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Review article

Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy

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ABSTRACT

The practice of social distancing and wearing masks has been popular worldwide in combating the contraction of COVID-19. Undeniably, although such practices help control the COVID-19 pandemic to a greater extent, the complete control of virus-laden droplet and aerosol transmission by such practices is poorly understood. This review paper intends to outline the literature concerning the transmission of virus-laden droplets and aerosols in different environmental settings and demonstrates the behavior of droplets and aerosols resulted from a cough-jet of an infected person in various confined spaces. The case studies that have come out in different countries have, with prima facie evidence, manifested that the airborne transmission plays a profound role in contracting susceptible hosts. The infection propensities in confined spaces (airplane, passenger car, and healthcare center) by the transmission of droplets and aerosols under varying ventilation conditions were discussed.

Interestingly, the nosocomial transmission by airborne SARS-CoV-2 virus-laden aerosols in healthcare facilities may be plausible. Hence, clearly defined, science-based administrative, clinical, and physical measures are of paramount importance to eradicate the COVID-19 pandemic from the world.

1. Introduction

Coronavirus disease 2019 (COVID-19) was first reported in Wuhan, China, in December 2019 (Chen et al., 2020). The disease is caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (Gorbalenya, 2020) and asseverated to be transmitted from human-to-human by multiple means, namely, by droplets, aerosols, and fomites (Wang and Du, 2020). It has been more than 120 days that COVID-19, later declared as a pandemic and highly contagious, was first reported. As of May 05, 2020, there have been more than 3.5 million confirmed cases and 243,401 deaths by the COVID-19 disease worldwide (WHO, 2020a). COVID-19 infection triggers severe acute respiratory illness, with fever, cough, myalgia, and fatigue as common symptoms at the onset of illness (Huang et al., 2020; Judson and Munster, 2019; Nicas et al., 2005).

Infectious agents may spread from their natural reservoir to a susceptible host in different pathways. There are various classifications reported in the literature for modes of transmission of different infectious agents. Morawska (2006) has presented a classification for virus transmission, including human-human transmission, airborne transmission, and other means of transmission such as endogenous infection, common vehicle, and vector spread. However, many respiratory viruses are believed to transmit over multiple routes, of which droplet and aerosol transmission paths become paramount, but their significance in transmitting the disease remains unclear (Morawska and Cao, 2020; Shiu et al., 2019). In general, infected people spread viral particles whenever they talk, breathe, cough, or sneeze. Such viral particles are known to be encapsulated in globs of mucus, saliva, and water, and the fate/behavior of globs in the environment depends on the size of the globs. Bigger globs fall faster than they evaporate so that they splash down nearby in the form of droplets (Grayson et al., 2016; Liu et al., 2016). Smaller globs evaporate faster in the form of aerosols, and linger in the air, and drift farther away than the droplets do.

Respiratory particles may often be distinguished to be droplets or aerosols based on the particle size and specifically in terms of the aerodynamic diameter (Hinds, 1999). One could dispute that, unlike larger droplets, aerosols may pose a greater risk of the spread of the COVID-19 disease among many susceptible hosts positioned far from the point of origin. Nevertheless, it has been proven that viral disease outbreaks via aerosol transmission are not as severe as one would think, because of dilution and inactivation of viruses that linger for extended periods in the air (Shiu et al., 2019). There has been no discernible evidence on the minimum infectious viral load for COVID-19 pandemic,

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steel, copper, cardboard, and glass with durations (half-lives) lasting to 72, 8, 8, and 96 h, respectively (van Doremalen et al., 2020). The half-lives of the SARS-CoV-2 and SARS-CoV are almost the same in aerosols, with median estimates of approximately 1.1–1.2 h, indicating that both viruses have similar stability characteristics in transmitting through the air (van Doremalen et al., 2020). However, more profound epidemiological sustenance of SARS-CoV-2 virus may, therefore, be because of some other factors, including high viral loads in the upper respiratory tract and the capability of persons infected with COVID-19 to shed and transmit the virus while remaining asymptomatic (Bai et al., 2020; Zou et al., 2020).

Based on a study carried out by Nicas et al. (2005), it has been estimated that particles emitted from a cough of an infected person of a respiratory illness quickly decrease in diameter (with initial diameters of less than 20 μm) mainly because of the water loss by approximately half of the initial volume, amounting to 6×10^{-8} mL. Exhaust ventilation, particle settling, die-off, and air disinfection methods are some prominent mechanisms by which the removal of viable airborne pathogens often takes place; each removal mechanism follows a first-order reduction rate (Nicas et al., 2005). Based on 3-h viability of SARS-CoV-2 in the air (van Doremalen et al., 2020), prerequisites for the disease such as exposure, inhalation, and infection could occur minutes or a few hours later near and far from an aerosol source even in a stagnant environment (Bourouiba, 2020).

The actual airborne times for droplets may be greater in an environment where there are significant cross-flows (WHO, 2009). Such scenarios could be expected in quarantine and healthcare centers (e.g., with doors opening, bed and equipment movement, and people walking back and forth, constantly). Conversely, airborne durations for smaller droplet nuclei or aerosols may be profoundly shorter when they are subject to a significant downdraft (e.g., if they pass under a ceiling supply vent) (WHO, 2009). When the flow of mucus or saliva ejects from an infected person, its trajectory is determined primarily by the size of droplets and airflow patterns that govern the paths of movement (Tang et al., 2006). The Stokes' law describes the resultant trajectory of the droplets subjected to the forces of gravity downwards and air friction upwards, which governs the droplet movement in the air (Wells, 1934). Coughs and sneezes usually constitute a turbulent cloud of buoyant gas with suspended droplets of various sizes. The larger droplets follow a ballistic trajectory irrespective of flow in the gas phase, whereas the aerosols are buoyant to a varying degree within the turbulent gas cloud (Bourouiba et al., 2014).

In general, there exists an accepted notion of a 2-m safe exclusion zone to prevent possible droplet transmission from an infected person to a susceptible host; however, there are no comprehensive studies to support such a phenomenon. Wells (1934) has supported the 2-m exclusion zone concept taking into account the evaporation-falling curve. Wells (1934) has postulated that large droplets (> 100 μm) will fall to the floor within a horizontal distance of 2 m from the source. Simple calculations, assumptions, and inadequate empirical data of Wells's study have been later speculated by Xie et al. (2007). Xie et al. (2007) have corroborated that for respiratory exhalation flows, the larger droplets (diameter between 60 μm and 100 μm) were, depending on the exhalation air velocity and relative humidity of the air, carried away for more than 6 m of horizontal distance with the exhaled air having a velocity of 50 m/s at the point of expiration (Fig. 2a). Such scenarios simulate sneezing events. Conversely, larger droplets were found to carry for more than 2 m afar at a velocity of 10 m/s reordered at the point of exit, simulating coughing bouts (Fig. 2b). The same for exhaling events for which the velocity is at 1 m/s was found to carry large droplets only up to about 1 m horizontally (Fig. 2c). Other studies also have proven that when an infected person of a respiratory illness coughs or sneezes, a cloud of pathogen-bearing droplets of different sizes appears to come out and travels even up to 7–8 m from the point of source (Bourouiba et al., 2014; Bourouiba, 2016).

Moreover, recent experiments conducted after COVID-19 contagion by Bourouiba (2020) and Loh et al. (2020) have been in agreement with the findings of Xie et al. (2007). Xie et al. (2007) have reported that pathogen-bearing droplets of all sizes can travel for almost 7–8 m during sneezes and for more than 2 m (maximum of 4.5 m) during coughs. Surprisingly, there have been contradicting insights on the distance to be maintained between healthcare workers and COVID-19 infected patients [e.g., 1 m (WHO, 2020e) and 2 m (CDC, 2020b)]. However, most of the studies on the COVID-19 virus mentioned above have been carried out in laboratories with expiration devices set on manikins; hence, no convincing information can be deduced.

4. Behavior of droplets and aerosols against environmental factors

The most important environmental factors that could impact on the viability of airborne microorganisms are temperature, humidity, radiation (sunlight), and open-air (ventilation) (Marthi, 1994). Most viruses, including SARS-CoV-2, are less than 100 nm in size (Kumar and Morawska, 2019). Viruses in aerosols lose or gain the viability and infectivity because of environmental stresses caused by temperature, relative humidity, and sunlight before they reach a susceptible host. Environmental tolerance of the virus-laden aerosols depends on the specific phenotype available, the composition of the bioaerosols containing virus and their payload, and physical characteristics in the surrounding environment (Schuit et al., 2020). As the environmental factors play a major role in transmitting payloads of SARS-CoV-2 virus in different geographical locations of outdoor and indoor environments, it is worthy of exploring the effects of environmental factors on the transmission of SARS-CoV-2 virus. Furthermore, there have been associations between air pollution represented by air pollutants such as $PM_{2.5}$, PM_{10}, NO_2, and O_3 and COVID-19 infection (Zhu et al., 2020). SARS-CoV-2 could bind with particulate matter and could be airborne. In an indoor environment, such viral loads primarily become airborne by advective forces propelled by local ventilation patterns and travel further away through diffusion and dispersion processes. Table 2 summarizes the relationships of viral payloads resulted from different transmission routes with environmental parameters deduced by various researchers.

5. Safeguards against transmission of droplets and aerosols

The transmission of droplets and aerosols has significant implications on healthcare workers and caretakers managing patients infected with COVID-19, and providing appropriate PPE is, therefore, of utmost importance. The facemasks play a major role in preventing both droplets and aerosols from transmitting the disease from an infected person to a host. Facemasks are popular in controlling and preventing virus transmission, especially in connection with severe respiratory syndromes such as SARS-CoV, MERS-CoV, and SARS-CoV-2, since the absence of any vaccination or specific anti-infective treatments (Long et al., 2020). The surgical mask, N95 respirator, and elastomeric respirator have been popular among many countries with a different degree of success against the COVID-19 virus. Besides, with greater demand for masks in many countries, more sophisticated masks have been experimented by various researchers (Balachandar et al., 2020; Leung and Sun, 2020). Surgical masks and N95 respirators are very popular and ubiquitous among millions of people worldwide as the PPE for COVID-19, but surgical masks are believed to be not preventing aerosol transmission, and N95 respirators are recognized to be preventing aerosol and droplet transmission (Derrick and Gomersall, 2005; Leung et al., 2020; Sandaradura et al., 2020).

The live influenza virus in the air from, in front, and behind all surgical masks have been tested, and the results indicate that a surgical mask will reduce the exposure to aerosolized infectious influenza virus (average 6-fold), depending on the design of the mask (Booth et al., 2013). Another study on masks has manifested that when applied to