A Paradigm Shift to Align Transmission Routes with Mechanisms

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Abstract

Current infection control guidelines subscribe to a contact/droplet/airborne paradigm that is based on outdated understanding. Here, we propose to modify and align existing guidelines with a more accurate description of the different transmission routes. This will improve the effectiveness of control measures as more transmissible variants of SARS-CoV-2 emerge.

Commentary

With the relaxation of various non-pharmaceutical restrictions (masking and social distancing), and the opening of international borders to travel again, we need to prepare longer-term strategies for how we manage COVID-19 as it becomes more seasonal [1]. Highly transmissible SARS-CoV-2 variants, such as Delta (B.1.617.2), are rapidly spreading around the world, escaping complete vaccine protection [2-4], as well as transmitting quickly through unvaccinated and partially vaccinated populations. Hence, non-vaccine control strategies remain equally important. These can only be effective, however, if they target the main route(s) of transmission. Therefore, a correct and thorough understanding of how SARS-CoV-2 transmits underpins the design and implementation of effective control strategies. Just as importantly, it reduces the time, effort, and resources wasted on ineffective actions (i.e., “hygiene theater”).

The pandemic has revealed inconsistencies and inaccuracies in the traditional understanding of transmission of respiratory viruses. This misunderstanding, entwined with operational definitions for infection control, has led to confusion and disagreement. As a result, public health agencies were slow to recognize the importance of transmission of SARS-Cov-2 by aerosols, communication with the general public failed to emphasize the most effective interventions, and the actual mechanisms by which pathogens move through the environment while transmitting person-to-person have become obscured. Addressing these limitations is crucial to examining the ongoing response to the pandemic, as SARS-CoV-2 becomes more seasonal, as well as preparing for the next one.

In the same context, it is important to understand how and why such erroneous concepts and beliefs arose, in order to correct and update them more effectively. Traditional routes of transmission were established in the early 20th century as (1) direct contact with an infected person or indirect contact via a contaminated object known as a “fomite,” (2) droplets propelled in a cough or sneeze by an infected person onto the mucous membranes of a susceptible person, and (3) droplet nuclei or aerosols, consisting of dried residue from droplets that have evaporated [5, 6], that transmit disease over long distances. The latter is known as “airborne” transmission and became associated with particles smaller than 5 μm [7].

While these classifications seem like a reasonable way to think about transmission mechanisms, there are two main problems with them.

First, they introduce technical inaccuracies that defy physics and reflect an incomplete understanding of emissions during respiratory activities. This has led to incorrect assumptions and a misleading mental model about how pathogens actually move through the environment and reach a susceptible individual. According to this model, droplets larger than 5 μm follow ballistic trajectories (i.e., like when a ball is thrown) and travel a limited distance before falling to the ground. Droplets were believed to be *solely* responsible for transmission at close range (<1-2 meters). In contrast, aerosols were believed to be *only* of significance over longer ranges. Droplets and aerosols were thought to be produced mainly by coughing and sneezing or by aerosol generating medical procedures.

While previous publications, including our own, have attempted to separate droplets and aerosols by various criteria, here we start with a clean slate and build on widely-accepted definitions that are not encumbered by discipline-specific connotations. According to dictionaries, a droplet is "a small drop of a liquid"; no minimum or maximum size is specified. Thus, all bits of fluid that are released from the respiratory tract can be considered to be droplets initially. Depending on ambient humidity, they may partially or fully evaporate, shrinking to 20-40% of their initial diameter, in which case they may be solid or semi-solid [8]. According to dictionaries, an aerosol is "a suspension of fine solid particles or liquid droplets in a gas." Aerosol particles, whether solid or liquid, are often referred to simply as "aerosols." We will refer to droplets that are large enough to fall to the ground within a few seconds, and that do not evaporate significantly within this time period, as "large droplets." Based on these definitions, the threshold between aerosols and large droplets is approximately 100 μm (the average diameter of a human hair) and depends on environmental conditions such as humidity and air flow velocity and direction [9-11]. This threshold is also the upper limit of particles that can be inhaled [12, 13].

Using this terminology, we can now describe the transfer of pathogens in respiratory fluid from one person to another. People produce respiratory droplets spanning a wide range of sizes, from submicron to millimeter, when breathing, talking, singing, coughing, and sneezing. The size distribution is multimodal with a smaller mode around 1-3 μm, thought to originate in the bronchioles and larynx, and a larger mode around 100-200 μm, thought to originate in the oral region [14, 15]. The smaller ones are far more numerous than the larger ones, and the majority of any given pathogen is typically found in the smaller ones, even though the larger ones contain the majority of the volume of fluid [16]. Droplets are emitted as part of a turbulent cloud. After a few seconds, the initial respiratory jet slows down and merges with the background air, and the droplets then behave as individual entities [17, 18].

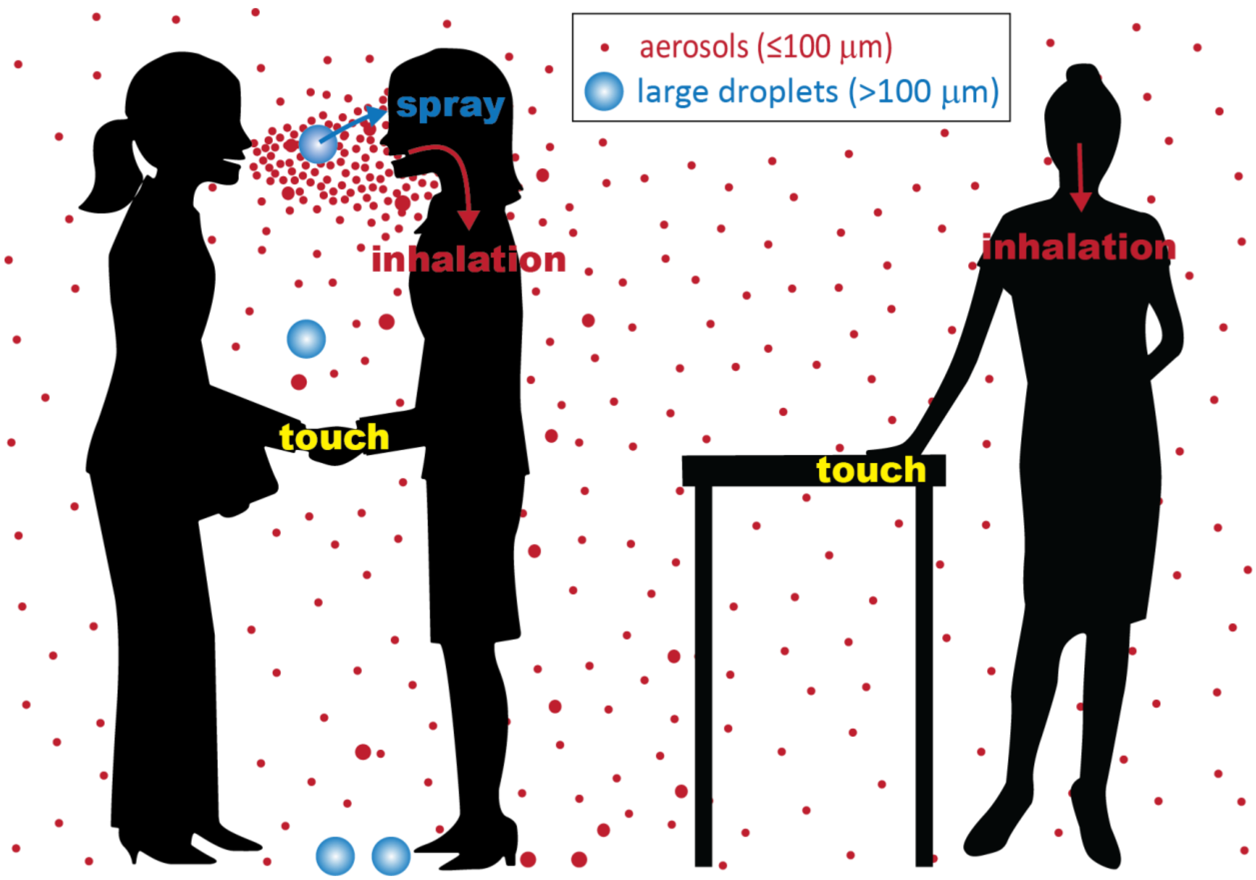

Figure 1. Schematic of an infected person talking and releasing respiratory droplets in a poorly ventilated room, where small aerosols can mix and accumulate throughout the space. Transmission routes are based on how pathogens move through the environment and how people are exposed to them: inhalation, spray, and touch. At close range, all routes are possible, whereas at a distance, transmission only by inhalation and touch of a previously contaminated surface are possible.

The second problem is that the three traditional transmission routes became entangled with and limited by the various *operational* definitions for the precautions required for infection prevention and control of different diseases. According to these operational practices, COVID-19 must be classified as *either* a “droplet” or “airborne” disease, where the latter has been thought to be relevant mainly at long distances. This dichotomy overlooks the reality that respiratory droplets of all sizes, including aerosols, are most concentrated close to the source (i.e., the infected individual) and that exposure at all but uncomfortably close distances is dominated by inhalation rather than the impaction of large droplets that are sprayed onto mucous membranes [19, 20]. Trying to impose this dichotomy and operational definitions on the actual mechanisms of transmission has contributed to incredibly confusing and inconsistent communication about how such pathogens actually behave in the environment and how people can best protect themselves.

To overcome these limitations, we propose a shift in how we define transmission routes, to better align them with the best available evidence for actual mechanisms of transmission. This framework will be more accurate and more truly representative of how pathogens move through the environment, and therefore how people are exposed to them.

Based on decades of multidisciplinary research on transmission mechanisms, a US National Academies of Sciences, Engineering, and Medicine workshop on transmission of SARS-CoV-2 [21], and publications by longtime researchers on the topic [12, 13, 22-24], we propose three major routes of transmission (**Figure 1b**):

1) **Inhalation**. Pathogens carried by aerosols can be directly inhaled into the respiratory tract and deposited at various sites, depending on the size of the aerosol. Aerosols are most concentrated close to the point of release (an infected person), and the smaller ones can remain floating in the air for minutes to hours and can be carried long distances on local air currents. Transmission can occur at any distance and is more likely when people are in close proximity.

2) **Spray**. Pathogens in large droplets may land directly onto external mucous membranes. Large droplets follow semi-ballistic trajectories [25] and settle to the ground within a few seconds. Usually, they do not travel farther than 1-2 meters, although a sneeze can propel them farther [26].

3) **Touch**. A susceptible individual transfers a pathogen, usually by hand, to their mucous membranes. This may occur, for example, if the individual shakes hands with an infected person who wiped their nose or touches a contaminated object.

These definitions directly correspond to different interventions: respirators and masks with excellent fit and filtration capability, along with ventilation and filtration to reduce transmission by inhalation; distancing and face shields to mitigate transmission by sprays (where surgical masks and face coverings are also effective to some degree); and hand hygiene, surface cleaning, and gloves to reduce transmission by touch.

An accurate understanding of transmission reduces the fear associated with it and informs and empowers people to select and plan for more effective interventions. We believe that aligning how we talk about different transmission routes, particularly within an infection control context, with actual mechanisms of transmission, will lead to clearer communication and an improved understanding of and compliance with public health guidance.

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Figure Caption

Figure 1. Schematic of an infected person talking and releasing respiratory droplets in a poorly ventilated room, where small aerosols can mix and accumulate throughout the space. Transmission routes are based on how pathogens move through the environment and how people are exposed to them: inhalation, spray, and touch. At close range, all routes are possible, whereas at a distance, transmission only by inhalation and touch of a previously contaminated surface are possible.