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EDITORIAL

Airborne Transmission of COVID-19

The global spread of COVID-19 is teaching us how little we know about the SARS-CoV-2 virus. For example, the mechanisms by which that viral disease spreads from person to person and the relative importance of different paths of infection remain uncertain. It is generally agreed that the SARS-CoV-2 virus can be spread from an infected person to others by both direct contact and airborne transmission, but there is less agreement about the specific nature of that airborne spread. The implications of such uncertainty are significant, ranging from decisions about the need for and nature of 'social distancing' to recommendations for appropriate choices of respiratory protection for healthcare workers and others.

The COVID-19 virus spreads mainly via droplets of saliva or nasal discharge ('mucosalivary droplets') emitted when an infected person coughs, sneezes, talks or breathes [1,2]. Evidence from chamber studies and models of computational fluid dynamics provide perspectives on that process. During normal breathing and speech, particles are emitted by a mechanism involving 'fluid-film burst' in the small airways, which leads to the emission of particles ≤1 μm in diameter [3]. By contrast, the more forceful 'explosive' exhalations associated with sneezing, coughing, shouting and loud singing result in greater numbers of much larger particles [4]. Figure 1 shows progressively larger numbers and sizes of emitted particles as loudness of speech increases. Much greater numbers and much larger sizes of droplets, up to 500 μm, are emitted during a sneeze [4]. It should be anticipated that similarly great numbers of large size droplets would result from coughing and 'full throated' singing. Thus, it should be appreciated that under some situations most emitted droplets are large (i.e. 5–500 μm), while other situations yield mostly much smaller droplets (<1 μm).

The differing sizes of aerosolized droplets directly impact their transmission. Due to gravitational forces, larger particles tend to settle close to their source, with settling velocities proportional to the square of the particles' aerodynamic diameters [5]. The larger they are, the faster they fall. In general, droplets >5 μ are expected to settle within 1–2 m of the emission source. This expectation is the basis for the recommendation that social distancing requires a minimum of 1–2 m, a distance believed to be sufficient to avoid direct contact with aerosolized droplet emissions.

However, as noted above, many aerosolized droplets are actually smaller particles, which tend to settle more slowly, remain airborne longer and disperse more widely. In addition, there is evidence that emission of droplets, whether from speech or cough, is affected by air turbulence that propels and carries droplets further than would be expected otherwise in still air [2]. Thus, a 1–2 m social distance may be protective from viral spread due to civil speech, but not due to shouting or singing, coughing or sneezing.

In addition, water droplets tend to evaporate quickly: droplets ≤1 μm evaporate in a few milliseconds; droplets of 10 μm evaporate in less than a second; but large droplets, with diameters of ≥100 μm, can survive for 'almost a minute' [5,6]. When they evaporate, droplets become 'droplet nuclei', dry particles that may include viruses and other pathogens and which tend to remain airborne and are thus distributed over a greater area. Because the rate of evaporation is directly related to ambient humidity and temperature, the formation and dispersion of droplet nuclei depends on ambient conditions. Hotter and more humid conditions lead to the longer persistence of larger droplets, which in turn results in less wide dispersion of virus-containing particles. That may explain the observation that the spread of viral respiratory infections is greater during cold, dry winters than during hot, humid summers.

Given various combinations of environmental conditions and patient characteristics, emitted clouds of pathogen-bearing droplets may travel up to 7–8 m [2]. Moreover, in a recent NIH experimental study, aerosolized COVID-containing droplets <5 μm remained airborne for at least 3 h, the duration of experimental observations [7]. Thus, there are reasons to doubt the adequacy of the traditional 1–2 m social distance.

Further complexity is added by observations that COVID infections may also be spread by particulate air pollution. Two very recent sets of observations, both still in pre-publication stage, support that possibility. In the first, researchers at Harvard School of Public Health evaluated associations between ambient levels of $PM_{2.5}$ and COVID death rates across the USA. A small increase

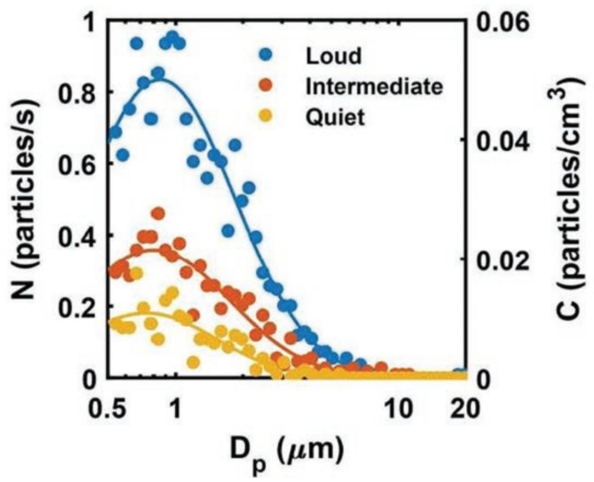

Figure 1. This figure is from Asadi S, Wexler AS, CAppa CD, Barreda S, Bouvier SM, Ristenpart WD. Aerosol emission and superemission during human speech increase with voice loudness (https://doi.org/10.1038/s41598-019-38808-z). Scientific Reports 2019; 9:2348This article is licensed under a Creative Commons Attribution 4.0 International License http://creativecommons.org/licenses/by/4.0/ No changes were made to this image.

in $PM_{2.5}$ was associated with a large increase in COVID-19 death rates: the magnitude of that increase was '20 times that observed for $PM_{2.5}$ and all-cause mortality' [8]. The second study, a collaboration of researchers at several Italian universities, determined the presence of SARS-CoV-2 viral RNA in PM_{10} samples obtained over a 3-week period in Bergamo, near the epicentre of Italy's COVID epidemic. These authors concluded that they had 'reasonably demonstrated the presence' of the viral RNA in those samples [9]. While both reports are still awaiting formal publication, and the finding of viral RNA does not necessarily indicate the presence of viable virus, both studies raise concerns about possible widespread airborne distribution of COVID-19, as has been reported previously for measles, avian influenza and other viral diseases [9].

Finally, there is the question of infectivity. There is more than enough evidence of the interpersonal spread of COVID infection via airborne transmission. A recent report of the unfortunate results of a choir practice in Washington State brings this point home. Sixty singers convened for their weekly rehearsal in a semi-rural county where no COVID cases had been previously detected. All reported that they had been in good health that day. Hand sanitizers were provided. The singers were conscious of self-distancing and they avoided 'the usual hugs and handshakes'. Nobody coughed, sneezed or appeared ill. Nevertheless, within 3 weeks 45 of the singers had been diagnosed with COVID and two had died [10]. This remarkable example of interpersonal 'super spreading' is best explained by the enhanced aerosolized transmission that resulted from enthusiastic singing. And the spread to so many, despite distancing, argues that transmission was not due solely to localized droplet dispersion, but more likely to wider dispersion of aerosolized droplet nuclei.

These observations and findings raise concerns that COVID-19 may spread widely via fine aerosolized droplets. That, in turn, poses two more questions that need answers. First, does the finding of COVID RNA indicate the presence of viable virus, or only the remnants of non-viable virus? In other words, it is not yet known whether such wider airborne dispersion will necessarily lead to greater spread of infection. Second, if fine COVID-related aerosols are infectious, then what is the most appropriate respiratory protection for healthcare workers and others with likely exposure? While not yet determined for COVID, this question has been studied for other viral respiratory infections (including coronaviruses). A just-published meta-analysis considered four random control trials of medical masks versus N95 respirators for the prevention of laboratory-confirmed viral respiratory infections in exposed healthcare workers. Although the evidence was judged 'low certainty', the analysis found no significant advantage of N95 over medical masks [11]. While premature to draw firm conclusions, these results suggest that the contribution of fine aerosolized particles to infectious spread of viral respiratory disease may be limited. Let us hope that this is true for COVID.

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