, D. et al. (1995, mars). An outbreak of measles at an international sporting event with airborne transmission in a domed stadium. *J Infect Dis*. 171(3):679-83. doi: 10.1093/infdis/171.3.679.

Ehresmann, K.R., Hedberg, C.W., Grimm, M.B., Norton, C.A., MacDonald, K.L. *at al.* (1995, mars). An outbreak of measles at an international sporting event with airborne transmission in a domed stadium. *J Infect Dis*. 171(3):679-83. doi: 10.1093/infdis/171.3.679. PMID: 7876616.

Endo, A., Centre for the Mathematical Modelling of Infectious Diseases COVID-19 Working Group, Abbott, S. *et al*. Estimating the overdispersion in COVID-19 transmission using outbreak sizes outside China [version 3; peer review: 2 approved]. *Wellcome Open Research* 2020, 5:67 https://doi.org/10.12688/wellcomeopenres.15842.3

Fernandez-de-Mera *et al*. (2020) Detection of environmental SARS-CoV-2 RNA in a high prevalence setting in Spain. *Transboundray and Emerging Diseases*. Doi: 10.1111/tbed.13817

Fisher et al. (2020). Seeding of outbreaks of COVID-19 by contaminated fresh and frozen food. *BioRxiv*. https://doi.org/10.1101/2020.08.17.255166

Günther, T., Czech-Sioli, M., Indenbirken, D., Robitailles, A., Tenhaken, P. et al. Investigation of a superspreading event preceding the largest meat processing plant-related SARS-Coronavirus 2 outbreak in Germany. *SSRN.* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3654517. Consulté le 6 octobre 2020.

Gustin, K.M., Belser, J.A., Wadford, D.A. *et al*. Influenza virus aerosol exposure and analytical system for ferrets. *Proc Natl Acad Sci U S A*. 2011;108(20):8432-8437. doi:10.1073/pnas.1100768108

Hamner, L., Dubbel, P., Capron, I. *et al*. (2020, mars). High SARS-CoV-2 Attack Rate Following Exposure at a Choir Practice - Skagit County, Washington. *MMWR Morb Mortal Wkly Rep*. 2020;69(19):606-610. Published 2020 May 15. doi:10.15585/mmwr.mm 6919e6

Harbourt, D., Haddow, A., Piper, A., Bloomfield, H., Kearney, B. et al. (2020, 1er juillet) Modeling the Stability of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) on Skin, Currency, and Clothing. *medRxiv* 20144253; doi: https://doi.org/10.1101/2020.07.01.20144253

Harvey, A.P. *et al*. (2020). Longitudinal monitoring of SARS-CoV-2 RNA on high-touch surfaces in a community setting. *MedRxiv*. https://doi.org/10.1101/2020.10.27.20220905

Hu, X., Xing, Y., Ni, W., Zhang, F., Lu, S. et al. (2020). Environmental contamination by SARS-CoV-2 of an imported case during incubation period. *Science of The Total Environment*, *742*, 140620. 10.1016/j.scitotenv.2020.140620

Institute of Medicine. 2011. *Preventing Transmission of Pandemic Influenza and Other Viral Respiratory Diseases*: Personal Protective Equipment for Healthcare Personnel: Update 2010. Washington, DC: The National Academies Press. https://doi.org/10.17226/13027

Institut national de santé du Québec (2019). *Notions de base en prévention et contrôle des infections : précautions additionnelles*, Comité sur les infections nosocomiales du Québec (CINQ). https://www.inspq.qc.ca/sites/default/files/publications/2436_prevention_controle_infections_prescautions_additionnelles.pdf

Institut national de santé du Québec (2009). *Prévention de la transmission des maladies respiratoires sévères d'origine infectieuse (MRSI), de l'influenza aviaire A(H5N1) et de la grippe A(H1N1) d'origine porcine dans les milieux de soins,* Comité sur les infections nosocomiales du Québec (CINQ). https://www.inspq.qc.ca/pdf/publications/948_AvisInfluenzaAH5N1GrippeAH1N1.pdf

Institut national de santé du Québec (2020). *Revue rapide de la littérature scientifique : proportion de personnes asymptomatiques et potentiel de transmission de la COVID 19 par ces personnes* https://www.inspq.qc.ca/publications/2989-asymptomatique-transmission-covid19

Jiang, F.C., Jiang, X.L., Wang, Z.G., Meng, Z.H., Shao S.F. et al. Early Release-Detection of Severe Acute Respiratory Syndrome Coronavirus 2 RNA on Surfaces in Quarantine Rooms. https://wwwnc.cdc.gov/eid/article/26/9/20-1435_article?mod=article_inline

Jônatas Santos Abrahão et coll., Detection of SARS-CoV-2 RNA on public surfaces in a densely populated urban area of Brazil: A potential tool for monitoring the circulation of infected patients, *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.142645

Kampf, G., Brüggemann, Y., Kaba, H.E.J, Steinmann, J., Pfaender, S. et al. (2020). Potential sources, modes of transmission and effectiveness of prevention measures against SARS-CoV-2. *Journal of Hospital Infection*. 10.1016/j.jhin.2020.09.022

Kanamori, H., Weber, D.J. et Rutala, W.A. (2020). The role of the healthcare surface environment in SARS-CoV-2 transmission and potential control measures. *Clinical Infectious Diseases*. 10.1093/cid/ciaa1467

Karia, R., Gupta, I., Khandait, H., Yadav, A. et Yadav, A. (2020). COVID-19 and its modes of transmission. *SN Comprehensive Clinical Medicine*, 1-4. 10.1007/s42399-020-00498-4

Kutter, J.S., de Meulder, D., Bestebroer, T.M., Lexmond, P., Mulders, A. *et al* (2020, 19 octobre) SARS-CoV and SARS-CoV-2 are transmitted through the air between ferrets over more than one meter distance. *bioRxiv*.345363; doi: https://doi.org/10.1101/2020.10.19.345363

Lednicky *et al*. (2020). Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. *medRxiv*. https://doi.org/10.1101/2020.08.03.20167395

Li, Y., Qian, H., Hang, J., Chen, X., Hong, L. et al. (2020, 16 avril) Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant. *medRxiv*. 20067728; doi: https://doi.org/10.1101/2020.04.16.20067728

Lindsley, W.G., Blachere, F.M., Thewlis, R.E., Vishnu, A., Davis, K.A., *et al*. (2010, novembre). Measurements of airborne influenza virus in aerosol particles from human coughs. PLoS One. 30;5(11):e15100. doi : 10.1371/journal.pone.0015100.

Liu, Y., Li, T., Deng, Y., Liu, S., Zhang, D. *et al*. (2020). Stability of SARS-CoV-2 on environmental surfaces and in human excreta. *medRxiv*. https://doi.org/10.1101/2020.05.07.20094805

Lu, J., Gu, J., Li, K., Xu, C., Su, W. *et al*. (2020, 26 juillet) COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020. *Emerg Infect Dis.* (7):1628-1631. doi: 10.3201/eid2607.200764.

Luo, L., Liu, D., Zhang, H., Li, Z., Zhen, R. *et al*. (2020). Air and surface contamination in non-health care settings among 641 environmental specimens of 39 COVID-19 cases. *bioRxiv*. https://doi.org/10.1101/2020.07.09.195008

Marr, L.C., Tang, J.W., Van Mullekom, J. and Lakdawala S.S. (2019). Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence. *Journal of the Royal Society Interface*. http://doi.org/10.1098/rsif.2018.0298

Milton, D.K., Fabian, M.P., Cowling, B.J., Grantham, M.L., McDevitt, J.J. (2013). Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. *PLoS Pathog*. 9(3):e1003205. doi : 10.1371/journal.ppat.1003205

Moore, G., Rickard, H., Stevenson, D., Bou, P.A., Pitman, J. et al. (2020). Detection of SARS-CoV-2 within the healthcare environment: a multicentre study conducted during the first wave of the COVID-19 outbreak in England. *medRxiv*. https://doi.org/10.1101/2020.09.24.20191411

Mouchtouri, V.A., Koureas, M., Kyritsi, M., Vontas, A., Kourentis, L. et al. (2020). Environmental contamination of SARS-CoV-2 on surfaces, air-conditioner and ventilation systems. *International Journal of Hygiene and Environmental Health*, 113599. https://doi.org/10.1016/j.ijheh.2020.113599

Nelson, A., Kassimatis, J., Estoque, J., Yang, C., McKee, G. et al. (2020). Environmental Detection of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from Medical Equipment in Long-Term Care Facilities undergoing COVID-19 Outbreaks. *American journal of infection control*, S0196-6553(20)30643-X. Advance online publication. https://doi.org/10.1016/j.ajic.2020.07.001

Nguyen-Van-Tam, J.S., Killingley, B., Enstone, J., Hewitt, M., Pantelic, J. et al. (2020, 13 juillet). EMIT Consortium. Minimal transmission in an influenza A (H3N2) human challenge-transmission model within a controlled exposure environment. *PLoS Pathog*. 16(7):e1008704. doi : 10.1371/journal.ppat.1008704.

NIPH, K.G. (2020). Transmission of SARS-CoV-2 via contact and droplets, 1st update – a rapid review. *Norwegian Institute of Public Health*. https://www.fhi.no/en/publ/2020/Transmission-of-SARS-CoV-2-via-contact-and-droplets-1st-updat-/

Oberdörster, G., Oberdörster, E., Oberdörster, J. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles [published correction appears in Environ Health Perspect. 2010 Sep ; 118(9):A380]. *Environ Health Perspect*. 2005 ; 113 (7) : 823-839. doi:10.1289/ehp.7339

Ong, S.W.X., Lee, P.H., Tan, Y.K., Ling, L.M., Ho, B.C.H. et al. (2020, 21 octobre). Environmental contamination in a coronavirus disease 2019 (COVID-19) intensive care unit- What is the risk? Infect Control Hosp Epidemiol. 1-9. doi: 10.1017/ice.2020.1278.

Park, S., Kim, Y., Yi, S., Lee, S., Na, B. et al. (2020). Coronavirus Disease Outbreak in Call Center, South Korea. *Emerging Infectious Diseases*, 26(8), 1666-1670. https://dx.doi.org/10.3201/eid2608.201274

Pasquarella, C., Colucci, M.E., Bizzarro, A., Veronesi, L., Affanni, P. et al. (2020). Detection of SARS-CoV-2 on hospital surfaces. *Acta bio-medica* : Atenei Parmensis, 91(9-S), 76–78. https://doi.org/10.23750/abm.v91i9-S.10137

Petersen, E., Koopmans, M., Go, U., Hamer, D.H., Petrosillo, N. et al. (2020, 20 septembre). Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics. *Lancet Infect Dis*. (9) : e238-e244. doi : 10.1016/S1473-3099(20)30484-9.

Peyrony, O., Ellouze, S., Fontaine, J.P., Thegat-Le Cam, M., Salmona, M., *et al*. (COvid REsearch) group (2020). Surfaces and equipment contamination by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in the emergency department at a university hospital. *International journal of hygiene and environmental health*, *230*, 113600. Advance online publication. https://doi.org/10.1016/j.ijheh.2020.113600

Prakash KM. Eat, Pray, Work: A meta-analysis of COVID-19 Transmission Risk in Common Activities of Work and Leisure. medRxiv 2020.05.22.20110726; doi: https://doi.org/10.1101/2020.05.22.20110726 (Non révisé par les pairs)

Public Health Ontario (2020, 12 janvier). COVID-19 Routes of Transmission – What We Know So Far. https://www.publichealthontario.ca/-/media/documents/ncov/wwksf-routes-transmission-mar-06-2020.pdf?la=en

Razzini, K., Castrica, M., Menchetti, L., Maggi, L., Negroni, L. et al. (2020). SARS-CoV-2 RNA detection in the air and on surfaces in the COVID-19 ward of a hospital in Milan, Italy. *Science of The Total Environment*. 742, 140540. https://doi.org/10.1016/j.scitotenv.2020.140540

Richard, M., Kok, A., de Meulder, D., Bestebroer, T.M., Lamers, M.M., et al. (2020). SARS-CoV-2 is transmitted via contact and via the air between ferrets. *Nature communications*, 11 (1), 3496. https://doi.org/10.1038/s41467-020-17367-2.

Ryu, B.H., Cho, Y., Cho, O.H., Hong S.I., Kim, S. *et al*. (2020). Environmental contamination of SARS-CoV-2 during the COVID-19 outbreak in South Korea. *American Journal of Infection Control*. https://doi.org/10.1016/j.ajic.2020.05.027

Roy, C.J., Milton, D.K. Airborne transmission of communicable infection - the elusive pathway. *N Eng J Med* 2004;350:1710-2

Santarpia *et al*. (2020A). The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. *medRxiv*. https://doi.org/10.1101/2020.07.13.20041632

Santarpia, J.L., Rivera, D.N., Herrera, V.L., Morwitzer, M.J., Creager, H.M. et al. (2020B). Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. *Scientific reports*, 10(1), 12732. https://doi.org/10.1038/s41598-020-69286-3

Shen, Y., Li, C., Dong, H., Wang, Z., Martinez, L. et al. Community Outbreak Investigation of SARS-CoV-2 Transmission Among Bus Riders in Eastern China. *JAMA Internal Medicine*. doi:10.1001/jamainternmed.2020.5225

Sia, S.F., Yan, L.M., Chin, A.W.H., Fung, K., Choy, K.T. et al. (2020). Pathogenesis and transmission of SARS-CoV-2 in golden hamsters. *Nature*, *583*(7818), 834-838. 10.1038/s41586-020-2342-5

Tan, L., Ma, B., Lai, X., Han, L., Cao, P. et al. (2020). Air and surface contamination by SARS-CoV-2 virus in a tertiary hospital in Wuhan, China. *International journal of infectious diseases* : IJID : official publication of the International Society for Infectious Diseases, S1201-9712(20)30571-3. Advance online publication. https://doi.org/10.1016/j.ijid.2020.07.027

Tellier, R. (2006). Review of aerosol transmission of influenza A virus. *Emerging infectious diseases*, *12*(11), 1657–1662. https://doi.org/10.3201/eid1211.060426

Turgeon, N., Hamelin, M.È., Verreault, D., Lévesque, A., Rhéaume, C., *et al*. Design and Validation with Influenza A Virus of an Aerosol Transmission Chamber for Ferrets. *Int J Environ Res Public Health*. 2019 Feb 19;16(4):609. doi: 10.3390/ijerph16040609.

Van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A. et al. (2020). Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *New England Journal of Medicine*, NEJMc2004973. 10.1056/NEJMc2004973

Vella, F., Senia, P., Ceccarelli, M., Vitale, E., Maltezou, H. et al. (2020). Transmission mode associated with coronavirus disease 2019: a review. *European Review for Medical and Pharmacological Sciences*, *24*(14), 7889-7904. 10.26355/eurrev_202007_22296

Vincent, J.H. Health-related aerosol measurement: a review of existing sampling criteria and proposals for new ones. *J Environ Monit*. 2005 Nov;7(11):1037-53. doi: 10.1039/b509617k.

Walsh, K.A., Jordan, K., Clyne, B., Rohde, D., Drummond, L. et al., (2020, juin). SARS-CoV-2 Detection, Viral Load and Infectivity over the Course of an Infection: SARS-CoV-2 Detection, Viral Load and Infectivity. J Infect. 2020 ; 81 (3) : 357-371. doi:10.1016/j.jinf.2020.06.067

World Health Organisation (WHO) (2020). *Transmission of SARS-CoV-2: implications for infection prevention precautions*. World Health Organization. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions

World Health Organisation. (2014) Infection Prevention and Control of Epidemic-and Pandemic-prone Acute Respiratory Infections in Health Care. Geneva: https://apps.who.int/iris/bitstream/handle/10665/112656/9789241507134_eng.pdf;jsessionid=41AA684FB64571CE8D8A453C4F2B2096?sequence=1. Consulté le 11 octobre 2020.

Wu, S., Wang, Y., Jin, X., Tian, J., Liu, J., & Mao, Y. (2020). Environmental contamination by SARS-CoV-2 in a designated hospital for coronavirus disease 2019. American Journal of Infection Control. https://doi.org/10.1016/j.ajic.2020.05.003

Xie, C., Zhao, H., Li, K., Zhang, Z., Lu, X. et al. (2020). The evidence of indirect transmission of SARS-CoV-2 reported in Guangzhou, China. *BMC Public Health*, *20*(1), 1202. 10.1186/s12889-020-09296-y

Yamagishi, T. (2020). Environmental sampling for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) during a coronavirus disease (COVID-19) outbreak aboard a commercial cruise ship. *medRxiv*. https://doi.org/10.1101/2020.05.02.20088567

Ye, G., Lin, H., Chen, L., Wang, S., Zeng, Z. et al. (2020). Environmental contamination of SARS-CoV-2 in healthcare premises. Journal of Infection. https://doi.org/10.1016/j.jinf.2020.04.034

Zhang, Y., Li, Y., Wang, L., Li, M., Zhou, X. Evaluating Transmission Heterogeneity and Super-Spreading Event of COVID-19 in a Metropolis of China. *Int J Environ Res Public Health*. 2020 ; 17 (10) : E3705. Published 2020 May 24. doi:10.3390/ijerph17103705

Zhou, J., Wei, J., Choy, K.T., Sia, S.F., Rowlands, D.K. et al. (2018, 6 mars). Defining the sizes of airborne particles that mediate influenza transmission in ferrets. *Proc Natl Acad Sci U S A*.;115(10):E2386-E2392. doi : 10.1073/pnas.1716771115.

Zhou, J., Otter, J.A., Price, J.R., Cimpeanu, C., Garcia, D.M. et al. (2020, 8 juillet). Investigating SARS-CoV-2 surface and air contamination in an acute healthcare setting during the peak of the COVID-19 pandemic in London. *Clin Infect Dis*. ciaa905. doi : 10.1093/cid/ciaa905. Epub ahead of print. PMID: 32634826; PMCID: PMC7454437.

Zhou *et al*. (2020). Investigating SARS-CoV-2 Surface and Air Contamination in an Acute Healthcare Setting During the Peak of the COVID-19 Pandemic in London. *Clinical Infectious Disease*. doi: 10.1093/cid/ciaa9

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