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Epidemiological study of novel coronavirus (COVID-19): macroscopic and microscopic analysis

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ABSTRACT

Background: This study aimed to unravel the microscopic behaviour by introducing health functional for individuals during coronavirus (COVID-19) epidemic and understand the macroscopic behaviour of epidemic infection dynamics by growth models.

Methods: Virus strength, immunity and medications are taken as independent parameters for health functional in the stochastic simulation for microscopic investigation. For macroscopic understanding, Logistic, Weibull and Hills growth models are considered to obtain power indices.

Results: Microscopically, the effect of medication that inhibits virus strength with increasing immunity is shown through the simulation. While, without medication and increasing viral strength lead the individual to death, improved medication and increasing immunity strength lead back to normal life. Macroscopically, scale invariance of power indices over time reveals similarity of spreading of infection in most of the countries.

Conclusions: Proper medication needs urgency for the infected person to keep the health well. Overall this issue warrants federal policy to maintain the social distance, public awareness to prevent the infection, and healthcare facilities for early detection by tracing the infected people for potential treatment.

Keywords: Coronavirus (COVID-19), Data analysis, Epidemiology, Growth model, Health functional, Power index

INTRODUCTION

Health is wealth. To keep the health fit, good food, exercises and sound sleep are mandatory. Sometimes external agents like virus, bacteria, etc. attack the body that deteriorates it and to overcome, medical assistance is necessary. For instance, at present the outbreak of coronavirus (COVID-19) from Wuhan, China, that causes severe respiratory tract infections in humans has become a global health concern.^{1,2} Although the major mode of transmission via respiratory droplets, contaminated hands, surfaces have been found out, the other modes can't be neglected.³⁻⁹ The factors like low temperature and low humidity highly influence the transmission of COVID-19.^{10,11} The population density, qualitative medical care

also affect the control of COVID-19.^{12,13} The outcome of all the factors and modes of transmission lead to the infection in humans with suffering in pain and to death in one hand. On the other hand, although there is no direct vaccine available for it (some vaccines are under trial at the time of publication of this manuscript), alternative medicines are used to treat the patients to recover.^{1,2} It is still not controlled in most countries, despite their attempts in various modes. There are attempts to understand the behavior of the epidemic in different mathematical formalism of which most of them are based on susceptible, infected and recovered (SIR) or its derivative models.^{12,14,16-18-22} However some models also tried to predict the outcome of the epidemic.^{16,23-28} Attempts are done for understanding the pandemic

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spreading with various growth models.^{29,30} But individual description of human being is not studied. While we were working on this aspect, it has been alarmed.³¹ We introduce a health functional to model the microscopic behaviour and investigate the statistical analysis for macroscopic behaviour of the epidemic.

The main objective of this work was to understand the coronavirus (COVID-19) infection dynamics by the different growth models and both microscopic and microscopic behaviour of individuals by introducing health functional.

METHODS

We have taken the data from Johns Hopkins University Center for Systems Science and Engineering (JHUCSSE).² However, we have also rechecked the results from the database of world health organization (WHO).¹ The cumulative infected data were analysed based on various growth models (e.g. Logistic, Weibull and Hill) to obtain the power index.

This study involves the theoretical modeling and statistical analysis of COVID-19 infection data obtained from the database of JHUCSSE and WHO.^{1,2} This study was carried out by taking the COVID-19 infection data from 22nd January, 2020 to 18th August, 2020. The collected data are analyzed by the computer program developed by the authors.

Inclusion criteria

We study the COVID-19 infection data of top ten highly infected countries and carried out the stochastic simulation to understand the infection dynamics of individuals.

Exclusion criteria

We exclude the COVID-19 infection data of countries which contain less number of infected individuals during the study period.

Model

We propose a health functional model H for a person with two functional parameters, (a) the strength of virus (external), which attacks the body of a person and (b) immunity (internal) of the body. Later we add parameters such as medication which reduces the virus strength inside the body and increasing the immunity. Let dv/dt and di/dt be the time derivative of viral infection and immunity, where v and i are the virus strength and the immunity respectively. A body, which is a dynamical system, flows with time. (We neglect the spatial factor, i.e. different parts of the body for simplicity). With some specific medication the viral infection decreases. Hence the -dv/dt is replaced by $(-dv/dt) + (dm_v/dt)$, where (dm_v/dt) is the opposing term for the virus with certain

medications. With some other specific medications the immunity of the body increases. Hence the di/dt is replaced by $(di/dt)+(dm_i/dt)$, where (dm_i/dt) is the supporting term for the immunity. Hence, the health functional is $H=H((-dv/dt)+(dm_v/dt)+(di/dt)+(dm_i/dt))$.

From the original SIR model, the time derivative of susceptible S is dS/dt = -bS(t)I(t). We relate the parameter b with virus strength dv/dt of many individuals. From the recovered equation dR/dt = k.I(t), we relate k with each person's medications $(dm_v / dt, dm_i / dt)$ and immunity (di/dt) which altogether are much higher than the virus strength. Contrary, it leads to the death of individuals and in the extended SIR model the death rate increases. For the macroscopic infected equation dI/dt = bS(t)I(t) - kI(t), which is valid over a large population, has its microscopic connection with many individuals health functional $H((-dv/dt) + (dm_v / dt) + (di/dt) + (dm_i / dt))$.

RESULTS

The COVID-19 is spreading rapidly all over the world and WHO declared it as a public health emergency of international concern (PHEIC). Globally there are more than 25 million infected cases and 8 lakh death cases since its first detection in China.^{1,2}

The cumulative data of top ten highly infected countries are shown in Figure 1 (a). The daily infected people of top ten countries are shown in Figure 1 (b). The mean of newly infected people is quite high for most of the countries. At present the USA, Brazil and India show the highest daily infected cases, contrary to China, Italy and Iran in 21st March. The change in characteristics at different geographical locations reflects by the social behaviour. The policy implementation such as lockdown affects the increase in social distance, thus reduces the infection. Population density of India (~416) is higher than Brazil (25) and USA (34) compared to China (146), Italy (~200) and Iran (~51) (ST1. Supplementary material). So the measure of social distance plays an important role than other factors.

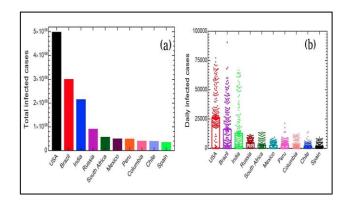


Figure 1: Top ten infected countries till 18th August 2020; (a) total infected cases, (b) daily infected cases.

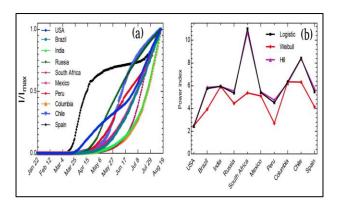


Figure 2: (a) Normalized cumulative data of top ten highly infected countries, (b) power index obtained from different models for top ten highly infected countries.

For comparison of infection rate, the normalized data are plotted for these countries (Figure 2 (a)). The flatness of the top data of any country represents the saturation of new infections. Initially the infection rate may be low, but increases as time progresses and reaches a saturation value. Spain shows intermediate flatness (after initial increase) but later shows increasing in trend. The USA shows two major growths, initially the slope is less (0.005) and later with more slope (0.011). While for most of the countries the infection trend is increasing, their trends slightly vary from each other revealing dissimilar local transmission dynamics. For instance, the tail end data of the USA and Spain shows a similar trend (slope 0.009). While the intermediate data for Chile is similar with Peru (0.014), but later data is similar with Russia (0.008). Interestingly, the trend in curves for India and Columbia looks identical and that of Mexico and Brazil looks identical in full range. The actual infected data, population density, geographical locations and conditions vary for compared countries (Supplementary material), but the similarity in infection trends shows the similar transmission dynamics.

The cumulative infection data are fitted with the various growth models i.e. Logistic, Weibull and Hill equations (see Eq. 1-3) and the obtained power indices (α) are shown in Figure 2(b).

$$N(t) = \frac{A_1 - A_2}{1 + (t/t_0)^{\alpha}} + A_2 (1)$$

$$N(t) = B_1 - (B_1 - B_2)e^{-(kt)^{\alpha}}$$
(2)

$$N(t) = \frac{c_1 t^{\alpha}}{c_2 + t^{\alpha}} (3)$$

In Eq. 1, A_1 , A_2 , t, t_0 and α are the initial value, final value, time, center and power exponent of the logistic curve respectively. Similarly, in Eq. 2 B_1 , B_2 , and k are the lower initial value, top asymptote value and coefficient respectively. In the case of the Hill equation (Eq. 3), C_1 , C_2 are the maximum value and coefficient of the growth

curve. The power indices values (~2-8, except for South Africa) are very close to each other for all the models. However, higher values of power indices were obtained for top ten countries till 21st March (Figure 3, Supplementary material).

For comparison, the variation of power indices as a function of time for various countries are shown in Figure 6 (a) and 6 (b) respectively. As of 21st March, the top ten countries are not the same at present (Figure 3 and 4, Supplementary material). It is observed that the power indices reduce and become asymptotic in nature. The signatures can be inferred as (a) macroscopically the overall growth is similar in nature, irrespective of the discrepancy in local topographical condition. (b) Over the period of time, the decrease in power indices are due to lockdown imposed by most of the countries, spreading the key message to the community to prevent the infection, quarantining their susceptible and tracing the infected people. (c) Healthcare facility for early detection and potential treatment.

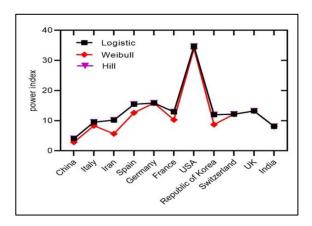


Figure 3: Power index obtained from different models for top ten highly infected countries as of 21st March 2020.

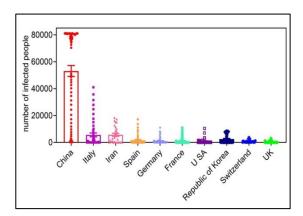


Figure 4: Cumulative infected data from the top ten highly infected countries as of 21st March 2020.

The global infected data of COVID-19 shows a power law behaviour with exponent 1.70 (Figure 6 (c)) as of 21st March 2020, but as time progresses the exponent value

increases to ~ 2.68 till the date 18th August 2020 (Figure 3(d)). Although the spreading of coronavirus is different in respective countries, the growth of total infected cases (N(t)) shows a scale invariance behaviour. Initially, the exponent is low because the spreading of virus is low but with time increases, COVID-19 cases were observed for almost all the countries of the world. It has also been observed that the total infected cases in highly infected countries show power law behaviour and that could be one of the reasons as a whole, the scale invariance is seen.²⁹ Country specific scaling exponents can be different because of their standard caution exercised by the Government and the lockdown policy to maintain the social distance. This is because, no Government would like to see the entire population infected with such a pandemic.

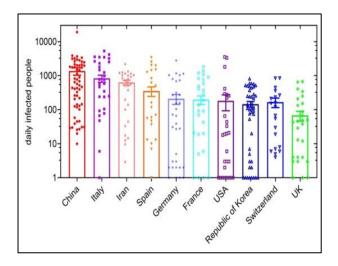


Figure 5. Daily infected data from the top ten highly infected countries as of 21st March 2020.

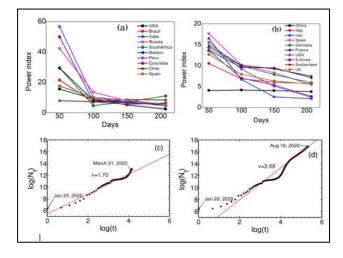


Figure 6: Trend in power index of top ten countries as of (a) 21st March, and (b) 18th August 2020. Power law behaviour of infection spread as of (c) 21st March, and (d) 18th August 2020.

Looking at the preventive measure of spreading of the virus, it is noted that the main cause of transmission of

the virus is through droplets, either it is a direct or indirect method. The direct method is when the airborne virus with droplet comes in contact with the susceptible person or by physical contact (sneezing, coughing, hand shake, hugging etc.)^{2,33} In the indirect way if the airborne virus comes in contact with the susceptible person with an object (currency, cloths, furniture, metal surface, etc.) which was previously contaminated by the infected person (Figure 7).

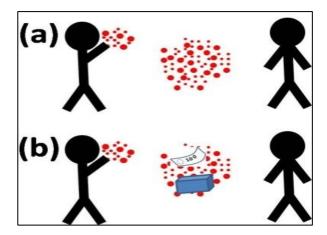


Figure 7: Schematic mode of transmission (a) with airborne, (b) with contaminated objects.

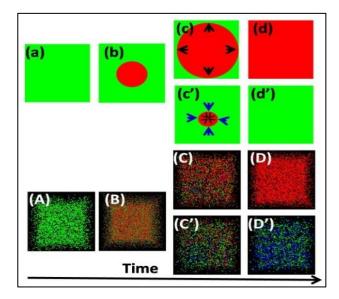


Figure 8: Schematic diagram depicting health functional; (a) Green colour represents a healthy body with a good immune system, (b) Red colour represents infection, (c) Black arrow outward in the red region represents the increase in viral strength, (c') Black arrow inwards in the red region represents the decrease in viral strength due to medication. Blue arrow inwards in the green region represents the increase in immunity strength due to medication. (d) Red colour represents death, (d') Green colour represents the full recovery, (A, B,C,C',D'D' represents the corresponding stochastic simulation data).

DISCUSSION

Though phenomenological depiction for the society, mathematical representation for the epidemic analysis owes to the macroscopic behaviour, we try to unravel the microscopic behaviour by introducing the health functional. We assume the origin of a health functional starts during the birth and it is inherited from its creator/parents. The propagation of health is valid until the death of the person (accidental and unnatural death are not considered). The schematic diagram of the health functional is depicted in Figure 8.

Let at any instant of time a person is well behaved (Figure 8 (a)). When the body is affected by the infection, it reveals the change in behavioural activity (Figure 8 (b)). With medical attention, there are two possibilities. Either the person's health condition worsen (Figure 8 (c)) (along with other several factors) and ultimately death occurs (Figure 8 (d)), or the person's health condition improves (Figure 8 (c')) and the body recovers (Figure 8 (d')).

During COVID19 pandemic, the most affected organ is the respiratory system (lungs) which causes breathlessness, when a person needs urgent medical attention. The normal function of the lungs is deteriorated by the virus and medication is provided to improve it. Our health functional is mimicked for this situation and stochastic simulation is carried at various stages as shown in Figure 5(A-D). We take three variables i.e. virus strength, immunity and medications for our calculation. Initially, an individual has a certain level of immunity and that helps to create the antibody to suppress the virus growth. Further, the immunity also increases with proper medications and the person gets cured as time progresses (Figure 8 (C',D')). If the immunity is below a certain threshold then the virus dominates and there is high risk of death. Our calculations capture the overall full scenario of the infection process. We are in the process of further development for better improvement for specific cases with detailed medication.

CONCLUSION

Our health functional captures the first hand microscopic behaviour (of individual information) due to viral infection. The goal of depletion of viral strength for the survival of the individuality is depicted with medications. The overall macroscopic behaviour shows the scale invariance, owing to the reduction of power indices irrespective of the countries. Our microscopic model can be generalized for other infectious diseases and can be improvised with various other parameters for better visibility.

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Institutional Ethics Committee

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