An analysis of the transmission modes of COVID-19 in light of the concepts of Indoor Air Quality

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Introduction

The doubts raised by the author regarding the importance that health authorities, both nationally and internationally, give to the role that different modes of transmission play in the spread of viral infections and the consequences that may arise from this were the main motivation for writing this text.

It has been repeatedly affirmed that the transmission takes place mainly by contact and through the drops that, emitted by the infected person, reach the sensitive receiver in its path, so that a safety distance of the order of 1 to 2 m is maintained, the risk of contamination and spread of the disease will be greatly minimized.

The author considers that, without there being scientific evidence to justify it, the role that can be played by transmission through the airborne particles mode has been diminished and that, consequently, some of the protective measures that, probably, have been discouraged in some European countries, will be at the basis of the more modest epidemic spread rates in some Asian countries.

Particulate Matter in Indoor Air

While there is no doubt that the Corona virus SARS 2, which originates the disease COVID-19, is transmitted mainly through the particles exhaled by infected patients, it is important to start with a basic explanation of how the particulate matter, usually designated by the acronym PM, is classified. When we are referring to particle size classes, after PM a number is written that corresponds to the equivalent diameter expressed in microns (1 μm = 0.001 mm). Thus, for example, the designation PM10, should be understood as the set of all particles with a size less than 10 μm in the air sample that we are analyzing.

Figure 1 shows the main types of particles present in indoor air, classified according to their size ranges.

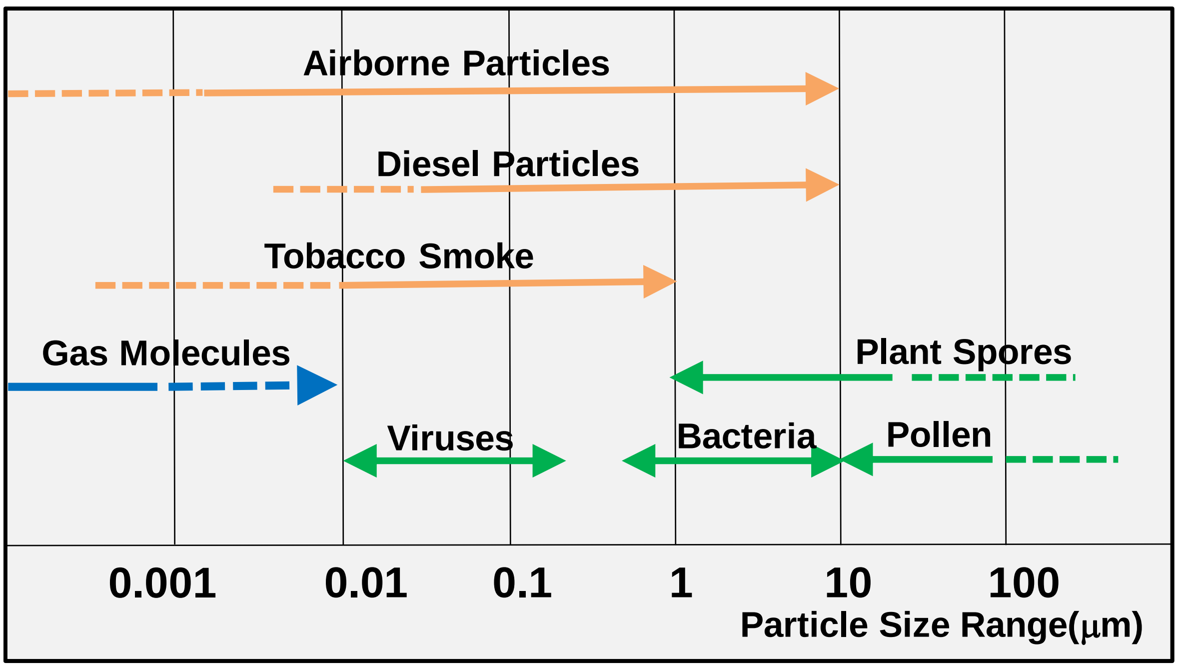
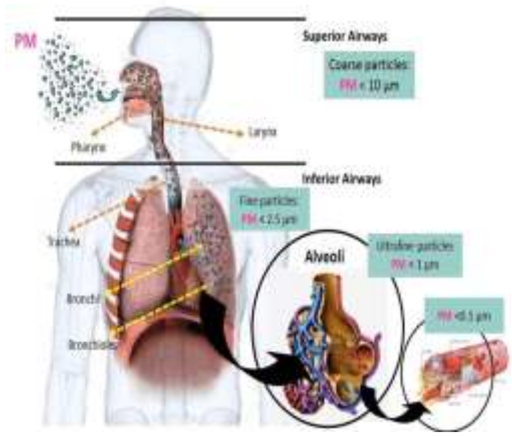


Figure 1 - Size ranges of the main types of particulate matter in indoor air

In terms of how these particles interact, from a strictly physical point of view, with our respiratory system, they are classified, according to their level of penetration, into inhalable, thoracic and breathable, being the correspondence between this classification and the size ranges shown in figure 2. The inhalable particles are retained in the hair existing in the nose or by the mucus in the oral, nasal or larynx cavities. The thoracic particles are able to penetrate up to the trachea and the bronchi, being retained by the mucus that exists there, while the breathable particles go until the bronchioles and the alveoli. Regardless of their degree of infectivity, from a strictly physical point of view, the most dangerous particles are the smallest ones, since they can lodge in the alveoli and cause their clogging, preventing or harming the gas exchanges carried out there, fundamental for human life.



Diameter (µm)	Penetration Level	Classification
> 7	Oral and Nasal Cavities	Inhalable
4.7 – 7	Larynx	
3.3 – 4.7	Trachea and Bronchi	Thoragics
2.1 – 3.3	Secondary Bronchioles	
1.1 – 2.1	Bronchioles	Breathable
0.65 – 1.1	Alveoli	

Figure 2 - Classification of particles according to the level of penetration into the respiratory system

Depending on their size, particles can behave differently in relation to their trajectories in the air. This diversity of behavior results from the different balances between the forces that act on the particles in their movement in the air. The main forces that are considered to act on a particle are the force of gravity and the aerodynamic forces. The relationship between these two types of forces is different according to the size of the particles, with the result that, for equivalent particle diameters smaller than 10 µm, the aerodynamic drag forces are more important than the forces of gravity (the weight of the particle), and, thus, the particle floats, following the flow current lines, in a similar way to what happens to a surfer when surfing a wave. In the case of larger particles, their trajectory is usually parabolic, and they will settle on the ground or other surfaces, because the force of gravity, due to its weight, is greater than the vertical component of the aerodynamic force. The greater or lesser distance traveled horizontally by the particles will depend on their size, the flow velocity field and also on their initial velocity. These different types of behavior are shown in figure 3.

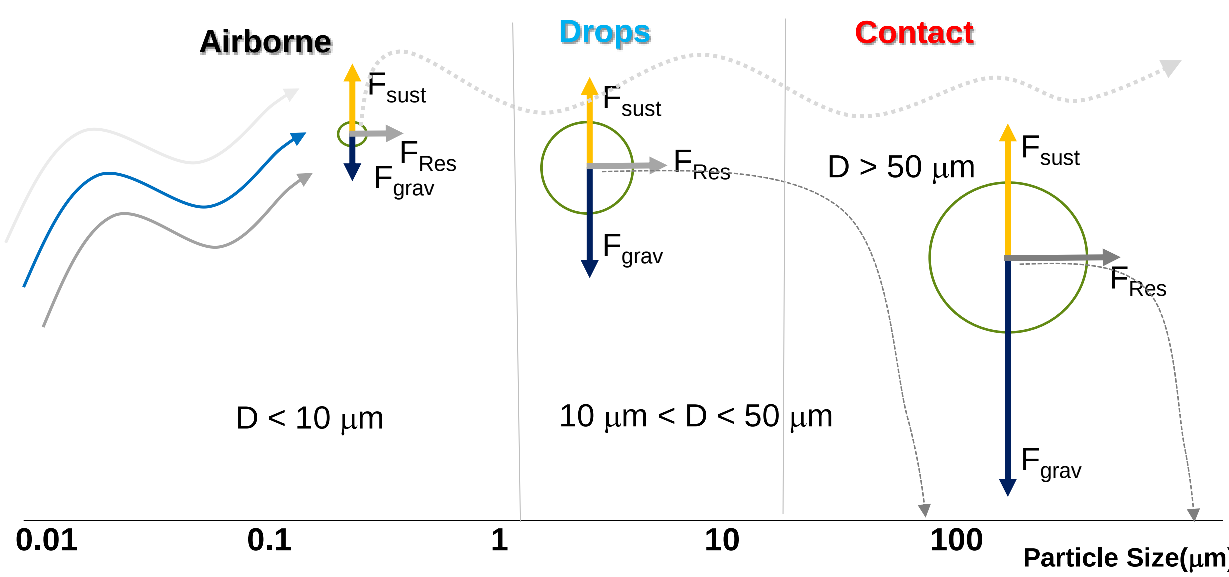


Figure 3 - Typical trajectories of particles in the air, depending on their size

The justification for what was previously described, results from the fact that the aerodynamic resistance coefficient of a spherically shaped body is not constant, relatively to a dimensionless coefficient called Reynolds number. This coefficient represents the relationship between the pressure forces and the viscous forces that originate from the interaction of a body with a fluid. In its calculation one of the variables is a geometric dimension characteristic of the body, in this case the diameter. Thus, in the graph shown in figure 4, if we have two particles of different diameters subject to the action of the same fluid, the smaller particle will be more to the left, with a higher coefficient of resistance and the larger particle will be more to the right, with a lower resistance coefficient. This will have the consequence that the smallest particle will be more dragged and will follow the air currents more easily, reason why it is classified as a airborne particle, while the larger particle after some time will be deposited because its weight is the dominant force and makes it fall down.

The area in which the typical phenomena that occur with particles in the natural ventilation or mechanical ventilation flows inside the buildings is marked on the left side of the graph by the dashed red ellipse.

As a curiosity, the difference between the behavior of bodies with smooth or rough surfaces, for the zone of the Reynolds number, in the range of 10^5 to 10^6, is what justifies the fact that golf balls have a protruding surface. This roughness causes the occurrence of the so-called critical regime that corresponds to an abrupt decrease in the value of the resistance coefficient to occur earlier, which allows the ball to travel longer distances.

It is also this graph that explains the reason why water vapor molecules in clouds remain in suspension and also the occurrence of rain due to the condensation of these molecules and the appearance of drops that coalesce and gain dimension, in such a way that the force of gravity becomes dominant.

$$Cd = \frac{F_d}{\frac{1}{2}\rho v^2 A} \qquad Re = \frac{\rho v D}{\mu}$$

F_d	Aerodynamic drag force(N)
ρ	Air specific mass(kg.m^{-3})
v	Air Velocity(m.s^{-1})
A	Front Area(m^2)
D	Characteristic dimension(m)
μ	Air Dynamic Viscosity(kg.m^{-1}.s^{-1})

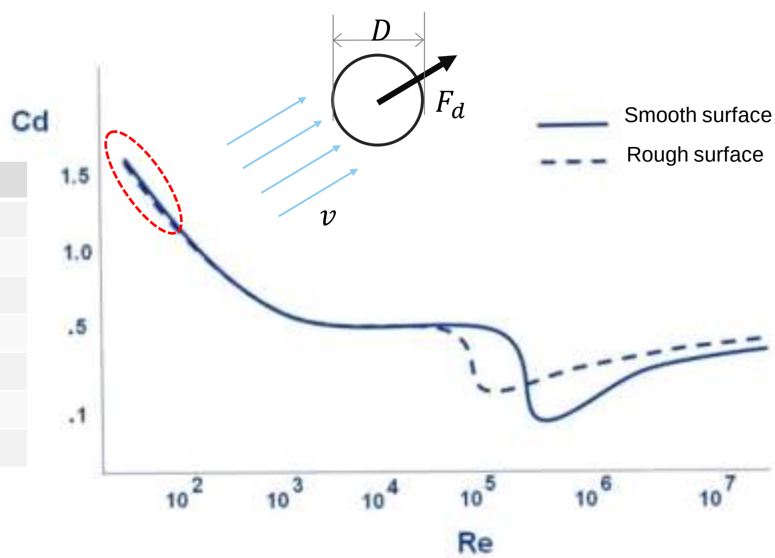


Figure 4 - Aerodynamic resistance coefficient as a function of Reynolds Number for a sphere

Corona Virus 2 (SARS-CoV-2) and Transmission Modes

Corona Virus 2 (SARS-CoV-2) has a spheroid shape, with diameters in the range of 80 to 140 nm (≈0.1 μm). Figure 5 shows a comparison of its dimensions with some of the classes commonly used for suspended particulate matter.

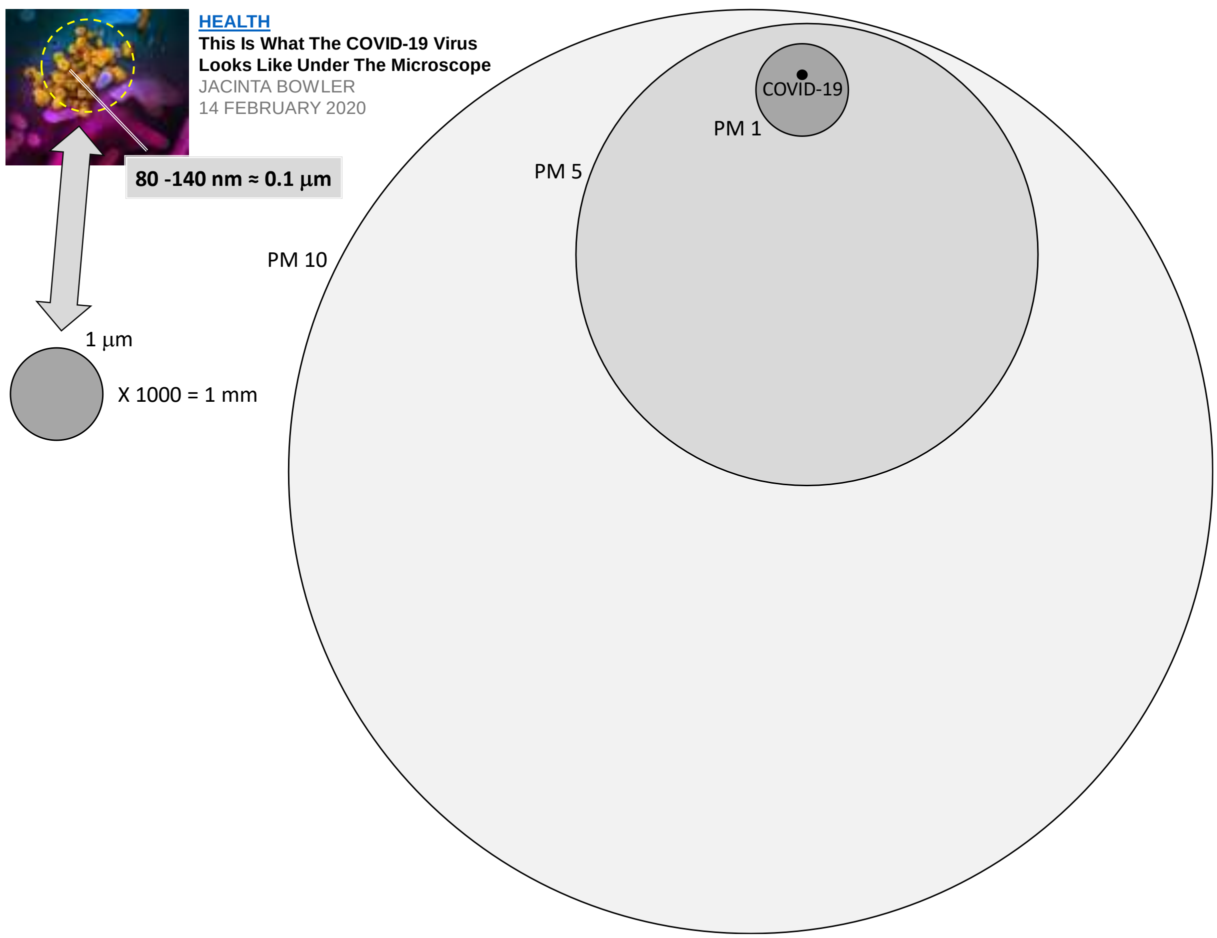


Figure 5 - Comparison of the dimensions of **SARS-CoV-2** with some classes of particulate matter

There are three possible modes of transmission from pathogens that have been expelled in the respiratory process of infected people: infection by suspended particles (bioaerosols), droplets and contact. Figure 6 shows an adapted image of a brochure from the Office of the Prime Minister and the Ministry of Health, Labor and Welfare of Japan, recently published in a joint Position Paper by the Japanese Society of Heating, Air Conditioning Sanitary Engineering (SHASE) and the Japan Institute of Architecture (AIJ), which illustrates the modes of transmission mentioned above. The origin of the emission of the droplets from the infected individual may come from different processes, such as coughing, sneezing, vomiting, speaking and breathing, with naturally different amounts and distributions by size classes of the exhaled particles, depending on the type of process.

In the airborne transmission mode, where particles will typically have dimensions less than 10 μm, the phenomenon usually involves the evaporation of a substantial part of the droplet's water mass, which is reduced to what is called the droplet nucleus where there may be some viruses or bacteria, which can be inhaled by the infected susceptible host.

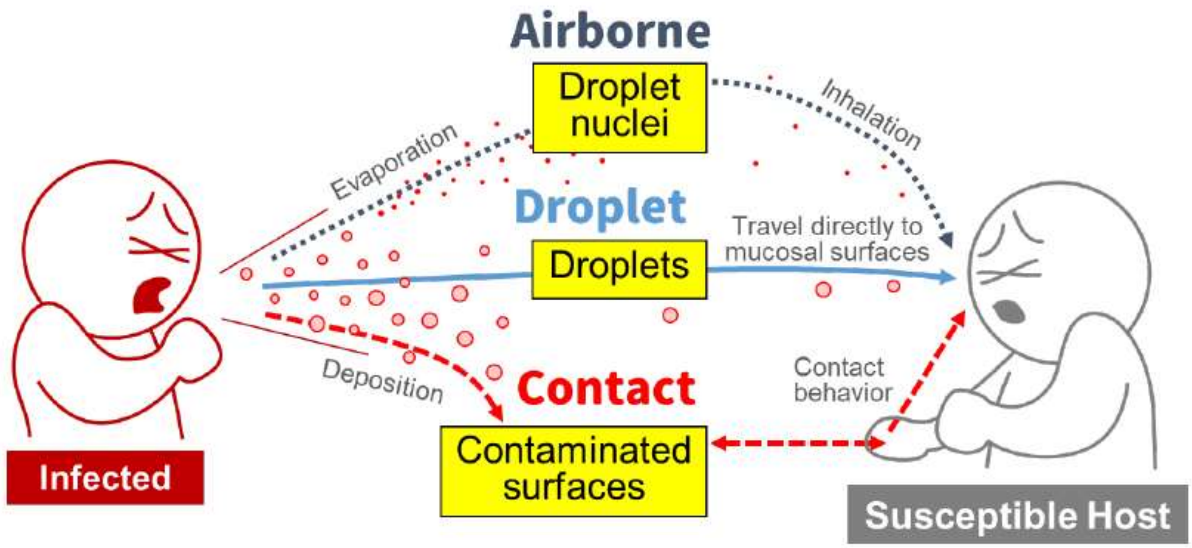


Figure 6 - Modes of Transmission from Exhaled Pathogens (adapted from leaflet of the Office of the Prime Minister and the Ministry of Health, Labor and Welfare of Japan (2020))

In figure 7, a figure transcribed from Morawska (2006) is presented, showing the evaporation times of the water droplets, depending on their diameter and the relative humidity of the environment. The smaller droplets (1 μm) evaporate quickly and are reduced to what is called the droplet nuclei or or residue core. If the drop is contaminated with viruses, they will remain in suspension, its persistence depending on factors such as temperature, humidity and the component of ultraviolet radiation existing at the site. There is a significant number of studies on the survival of viruses in the air, which are also reported in Morawska (2006), with different behavior depending on whether viruses have or not an outer shell of fat. Thus, in the case of Corona Virus-type viruses that have a protective outer layer of fat, the conclusion is that this layer persists better in dry environments and that it is destabilized in more humid environments, unlike what happens with viruses that do not have a protective layer of fat (Roe (1992) and by Pillai and Ricke (2002)). As regards the effect of temperature, typically, virus persistence is higher in cold temperatures than in hot temperatures. Solar radiation has a component of ultraviolet radiation that impairs the persistence of viruses so that, in indoor environments without direct natural light, there are more favorable conditions for the persistence of viruses as airborne particles. In summary, the persistence of SARS CoV-2 type viruses as a bioaerosol, following the trajectories of existing air streams at the site, is greatest in cold, dry environments without natural lighting.

The second mode of transmission referred to in figure 6 is direct transmission by droplets that travel from the infected emitter to the susceptible host and which are inhaled by the latter. It happens normally with drops with an intermediate dimension, between about 10 μm and 50 μm, that may fulfill the path between the emitter and the receiver before its complete evaporation. In a coughing or sneezing episode, the initial velocity of the jet that leaves the mouth of the emitter can have typical values of 10 to 30 m/s, so the particles quickly make the paths of about 1 m between the emitter and the receiver, in an approximately horizontal trajectory, due to the situation of balance between the aerodynamic lift forces and the force of gravity, which present similar magnitudes and opposite directions.

The largest droplets, with diameters between 50 μm and 300 μm, are the ones that originate the contact transmission mode. As, in its case, the force of gravity is dominant because the forces of an aerodynamic nature lose relative influence, these particles fall faster and settle on surfaces, creating what is called fomites (objects or materials contaminated by pathogenic elements). There are several types of behavior that can contribute for the pathogens to be transported in order to come into contact with an area of entry into the body of the receptor element (mouth, eyes, nose). A relevant set of papers on this mode of transmission has been published, for example, articles by Rheinbahen et al. (2000) and Barker et al. (2001).

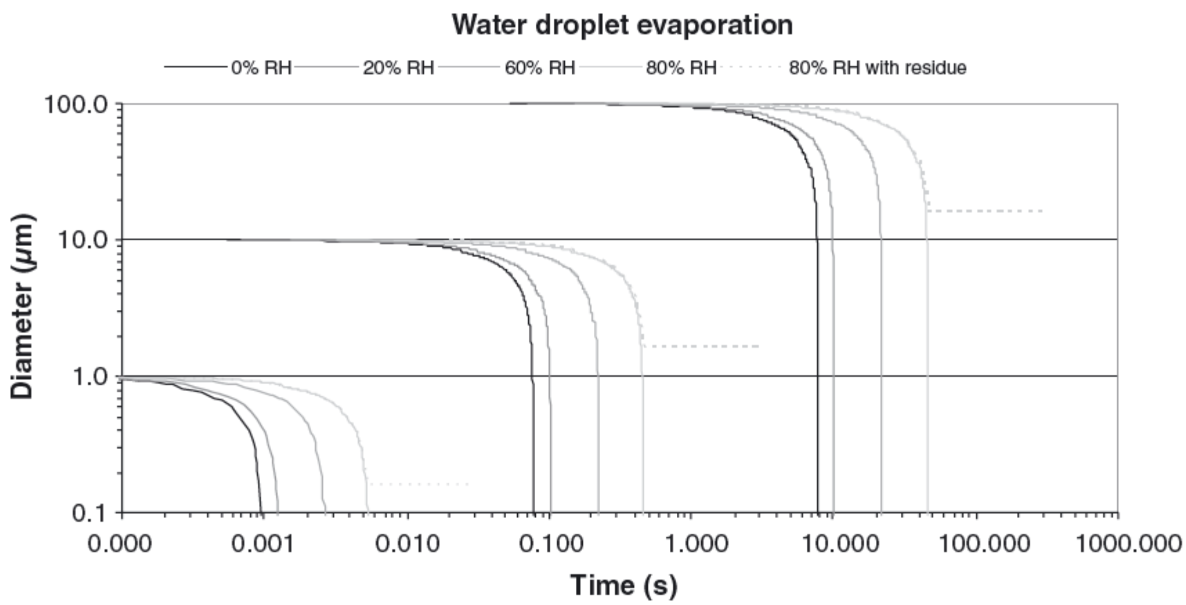


Figure 7 - Evaporation times of the liquid phase in water droplets depending on its size and local relative humidity

It is more or less consensual that the contact transmission mode and the droplets transmission mode are present in virus transmissions of the SARS-2 type, but there was, until some time ago, the conviction that the airborne particles contamination mode was not relevant in cases of viral infections and it happened mainly with bacteria (tuberculosis, legionella, ...). Probably the difficulty of establishing the cause-effect relationship, because it is a more difficult type of investigation and involves the need for much more sophisticated means, is at the basis of this fact, although it is already known that, for example, in the case of measles, which is viral, there is also transmission by suspended particles. There was no complete unanimity on the role of aerosol airborne transmissions, but the evidence for its existence in cases of viral transmissions has increased substantially in the most recent articles. The following table presents some of the articles that support the existence of transmission of viral infections through the mode of airborne particles.

Author(s)	Vírus	Ambiance	Case / Evidence
McLean (1961)	Influenza	Veterans Nursing	80% reduction in floor to floor transmission due to the installation of ultraviolet
Moser et al. (1979)	Influenza	Airplane on the ground in Alaska with ventilation system off	1 person infected 54 people sitting on board (72%). Aircraft ventilation systems today have much more efficient filtration systems
Klontz et al (1986)	H1N1	US Navy airplanes	Episode of generalized transmission between people sitting more than 2 m away
Mendell et al. (2002)	Various	Military Buildings	Influence of air recirculation on the incidence of infectious diseases
Yu et al (2005), Li et al (2005)	SARS	Amoy Gardens building park (Hong-Kong)	Transmission to neighboring buildings from bathrooms exhaust system
Li et al. (2005b)	SARS	Prince of Wales Hospital, Hong-Kong	Contamination pattern in hospital ward strongly correlated with ventilation flow pattern
Sun et al. (2011)	Influenza	Student Dormitories	Reduction of 35% of infected to 5%, due to air exchange rate

In an article published in Indoor Air, by Li et al. (2007), a group of experts from several countries, made a systematic multidisciplinary analysis of 40 articles on the role of airborne particulate transmission mode, published between 1960 and 2005, considering that 10 of the 40 articles were conclusive, with strong evidence the relationship between building ventilation and transmission/dissemination through airborne particles of diseases such as measles, tuberculosis, smallpox, influenza, bird flu, and SARS.

In an attempt to explain the differences in the spread rate between SARS-1 and SARS-2 (COVID-19), several American authors carried out a comparative study in terms of the survival of the two types of viruses in different environments and surfaces. On March 17, 2020, in a letter to the editor of the New England Journal of Medicine, they state that both remain viable and infectious for more than 3 hours in aerosols.

Following this information, the World Health Organization (WHO) considered that “precautions regarding particulate matter” should be taken by health professionals. The Director of the Division of Urgent Diseases, Dr. Maria Van Kerkhove, informed the media during a press conference on March 23, 2020 that “When a clinical procedure that generates aerosols is performed in a health care unit, there is the possibility of aerosolizing these particles, which means that they can remain in the air a little longer”.

She added: "It is very important that health workers take additional precautions when they are working with patients and do this type of procedures".

It is hard to understand that, at the level of the WHO directive board, there is no perception that aerosolization does not occur only when performing clinical acts with some type of equipment in a hospital environment, but also occurs naturally in the processes related to the person's respiratory system (coughing, sneezing, verbalization, breathing, etc.).

Thus, the implications of recent knowledge about the persistence of SARS-2 in aerosols should be much wider, namely in terms of redefining the concept of safety distance between people and the need for widespread use of upper airway protection equipment. (masks and visors) whenever it is anticipated that someone will be in an environment with multiple occupancy.

Analyzing, for example, the size distribution of the droplets that are emitted when a person coughs (Bourouiba et al. (2014)), shown in figure 8, it turns out that an important part has the potential to aerosolize because this is expected to happen, on account of the loss of water by evaporation, up to a dimension of 16 μm, at the time of exhalation.

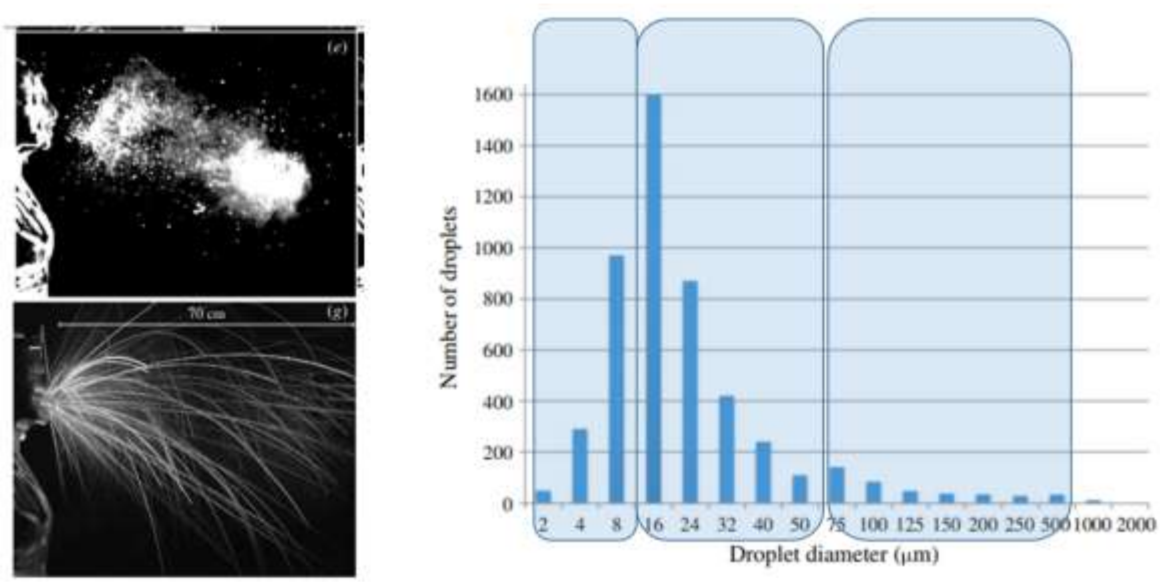


Figure 8 - Distribution by size classes of the drops exhaled in the cough

In an article published in Building and Environment, Jianjan Wei and Yuguo Li (2015), present the results of a computer simulation for the destinations of exhaled particles, with dimensions of 10 μm, 50 μm and 100 μm by a person who coughs , with an initial jet velocity coming out of the mouth of 10 m / s. Figure 9 shows an image assembled from the results of that article, in which it is clear that there is a risk that the airborne particles are inhaled by people who are at distances greater than 2 m recommended as a safety distance.

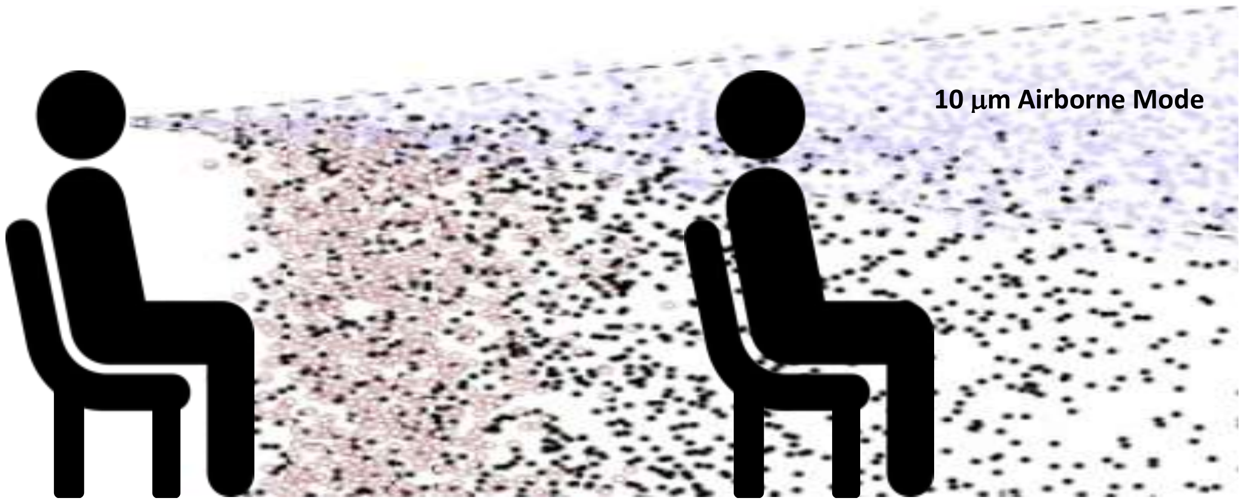


Figure 8 - Spatial zones potentially occupied by 10 μm, 50 μm and 100 μm particles exhaled by a person with a cough.(adapted from Jianjan Wei and Yuguo Li (2015))

It should be noted that the viral load will, in principle, be proportional to the size of the drops or droplets, so in smaller particles, the probability of causing infection, surely will be not zero, but may l be lower than in larger ones. Anyway, in case measures are taken only for the Contact and the Droplets transmission modes, as it is happening in various countries, the transmission will not be broken and the Airborne transmission mode may become the dominant one.

The main strategies to combat an eventual possibility of transmission are:

<u>For the Contact Transmission Mode</u>: Frequent cleaning and disinfection of workplaces and surfaces that can function as transmission sites in buildings and transportation means. Disinfection of tools and other objects. Frequent hand washing.

<u>For the Droplets Transmission Mode</u>: Social distancing and restrictions on the movement and agglomeration of people

<u>For the Airborne Transmission Mode</u>: To decrease the concentration of these particles by diluting them with fresh air provided by the ventilation process. To minimize the risk of inhalation through the airways through the use of masks and visors

Suggestions / Conclusions

Since most of the countries, implemented the combat measures against Contact and Droplets modes the following complementary measures should be put in place:

• As long as the epidemic crisis continues, face-to-face meetings should not be held;

• Indoor spaces with human occupancy must be heavily ventilated, exclusively with fresh air, to decrease virus concentrations, in the event of a possible contamination by suspended particles, and, thus, reduce the risk of infection;

• When planning an exit, to places frequented by other people, you should wear a mask and, if possible, a visor. Normal masks are not completely effective in retaining the smallest particles, so the use combined with a visor substantially increases the retention effectiveness;

• Those who work in public places must wear a mask and visor to protect the upper airways.

• Extreme protection measures should be applied to health professionals due to their high risk of infection.

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