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The Basics on Aerosols and Aerosol-generating Procedures

Lateef F[1,2,3,4,5]*

[1]Senior Consultant, Department of Emergency Medicine, Singapore General Hospital, Singapore

[2]Adjunct Professor, Duke NUS Graduate Medical School, Singapore

[3]Adjunct Professor, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

[4]Director, Sing Health Duke NUS Institute of Medical Simulation (SIMS), Singapore

[5]Board and Founding Member, World Academic Council in Emergency Medicine (WACEM), Singapore

Abstract

COVID-19 was first detected in Wuhan City, China in Dec 2019. Following the World Health Organisation declaration of it as a public health emergency of international concern and then subsequently, as a global pandemic, COVID-19 has been confirmed in over 180 countries, across all continents, except Antarctica. It has been called the "pandemic of the century". What is the root cause for such rapid and robust transmission? Thought initially to be transmitted mainly by droplets and through contact and fomites, aerosol transmission begun to surface more prominently as the pandemic progressed. This led to changes in the advisories and guide for healthcare workers' safety at the front line as well as public health measures.

This paper discuss some of the salient points pertaining to droplet and aerosol science as well as transmission, in the context of the current COVID-19 pandemic.

Keywords: COVID-19; Coronavirus; Aerosols; Droplets; Transmission; Nebulizer; Aerosol-generating procedures

Introduction

Coronavirus disease 2019 is an infection whereby the etiological agent is a novel coronavirus, Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2, COVID-19). It is a beta-coronavirus closely linked to the original SARS virus. Most of the patients affected by COVID-19 have mild and uncomplicated manifestations, but between 10-15% of them may develop more severe disease requiring oxygen support. About 5% of the patients will need Intensive Care Unit management [1,2]. Transmission rates have been noted to be high with COVID-19, including the rate of nosocomial spread where some countries report this to be as high as 40% [2,3].

Covid-19 continues to wreck havoc globally. Epidemiologists, virologists and even clinicians are racing to understand more about the virus, its transmission and manifestations. Understanding the transmission modes of COVID-19 is key in our understanding of the disease and is highly relevant for advisories guiding the safety of healthcare workers as well as implementation of effective public health measures (Table 1). With the recent pandemic, there has been an upsurge in the discussions about transmission by contact, respiratory droplet, aerosolization as well as infection control measures. Queries about what type of Personal Protective Equipment (PPE) is adequate and under what circumstances; for frontline healthcare workers, other healthcare workers and even the man in the street. This pandemic has seen the most active discussions on safe and social distancing [4,5].

Before we look at some of the controversial and most current debates on transmission, it is important to understand the definitions of some commonly used terminology [5-8]:

Transmission by contact: This is where the infection is transmitted from an infected person to a susceptible person through the transfer of virus-laden respiratory secretions via physical contact or through contact with a common intermediary surface or object.

Transmission by droplets: In this case, the infection is transmitted by the deposition of the virus-laden respiratory droplets from an infected person onto the mucosal surface (eyes, nose and mouth) of another person. This will explain why the advisory to not 'touch the face' is often heard. The droplets from the secretions of infected persons are usually between 1-5 mm in diameter and they are said to be able to potentially spread within a radius range of 1-2 metres.

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***Correspondence:**
Fatimah Lateef, Department of Emergency Medicine, Singapore General Hospital, Singapore.
Tel: *65 63213558*
Fax: *65 63214873*
E-mail: *Fatimah.abd.lateef@singhealth.com.sg*

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Table 1: Comparing the precautions needed for droplet versus airborne transmission.

Precautions for Droplets Transmission	Precautions for Airborne (aerosol) Transmission
Need to protect against the spread of droplets	Need to protects against airborne particles (aerosols)
The focus is on prevention/ reduction of spread through the mouth, nose and conjunctiva	The focus is on prevention/ reduction of entry through the respiratory system or respiratory tract
Infected person should be placed in a single patient occupant room	The infected person should preferably be placed in a specially designed isolation or sealed room or cubicle
Requires PPE for protection	PPPE may not always provide full protection

PPE: Personal Protective Equipment

Transmission by aerosol: Here, the infection is spread via the inhalation of the virus-laden fine respiratory droplets (also known as aerosols) in the air. These aerosols are usually generated:

a. Directly from the respiratory droplets of an infected person or

b. Through Aerosol Generating Procedures (AGPs) that are being carried out in infected patients.

Roy and Milton classified aerosol transmission into three types [8]:

Obligate transmission: This refers to transmission solely by aerosols

Preferential transmission: Transmission through multiple routes but predominantly via aerosols and

Opportunistic transmission: Transmission which occurs predominantly through other routes but may also spread *via* aerosols

Just from these definitions, it can be seen that the potential for transmission *via* aerosolization encompasses a wide spectrum. The possibility of more than one route of transmission is also true.

Aerosols and Aerosolization

Aerosolization is now thought to have significant contribution towards the high transmissibility of COVID-19, especially within a closed environment or space. It appears that the highest risk of airborne transmission is mainly via these aerosols. These aerosols are small solid or liquid particles which are dispersed or suspended in the air, and they may contain micro-organisms, small particulate matter from air pollution, soil, plant emitters and others. When a patient with an infectious disease coughs, sneezes, talk or breathe exuberantly, the infectious agent/ virus will be excreted from their respiratory tract, dissolve and be transported in these aerosols. These are sometimes called bio-aerosols. The latter can have diameters ranging from 0.3 to 100 microns. The larger bio-aerosols may sink or get deposited on surfaces, whilst the smaller ones (<5 microns) can remain suspended in the air, for some hours [4,8-10]. Contrary to droplets, these bio-aerosols can travel hundreds of metres, thus the potential to infect many more persons. Some examples of clusters of spread during COVID-19 can be illustrated by the case of the "Dream Cruise Princess" cruise ship cluster, the transmission to persons attending a large conference and several nursing/old age home clusters [10].

Asymptomatic or pre-symptomatic persons usually do not cough or sneeze to any significant extent. Yet it has been seen that they can still excrete and thus, transmit the virus by [4,11]:

a. Direct or indirect contact (thus the advice on hand hygiene and contact precautions) and

b. Aerosolization

It has also been noted that the greater the force of the air movements (turbulence), the smaller will be the size of the aerosols generated. These can then travel further and longer distances and thus the potential to infect will be higher as well. During this COVID-19 pandemic, precautions such as using various types of masks, as well as safe distancing measures and practices are thought to reduce the risk and rate of spread of the infection (Table 1). 17 years ago, people infected by the SARS virus were noted to be emitting the virus through aerosolization. It is likely to be the same with COVID-19 as well [5,12-14].

Aerosol science is a field that enables studies into some of these aspects of viral shedding and transmission. There are some interesting findings noted from cohort studies in the field. For example, airflow modelling has previously suggested that turbulence may form under the beds of patients and thus cause contamination from there [15]. Other sampling studies have shown that virus containing particles can be carried from rooms to the hallway. This is likely to be caused by virus laden aerosols, likely transported by persons exiting the room [16]. Recent studies have shown that a significant portion of human expired aerosols is less than 10 microns across all range of activities eg: breathing, talking and coughing [16-18].

Von Doremalen et al demonstrated aerosolized SARS CoV-2 remains viable in the air with a half-life of about 1 hour. They concluded that aerosol and fomite transmission is plausible and the virus can remain viable and infect *via* aerosols for hours and in fact, for days on certain surfaces [19]. Asadi S et al., showed that the louder one speaks the more aerosols are generated. They have come up with the term "speech super-emitters", which refers to individuals who emit more such aerosols than the average person, which happens to be about 10 particles per second. Using this value for calculation, it may mean that a 10 minute conversation can generate approximately 6 000 aerosol particles [17]. These are interesting individual studies but may not always be fully generalizable to the broader picture [20-28].

Super-Spreader (SS) is a generic term referring to a person who can disproportionately infect more people with the virus, than an average person would. They are thus viewed as "efficient" in this context [12,13,26,27]. In 2003 during the SARS outbreak an index case could infect 2.75 other persons on average but a SS can infect 10 persons [12,13]. SS happens not just with coronaviruses, but with other infections such as measles and pulmonary tuberculosis. There is a term, basic reproduction number, Ro, which is the expected number of cases generated directly by one case in the population, where all individuals are assumed susceptible to the virus. For COVID-19 it is said to be 2.2 (1.4-3.8) in general. However if we look at the Ro on the Diamond Princess Cruise, the Ro is 14.8 [10]. It is also important to be aware that the Ro may not necessarily capture the heterogeneity of transmission amongst infected persons and it reflects both virus and human behavior, which are affected by multiple variables [29,30].

Table 2: Common aerosol-generating medical procedures.

Intubation, Extubation
Open suctioning of airway (induce cough)
Testing of gag reflex
Tracheostomy
Disconnection from ventilator
Bronchoscopy +sputum induction
Non-Invasive ventilation: CPAP, BiPAP
Nebulization
High flow nasal oxygen
Bag valve mask use
Cardiopulmonary resuscitation/ chest compressions

Aerosol Generating Medical Procedures and Tasks

It would appear aerosols are ubiquitous in our environment and there are many ways these can be generated; from simply talking and breathing to the more complex medical procedures such as intubation and even the use of high speed cutters in spine surgeries. The understanding is that the greater the force generated, the higher will be the radius of spread of the virus laden aerosols, and thus the higher the risk of transmission [14,31,32]. However the equation is not so simple as there are many other variables involved, such as the size of the aerosols and the weight (eg: the heavier ones may not travel as far and may drop to the ground faster). It is also difficult to prove these in marker studies as in the experimental setting smoke emission or water vapour is used and this can be very different from actual act of coughing/ sneezing [19,27]. In the practice of Medicine, there are many aerosol generating procedures. To date getting the evidence documented for some of these procedures has been challenging.

The list of common Aerosol Generating Medical Procedures (AGMP) are shown in Table 2. Do note this may not be entirely comprehensive as there are also other procedures and tasks that may generate aerosols. These may at times be less obvious and thus, be taken for granted. For example the point of care test of performing Arterial Blood Gases (ABG) has the potential to aerosolize small amounts of blood in an open system. This is also the reason why in some departments, the ABG is sent to the main laboratory to be done during periods of infection outbreaks. For blood sugar level checks via finger prick, dedicated glucometers are usually provided for infected patients. Even manual bagging of a patient can generate aerosols [33-39].

During the COVID-19 pandemic, lots of oropharyngeal and nasopharyngeal swabs were taken. These are high risk procedures. At the Emergency Department (ED), Singapore General Hospital (SGH), a swab booth is provided, whereby the person performing the swab is within the booth and this reduces the risk of transmission by droplet and aerosols (Figure 1). Also, during infectious diseases outbreaks, pandemics and for any high risk patients, we use the negative pressure rooms for endotracheal intubation, with full PPE and PAPR (Powered Air Purifying Respirator). Rapid sequence intubation is used to minimize coughing and thus reduce the risk of aerosol dispersion. During these times, the most senior and experienced person will perform the intubation, with video-laryngoscopy. An intubation check list is used in order to ensure all necessary preparation are done in a timely fashion.

Even as there are many AGMPs in Table 2, it is important to realize that for many of these, it is challenging to get the best evidence of transmission. There are reasons for this. Take the example of a cardiac arrest patient, who will require cardiopulmonary resuscitation with chest compressions, bag valve mask use, intubation and suction.

Figure 1: The SG SAFE (Swab Assurance for Everyone) Booth for conducting swabs at the Emergency Department, Singapore General Hospital. This is a foldable three panel transparent booth, equipped with Bio-safety Level 3 long gloves for the person conducting the swab to insert their arms into.

If a healthcare worker involved in the management of this patient gets infected, it is going to be difficult to pinpoint exactly at which point and during which of these procedures and tasks, the transmission occurred. This difficulty in generating the evidence pertaining to the transmission dynamics is also the reason why the guidelines on the use of PPE as well as isolation criteria continue to shift. This was seen in the early phases of the COVID-19 outbreak [14,31,32]. Even amongst individuals who were confirmed positive for COVID-19, their spectrum of symptoms and degree of viral shedding varied considerably. There are still other tasks (not listed in Table 2) that may potentially generate aerosols; naso-gastric tube insertion (which can induce cough) naso-endoscopy and even more complex procedures such as trans-sphenoidal surgery [27,38,39].

The following section will discuss two of the AGMPs and their risk of virus transmission:

Nebulization: In most papers and discussion on the use of nebulization, it is advised that healthcare workers don PPE as the risk of transmission is present. Most agree that the nebulization procedure can generate small aerosols (<5 microns), which can be dispersed and propelled to some distance. However, there is the argument that these aerosols are generated from the nebulizer liquid or medication and less likely to be from the secretions of patients. This can be challenging to prove, but it is still possible for patients getting the nebulizer to cough, sneeze and gag; therein lies the risk. The latter can generate virus-laden aerosols. Thus, due to the difficulty in excluding this, most guidelines and recommendations advise on the use of PPE when preparing for and performing nebulization [31,32,40-43].

Simonds et al., shared in their study that nebulization increases the generation of droplets in the 100s of millions [42]. However, how many of these are virus-laden is hard to show. Others have noted that the differences noted across various studies may be due to the differences in the viscosity of the fluid in the patients' lungs. This it appears can make a difference to the numbers and size of the bio-aerosols generated [19,29,39]. In our ED, we had switched to the use of Metered Dose Inhalers (MDI) with valved holding chambers, since the outbreak of SARS in 2003. This is because it has been shown that the risk of widespread propulsion of the bio-aerosols are reduced due to the enclosed space within the 'spacer' [40,43-45].

Endotracheal intubation: This is definitely a high risk procedure as one looks down the throat of a patient to secure the airway. The potential for droplet and aerosol generation is very high. Recommendations across the board have advised for full PPE, including PAPR [14,31,32]. During SARS, there were some observations that this could be the source of nosocomial spread to healthcare workers. Whilst some studies warned of increased aerosols during intubation, others have disagreed. For example one counter-view is that with paralyzed patients being prepared for intubation, there is reduced risk of them coughing, sneezing or having a gag reflex; all of which can reduce the significant forceful generation of aerosols. Whatever the views, the safest advice if still for full PPE during intubation and airway suctioning procedures [29,44,45].

Conclusion

The ongoing COVID-19 pandemic has taught us a lot of new things in terms of our practice and the handling of new and emerging infectious diseases. The importance of having a pandemic preparedness plan cannot be over-emphasized and yet it still has to be one that allows flexibility, expansion, versatility and the dynamism required to face the unsurmountable challenges COVID-19 has posed to all of us. Knowledge and best practice sharing is crucial across the globe, as waves of transmission vary from country to country. As we grapple to understand the high transmission rate, more research is needed in the area of aerosol science and technology. Perhaps with all the research work ongoing now, we may be better equipped to face another novel virus coming our way.

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