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

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

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Abstract: To understand and fight SARS-CoV-2, different models are needed (i.e. one model cannot answer all the questions). A mathematical model can be an effective tool for understanding SARS-CoV-2 transmission and evaluating possible strategies. Here, we present two models based on the indirect transmission of SARS-CoV-2 that explain the impact of ambient temperature and air pollution on SARS-CoV-2 outdoor and indoor behavior. These models discuss temperature-based lethality of SARS-CoV-2 and its spread. In addition, if SARS-CoV-2 is transmitted through particulate matter or surfaces, the temperature effect on its half-life is discussed. The dew point should also be considered instead of just the humidity factor, since a combination of temperature and humidity may play an important role in SARS-CoV-2 transmission.
Key Words : Half-life ; Strength of viral dose ; Temperature effect ; Dew point.

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1. INTRODUCTION

Despite the recent SARS-CoV-2 outbreak in Wuhan and the WHO China Country Office being informed of pneumonia cases of unclear etiology (unknown cause) in December 2019, very little is known about the spread of this disease. It is imperative that alternative models be proposed urgently to address this uncertainty as soon as possible, since it has a huge impact on our economy, health, and politics[1,2]. According to Worldometer SARS-CoV-2 data, there does seem to be a geographic (human and physical) factor affecting IFR (Infection Fatality Ratio). It is evident from 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^{th} March 2020, SARS-CoV-2 is primarily transmitted between people through respiratory droplets and contact route[3,4,5]. Droplets of respiratory fluid can be spread by sneezing, coughing, or speaking. A pathogen-filled droplet can transmit infection when it travels directly from an infectious individual's respiratory system to the mucosal membrane of a recipient, generally within a short distance. Generally speaking, large droplets (>5μ) fall rapidly to nearby surfaces or the ground under gravity, while small droplets (<5μ) remain suspended in the air for a considerable amount of time. These small droplets can enter someone's respiratory system when two people are in close proximity ($<$ 1m). Studies have shown that environmental surfaces play a crucial role in endemic and epidemic transmission of certain pathogens that cause infections[6]. Many respiratory viruses are believed to be transmitted via multiple routes, including droplet and aerosol-mediated paths, although their significance in transmitting disease is unclear[7]. Morawska et al. report that WHO guidelines like hand washing and maintaining social distance do not prevent infection by droplets exhaled from an infected person that can travel a distance of meters or tenths of meters in the air and spread their viral content[8]. According to literature, public health authorities marginalized the significance of the fact that airborne transmission of SARS-CoV-2 or influenza may be related to difficulties in detecting the viruses in the air[8] SARS virus can remain viable and infectious in aerosols for hours and on surfaces for up to two days, thus making aerosol and fomite transmission plausible[9]. Therefore, it is important to understand any involvement of air pollution in the transmission of viruses. PM2.5 is a particulate matter with a diameter of less than 2.5μm, which can transmit SARS-CoV-2. It is possible for respiratory droplets to contaminate this PM2.5 and dehydrate over time as water content (99%) in saliva evaporates while dehydration occurs[10,11]. Hence, SARS-CoV-2 can adhere to PM2.5 depending on the electrostatic attraction, the contact angle, and the bonding capability between PM2.5 and SARS-CoV-2. Eventually, it can easily penetrate our respiratory system, resulting in outdoor spreading. The lethality of the dose depends on the amount of virus bound to particulate matter. In urban areas, ambient air pollution with an aerodynamic diameter of 2.5μm can range from less than 10 to over 100 μg/m^3, according to data from the global health observatory (GHO). 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. If a confined area is polluted and occupied by infected people, contaminated PM2.5 can contribute to the spread of diseases. Nevertheless, the lethality of viral dose is very mild in open areas due to dilution of contaminated particles with air. Therefore, compared with indoor gatherings, outdoor gatherings are unlikely to have a significant impact on our lives in terms of lethality. 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 emissions from vehicles, industries, power plants, etc. contribute to outdoor pollution. Nonetheless, a lethal dose of SARS-CoV-2 will develop a more severe illness, which is why it is necessary to understand the strength of the SARS-CoV-2 dose (i.e. harmfulness) and how it is transmitted. In a separate note, although WHO declared SARS-CoV-2 a pandemic on11th March 2020, SARS-CoV-2 infections were likely being exported from China several months earlier. 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). There was a question at the beginning of the pandemic as to why the cabin crew was not significantly affected by these passengers. The answer could be airborne transmission of SARS-CoV-2 is hindered due to the quality of cabin air. Airline HEPA filters, for example, remove 99.7% of airborne particles (such as those used by United Airlines) to 99.999% (such as those used by Delta Air Lines), so direct transmission is the only way to catch the infection. According to the Association of Flight Attendants, hundreds of cabin crew have tested positive for SARS-CoV-2 and at least seven have died. Nevertheless, cabin crew members leave the airplane after they have completed their journey and can be infected in any other way. Therefore, we can not conclude that these crew members were infected during air travel. However, further research is needed to eliminate SARS-CoV-2 related air travel fears.

A. *Survival of SARS-CoV-2*

It was revealed that simulated sunlight rapidly inactivates SARS-CoV-2 on surfaces[12]. As saliva can absorb a good portion of ultraviolet radiation, saliva may act as a shield to prevent SARS-CoV-2 from being exposed to UVB light (280-315nm) as saliva absorb good portion of UV(λ >220nm)light. It is therefore important to remove this shield to inactivate SARS-CoV-2, and evaporation of saliva depends on dew point and 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 a comprehensive analysis of SARS-CoV-2 transmission and its impacts[13,14].Furthermore, it has been reported that the growth rate of some viruses and bacteria decreases slowly with decreasing temperature and more rapidly with increasing temperature[15].

2. METHOD

A detailed study of the behavior (the strength of the viral dose and its survival in our environment) of SARS-CoV-2 in the ambient temperature, before it enters 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]. To better understand the effects of temperature and air pollution on the strength of SARS-CoV-2 dose, this research proposes two mathematical models based on two different hypotheses. However, the term "strength of SARS-CoV-2 dose" used in this non-conventional approach is different from the term "infectious dose" which refers to the amount of virus necessary to cause illness or 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. While SARS-CoV-2's chemical potential varies after entering the human body, its number of active viruses remains the same prior to internalization. Eventually, proteolytic enzymes (RNA olymerase) are involved in the replication of SARS-CoV-2 in which the factor "Strength of SARS-CoV-2 dose" may play an important role. As a result of this non-conventional approach, the strength of SARS-CoV-2 dose(A) before entering the human body is expressed as a function of temperature, f (t)..

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

where K and κ are considered as constants, even though they may depend on other physical parameters (e.g. dew point, etc.). 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 before declining. The following is one of the pieces of evidence supporting this hypothesis. Prince et al. reported that, the human metapneumovirus (HMPV) is most prevalent when the temperature becomes slightly warmer, (7.4 C)[17]. In this case , we assume that SARS-CoV-2 virus is transmitted via dust particles (e.g., PM2.5, aerosols, etc.) and shows its greatest strength at temperature T(K). It is known that virus droplets remain infectious for a while 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 the surface properties of the particle. In contrast, the survival time of SARS-CoV-2 varies with the type of surface and ambient temperature, and it was estimated that the median half-life of SARS-CoV-2 was 5.6 hours on stainless steel and 6.8 hours on plastic[9]. As you can see, equation (1) should be rearranged to reflect these circumstances.

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

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). In order to construct a graph, we assign 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 Figure 1 which shows its highest strength of 15.372 kJ mol^{-1}. at 275K.

Hypothesis 2

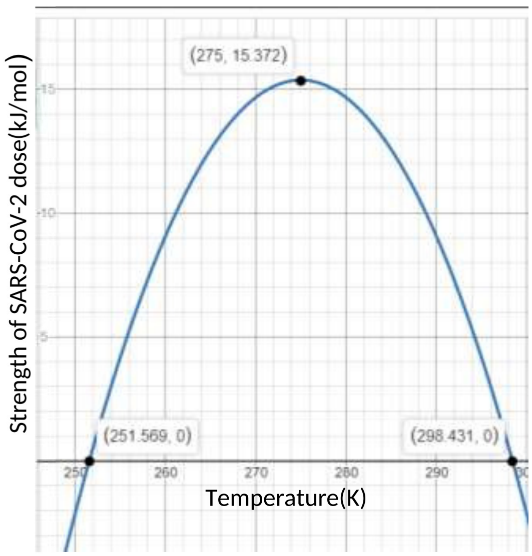

Fig. 1. Graphical illustration of temperature effect on strength of SARS-CoV-2 for indirect transmission of SARS-CoV-2 according to hypothesis-1

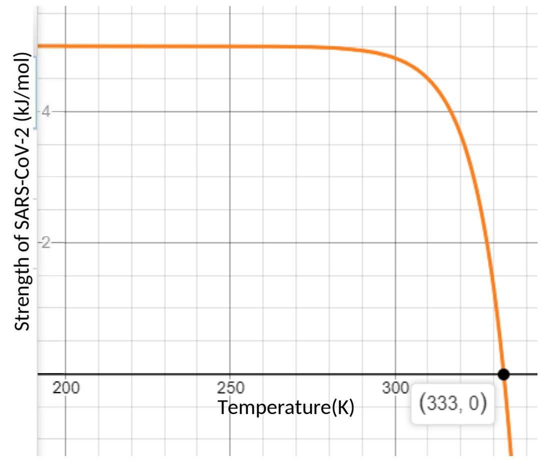

Fig. 2. Graphical illustration of temperature effect on strength of SARS-CoV-2 for indirect transmission of SARS-CoV-2 according to hypothesis-2

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), assume 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).

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

Where t is the ambient temperature and T is the temperature at which the activity of the 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. As before, let's use some arbitrary values for the constants of equation (3). 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

Temperature alone, however, cannot explain the global variation in the IFR, but according to these models, the temperature factor plays an important role in indirect transmission. It was also noticed that the SARS-COV-2 transmission is poorly controlled despite the majority of people wearing face masks because of indirect transmission.The constants α and β are elements of κ in 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. A virus's ability to spread depends on its ability to survive in the environment, and the lethality of the viral dose is dependent on the strength of SARS-CoV-2 dose assuming direct transmission is suppressed by following the WHO guidelines. However, exposure to SARS-CoV-2 for prolonged periods of time, especially with poor ventilation, can result in IFR. Winter is a dangerous time for enclosed spaces due to poor ventilation, and the SARS-CoV-2 contaminated fomites (e.g. PM2.5, aerosols) can carry a small dose, but prolonged exposure to SARS-CoV-2 contaminated air can be deadly. Additionally, 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. the virus can float in the air once the saliva evaporates). The amount of SARS-CoV-2 contamination also depends upon the size of the enclosed space and the number of infected people living there (e.g. asymptomatic carriers). The outdoor spread of SARS-CoV-2 depends on a variety of factors, including dew point, temperature, UVB intensity IFR may not be significantly affected by SARS-CoV-2 outside transmission if social distance is maintained and vulnerable people are confined to the indoors (in other words, a small virus dose from air or contaminated surfaces can still cause infection), but indoor infection may cause it. In contrast, weather pattern and surface properties of particulate matter in the air 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 IFR and spread. There is also evidence that temperature affects viral activity, especially in the case of enveloped viruses like SARS-CoV-2[17,18]. Thus, two different mathematical models are presented to understand the effect of temperature on IFR in this communication. According to these models, indirect transmission can have a temperature affect on "strength of SARS-CoV-2 dose" and its transmission, assuming direct transmission has no substantial temperature effect (i.e. SARS-CoV-2 enters 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. Based on all possibilities, the strength of SARS-CoV-2 dose can be used to determine the lethality of the viral dose, a measure that may be used to explain variation in IFR. Ambient temperature may affect half-life of SARS-CoV-2, which influences the lethality of the viral dose. SARS-CoV-2 doses are less lethal at high temperatures, but the virus is still easily transmitted with just a small amount of virus. 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, especially the robust ones from hot countries in future. As a worst-case scenario, SARS-CoV-2 could exhibit properties of increased transmissibility and severity (e.g., IFR could rise despite vaccination programs). As a result, the virus continues to spread until all continents achieve herd immunity, as happened during the 1918 influenza pandemic (Spanish flu). Nevertheless, some vaccines may be able to control IFR. In contrast, the proposed models can be used to benchmark the lethality of SARS-CoV-2. Understanding the transmission and lethality of SARS-CoV-2 will make controlling its effects on society easier.

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Supplementary Files

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- Appendix1A.pdf
- Appendix2.pdf