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REVIEW ARTICLE

Effect of wet deposition on the transmission of aerosolized SARS-CoV-2: Facts and mechanisms

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Abstract

Objectives: Rapid spreading of COVID-19 (coronavirus disease 2019) causes increasing morbidity and mortality worldwide. Researchers believe that SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) uses the airborne mode of transmission. Airborne transmission is crucial because in this way viral particles are dispersed maximum in the air. SARS-CoV-2 can be present in respiratory droplets and atmospheric aerosols. Aerosols having a diameter <10 µm can easily penetrate deep inside the lung and interact with alveolar epithelial cells. Thus, the accumulation of infectious aerosols in the air may rapidly spread COVID-19. Therefore, clearance of aerosols from the air is crucial to minimize airborne transmission of SARS-CoV-2.

Methods/Results: In this review, the latest and peer-reviewed publications obtained from Pubmed, Google Scholar, Web of Science, Scopus are evaluated to understand the underlying mechanisms of wet deposition and aerosolized SARS-CoV-2 dispersion. Infectious respiratory droplets may undergo the process of evaporation to produce respiratory droplet nuclei (≤5 µm in diameter), which is capable to suspend in the air for a long time. However, low relative humidity, high temperature, and speed of air are factors to influence aerosolized virus dispersion. Rain or precipitation is useful to remove air particulate matter to provide good air quality. It is reported that COVID-19 cases are less during monsoon. The wet deposition also affects the downward flux of aerosolized virus particles.

Conclusion: Overall, precipitation may reduce the airborne SARS-CoV-2 transmission by removing aerosolized virus particles by wet deposition. However, rain intensity and total days of rainfall are crucial in this case.

Keywords: COVID-19, SARS-CoV-2 transmission, aerosol, particulate matter, rain, wet deposition

Introduction

Increasing cases of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection cause major health risks for humankind. Fast and frequent human-to-human transmission of SARS-CoV-2 results in worldwide growing incidents of COVID-19 (coronavirus disease 2019). Since the first identification of SARS-CoV-2 in December 2019, the confirmed cases of COVID-19 have crossed 433 million having approximately 5.9 million deaths so far.[1] In this devastating time, researchers and health care providers together are working hard to fight against COVID-19. Newly discovered vaccines and prophylactic antibiotics are shown to be effective against COVID-19.[2] Besides, reduction in viral transmission and COVID-19 spread among the population is achieved by lockdowns, travel restrictions, self-quarantine, physical distancing, physical barriers, use of personal protective equipment, etc.[1] It is in this context that fundamentals of nature or natural factors may have a potential role in the community spreading or country-wide spreading of COVID-19. Researchers believe that natural factors like temperature, relative humidity are crucial for the spreading of COVID-19.[3] Additionally, natural wind flow also affects viral transmission.[4] Likewise, virus-mediated respiratory infections may be influenced by different environmental factors and rain is among them. Precipitation with increased warming velocity is reported to be associated with fewer COVID-19 cases.[5] However, the exact reason behind this is not clear. Besides, the transmission of SARS-CoV-2 takes place maximum at high temperatures.[6]

The collective evidence from recent studies supports the airborne mode of SARS-CoV-2 transmission, which may be recognized as the primary route of infection for COVID-19.[7-10] According to the recent update from the Centers for Disease Control and Prevention, inhalation of virus particles is one of the important modes of SARS-CoV-2 transmission.[11] However, aerosol plays a major role in the process of airborne mode of viral transmission in respiratory infections.[12] Although very few articles are available where it has been postulated that possible SARS virus and SARS-CoV-2 transmission takes place by aerosols.[13,14] Presumably, there are two types of aerosols that can be defined for the explanation of SARS-CoV-2 transmission - (i) respiratory aerosols or droplets released by an individual, and (ii) atmospheric (natural and anthropogenic) aerosols made by soil dust particles, volcanic ashes, industrial pollutants, sulfate, etc. The migration of free-falling and free-floating respiratory droplets/ aerosols depends on their size and environmental factors such as relative humidity and speed of airflow.[14,15] It is crucial to mention that speed of airflow is one of the important factors, which facilitates long-distance traveling of aerosols in the air.[4,16] It is evidenced that having high velocity the respiratory droplets travel more distance during sneezing (50 m/s; >6 m) compared to coughing (10 m/s; >2 m) and breathing (1 m/s; <1 m).[17] This study has been organized under indoor environmental conditions, where the diameter of respiratory droplets varies from 0 to 200µm. Virus particles often can be found inside the respiratory droplets. A recent study on COVID-19 shows that exhaled turbulent aerosol clouds contain virus-laden droplets, which can travel a maximum of over 30 meters during coughing and sneezing.[18] However, the traveling distance of respiratory droplets/ aerosols may be influenced by outdoor natural factors like relative humidity, the velocity of natural wind flow, sunlight, etc. Nonetheless, virus-laden aerosols along with air pollutants may naturally exist in an outdoor environment, which is also known as “infectious aerosols”.[19] It is reported that natural aerosols having a diameter of 0.5–20 µm reaches maximum speed (33.1 m/s) during cyclone.[20] Besides, mineral-based aerosols with a diameter >75 µm can travel a maximum >10000 km from their source.[10] These data are raising possibilities of long-range transportation of virus-laden aerosols during SARS-CoV-2 transmission and the spread of COVID-19 in the air.

SARS-CoV-2 can remain viable for at least 3h inside respiratory droplets (<5 µm).[21] However, viral viability may last for 4 to 84h based on the type of material such as plastic, steel, glass, etc. It is important to mention that less than PM10 (particle matter diameter <10 µm) can invade deeply inside the lung and is capable to damage the human respiratory system.[22] Thus infectious respiratory droplets emitted by a SARS-CoV-2 infected individual or SARS-CoV-2-laden aerosols formed naturally may have the potential to spread COVID-19 in a certain community or within a wide range of areas. Presumably, lowering such aerosols may reduce the chance of viral transmission and COVID-19 spread. It is in this context that precipitation or rain is efficient to reduce atmospheric particulate matter through the process of wet deposition.[23-25] A study conducted between 2007 and 2013 on rainfall has revealed the clearance of aerosol nuclei (>PM10) by large-scale precipitation.[26] Additionally, it has been reported that rain can minimize the transmission of respiratory pathogens such as influenza and respiratory syncytial virus by lowering virus-laden aerosols in the atmosphere.[27]

Based on the above-mentioned experimental data and facts it is hypothesized that rain may reduce SARS-CoV-2 transmission and spread of COVID-19 by wet deposition of virus-laden respiratory droplets or atmospheric aerosols.

Distribution of aerosol in air:

Aerosol is present throughout nature and it has a great impact on air quality and public health. However, the size and concentration distribution of aerosols are not the same in all places. Out of different sizes of aerosols, PM2.5 and PM10 are extensively studied as inhalation of these particles contributes to severe respiratory dysfunctions and airway epithelial cell toxicity.[28,29] Data from different studies reveal the variation of aerosol distribution in residential places, industrial areas, deserts, seas, forests, and at high altitudes. A study conducted in Ulsan, South Korea in 2014 September-October shows that the total concentration of PM (TPM) (0.06-18.0 μm in diameter) is more in an industrial area (56.7 μg/m3) compared to residential area (38.2 μg/m3).[30] Additionally, trace metal types such as arsenic, lead, cadmium, selenium, etc. are reported to be high in industrial areas than in residential areas. Besides, forest aerosols contain sulfates having a typical diameter of 0.3 and 0.675 microns.[31] The presence of aerosols (0.10-0.14 μm in diameter) may be increased by 20 times during wildfires.[32] However, forest fire sometimes produces aerosols having a typical size of 0.1-1 μm in diameter.[33] Road traffic-originated nanocluster aerosol is mainly generated by vehicular emission. A study based on Swedish cities reveals that the average emission of PM10 and PM2.5 due to road traffic shows a concentration of 21 ± 20 and 8 ± 6 μg m−3 respectively. The presence of PM10 and PM2.5 in traffic is higher compared to urban areas.[34] Desert dust outbreak is associated with a daily 10 μg m−3 increase of PM10 in the air. PM2.5 concentration in the remote desert area of Kuwait is recorded to be 31 μg m−3.[35] A study conducted on the North Sea and Baltic Sea shows the concentration of PM10 and PM2.5 as 18–28 μg/m3 and 15–25 μg/m3 respectively. However, combustion emission from a ship's diesel engine may cause an almost 10% increase in PM2.5 concentration in the air.[36] In contrast, the concentration of PM10 and PM2.5 in Lhasa, Tibet at high altitude (3663m from sea level) are recorded to be 57.2±46.7 μg/m3 and 25.7±21.7 μg/m3 respectively.[37]

Understanding the airborne mode of SARS-CoV-2 transmission:

Transmission of SARS-CoV-2 from an infected host to a susceptible individual is possible through multiple ways such as airborne, fomites, direct contact of infectious mucous or saliva, mother to fetus vertical transmission, etc.[38] However, the airborne mode of SARS-CoV-2 transmission is important because it may enhance the chance of COVID-19 super spreading phenomena.[39] Respiratory droplets and environmental aerosols play crucial roles in SARS-CoV-2 transmission in the air. Hence, there is a possibility that SARS-CoV-2 trapped inside the respiratory droplets travels in the air and infects more susceptible individuals. Respiratory droplets majorly contain water along with the host's salivary contents such as epithelial cells, immune cells, electrolytes, and pathogens.[40] The sustainability of droplets in the air is dependent on evaporation (Figure 1). Evaporation results in the formation of dried droplet nuclei (≤5 μm in diameter) from respiratory droplets. The process of droplet evaporation has been demonstrated first in 1934 by Wells and later its application is experimentally performed to explain the airborne transmission of pathogens.[17] Evaporation occurs maximum under high temperature and low humidity, which facilitates droplets to be suspended in the air for a longer time. Hence, comparatively larger virus-laden droplets released during talking, coughing, and sneezing fall on the ground rapidly by gravity and produce fomites on the surface, while residual droplet nuclei after evaporation are capable to continue SARS-CoV-2 transmission in the air.[41] While the speed of airflow can induce the spreading of these aerosols more in the environment. It is reported that respiratory droplets can reach up to 6 m in 1.6 s by a wind speed of 15 Km/h.[42] Hence, this meteorological condition may be ideal for the spreading of COVID-19 in a certain range of areas. Besides, the densely populated areas having COVID-19 positive patients may show a high SARS-CoV-2 viral load in the air.[42-45]

Similar to respiratory droplets, natural and anthropogenic aerosols are also important for spreading COVID-19. As mentioned earlier natural aerosols are composed of soil/rock dust, forest fire/volcanic ashes, sea salt, nitrate, sulfate, etc. Besides, anthropogenic aerosols are generated by direct emissions from combustion/industry, heavy metals, etc. Both natural and anthropogenic aerosols are distributed throughout nature, which may be ideal for long-range transmission of the virus and outbreaks of COVID-19. Aerosol-mediated transmission of respiratory viruses is already reported.[39, 46] A study conducted in Bergamo, northern Italy has shown that PM10 obtained from industrial aerosols contain RNA of SARS-CoV-2.[47] However, increased atmospheric pollutants in form of aerosols may be correlated with the COVID-19 pandemic wave, where

PM2.5 and PM10 concentrations are recorded up to 70 µg/m3 and < 50 µg/m3 respectively.[48] As per the guidelines of WHO, the daily mean concentration of PM2.5 and PM10 in the air are 25 µg/m3 and 50 µg/m3 respectively.[49]

The infectious dose of SARS-CoV-2 is computationally estimated to be 100 viral particles, which needs further experimental evidence.[50] Presumably, SARS-CoV-2-laden aerosols (≤PM10) can easily penetrate the lung deeply, where it primarily targets alveolar type-I and II epithelial cells. Ultimately, SARS-CoV-2 binds to the ACE II receptor present on the surface of target epithelial cells and initiates the COVID-19 pathogenesis.[51]

Plausible effect of wet deposition on aerosolized SARS-CoV-2:

Based on various experimental studies as mentioned earlier, it is evidenced that both respiratory droplets and atmospheric aerosols play major roles in the airborne mode of viral transmission. However, this transmission majorly depends on environmental factors such as relative humidity, temperature, and other factors. On the other hand, infectious droplets and aerosols travel maximum in the air based on the speed of air/wind velocity. Speed of airflow probably enhances the viral transmissibility and helps virus-laden aerosols to infect more individuals in a long range of areas. Similarly, SARS-CoV-2-laden particulate matter may be capable to spread COVID-19 in long-range areas, which needs the ideal meteorological conditions having high temperature and low relative humidity.

Rain is capable to reduce aerosols present in the air.[52] Wet deposition of both PM2.5 (>1.4 mm/h) and PM10 (>1.0 mm/h) by rainfall are already reported.[15] As per the study conducted by Reche et al., long-distance traveling and deposition rates of the aerosolized virus particle are associated with many uncertainties.[53] Authors have demonstrated that the downward flux of viruses ranges from 0.26 × 109 to >7 × 109 /m2/day. This deposition rate is much higher than bacteria (0.3 × 107 to >8 × 107 /m2/ day). The deposition rate of the virus is more in the case of marine rather than the dry land source. Additionally, it has been reported that virus deposition rate is directly correlated with organic aerosolized particles having a size of more than <0.7 µm. These reports suggest that virus particles can be sustained in the air for a longer time, which triggers the possibility of viral dispersion further. The deposition rate for the virus may be calculated as per the published literature.[54]

$$\text{Deposition rate for virus/ m}^2\text{/ day: } \frac{\text{Virus/mL} \times \text{Collector volume/mL}}{\text{A (m}^2\text{)} \times \text{Time (day)}}$$

The deposition rate is normalized by flow cytometry using virus/Milli-Q water in a dry collection tube, where "A" stands for the area (m2) of the collection tube. The time (days) signifies the exposure time of the collection tube.

Analyzing published data, it may be suggested that rainfall contributes to minimizing SARS-CoV-2-laden droplet nuclei and aerosol in the air, which will reduce the viral transmission and COVID-19 spread in a long range of areas (Figure 2). However, rainfall intensity, spectrum, terminal velocity, and raindrop size distribution may be strongly associated with the process of wet deposition of SARS-CoV-2-laden particulate matter.[55,56] Additionally, it may be expected that heavy rainfall in the monsoon will reduce the chance of airborne mode of SARS-CoV-2 transmission and the spread of COVID-19. Subsequently, the total number of COVID-19 cases may vary based on the annual average rainfall along with seasonal (e.g. winter, summer, and monsoon) rainfall distribution of a certain place.[57]

Conclusion

Respiratory droplets and atmospheric aerosols are crucial for an airborne mode of SARS-CoV-2 transmission. Respiratory droplets are capable to infect a susceptible individual from close proximity. However, respiratory droplet nuclei and atmospheric aerosols may have the potential to transmit viral particles up to a long range of areas. It is important to be mentioned that air pollutants such as PM2.5 and PM10 can carry SARS-CoV-2. These pollutants may act as vectors to transport viral particles deep inside the lung. Thus, the reduction of droplet nuclei/aerosols in the air is crucial to minimizing SARS-CoV-2 transmission. It is in this context that rainfall acts to clear particulate matters from the air by wet deposition. Hence, it is plausible that rain or precipitation plays an important role to control the airborne mode of SARS-CoV-2 transmission by modulating SARS-CoV-2-laden particulate matter in the air.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

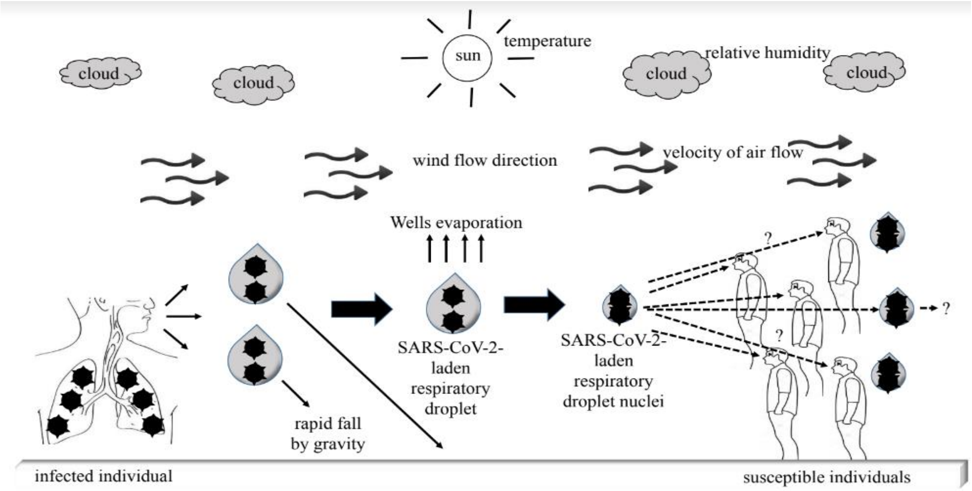

Figure 1. Schematic diagram is showing the plausible mechanism of the airborne mode of SARS-CoV-2 transmission from an infected individual to other susceptible individuals by respiratory droplets. Exhaled respiratory droplets cannot travel long in the air and fall on the ground surface by gravity. However, few of the respiratory droplets undergo the process of evaporation (Wells evaporation) and produce even smaller respiratory droplet nuclei. Infectious respiratory droplet nuclei (≤5 μm in diameter) loaded with SARS-CoV-2 may be suspended in the air for a longer time and capable to infect more susceptible individuals. High temperature, low relative humidity, and speed of air-flow are plausible factors to influence this mechanism. The sign "?" indicates the possibility of long-distance traveling of SARS-CoV-2-laden droplet nuclei in the air to infect more individuals.

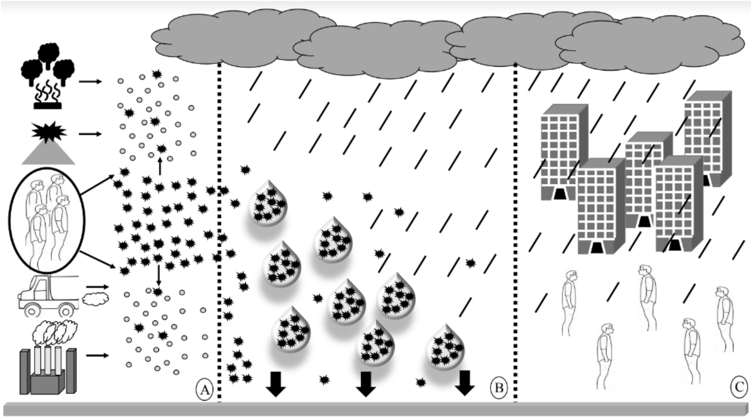

Figure 2. Schematic diagram on hypothetical views to show how rain can reduce the airborne mode of SARS-CoV-2 transmission by clearing droplet nuclei and atmospheric aerosol by wet deposition. (A) Respiratory droplet nuclei released by infected individuals may be suspended in the air as free-floating condition. Natural and anthropogenic aerosols (gray circles) may play a major role to carry SARS-CoV-2 (black stars) viral particles and trigger the transmission process. (B) Plausibly, virus-laden aerosols are captured by rain drops and removed from air by wet deposition. (C) Continuous rainfall may result in good air quality, which make air free from virus-laden aerosols and reduce SARS-CoV-2 transmissibility.

Statements and Declarations

The author declares that there are no known competing financial interests to interfere with the work reported in this article.

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