Communication

Bioaerosol Size Effect in COVID-19 Transmission

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Abstract: The fast spread of COVID-19 constitutes a worldwide challenge to the public health, educational, and trade systems, affecting the overall wellbeing of human societies. The high transmission and mortality rates of this virus, and the unavailability of a vaccine and antidote, resulted in the decision of multiple governments to force measurements of social distancing. Thus, it is of general interest to consider the validity of the proposal for keeping a social distancing of at least 6.0 ft (1.8 m) from persons with COVID-19. The eventual exposure to the bioaerosol can result in the deposition o the pathogen in the respiratory track of the host causing disease and an immunological response. In the atmospheric context, the work evaluates the effect of aerodynamic particle size in carrying RNA copies of the novel coronavirus. A COVID-19 carrier person talking, sneezing, or coughing at distance of 1.8 m can still provide a pathogenic bioaerosol load with submicron particles that remain viable in air for up to 3 hours for exposure of healthy persons near and far the source in a stagnant environment. The deposited bioaerosol creates contaminated surfaces, which if touched can act as a path to introduce the pathogen by mouth, nose, or eyes and cause disease.

Keywords: COVID-19; SARS-CoV-2; virus, bioaerosol; social distancing; aerodynamic size; infection.

1. Introduction to COVID-19 Pandemic

The recent global spreading of a novel coronavirus disease 2019 (COVID-19), capable of causing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), constitutes an unprecedent challenge in recent history to the international public health, educational, and trade systems, affecting the overall wellbeing of human societies [1]. By April 5, 2020, this labeled pandemic by the World Health Organization (WHO) [2], has caused more than 1,237,000 cases of COVID-19 in at least 183 countries, resulting in more than 67,000 deaths and more than 253,000 recoveries [3]. The high transmission and mortality rates of this virus, and the unavailability of a vaccine and antidote, resulted in the decision of multiple governments to force social distancing and related measurements as friendly alternatives to the enforcement of strict quarantine of affected areas. The idea of establishing a physical distancing is to slow down and eventually stop the spread of the pathogen by reducing the probability of contact between persons carrying the disease, and others who are not infected [4].

Recent epidemiological information indicates an incubation period of COVID-19 of 1 to 14 days, with active transmission during the latency period, especially to persons with underlying diseases and elders [5]. Among the different symptoms exhibited by COVID-19 patients are included fever, headaches, sore throat, diarrhea, vomiting, loss of taste and smell, red eyes, shortness of breath, fatigue, chest pain, and dry cough; with extreme conditions extending quickly to acute respiratory distress syndrome, respiratory failure, multiple organ failure, and even death [6-9]. Despite the loss of benefits from human interactions, social distancing [4] is expected to be an effective mechanism to prevent the COVID-19 infection via bioaerosol contact (e.g., from talking, coughing, or sneezing), and by indirect physical contact by touching a contaminated surface (e.g., a fomite). The airborne transmission of COVID- 19 could, in theory, also originate from particulates emitted during vomiting and toilet flushing (e.g., toilet water aerosolization) following fecal excretion [10].

The focus of the information below is on the bioaerosol emission from persons carrying COVID-19, who aerosolize individual particles containing the virus, which are categorized by their aerodynamic diameter. The source mechanism of bioaerosols emitted by humans constrains the particle size distribution. Normal breathing creates particles in the <0.8 to 2.0 μm range [11]. While speaking, two size distributions have been observed, 16-125 μm [12,13] and <0.8 to 7.0 μm [11] with a mean of 1.0 μm for shouting [14]. Similarly, coughing also displays a dual range of 0.6 to 16 μm [11,12,15,16] and 40 to 125 μm [13,17]. Sneezing largely contributes particles in the 7 to 125 μm range [17,18]. Even Though humans can only inhale particles < 100 μm, it should be considered that the initial larger particles can undergo rapid evaporation depending on the environmental relative humidity [19-21]. This work is focused on the factors governing particle size, deposition site, clearance, and inhalational infection of COVID-19. The final inhaled particle size depends among other factors on the solid organic content of the original particle including the virus and the distance of an individual to the bioaerosol source. Other factors that impact on air mass movement, (e.g., ventilation) may offset the terminal velocity of particles in still air [19,21]. This communication is focused on discussing the generation and transport of bioaerosols with pathogenic COVID-19 by talking, breathing, sneezing, and coughing as governed exclusively by particle size (in the range < 1 to > 100 μm). The work connects the particle size distribution to deposition in the respiratory system causing infection.

2. Sampling Methods and Characterization of Bioaerosols with SARS-CoV-2 RNA

The complete genome of a strain of SARS-CoV-2 totaling 29.9 kb was characterized from a pneumonia patient with COVID-19 in Wuhan [22]. SARS-CoV-2 (50-200 nm virion diameter [23]) can be transmitted through human respiratory bioaerosols and direct contact with infected persons. The aerosol transmission of SARS-CoV-2 has been recently reported from the analysis of 35 aerosol samples collected from patients and medical staff areas in Wuhan and Fangcang hospitals in China.[24] Three different types of aerosols were studied during this originating COVID-19 outbreak, (1) total suspended particles, (2) size segregated (> 2.5 μm, 1.0 to 2.5 μm, 0.50 to 1.0 μm and 0.25 to 0.50 μm, and 0 to 0.25 μm), and (3) deposition aerosol [24]. The determination of the concentration of aerosol with viral SARS-CoV-2 RNA was enabled by a droplet digital polymerase chain reaction (ddPCR) method [24]. The ddPCR method specifically detects SARS-CoV-2, discarding any possible artifact from using presterilized gelatin filters that could contain bacterial DNA [25].

Figure 1 displays the relative high concentration of SARS-CoV-2 RNA in two protective apparel removal rooms and a medical staff office of the Fangcang Hospital. Each zone of the Fangcang Hospital hosted > 200 patients at top of the COVID-19 outbreak Based on the information of this hospital setting, there are two size ranges with high concentration of SARS-CoV-2 aerosols (Figure 1), one dominated by submicron aerodynamic diameter particles (0.25 to 1.0 μm), and another by particulates with diameter > 2.5 μm [24]. The maximum concentrations in the so called apparel removal zones (B and C) were 40 and 9 copies of SARS-CoV-2 RNA per cubic meter in the 0.25 to 0.5 μm, and 0.5 to 1.0 μm intervals, respectively [24]. Instead, maxima concentrations of 7 and 9 SARS-CoV-2 RNA copies m^{-3} for supermicron particles were identified in the apparel removal zone C and the medical staff office [24]. The distribution of submicron and supermicron aerosol with the pathogen can or not coexist due to the variable generation pathways. The supermicron aerosols in the apparent bimodal size distribution of SARS-CoV-2 particulates (from apparel removal zone C) is likely associated with the resuspension of deposited pathogenic dust that generates a secondary aerosol.
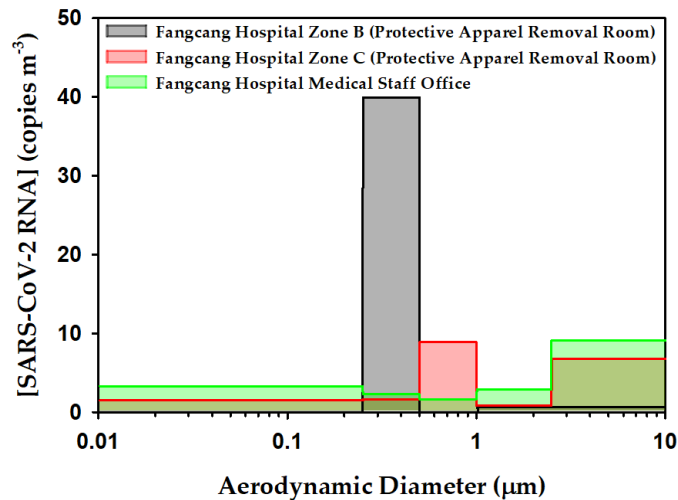
Figure 1. Concentration of airborne SARS-CoV-2 RNA in aerodynamic size segregated aerosol samples at three different locations of Fangcang Hospital as reported in Ref. [24].

Because the aerosolized copies of the virus deposited on the protective apparel of medical staff during their long working hours can be resuspended during movements, a prior sanitation step before removal is needed [24]. The deposition of the pathogen resulting from particulates emitted during respiration, coughing, and sneezing may also cause infection of people touching the contaminated surfaces. For example, related measurements of aerosol deposition rates for samples collected $\geq$ 2 m far from patients beds inside an intense care unit at the Renmin Hospital were up to 31 and 113 SARS-CoV-2 RNA copies $m^{-2}\,h^{-1}$ [24]. The infectious dose of SARS-CoV-2 particles needed to cause COVID-19 is not known yet but should be expected to be relatively low (100-1000 particles) as the disease spreads rapidly [26].

3. Aerodynamic Size Effect on Deposition and Clearance on the Respiratory System

The aerodynamic diameters reported in Figure 1 are key to determine where the inhaled particles with the pathogen are deposited in the respiratory tract of an exposed person. Various deposition mechanisms can exist, including inertial impaction, gravitational settling, Brownian motion, turbulent deposition, interception, and electrostatic attraction [27]. The smallest particles (<1–3 μm) can diffuse directly deep into the lung tissue, where they get deposited on the alveoli by diffusion, sedimentation, and electrostatic attraction. Instead, inertial impaction in the upper airways determines that the largest particles (>8 μm) are size dependently deposited from the nasal passage to the bronchioles. Multiple factors, (e.g., age, weight, sex, physical activity level, and disease state) impact respiration and deposition profiles [28]. Larger particles can be inhaled into the respiratory tract under exertion breathing because the oral cavity is larger and results in bypassing of the nasal cavity filtration mechanism [28].

Figure 2 illustrates the respiratory system needed for the discussion of possible deposition sites affecting the clearance of tissues and infection rates for inhaled SARS-CoV-2 pathogen. Assuming good hygiene protocols are put in place to avoid spreading of COVDID-19 by direct contact, the major mechanism of infection involves bioaerosols and respiratory secretions [29]. Particulates with SARS-CoV-2 RNA in the <1-10 μm range of aerodynamic diameter can penetrate into the respiratory tract through the nose and/or mouth (Figure 2), from where it can be further disseminated. Effective filtering in the nose prevents large supermicron particles >5 μm to penetrate further in than the nasal, pharyngeal and laryngeal regions. Particle in the 2.5-5 μm range are deposited in the tracheas, while fine ($\leq$2.5 μm) and ultrafine particles ($\leq$0.1 μm), due to their small size, reach deep into the lungs, to be deposited in the alveolar ducts and sacs. It is believed that angiotensin-converting enzyme 2 (ACE2), an abundant protein on epithelial cells of the lung alveolar surface as well as of enterocytes in the small intestine [30], play a major role during infection.
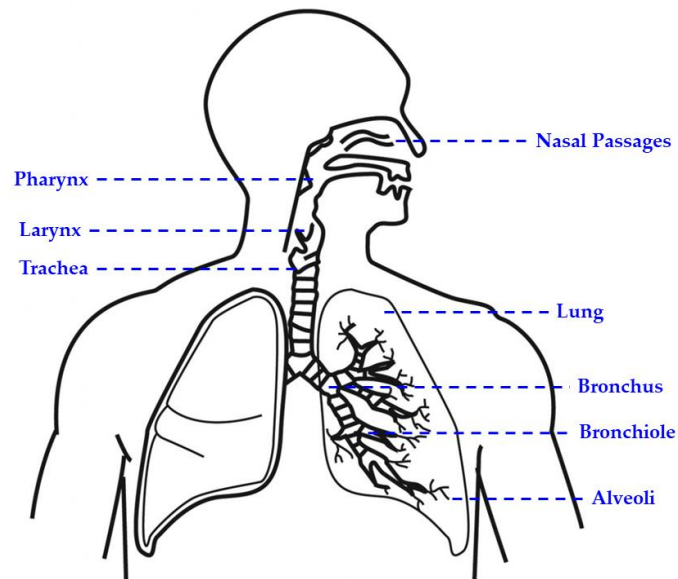
Figure 2. Schematic representation of the respiratory system.

The speed of clearance of deposited supermicron particles depends on the exact location in the nasopharynx and in the person's health state. Fundamental studies have shown that the typical clearance from the ciliated anterior region of particles with other pathogens occurs in the range from 1.3 to 12.6 mm min^{-1}, which is considerably faster than for the non-ciliated poster region [31]. Similarly, clearance from the tracheal and bronchial mucociliary are in the range from 0.8 to 12.4 mm min^{-1} [32,33]. The presence of mucus on the surface of the nasal and tracheobronchial regions typically serve to capture deposited particulates, which are then removed to the gastrointestinal track via the cumulative action of the cilia. The viscoelasticity, wettability, and adhesiveness of the mucus depends on its variable composition of glycoproteins (mucins), proteins, proteoglycans, and lipids. Therefore, the concentration of these components controls the size of particles emitted by coughing or sneezing [34-36]. The specific structure of the oligosaccharide chains present on these respiratory mucins and proteoglycans can play a major role and provide a pathway for pathogen interaction and clearance [37].

A significant factor believed to enhance the infection caused by SARS-CoV-2 seems to be connected to existing underlying diseases (e.g., influenza, cystic fibrosis, smoking, diabetes, etc.), which reduce the rate of clearance [31,32,34,38]. In other words, other diseases may enhance the residence time for deposited SARS-CoV-2 RNA within the respiratory tract. When considering the bioaerosol particles reaching the not-ciliated tissue covering the lungs, all clearance work is executed by available alveolar macrophages. These macrophages react to phagocytose the particles and transport them to resident lymph nodes, contributing to the fight of the immune system against the virus [39-41].

4. Conclusions

Understanding the sources, transport, clearance, transmission, and inactivation of SARS-CoV-2 RNA from emitted bioaerosols is an urgent matter for society. Such effort requires interdisciplinary collaborations, the use of modern techniques, and the implementation of new technological solutions. There are still limitations in translating the concentration of airborne infectious particles with SARS-CoV-2 RNA and their particle size from a single study (Figure 1), to a practical evaluation of infection rates under variable airflow conditions and exposure intervals among other variables. Such valuable information would contribute to reducing COVID-19 airborne transmission. The general recommendation to keep at least 2 m (6 ft) separation [42,43] from a person showing symptoms of COVID-19 (e.g., coughing) should be valid for well ventilated environments but fluctuates with the time scale of exposure among other parameters. Fine and

ultrafine aerosols that remain in suspension for hours and travel long distances may still transmit a payload of SARS-CoV-2 RNA if directly inhaled.

There is a large scientific agreement that COVID-19 can be airborne transmitted efficiently. Based on the 3 hours viability of SARS-CoV-2 in air [44], exposure, inhalation, and infection could occur minutes or a few hours later near and far from an aerosol source [45] in a stagnant atmosphere. The average number of people one infected person has been passing the virus to others is in the range $2 \leq R_0 \leq 2.5$. This large virus's reproduction number, R_0, together with the severity of respiratory distress syndrome has severely affected the capacity of hospitals, the operation of office building, the aircraft transportation sector, touristic cruise ships, and hotels among many other similar examples that could be provided. Government officials, advised by responsible health professionals, aim to prevent further population infection by controlling the CODIV-19 pandemic through the principle of keeping social distancing and quarantine. In addition, as there is a large uncertainty in the application of exciting technologies to solve the transmission through bioaerosols, efficiency filtration (i.e., with N95 filtering respirators) [46] will remain the most widely protective equipment used by first health workers.

Conflicts of Interest: The author declares no conflict of interest. The funder had no role in the design of the study, or interpretation of data; in the writing of the manuscript, or in the decision to publish this material.

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