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Commentary

Consideration of the Aerosol Transmission for COVID-19 and Public Health

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ABSTRACT: This article analyzes the available evidence to address airborne, aerosol transmission of the SARS-CoV-2. We review and present three lines of evidence: case reports of transmission for asymptomatic individuals in association with studies that show that normal breathing and talking produce predominantly small droplets of the size that are subject to aerosol transport; limited empirical data that have recorded aerosolized SARS-CoV-2 particles that remain suspended in the air for hours and are subject to transport over distances including outside of rooms and intrabuilding, and the broader literature that further supports the importance of aerosol transmission of infectious diseases. The weight of the available evidence warrants immediate attention to address the significance of aerosols and implications for public health protection.

1. INTRODUCTION

Risk assessment and risk management approaches were first adopted in 1976 to address the need to make public health protective policy decisions in the face of scientific uncertainty (Albert, Train, & Anderson, 1977; Anderson, 1983; Interagency Regulatory Liaison Group, 1980; National Research Council, 1983). While initially applied to suspect carcinogens, these approaches have now been adopted worldwide for addressing global issues of public health concern. This article uses this framework to contribute to the global attention focused on the transmission and mitigation of the 2019 Coronavirus, SARS-CoV-2, and the resulting pandemic disease, COVID-19. The elements of risk consideration rely on the currently available evidence to assess hazard, dose response, exposure assessment, and overall risk. Gaps in knowledge are then identified that point to research needed to affirm or support the next tier of public health protection. For COVID-19, the certainty of hazard is known, dose response is unknown, and exposure pathways are being explored.

This article focuses on the limited evidence available to address airborne, aerosol transmission of SARS-CoV-2. The dichotomy between small and large droplets in infectious disease transmission, originally developed in the 1930s by William F. Wells, is reflected in current World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) guidance and other published literature that use a cut off of 5 μm or 5–10 μm aerodynamic droplet diameter to define the upper end of the size of small droplets (Tellier, Li, Cowling, & Tang, 2019; U.S. CDC, 2007; World Health Organization, 2014). Consistent with WHO, CDC, and the literature, throughout this article we use the term *aerosol* to mean the small respirable particles <5–10 μm that can remain airborne and are capable of short- and long-range transport. Larger droplets >20 μm settle under the influence of gravity and are too large to follow inhalation airflow streamlines; the intermediate range of 10–20 μm may either settle or remain suspended (Tellier et al., 2019).

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To date, primary concern has focused on near-field transmission, particularly protective of coughing and sneezing from infected individuals, and hand-to-face transport from surfaces. These potential pathways have prompted public health guidance for social distancing, hand washing, surface decontamination, “shelter in place,” and some guidance to encourage respiratory protection. Although mentioned, other pathways have not received as much attention nor prompted specific public health guidelines to intercept, curb, or prevent the continued spread of the virus. One such potentially important pathway for transmission is by the inhalation route of aerosols.

Below we present three lines of evidence that when considered together provide substantial weight of evidence that aerosols may be an important pathway for transmission. If this is so, a second tier of public health guidance that goes beyond the current recommendations may provide more specific relief going forward. Below we discuss specific research to expeditiously address the scientific uncertainties and potential importance of aerosol transmission of SARS-CoV-2.

2. CASE REPORTS OF ASYMPTOMATIC PERSONS TRANSMITTING SARS-CoV-2 TO OTHER INDIVIDUALS

There are many accounts of SARS-CoV-2 spreading by proximity with asymptomatic individuals who do not know they are infected; these individuals are presumably not coughing or sneezing. On almost a daily basis, scientists from the CDC and the National Institutes of Health (NIH) discuss the importance of curbing transmission from asymptomatic individuals. Here we present some of these accounts for illustrative purposes; an exhaustive listing has not been attempted.

Early on, when the main geographical regions with cases of COVID-19 were in China, there were reports in the press regarding asymptomatic transmission. This reporting suggests that coughing and sneezing might not be the only important means of spreading active virus, leading to hypothesized pathways such as touching of surfaces and shedding of particles in the process of normal breathing.

Researchers in China indicated early on that asymptomatic transmission was a possibility after studying five family members who became symptomatic after contact with an asymptomatic family member who was visiting from Wuhan (Bai et al., 2020). Other researchers identified viral loads in an asymptomatic subject, with unremarkable CT scans, that were similar to the symptomatic subjects (Zou et al., 2020).

Wei et al. (2020) investigated all 243 cases of COVID-19 reported in Singapore between January 23 and March 16. The researchers were able to identify presymptomatic transmission as the most likely explanation in seven clusters of cases. In addition, researchers have estimated that in China that a large proportion of transmission cases, 79%, were from individuals who had not been tested, presumably a large fraction of these were asymptomatic (Li et al., 2020).

An additional study in a Wuhan hospital, measured SARS-CoV-2 surface and aerosol distribution in various locations in the ICU and general ward sections of the hospital. The authors state that their findings “confirm that SARS-CoV-2 aerosol exposure poses risks” (Guo et al., 2020). The authors suggest that the transmission distance may be 4 meters (13 ft) while noting that the “transmission distance cannot be strictly determined” due to limitations in the quantification of viable virus in their samples and the infectious dose.

Perhaps the one press report that drew the most attention in the United States to the possibility of asymptomatic transmission and the likelihood of an airborne aerosol form of active SARS-CoV-2 was the Skagit Valley Chorale rehearsal in Mount Vernon, Washington, that took place on March 10. According to interviews with members present, the attendees were not symptomatic, they limited their physical contact and maintained distance from one another. *The Los Angeles Times* (LA Times) reported that after the 2½-hour practice session, 45 of 60 members present tested positive for SARS-CoV-2 or had symptoms of COVID-19; three of those had been hospitalized, and two had died (Read, 2020).

A co-author of a recent study that looked at survival time of the virus in aerosols (van Doremalen et al., 2020) suggested in the LA Times article that the forceful breathing action of singing may have increased dispersion of the virus at the church (Read, 2020). Many other notable examples are mentioned often in the press, for example that of a ski group in Ketchum, Idaho, where a group of about 700 seemingly healthy individuals gathered to ski. Reportedly, within a week, 126 of the group showed symptoms of COVID-19, 20 tested positive, eight were hospitalized, and two have since died (Ames, 2020).

In the absence of overt symptoms, such as coughing and sneezing, these observations raise the question of how infectious transmission is occuring. Ample literature reports that aerosol droplets <5 μm associated with normal breathing and talking and occasional coughing of healthy individuals predominate (Fabian, Brain, Houseman, Gern, & Milton, 2011; Johnson et al., 2011; Johnson & Morawska, 2009; Morawska et al., 2009). Furthermore, there is good agreement across the studies that normal breathing and talking result in size distributions of droplets with the majority, 80–90%, in the <1 μm range (Morawska et al., 2009). In short, from these and other similar observations, there has been growing acceptance in the daily public press and discussions among health experts that transmission occurring from asymptomatic persons is an important pathway (Asadi, Bouvier, Wexler, & Ristenpart, 2020; Lewis, 2020; Meselson, 2020; Morawska & Cao, 2020).

2.1. Supporting Evidence from Analytical Samples of SARS-COV-2 and SARS-COV-1 in Aerosol Form

The available literature reports limited information that directly addresses aerosol transport of SARS-CoV-2. Limited sampling results in medical and laboratory settings have identified SARS-CoV-2 and SARS-COV-1 in aerosol form that lingers in the air and has been reported to travel intra-building and over long distances from the sources.

In a hospital setting, viral RNA has been detected in air inside patient rooms where SARS-CoV-2 patients were receiving care and in nearby hallways (Santarpia et al., 2020). The authors note "the data is suggestive that viral aerosol particles are produced by individuals that have the COVID-19 disease, even in the absence of cough" and "recent literature investigating human expired aerosol indicates that a significant fraction of human expired aerosol is less than 10 μm in diameter across all types of activity (e.g., breathing, talking, and coughing)."

Another hospital study raises concerns for SARS-CoV-2 being transported as aerosols from droplet contaminated surfaces. This concern was based on measurement data associated with removing personal protective equipment, cleaning floors, and moving staff (Liu et al., 2020). The study also found SARS-CoV-2 in the air in outdoor areas at the hospital entrance and in front of a department store; the authors conclude it is possible that asymptomatic individuals in these areas may have contributed to these results.

During the 2003 SARS outbreak, an increased risk of infection with SARS-CoV-1 to residents on higher floors of a building was associated with aerosol transport from an infected individual living on a lower floor (Yu et al., 2004), raising concerns about intra-building transport and infiltration of inhalable aerosols containing the infectious agent.

These three studies are referenced in the National Academy of Sciences (NAS) committee on emerging infectious diseases and 21st century health threats letter of April 1, 2020, as the primary basis for their conclusion that "While the current SARS-Cov-2 specific research is limited, the results of available studies are consistent with aerosolization of virus from normal breathing" (National Academy of Sciences, 2020). The letter was responding to a question from the Office of Science and Technology Policy "concerning the possibility the SARs-CoV-2 virus could be spread by conversation, in addition to sneeze/cough-induced droplets." We have found no further study of this topic by this NAS committee.

The recent laboratory study (van Doremalen et al., 2020) of SARS-CoV-2 survivability on various surfaces included data on the aerosol form. It concluded that "virus can remain viable and infectious in aerosols for hours and on surfaces up to days (depending on the inoculum shed)." The correspondence indicates aerosolized SARS-CoV-2 remained "viable in aerosols throughout the duration of our experiment (three hours)," with the infectious titer attenuating by approximately 6-fold over that time frame. van Doremalen et al., 2020 also notes the results are similar to those of SARs-CoV-1: "[t]he half-lives of SARS-CoV-2 and SARS-CoV-1 were similar in aerosols, with median estimates of approximately 1.1 to 1.2 hours and 95% credible intervals of 0.64 to 2.64 for SARS-CoV-2 and 0.78 to 2.43 for SARS-CoV-1."

2.2. Scientific Publications that Record the Importance of Aerosol Transport for Similar Viruses

Since data for SARS-CoV-2 are limited, we have reviewed the literature to further inform the weight of evidence to address aerosol transport of SARS-CoV-2. While no virus can be directly compared to another, this information is helpful to consider in light of the rapid spread of SARS-CoV-2 and its deadly impact on some of its victims. Infections that are known to manifest in the respiratory tract can often be expected to generate aerosols from breathing, talking, singing, coughing, and sneezing. These aerosols are likely to create longer-range transport and potential infection from the pathogens.

In a review article from 2006 (Tang, Li, Eames, Chan, & Ridgway, 2006), the authors found for SARS-CoV-1 that "particles of diameters 1–3 μm remained suspended almost indefinitely, 10 μm took 17 min, 20 μm took 4 min, and 100 μm took 10 seconds to fall to the floor" (Tang et al., 2006). This article notes that aerosol transmission is a well-known and important exposure pathway for infectious agents such as influenza and other viruses including coronaviruses. As discussed in this article, SARS-CoV-1 viral RNA was found in air samples, and long-range aerosol transport was implicated as the cause of the spread of the disease in several studies. The authors noted reports that indicate viruses such as influenza can become truly airborne in pandemic situations and that some agents can be transmitted over atypically large distances due to aerosol formation. They also note that the potential for infection is a function of dose and the individual's immune response. The article also discusses the importance of relative humidity, temperature, and other environmental factors for the survival of viruses when airborne. For example, a lipid enveloped virus (like SARS-CoV-2) was observed to have a half-life of about 3 hours at 80% relative humidity, 67 hours at 50%, and 27 hours at 30%; the authors conclude that lipid enveloped viruses have better survivability at low (<50%) relative humidity.

A recent, related, study, focuses on respiratory pathogen emission and transport in turbulent gas clouds (Bourouiba, 2020). In this article pathogen-bearing droplets are reported to travel up to 23–27 feet, with droplet size, turbulence, speed of the gas cloud, humidity, and temperature being important factors for the distance travelled. The article states with respect to the current guidance for separation, "these distances are based on estimates of range that have not considered the possible presence of a high-momentum cloud carrying the droplets long distances." A need for further evaluation of the dispersion behavior is suggested by these data.

In addition, in a recent commentary on aerosol transmission of infectious agents (Tellier et al., 2019), the authors associate the term "aerosol transmission" with infectious agents known to be transmissible via the airborne aerosol route compared to host-related transmission from an infected person to another individual. In addition to discussing the importance of small droplets of less than 5–10 μm for aerosol transport, the authors discuss the importance of size distribution and penetration of the respiratory airways in disease causation. They note that small droplets in the <5-μm range can penetrate airways down to the alveolar space where they are more capable of replication and potentially more serious infections; particles <10 μm can penetrate past the glottis; while large droplets of diameters of >20 μm are described as following "a more ballistic trajectory (i.e., falling mostly under the influence of gravity), where the droplets are too large to follow inhalation airflow streamlines." Furthermore, chickenpox and measles are described in this article as examples of lipid-enveloped viruses that have strong evidence for the transmissibility via airborne routes. These routes can, for example, include air flows through open windows, corridors, stairwells and ductwork.

3. CONCLUSION

Our current state of knowledge about the role of aerosols in the transmission of SARS CoV-2 warrants urgent attention.

Three lines of reasoning provide a weight of evidence that aerosol transmission is an important pathway of disease communication and may be significant for the transmission and control of SARS-CoV-2:

- Case reports of asymptomatic individuals passing on SAR-CoV-2 to infect others in association with studies that show that normal breathing, talking, etc. produce small droplets in the size range of predominantly <1 μm that are subject to aerosol transport.
- Limited empirical data that have recorded aerosolized SARS-CoV-2 and SARS-CoV-1 particles that remain suspended in the air for hours and as such are subject to transport over long distances including outside of rooms and intra-building.
- Support from the broader literature that reports the importance of aerosol transmission of infectious diseases and explores survival time and distances, concentrations of infectious agent, the effects of temperature and humidity, and implications of dose delivery of various particle sizes to the respiratory tract.

To date, guidance and public health information has not focused specifically on aerosols as a potentially significant transmission pathway. The absence of the prevalent symptom of coughing and sneezing in asymptomatic individuals turns attention to aerosol transmission, predominately associated with breathing and talking, where the role of small aerosol transport may bemostprevalent.

In the interest of curbing the spread of COVID-19, the currently available evidence strongly suggests the immediate need to address the significance of SARS-CoV-2 aerosol transmission. The weight of evidence suggests that sufficient inhalation protection could be important to curb COVID-19 and to refine guidance.

4. RECOMMENDATIONS

- Collect data to explore the concentration, duration of survival, and transport distances for SARS-CoV-2 in aerosol form under differing conditions of temperature and humidity. This work should be low cost and results available in a relatively short time.
- If aerosols are confirmed as an important transmission pathway for SARS-CoV-2, further explore airborne concentrations and the role of dose to various parts of the respiratory tract in the progression and severity of the disease. This information may inform public policy and earlier treatment decisions.
- Investigate the potential for aerosol contamination of buildings, rooms, and surfaces to provide a basis for decontamination and related public health protective decisions and guidance.
- Explore and record data to determine the role human activities play in potentially generating aerosols capable of transmitting SARS CoV-2 in both enclosed and open spaces. The evidence that supports the hypothesis that aerosol transmission may be occurring in enclosed spaces does not preclude the phenomenon from occurring in larger enclosed spaces (arenas, churches) or even open spaces. The above referenced choir's incidence rates may have been affected by higher exposures, and possibly high exposure deep into the lungs due to higher inhalation rates, despite lower concentrations in aerosols that might be postulated for asymptomatic individuals. The same might be said for persons exercising. Higher air flows in open or larger spaces would have a diluting effect depending on important factors including wind speed, humidity, and temperature.
- In light of the current weight of evidence that aerosols can transport SARS-CoV-2, and as new evidence emerges, further explore appropriate measures to curb inhalation exposure to small aerosols, including 5 μm or less, within buildings, rooms, and surfaces where these aerosols might travel and settle.

As more detailed information becomes available, longer-term protective strategies for curbing the transmission of SARS-CoV-2 and incidence of COVD-19 can be developed. The weight of the currently available evidence warrants immediate attention to address the significance of aerosols with important implications for public health protection.

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