VIEWPOINT

Airborne Transmission of SARS-CoV-2
Theoretical Considerations and Available Evidence

Michael Klompas, MD, MPH
Harvard Medical School and Harvard Pilgrim Health Care Institute, Department of Population Medicine, Boston, Massachusetts; and Department of Medicine, Brigham and Women's Hospital, Boston, Massachusetts.

Meghan A. Baker, MD, ScD
Harvard Medical School and Harvard Pilgrim Health Care Institute, Department of Population Medicine, Boston, Massachusetts; and Department of Medicine, Brigham and Women's Hospital, Boston, Massachusetts.

Chanu Rhee, MD, MPH
Harvard Medical School and Harvard Pilgrim Health Care Institute, Department of Population Medicine, Boston, Massachusetts; and Department of Medicine, Brigham and Women's Hospital, Boston, Massachusetts.

Author Audio Interview

Corresponding Author: Michael Klompas, MD, MPH, Harvard Medical School and Harvard Pilgrim Health Care Institute, Department of Population Medicine, 401 Park Dr, Ste 401, Boston, MA 02215 (mklompas@bwh.harvard.edu).

The coronavirus disease 2019 (COVID-19) pandemic has reawakened the long-standing debate about the extent to which common respiratory viruses, including the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), are transmitted via respiratory droplets vs aerosols. Droplets are classically described as larger entities (>5 μm) that rapidly drop to the ground by force of gravity, typically within 3 to 6 feet of the source person. Aerosols are smaller particles (≤5 μm) that rapidly evaporate in the air, leaving behind droplet nuclei that are small enough and light enough to remain suspended in the air for hours (analogous to pollen).

Determining whether droplets or aerosols predominate in the transmission of SARS-CoV-2 has critical implications. If SARS-CoV-2 is primarily spread by respiratory droplets, wearing a medical mask, face shield, or keeping 6 feet apart from other individuals should be adequate to prevent transmission. If, however, SARS-CoV-2 is carried by aerosols that can remain suspended in the air for prolonged periods, medical masks would be inadequate (because aerosols can both penetrate and circumnavigate masks), face shields would provide only partial protection (because there are open gaps between the shield and the wearer's face), and 6 feet of separation would not provide protection from aerosols that remain suspended in the air or are carried by currents.

> Demonstrating that speaking and coughing can generate aerosols or that it is possible to recover viral RNA from air does not prove aerosol-based transmission...

Experimental data support the possibility that SARS-CoV-2 may be transmitted by aerosols (so-called airborne transmission) even in the absence of aerosol-generating procedures (such as intubation or noninvasive positive pressure ventilation). Investigators have demonstrated that speaking and coughing produce a mixture of both droplets and aerosols in a range of sizes, that these secretions can travel together for up to 27 feet, that it is feasible for SARS-CoV-2 to remain suspended in the air and viable for hours, that SARS-CoV-2 RNA can be recovered from air samples in hospitals, and that poor ventilation prolongs the amount of time that aerosols remain airborne.[1]

Many of these same characteristics have previously been demonstrated for influenza and other common respiratory viruses. These data provide a useful theoretical framework for possible aerosol-based transmission for SARS-CoV-2, but what is less clear is the extent to which these characteristics lead to infections. Demonstrating that speaking and coughing can generate aerosols or that it is possible to recover viral RNA from air does not prove aerosol-based transmission; infection depends as well on the route of exposure, the size of inoculum, the duration of exposure, and host defenses.

Notwithstanding the experimental data suggesting the possibility of aerosol-based transmission, the data on infection rates and transmissions in populations during normal daily life are difficult to reconcile with long-range aerosol-based transmission. First, the reproduction number for COVID-19 before measures were taken to mitigate its spread was estimated to be about 2.5, meaning that each person with COVID-19 infected an average of 2 to 3 other people. This reproduction number is similar to influenza and quite different from that of viruses that are well known to spread via aerosols such as measles, which has a reproduction number closer to 18. Considering that most people with COVID-19 are contagious for about 1 week, a reproduction number of 2 to 3 is quite small given the large number of interactions, crowds, and personal contacts that most people have under normal circumstances within a 7-day period. Either the amount of SARS-CoV-2 required to cause infection is much larger than measles or aerosols are not the dominant mode of transmission.

Similarly, the secondary attack rate for SARS-CoV-2 is low. Case series that have evaluated close contacts of patients with confirmed COVID-19 have reported that only about 5% of contacts become infected. However, even this low attack rate is not spread evenly among close contacts but varies depending on the duration and intensity of contact. The risk is highest among household members, in whom transmission rates range between 10% and 40%.[2-4] Close but less sustained contact such as sharing a meal is associated with a secondary attack rate of about 7%, whereas passing interactions among people shopping is associated with a secondary attack rate of 0.6%.[4]

The secondary attack rate among health care workers who unknowingly care for a patient with COVID-19 while wearing face masks alone or not using any personal protective equipment is also low; transmission studies suggest less than 3% (and the few health care worker infections that were documented in these transmission studies were associated with aerosol-generating procedures or prolonged exposures with inconsistent use of face masks).[5,6] People infected with SARS-CoV-2 may be producing both droplets and aerosols on a constant basis but most of these emissions are not infecting other people. This pattern seems more consistent with secretions that fall rapidly to the ground within a narrow radius of the infected person rather than with virus-laden aerosols that remain suspended in the air at face level for hours where they can be inhaled by anyone in the vicinity. An exception may be prolonged exposure to an infected person in a poorly ventilated space that allows otherwise insignificant amounts of virus-laden aerosols to accumulate.

Proponents of aerosol-based transmission cite well-documented clusters of infections among choir participants, restaurant patrons, and office workers sharing closed indoor spaces. However, based on the reproduction number for SARS-CoV-2, these events appear to be the exception rather than the rule. Furthermore, it is difficult to determine in retrospect all the potential person-to-person interactions that may have happened before, during, and immediately following these events. The potential capacity of viruses to spread widely and rapidly among tightly packed groups within closed environments via multiple mechanisms should not be underestimated. Experiments using labeled phages show that viruses can spread from a single contaminated door handle or the hands of 1 infected person to people and equipment throughout an office building within hours.[7] These caveats are also speculative and do not exclude the possibility of aerosol-based transmission, particularly in crowded poorly ventilated spaces, but do provide potential alternative explanations for these clusters.

Perhaps the most practical gauge of the relative importance of aerosols vs droplets are studies on the relative effectiveness of respiratory protection targeting aerosols vs droplets. If respiratory viruses are predominantly spread via aerosols, N95 respirators and their equivalents would be more protective than medical masks alone. A recent meta-analysis made this claim.[8] However, the meta-analysis was not based on direct comparisons of N95 respirators vs medical masks but rather on a post hoc bayesian analysis of 2 independent analyses, one on N95 respirators vs no masks and the other on medical masks vs no masks.

Both N95 respirators and medical masks were protective compared with no masks; however, the validity of then comparing these 2 analyses is questionable given the highly divergent source studies for each comparison. The included studies were small, heterogeneous case-control studies that variably adjusted for possible confounders, had disparate results, and wide confidence intervals.

Moreover, 9 of the 10 studies in this meta-analysis[8] involved SARS coronavirus 1 and Middle East respiratory syndrome virus rather than SARS-CoV-2. To extrapolate about the effectiveness of respiratory protection for SARS-CoV-2 from other viruses, it would make more sense to extrapolate from the 4 randomized trials that have directly compared N95 respirators vs medical masks and found no difference between them in the rates of confirmed non–SARS coronavirus infections and influenza infections among health care workers.[9]

All told, current understanding about SARS-CoV-2 transmission is still limited. There are no perfect experimental data proving or disproving droplet vs aerosol-based transmission of SARS-CoV-2. The balance of evidence, however, seems inconsistent with aerosol-based transmission of SARS-CoV-2 particularly in well-ventilated spaces. What this means in practice is that keeping 6-feet apart from other people and wearing medical masks, high-quality cloth masks, or face shields when it is not possible to be 6-feet apart (for both source control and respiratory protection) should be adequate to minimize the spread of SARS-CoV-2 (in addition to frequent hand hygiene, environmental cleaning, and optimizing indoor ventilation).

To be sure, there are rarely absolutes in biological systems, people produce both droplets and aerosols, transmission may take place along a spectrum, and even medical masks likely provide some protection against aerosols.[6,10] It is impossible to conclude that aerosol-based transmission never occurs and it is perfectly understandable that many prefer to err on the side of caution, particularly in health care settings when caring for patients with suspected or confirmed COVID-19. However, the balance of currently available evidence suggests that long-range aerosol-based transmission is not the dominant mode of SARS-CoV-2 transmission.

ARTICLE INFORMATION

Published Online: July 13, 2020. doi:10.1001/jama.2020.12458

Conflict of Interest Disclosures: Dr Klompas reported receiving grants from the US Centers for Disease Control and Prevention; and receiving personal fees from UpToDate. No other disclosures were reported.

REFERENCES

1. Bourouiba L. Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. *JAMA*. 2020;323(18):1837-1838. doi:10.1001/jama.2020.4756

2. Cheng HY, Jian SW, Liu DP, Ng TC, Huang WT, Lin HH; Taiwan COVID-19 Outbreak Investigation Team. Contact tracing assessment of COVID-19 transmission dynamics in Taiwan and risk at different exposure periods before and after symptom onset. *JAMA Intern Med*. Published online May 1, 2020. doi:10.1001/jamainternmed.2020.2020

3. Rosenberg ES, Dufort EM, Blog DS, et al; New York State Coronavirus 2019 Response Team. COVID-19 testing, epidemic features, hospital outcomes, and household prevalence, New York State-March 2020. *Clin Infect Dis*. Published online May 8, 2020. doi:10.1093/cid/ciaa549

4. Chen Y, Wang AH, Yi B, et al. Epidemiological characteristics of infection in COVID-19 close contacts in Ningbo. Article in Chinese. *Zhonghua Liu Xing Bing Xue Za Zhi*. 2020;41(5):667-671.

5. Heinzerling A, Stuckey MJ, Scheuer T, et al. Transmission of COVID-19 to health care personnel during exposures to a hospitalized patient—Solano County, California, February 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(15):472-476. doi:10.15585/mmwr.mm6915e5

6. Ng K, Poon BH, Kiat Puar TH, et al. COVID-19 and the risk to health care workers: a case report. *Ann Intern Med*. 2020;172(11):766-767. doi:10.7326/L20-0175

7. Reynolds KA, Beamer PI, Plotkin KR, Sifuentes LY, Koenig DW, Gerba CP. The healthy workplace project: reduced viral exposure in an office setting. *Arch Environ Occup Health*. 2016;71(3):157-162. doi:10.1080/19338244.2015.1058234

8. Chu DK, Akl EA, Duda S, Solo K, Yaacoub S, Schünemann HJ; COVID-19 Systematic Urgent Review Group Effort (SURGE) Study Authors. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. *Lancet*. 2020;395(10242):1973-1987. doi:10.1016/S0140-6736(20)31142-9

9. Bartoszko JJ, Farooqi MAM, Alhazzani W, Loeb M. Medical masks vs N95 respirators for preventing COVID-19 in healthcare workers: a systematic review and meta-analysis of randomized trials. *Influenza Other Respir Viruses*. 2020;14(4):365-373. doi:10.1111/irv.12745

10. Dharmadhikari AS, Mphahlele M, Stoltz A, et al. Surgical face masks worn by patients with multidrug-resistant tuberculosis: impact on infectivity of air on a hospital ward. *Am J Respir Crit Care Med*. 2012;185(10):1104-1109. doi:10.1164/rccm.201107-1190OC