Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Bioaerosols and airborne transmission: Integrating biological complexity into our perspective

Caroline Duchaine, Chad J. Roy

Abstract

There is broad consensus that airborne disease transmission continues to be the thematic focus of COVID-19, the complexities and understanding of which continues to complicate our attempts to control this pandemic. Masking used as both personal protection and source reduction predominates our society at present and, other than vaccination, remains the public health measure that will faithfully reduce aerosol transmission and overall disease burden. Early in the advent of the COVID-19 pandemic, and especially after preliminary recognition of airborne transmission, there was considerable efforts in the application of computational fluid dynamics (CFD) modeling aerosols as well as risk models calculations, the products of which were detailed in the literature and even disseminated in media destined for the public. As the respiratory pathway emerged as the dominant exposure pathway for SARS-CoV-2 transmission, much of what was promoted from CFD was applied to risk models to estimate community infection and in some cases expected clinical outcome. COVID-19 proved to fit the profile of an obligate respiratory-transmitted pathogen, and the plausibility of using aerosol modeling when silhouetted with emerging COVID-19 epidemiology provided ample evidence for promotion of masking and ventilation optimization as a required public health measure. Masking is often included as a factor in developed risk models and it remains an essentially important part of our response to this airborne threat, and ultimately will agnostically reduce disease burden although efforts to improve ventilation in indoor spaces remain a challenge. Arguably the most important concept in the airborne transmission of infectious agents is the biologically active componentry that comprises the aerosol particle and the functional dynamic nature of particle contents. Specifically, the innate generation, transport, and ultimate deposition/disposition of bioaerosols; the aerosol particles that nearly exclusively harbor bioactive components, including viruses, when disease agents are transmitted through the air.

Discussion

Promoted from CFD was applied to risk models to estimate community infection and in some cases expected clinical outcome. COVID-19 proved to fit the profile of an obligate respiratory-transmitted pathogen, and the plausibility of using aerosol modeling when silhouetted with emerging COVID-19 epidemiology provided ample evidence for promotion of masking and ventilation optimization as a required public health measure. Masking is often included as a factor in developed risk models and it remains an essentially important part of our response to this airborne threat, and ultimately will agnostically reduce disease burden although efforts to improve ventilation in indoor spaces remain a challenge. Arguably the most important concept in the airborne transmission of infectious agents is the biologically active componentry that comprises the aerosol particle and the functional dynamic nature of particle contents. Specifically, the innate generation, transport, and ultimate deposition/disposition of bioaerosols; the aerosol particles that nearly exclusively harbor bioactive components, including viruses, when disease agents are transmitted through the air.

http://dx.doi.org/10.1016/j.scitotenv.2022.154117
0048-9697/© 2022 Elsevier B.V. All rights reserved.
modelize and predict the biological aspect of transmission has led to sometimes simplified approaches. Adding the biological perspective into the interpretation of models and capturing the breadth of biological variables and the complexity of predicting the behavior of viral aerosols and their consequences is an important part of transdisciplinary communication.

Bioaerosols are aerosol particles that harbor a constellation of biologic componentry packaged on a microbial scale. It is now widely accepted that biologically active agents when in aerosol form rarely travel through the air in a singular state. Rather, when viruses are propelled into the air through natural generation processes directly from the respiratory system (e.g., exhaled breath, cough, sneeze) or through fomite re-aerosolization in cases where viruses can maintain upon inanimate surfaces, they are carried on particles on which their own size have negligible impact. In the case of the former, the composition of the aerosol particle is liquid, and its potentially pathogenic componentry is susceptible to environmental manipulation once liberated from a warmed humidified respiratory system. The resulting plasticity of a hydrophobic (or -scopic) ambient environment alters any residual protection from other environmental hazards such as ultraviolet radiation that may ultimately effect replication competence or water activity, salt concentration and changes in the pH of the aerosol particle (Haddrell and Thomas, 2017). Prevailing size can also be affected during the transport process and change the overall trajectory of each particle depending upon the composition and relative density of the ‘solute’ or liquid carrier of the aerosol. The perspective of variable biochemical components and their impacts on bioaerosol fate is mostly lacking in the prediction models. Terminal settling velocity, or the time associated with settling to the ground in a theoretically static ambient environment, is the major force behind whether the bioaerosol particle travels more or less than the now-infamous six-foot ‘social distancing’ metric that has been followed for over two years now (Tang et al., 2021). Because the particle size is contingent upon the environment in which it is produced and travels through, the replication competence of the virus can be affected by the shrinking (or expanding) of the aerosol particle that has consequences on viral structures integrity and potential for viral fusion. This phenomenon is everchanging based upon the interactions of the contagious individual, respective generation rate, and the environment into which these particles are generated, and has been noted as an important physicochemical change that ultimately effects infection potential (Marr et al., 2019). Even the probability of virion presence within the aerosol particle has been theorized as being statistically functional as a Poisson distribution and thereby estimated to be present in only a very small percentage of total bioaerosols produced by someone clinically ill with the disease (Anand and Mayya, 2020).

Infectious particles resulting from the process of natural aerosol generation can and as we know from the epidemiology of the current pandemic, possess the capacity to be inhaled and induce disease. However, the third and terminal phase of respiratory deposition and implantation in the naive host may be more of a stochastic event than that of a deterministic fait accompli for infection. The probability associated with at least one replication competent virion in any one aerosol particle, even when generated from a clinically ill person, is certainly vanishingly low. If the required ‘dose’ of SARS-CoV-2 virus is quantified to any reasonable number based upon volumetric capacity of even the smallest of expired particles, the collective dose could theoretically be achieved with a singular inhalation based upon those probabilities. This circumstance, however, is just not the case in natural infection processes, which more than likely rely upon a multiplicity of replication competent virions to implant directly or proximal to tissues susceptible to viral invasion. Human infection threshold estimates for SARS-CoV-2 suggest that the quanta of infection may range from 10 to 1E+03 of virions inhaled (Buonanno et al., 2020b).

When considering biophysical complexities of bioaerosol transport and airborne disease transmission, the critical question remains “Is all of this biological chaos prior to infection ultimately relevant to clinical outcome?” SARS-CoV-2 has evolved in the human host to manifest in most as a self-limiting upper respiratory infection. In some cases of individuals that are susceptible, there is considerable lung involvement, including viral pneumonias, which dramatically increases the chance of a poor clinical outcome. A corollary of lower respiratory involvement includes surface tension changes to epithelial lining fluid in the lung, which results in the narrowing of airways from surrounding inflammation from the viral infection, and higher velocity airflow respiratory mechanics. The net effect to the biorheology of the lung ultimately increases production of exhaled breath aerosols (Edwards et al., 2004), which may in turn contain virus. Patients with higher production rates of exhaled breath particles may contribute at a higher rate to the cycle and perpetuation of disease by aerosol transmission (Edwards et al., 2021). Ironically, the physicochemical and biological composition of infectious bioaerosols is largely dependent upon the supporting lung physiology and biology of the contagious emitter - and the prevailing host factors present during generation that determines the particulars of the bioaerosols generated. The result of dynamic and variable generation processes ultimately complicates any reasonable estimation of viral spread through CFD modeling when interpreted in an insular mathematical fashion; interactions between naive host and bioaerosols remains far too complex when considering disease induction or severity of clinical outcome. This is not to suggest that CFD and other types of modeling are not useful for estimating disease transmission, however the biome encompassed within bioaerosols brings unusual complexities to estimating the risk of infection from aerosol exposure. This phenomenon is not limited to COVID-19; the paradigm of respiratory transmission via infectious bioaerosol is thought to be conserved for most preferential or obligate respiratory bacterial and viral pathogens. As we move through this pandemic and attempt to draw lessons from the current circumstance, anxiously awaiting the next zoonotic spillover event, let us all keep in mind the complexities of the phasic generation, transport, and anatomic deposition of microbiologically complex bioaerosols – and ground ourselves in the hypothesis of stochastic rather than deterministic disease when contemplating risk of infection.

CRediT authorship contribution statement

Drs. Roy and Duchaine equally contributed to this Discussion submission.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Anand, S., Mayya, Y.S., 2020. Size distribution of virus laden droplets from respiratory ejecta of infected subjects. Sci. Rep. 10 (1), 21174. https://doi.org/10.1038/s41598-020-78110-x.

Buonanno, G., Stabile, L., Morawska, L., 2020. Estimation of airborne virus emission: quanta emission rate of SARS-CoV-2 for infection risk assessment. Environ. Int. 141, 105794. https://doi.org/10.1016/j.envint.2020.105794.

Buonanno, G., Morawska, L., Stabile, L., 2020. Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: prospective and retrospective applications. Environ. Int. 145, 106132. https://doi.org/10.1016/j.envint.2020.106132.

Edwards, D.A., Man, J.C., Brand, P., et al., 2004. Inhaling to mitigate exhaled bioaerosols. Proc. Natl. Acad. Sci. U. S. A. 101 (50), 17383–17388. https://doi.org/10.1073/pnas.0408159101.

Edwards, D.A., Asemiello, D., Salzman, J., et al., 2021. Exhaled aerosol increases with COVID-19 infection, age, and obesity. Proc. Natl. Acad. Sci. U. S. A. 118 (8). https://doi.org/10.1073/pnas.2021830118.

Gandhi, M., Marr, L.C., 2021. Uniting infectious disease and physical science principles on the importance of face masks for COVID-19. Med. (N. Y.) 2 (1), 29–32. https://doi.org/10.1016/j.medj.2020.12.008.

Haddrell, A.E., Thomas, R.J., 2017. Aerobiology: experimental considerations, observations, and future tools. Appl. Environ. Microbiol. 83 (17). https://doi.org/10.1128/AEM.00809-17.

Marr, L.C., Tang, J.W., Van Mallekom, J., Lakdawala, S.S., 2019. Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence. J. R. Soc. Interface 16 (150), 20180298. https://doi.org/10.1098/rsif.2018.0298.

Morawska, L., Tang, J.W., Bahafteh, W., et al., 2020. How airborne transmission of COVID-19 indoors be minimised? Environ. Int. 142, 105832. https://doi.org/10.1016/j.envint.2020.105832.

Tang, J.W., Marr, L.C., Milton, D.K., 2021. Aerosols should not be defined by distance travelled. J. Hosp. Infect. 115, 131–132. https://doi.org/10.1016/j.jhin.2021.05.007.