

What drives transmission of severe acute respiratory syndrome coronavirus 2?

The coronavirus disease 2019 (COVID-19) pandemic represents the most severe public health crisis of the last 100 years both in terms of societal impact and illness. As of May 10th, more than 155 million individuals have contracted COVID-19 and more than 3.3 million have died from the disease. Even though the underlying pathogen, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is a member of the coronavirus family that has been studied extensively for many decades, the world was ill-prepared to deal with its high degree of contagion combined with its broad spectrum of virulence. Regrettably, knowledge gained about the physical underpinnings of respiratory viral transmission after the 1918 Spanish flu pandemic was largely ignored by the public health community at the outset of the COVID-19 pandemic.

Infections with respiratory viruses are principally transmitted through three modes: contact, droplet and airborne, requiring different actions to reduce the spread of infection.

- Contact transmission is an infection spread through direct contact with an infectious person (e.g. touching during a handshake) or with an article or surface that has become contaminated. The latter is sometimes referred to as 'fomite transmission', such as occurs with the respiratory syncytial virus.
- Droplet transmission is an infection spread through exposure to virus-containing respiratory droplets (i.e. larger ($>100\ \mu\text{m}$) and smaller droplets and particles) exhaled by an infectious person. Transmission is most likely to occur when someone is close to the infectious person, generally within about 6 feet, such as with the influenza virus.
- Airborne transmission is an infection spread through exposure to those virus-containing respiratory droplets comprised of smaller particles ($<100\ \mu\text{m}$) that can remain suspended in the air over long distances (usually greater than 6 feet) and time (typically hours) like rubeola (the virus that causes measles) and varicella-zoster (the virus that causes chickenpox).

Valentyn Stadnytskyi, Philip Anfinrud and Adriaan Bax from the NIH have carefully dissected current

scientific evidence for how and what drives the transmission of SARS-CoV-2. Using data from superspreader events, they demonstrate solid evidence supporting airborne transmission via speech as the dominating route for the spread of SARS-CoV-2 [1]. Indeed, epidemiological data demonstrate that superspreaders may account for 80% of SARS-CoV-2 transmission [2]. In addition, the authors provide evidence that air is not only the dominant pathway for transmitting COVID-19, but also unmasked speech in confined spaces represents the activity that poses the greatest risk to others. Since eating and drinking often take place indoors and typically involve loud speaking, it should come as no surprise that bars and restaurants have become the epicentres of multiple recent superspreading events. Individuals shedding high levels of virus in indoor crowded settings with poor ventilation account for most infections, which is supported by contact tracing data from several countries [3, 4].

There are several claims that the lack of recoverable viral culture samples of SARS-CoV-2 from the air prevents firm conclusions to be drawn about airborne transmission [5]. However, measles and tuberculosis, two primarily airborne diseases, have never been cultivated from room air [6]. Findings from studies that seek to detect viable pathogens in the air are therefore insufficient grounds for concluding that a pathogen is not airborne if the totality of scientific evidence indicates otherwise. Decades of painstaking research, which did not include capturing live pathogens in the air, show that diseases once considered to be spread by droplets are indeed airborne [7, 8]. The convincing evidence that is forwarded by Stadnytskyi et al. is based on careful evaluation of the air spread of SARS-CoV-2 identified by the transfer of specific muted SARS-CoV-2 signatures (Fig. 1).

Valentyn Stadnytskyi, Philip Anfinrud and Adriaan Bax have made analyses of human behaviours and interactions, room sizes, ventilation and other variables in choir concerts, cruise ships and care homes, among other settings, where they identified long-range transmission and overdispersion of the basic reproduction number, consistent with

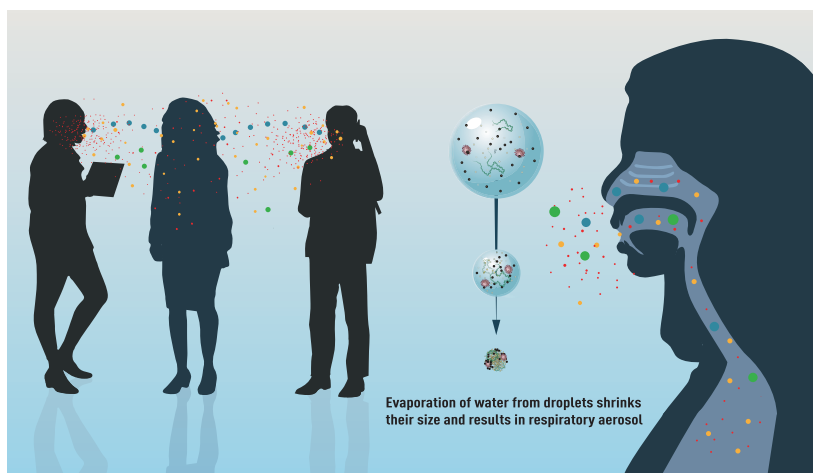


Fig. 1 Airborne transmission via speech is the dominating route for spread of SARS-CoV-2. Respiratory particles and droplets originate in the lungs, trachea, larynx and oral/nasal passages and consist of $\geq 95\%$ water at the time they are first generated. Viral replication in lower respiratory tract comprises smaller particles. This generates an aerosol where most viral content exists and that is intermediate in size of 20–100 μm . They remain suspended in the air for minutes and can be transported over considerable distances by convective air currents. The hydration that occurs in the air then reduces the size of the particles. This reduced-sized fraction facilitates the inhalation and spread. The lesser the humidity, the higher the risk for spread. Thus, relatively large particles up to 100 μm are exhaled during speech and subsequently hydrated and reduced-sized particles of 5–20 μm are then inhaled and responsible for infection in the respiratory tract of susceptible individuals.

airborne spread of SARS-CoV-2 that cannot be adequately explained by droplets or fomites [1]. Furthermore, they provide evidence from laboratory set-up that a specific particle size of 1 to 100 μm generates transmission. The duration and spread are dependent on the size, the viral content, the humidity and temperature, and the level of air replacement.

The authors have made direct measurements that show that speaking produces thousands of aerosol particles and few large droplets and demonstrate that viable SARS-CoV-2 can be detected in the air for several minutes to hours depending on particle size and level of humidity in the air. This is also supported by the notion that nosocomial infections have been documented in healthcare organizations, where there have been strict contact-and-droplet precautions and use of personal protective equipment designed to protect against droplet but not aerosol exposure [9]. In addition, SARS-CoV-2 has been identified in air filters and building ducts in hospitals with COVID-19 patients; such locations could be reached only by aerosols [10].

Experimental set-up in animal and human studies has examined the size, virion content and durability of airborne particles under different conditions. Stadnytskyi et al. provide results showing that respiratory droplets emitted while breathing, speaking/singing, coughing and sneezing span a continuum of sizes depending on their generation mechanism and their site of origin. Respiratory particles and droplets originate in the lungs, trachea, larynx and oral/nasal passages and consist of $\geq 95\%$ water at the time they are first generated. Viral replication in the lower respiratory tract results in compost of smaller particles. However, of most concern is the large fraction of speech aerosol where most viral content exists. These intermediate-sized particles of 20–100 μm remain suspended in the air for minutes and can be transported over considerable distances by convective air currents. The hydration that occurs in the air then reduces the size of the particles. This facilitates the inhalation and spread. The lesser the humidity, the higher the risk for spread. Thus, relatively large particles up to 100 μm are exhaled during speech and subsequently hydrated. Reduced-sized particles of 5–20 μm are then

inhaled and responsible for infection in the respiratory tract of susceptible individuals.

Implications of findings

If the authors' conclusion that speech-generated aerosol, combined with its high viral load in pre- and asymptomatic individuals, is the primary airborne transmission route of SARS-CoV-2 had been considered in the original preventive measures, the spread of the pandemic most likely could have been reduced. SARS-CoV-2 propagates primarily by hitching a ride inside an airborne respiratory particle from its host and then being inhaled into the respiratory tract of its next, unsuspecting victim. Thus, increase in ventilated air, humidification of air indoors and restrictions in café and restaurant visits would have been of value. The use of any type of face mask will reduce the number of exhaled particles of 1–100 μm size from infected individuals. However, smaller pores in the filters must be considered for protection since hydrated particles of 1–20 μm are responsible for the inhaled threat in susceptible individuals. Next to vaccination, mitigation strategies should emphasize the use of face masks when speaking indoors and ensuring adequate ventilation to flush out long-lived aerosols that might otherwise accumulate in closed environments and enhance the risk of more serious lower respiratory tract infections.

Conflict of interest statement

No conflict of interest was declared.

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