A Non-conventional Approach to Understanding the Geographical Influence on the Transmission of SARS-CoV-2 and IFR

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Research Article

Keywords: Half-life, Strength of viral dose, Temperature effect, Dew point

Posted Date: July 15th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-479777/v5

A Non-conventional Approach to Understanding the Geographical Influence on the Transmission of SARS-CoV-2 and IFR

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Compiled July 14, 2021

Abstract : The transmission of SARS-CoV-2 is not well understood and different models are needed (i.e. one model cannot answer it all) to understand and fight this disease. Mathematical modelling is a powerful tool for understanding the transmission of SARS-CoV-2 and evaluating possible events or scenarios. Here, we present two models based on indirect transmission of SARS-CoV-2 that explain the influence of ambient temperature and air pollution on outdoor and indoor behavior of SARS-CoV-2. These models discuss the temperature dependency of the lethality of SARS-CoV-2 and its spread during indoor and outdoor exposure. Furthermore, the temperature effect on the half-life of SARS-CoV-2 is discussed if SARS-CoV-2 is transmitted via particulate matter or surfaces. It is also important to understand the role of dew point instead of the humidity factor alone as the combined effect of temperature and humidity might play a major role in the transmission of SARS-CoV-2 .
Key Words : Half-life ; Strength of viral dose ; Temperature effect ; Dew point.

http://dx.doi.org/10.1364/ao.XX.XXXXXX

1. INTRODUCTION

Although the SARS-CoV-2 outbreak in Wuhan, China was reported initially to the World Health Organization(WHO)in December 2019, there is no clear understanding of its spread and survival up until now and therefore, there is genuine urgency in proposing different models.[1,2] This uncertainty has a huge impact on our health, economy, and politics, and therefore it is important to eradicate this uncertainty sooner than later. However, according to Worldometer SARS-CoV-2 related data, it seems like there is a geographic (human and physical) factor involved in IFR (Infection Fatality Ratio). This is evident by the low IFR for highly populated countries (e.g. Singapore, Bahrain, etc.) and the high IFR for many European countries. For example, IFR in Singapore (population density is 7810 people per square kilometer respectively) is 0.049 whereas in the UK (population density in London and the UK are 5630 and 275 people per square kilometer respectively) it is 2.79 as of 4^{th} January 2021 (Worldometer data). To understand the transmission and variations in the IFR, there are factors that have to be taken into account such as UVB (ultraviolet B) intensity of sunlight, dew point, temperature, pollution (e.g.PM2.5 particle density), indoor ventilation, population density, social events,immunity, age, lifestyle, underlying health conditions, unknown genetic factors, etc. As per the WHO scientific brief circulated on 29 March 2020, SARS-CoV-2 is primarily transmitted between people through respiratory droplets and contact route.[3–5] Transmission via respiratory droplets can be in the form of sneezing,coughing, or speaking. Tiny respiratory droplets filled with pathogens can transmit infection when they move directly from the respiratory system of an infectious individual to a susceptible mucosal membrane of a recipient, generally within a short distance. In general, large droplets ($> 5\mu$) fall rapidly to the ground under gravity or nearby surfaces whereas the small particles ($< 5\mu$) can remain suspended in the air for a significant period. These small droplets can enter someone's respiratory system when two people are in close proximity ($<$ 1m). Some studies have revealed that environmental surfaces play an important role in the endemic and epidemic transmission of certain pathogens that cause infections.[6] Although many respiratory viruses are believed to transmit over multiple routes, of which droplet and aerosol transmitted paths are involved, their significance in transmitting the disease is unclear.[7] Morawska et al. have highlighted that WHO guidelines such as hand washing and maintaining social distance do not prevent infection by small droplets exhaled by an infected person that can travel distance of meters or tenth of meters in the air and carry their viral content.[8] According to literature, the public health authorities have marginalized the significance of the fact that airborne transmission of SARS-CoV-2 or influenza could be due to the problems associated with the detection of the viruses in the air.[8] Moreover,it was reported that aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days.[9]. Therefore, it is important to understand any involvement of air pollution in the transmission of viruses. PM2.5, a pollutant refers to atmospheric particulate matter that has a diameter of fewer than 2.5 microns, which may have the potential for transmitting SARS-CoV-2. Respiratory droplets can contaminate this PM2.5 and dehydrate over time as water content (99%) in saliva can evaporates during dehydration.[10,11] As a result, SARS-CoV-2 can adhere to the surface of PM2.5 depending on the electrostatic attraction, contact angle and bonding capability between the PM2.5 and the SARS-CoV-2. Eventually, it may easily enter our respiratory system while leading to an outdoor spread.The lethality of the dose depends on the amount of virus bound to particulate matter. According to global health observatory (GHO) data, the mean ambient air pollution of particulate matter with an aerodynamic diameter of 2.5μm ranges from less than 10 to over 100 $\mu g/m^3$ in urban areas. This implies that around 741289 PM2.5 particles are suspended in a cubic meter of air if the PM2.5 level is 10μg/m^3. Therefore, contaminated PM2.5 can contribute to the spread of diseases if a confined area is polluted and occupied by infected people. Nevertheless, the lethality of viral dose is very mild in open areas due to dilution of contaminated particles with air. Therefore, outdoor gatherings may have a insignificant impact on our lives in terms of lethality compared to indoor gatherings. These particles are released from a variety of indoor and outdoor activities. For example, burning candles, cooking, forming complex reactions of gaseous pollutants emitted by household cleaning products and air fresheners, smoking, etc. contribute to indoor pollution whereas emission from vehicles, industries, power plants, etc.contribute to outdoor pollution. However, being exposed to a lethal dose of SARS-CoV-2 will develop a more severe illness and therefore, it is worthwhile to understand the strength of SARS-CoV-2 dose (i.e. harmfulness) and its transmission. On a different note, although WHO declared SARS-CoV-2 a pandemic on 11^{th} March 2020, SARS-CoV-2 infections were likely being exported from china few months before this date. Therefore, many infected passengers might have crossed the continents and borders by air without knowing the magnitude of the risk (i.e. no face mask). Now the question is, at beginning of the pandemic, why the cabin crew members were not massively infected by these passengers. The answer could be airborne transmission of SARS-CoV-2 is hindered due to the quality of cabin air. For example, airlines calculate that their HEPA filters remove 99.7 percent of airborne particles (like ones used by United Airlines) to 99.999 percent (such as those in use on Delta Air Lines planes) and therefore, direct transmission is the only possible way of getting the infection. Despite everything, Association of Flight Attendants reported in May 2020 that hundreds of cabin crew have tested positive for virus, and at least seven died. However, the cabin crew leave the airplane after completion of their journey and can be infected by any other means. Therefore, we can not conclude that these crew members were infected during air travel. In contrast, further investigation is needed to overcome SARS-CoV-2 related air travel fears.

Survival of SARS-CoV-2

It was revealed that simulated sunlight rapidly inactivates SARS-CoV-2 on surfaces.[12] Anyway, saliva can act as a shield for protecting SARS-CoV-2 from exposure to UVB (280-315nm) as saliva absorb good portion of UV(λ >220nm) light. Therefore, it is important to remove this shield to inactivate SARS-CoV-2, and evaporation of saliva depends on the dew point and the ambient temperature. Although there have been some studies on the temperature and relative humidity effect on SARS-CoV-2 transmission, different models are needed for in-depth analysis of SARS-CoV-2 transmission and its effects.[13,14] It was also reported that the growth rate of some viruses and bacteria declines slowly with decreasing temperature and more rapidly upon temperature increase.[15]

2. METHOD

We believe that in-depth studies on the behavior (the strength of viral dose and its survival in our environment) of SARS-CoV-2 in the ambient temperature, before entering our body, will help us understand its spread and lethality. For example, a study revealed that increasing the temperature while maintaining humidity drastically reduces the survivability of SARS-CoV-2 (i.e. temperature affects the half-life of SARS-CoV-2).[16] Therefore, this investigation proposes two mathematical models based on two different hypotheses to understand the effects of temperature and air pollution on the strength of SARS-CoV-2 dose. However, the term "strength of SARS-CoV-2 dose" used in this non-conventional approach is different from the term "infectious dose" which is the amount of virus necessary to make a person sick or create an infection. Nevertheless, the strength of SARS-CoV-2 dose refers to the chemical potential of SARS-CoV-2 (μ) at a certain temperature, number of active virus per SARS-CoV-2 contaminated particle(N) in moles at that temperature (i.e. temperature may have an effect on the chemical potential of individual virus and half-life of a virus) and SARS-CoV-2 contaminated particle density(D) in air. However, the chemical potential of SARS-CoV-2 varies after entering the human body whereas the number of active SARS-CoV-2 virus remains same prior to its internalization. Eventually, proteolytic enzymes (RNA olymerase) involve in the replication of SARS-CoV-2 in which the factor "Strength of SARS-CoV-2 dose" may play an important role. In this non-conventional approach, the strength of SARS-CoV-2 dose(A) before entering human body is expressed as a function of temperature, f (t) as follows.

$$A = KD\mu N = \kappa f(t) \tag{1}$$

where K and κ are considered as constants, even though it may depend on other physical parameters (e.g. dew point, etc). Although direct and indirect transmission of SARS-CoV-2 is discussed in this communication, the temperature effect on the strength of SARS-CoV-2 dose is discussed under two hypotheses only for indirect transmission of SARS-CoV-2.

3. RESULTS

Hypothesis 1

SARS-CoV-2 is dormant at very low temperatures and its activity increases with increasing temperature and then decreases. Here is one of the evidences supporting this hypothesis. It was reported that human metapneumo virus (HMPV) is most prevalent when the temperature becomes slightly warmer (7.4 C).[17]. In this case, we assume that SARS-CoV-2 is transmitted via dust particles (e.g. PM2.5, aerosols, etc.) and shows its highest strength at temperature T(K). In general, virus droplets remain infectious for a time depending on where they fall (e.g. surface or dust particle). The interaction between SARS-CoV-2 and dust particles (e.g.PM2.5) depends on surface properties of the particle. However, the survival time of the SARS-CoV-2 depends on the surface type and ambient temperature and it was estimated that the median half-life of SARS-COV-2 was approximately 5.6 hours on stainless steel and 6.8 hours on plastic.[9] Now rearrange the equation (1) to fit this situation as follows

$$A = \alpha D[t - 0.5(t - T + 1)^2] \quad \textbf{(2)}$$

it is assumed that all the particles equally contaminated with the virus, t is the ambient temperature, α may depend on the dew point. Therefore, the virus shows its highest strength when the temperature(t) reaches T(K). To construct a graph, we give some random values to the constants in the above equation such that α=0.4, T=275k, and D=0.14. Now let's look at the graph in Figure 1 which shows its highest strength 15.372 kJ mol^{-1}. at 275K.

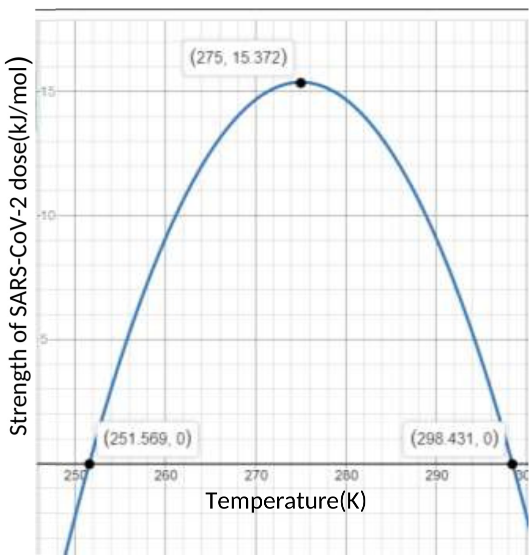

Fig. 1. Graphical illustration of temperature effect on strength of SARS-CoV-2 for indirect transmission of SARS-CoV-2 according to hypothesis-1.

Hypothesis 2

SARS-CoV-2 is not dormant at low temperatures and become weak at high temperatures Here, we consider a SARS-CoV-2 transmission via dust particles (PM2.5), expect that the strength of SARS-CoV-2 dose is constant at low temperature, starts to decline over time (i.e. half-life is temperature-independent at low temperatures). For example, it was reported that in a guinea pig model, influenza virus transmission is more effective in cold and dry conditions.[18] This phenomenon is explained mathematically in equation (3).

$$A = \beta D[\Lambda - e^{\varphi(t-T)}] \quad \textbf{(3)}$$

Where t is the ambient temperature and T is the temperature at which the activity of virus is stable. It is assumed that all the particles are equally contaminated,β may depend on the dew point, Λ and φ are constants. Let's give some arbitrary values to the constants in the equation (3) as we did previously. Suppose D=2, β=2.5, Λ =1, T=333k and φ =0.1. Then, the graph in Figure 2 explains that the strength of SARS-CoV-2 is going to decline after 280K and dies at 333K.

4. DISCUSSION

However, temperature alone cannot account for the global variation in the IFR, but according to these models, temperature

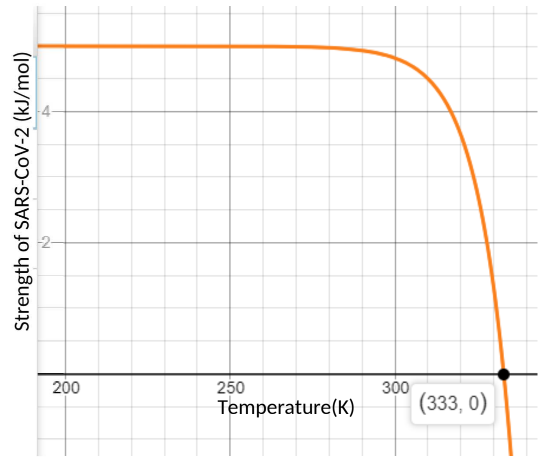

Fig. 2. Graphical illustration of temperature effect on strength of SARS-CoV-2 for indirect transmission of SARS-CoV-2 according to hypothesis-2

factor plays an important role in the case of indirect transmission. The constants α and β are elements of κ in the equation (1) (i.e. $\kappa = \{\alpha, \beta\}$) and Figure 1 and Figure 2 are drawn for illustration purposes only, and accurate experimental data are needed to improve these models. The spread of a virus depends on its ability to survive in the environment, and the lethality of the viral dose is judged by the strength of the SARS-CoV-2 dose assuming that the direct transmission is suppressed as a result of following the WHO guidelines. Anyway, in the case of indoors, exposure to a small dose of SARS-CoV-2 for prolonged period, especially with poor ventilation, can contribute to the IFR. For example, ventilation is poor during winter in most of the enclosed spaces, and the SARS-CoV-2 contaminated fomites (e.g. PM2.5, aerosols) can carry a small dose, but exposing someone to SARS-CoV-2 contaminated air for a prolonged period is dangerous.On a different note, the heavy droplets deposited on surfaces can float in the air if the adhesion between the surface and the SARS-CoV-2 is poor (i.e. SARS-CoV-2 can float in the air after water in the saliva is evaporated). The magnitude of SARS-CoV-2 contamination also depends on the size of the enclosed space and number of infected people (i.e. asymptomatic carriers) live within this enclosure. The outdoor spread of SARS-CoV-2 depends on many factors such as dew point, temperature, UVB intensity, etc. Although the outdoor transmission of SARS-CoV-2 may not significantly affect IFR if the social distancing is maintained and vulnerable people are confined to indoors (i.e. a small virus dose from air/contaminated surfaces may have an ability to make an infection for vulnerable;e people), indoor exposure to SARS-CoV-2 may contribute to IFR. In contrast, weather pattern and surface properties of particulate matter may contribute to the outdoor spread of SARS-CoV-2 whereas building structure(i.e. ventilation, surface properties of interior surfaces, etc.), relative humidity, the freshness of the air, immunity of the people live in enclosed spaces and their underline health conditions, number of people infected or infectious dose released by members within that enclosure, etc. may contribute to IFR.

5. CONCLUSIONS

In general, both direct and indirect transmission of SARS-CoV-2 contributes to the IFR and spread. It is also reported that the temperature has an important effect on viral activity, particularly in the case of enveloped viruses like SARS-CoV-2.[17,18] Therefore, two different mathematical models are discussed in this communication to understand the temperature effect on the IFR. According these models, indirect transmission could have a temperature effect on "strength of SARS-CoV-2" and its transmission, assuming that direct transmission has no considerable temperature effect (i.e. SARS-CoV-2 enter the human body within seconds). Respiratory droplets can contaminate particulate matter in the air or surfaces and exhale air can contaminate the particles trapped in the nasal airway. By considering all possibilities, the strength of SARS-CoV-2 dose is a measure of the lethality of the viral dose which may be used to understand the variation in the IFR. Ambient temperature may affect half-life of SARS-CoV-2 , which influences the lethality of the viral dose. Although temperature reduces the lethality of SARS-CoV-2 dose, the transmission of SARS-CoV-2 is not significantly controlled by the temperature as a small amount of virus is enough for the transmission. Moreover, the geographical influence on the transmission of SARS-CoV-2 and IFR may change over time due to the adaptions of SARS-CoV-2 to different environments and formation of new variants. In a worst-case scenario, SARS-CoV-2 can demonstrate properties of increased transmissibility and severity (e.g. IFR can go up) regardless of vaccination program. As a result, the virus continues its activity until all the continents achieve the herd immunity as happened during Spanish flu. Nonetheless, there are some vaccines may have a chance to control the IFR. In contrast, the proposed models might be used to benchmark the lethality of SARS-CoV-2 , a better understanding of the transmission of SARS-CoV-2 and its lethality will help control the impact of SARS-CoV-2 on our lives.

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