Original Article

A Study of COVID-19 with Limited Testing Kits

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Abstract

Introduction: In this paper, we consider a fundamental problem of testing faced by the health staff on testing COVID 19 patients. In general, the number of testing kits or testing capabilities is limited, and the number of COVID 19 patients is much larger than that. This paper tries to answer this fundamental question that how to perform COVID 19 testing to reduce the death rate. **Materials and Methods:** We consider that the survival rate of patients is dependent over two parameters: their age and severity of symptoms at a time. Based on these observations, we propose a survival rate function. Using the survival rates, the death rate for an individual is obtained. MATLAB was used for plotting the graphs. **Results:** It is shown by numerical results that by using the proposed mechanism, the average death rate can be significantly reduced. **Conclusion:** It is proposed to conduct the testing for those patients who lie in the high death rate regimen.

Keywords: COVID 19, death rate, survival rate, testing kits

Introduction

COVID-19 is a new threat to the world. It is a new disease, not previously known, spread by a virus called novel corona. A very large number of cases are noticed in many countries including USA, UK, India, and South Korea from January 2020 onward.[1] This virus is more dangerous for the class of people with low immunity, diabetic, suffering from blood pressure, old age, and medical problems, specially related to lungs.[2] Initially, the symptoms of this disease, observed in a person, are very much similar to flu such as cough, cold, and headache. Then, in later stage, infected people suffer from respiratory problem.[3] Moreover, the problem with this disease is that its symptoms are not apparent from very 1st day of infection; therefore, infected people move freely and contaminate various other subjects that come in contact with them. It is shown in the literature that the incubation period of novel coronavirus is of 14 days.[1-6] A minimum of 14 days isolation of infected person is needed to prevent the spread of this disease.[7] Preventive measures as suggested by medical authorities for COVID-19 are washing hands frequently, avoid touching the mouth, nose, and face, and by maintaining social distancing (1 m or 3 feet) with other people.[7,8]

Because of COVID-19, a major part of world is now facing a challenge. The World Health Organization declared COVID-19 as a pandemic.[2] Although extensive research is being done worldwide, no effective vaccination or treatment is available for the COVID-19 till date.[9-11] Consequently, the number of causalities is also increasing day by day.[12] There are reports that doctors and health workers are at a great risk due to community transmission or a very large number of patients in many countries.[7,13] Further, it is also reported that this disease is more dangerous for kids with less than 10 years and old people with more than 60–65 years of age.[14] Nonetheless, it is unavoidable to identify the infected cases initially to decrease the spreading rate of COVID-19 from the symptomatic or asymptomatic corona-positive patients.[15,16] Unfortunately, very limited numbers of testing kits are available as compared to population in developing countries like India for this newly emerged epidemic. Therefore, the present study was designed to propose a mathematical model to for the early diagnosis of COVID-19 by choosing the patients for COVID-19 test among the suspected patients to increase the accuracy and efficacy of the test itself.

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Materials and Methods

The present study is one of the first studies of its kind proposing a mathematical model in India.

The current study proposes a method to assign COVID-19 testing kits to the patients, based on their age and severity of symptoms, as testing kit assignment and availability of testing kits play an important role to prevent the spread and minimize the number of deaths.

It means that if two persons, one young and one old with same symptoms, come to the hospital, then testing priority should be given to the old person. However, if young person shows more severe symptoms than old person, then what should be the priority to assign testing kit? An important question in this situation is how to use testing kits effectively so that a total number of deaths can be minimized [Figure 1].

Proposed method for COVID-19 under limited testing capability

A common problem related to eradicating the spread of COVID-19 and minimizing the death toll is the testing capabilities available at a time. In this section, we will answer the question that how to decide upon a patient with COVID-19 symptoms whether to go for a test or not such that the death toll can be minimized due to the disease.

It is a well-known fact that the death rate (chance of death per person) depends upon the severity of symptoms of coronavirus disease. Further, it is also a known fact that COVID-19 disease affects different age group differently. It has been observed that the disease is fatal for old age persons (age >60 years) and for young persons (age <10 years). The possibility of survival is very high for a fully grown adult person, e.g., 35 years of age, but the possibility reduces for the persons having less than or greater than this age. Therefore, the death rate also depends upon the age of the patients. From the discussion, it can be inferred that the death rate depends upon two parameters: (i) age of the subject and (ii) severity of symptoms. Let us now first model the survival rates under the age and severity parameters.

Model of death rate for age parameter

It is apparent from the discussion that the survival rate (inverse of the death rate) for different age groups is different. The survival rate is highest in some middle-aged group but lowest in old and young age groups. Therefore, the survival rate S(k), where *k* denotes the age of a patient, can be modeled by the Poisson rate as

$$S_a(k) = \frac{s^k e^{-k/s}}{s!} \quad \text{Eq. (1)}$$

where *s* is the age hazard rate and (.)! denotes the factorial. Since the death rate (D(k)) is complementary to the survival rate, we have

$$D_a(k) = 1 - S_a(k) \quad \text{Eq. (2).}$$

Model of death rate for severity of symptoms

The severity of symptoms can be mapped to a real line and give a corresponding real number. Therefore, if severity is very high, then a very large real number represents this case. Similarly, for mild severity, a small real number denotes this severity. In general, exponential rate fits very well to the survival analysis; therefore, the rate of survival can be a negative exponential function of the severity. Hence, the survival rate as a function of severity is defined as:

$$S_s(x) = ve^{-vx} \quad \text{Eq. (3)}$$

where *v* denotes the severity hazard parameter. Let us divide the severity parameter into three groups: (i) highly severe, (ii) moderately severe, and (iii) mildly severe. The present text suggests that patients of COVID 19 can be divided into three categories according to the severity of the physical symptoms which can be easily identified by the physician. Therefore, the survival rates under these three scenarios can be easily obtained from Eq. (3) as

$$\begin{aligned} S_s(\text{High}) &= 1 - e^{-vx_1}, \\ S_s(\text{Moderate}) &= e^{-vx_1} - e^{-vx_2} \\ S_s(\text{Mild}) &= e^{-vx_2}, \end{aligned} \quad \text{Eq. (4)}$$

where *x*1 and *x*2 are the threshold values which discriminate the severity regions. From Eq. (4), the death rates for high, moderate, and mild symptoms by using the relation $D_s(\xi) = 1 - S_s(\xi)$, where $\xi \hat{I} \{\text{High, Moderate, Mild}\}$, can be given by

$$\begin{aligned} D_s(\text{High}) &= e^{-vx_1} \\ D_s(\text{Moderate}) &= 1 + e^{-vx_2} - e^{-vx_1} \\ D_s(\text{Mild}) &= 1 - e^{-vx_2} \end{aligned} \quad \text{Eq. (5)}$$

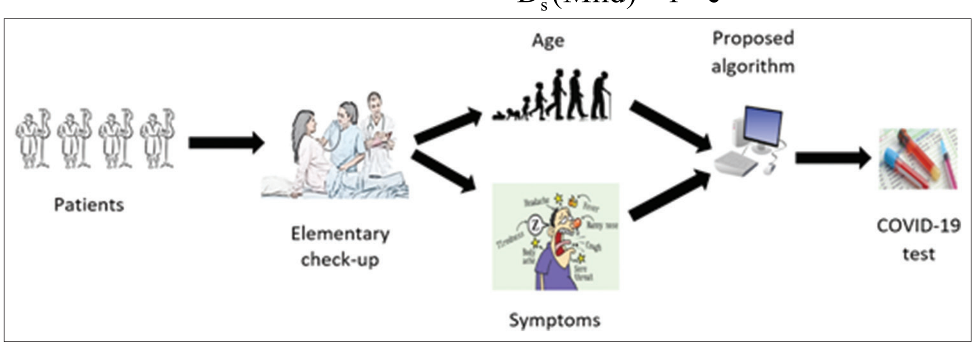

Figure 1: Proposed model to assign testing kits for COVID-19 patients

From Eq. (2) and Eq. (5), the overall death rate for a patient aged *k* years age and severity of symptom parameter, i.e., high, moderate, and mild, is given below.

$$D(k, High) = D_a(k)D_s(High) = e^{-vx_1}\frac{s^k e^{-k/s}}{s!}$$
$$D(k, Moderate) = D_a(k)D_s(Moderate)$$
$$= \left(1+e^{-vx_2} - e^{-vx_1}\right)\frac{s^k e^{-k/s}}{s!} \qquad \text{Eq. (6)}$$
$$D(k, Mild)$$
$$= D_a(k)D_s(Mild)\left(1-e^{-vx_2}\right)\frac{s^k e^{-k/s}}{s!}$$

The overall death calculated from Eq. (6) can be used to decide the eligibility of a patient for COVID-19 testing. Let there are *P* number of patients and only *K*<<<*P* kits are available, so only *K* patients can be tested for COVID-19, but remaining must wait for the next time. There are actually ${}^{P}C_{K}$ ways of choosing *K* patients out of *P*. However, most of them are suboptimal because they may increase the death toll. Therefore, we need a deliberately designed method such that the testing can be performed in such a limited environment by keeping the death rate to minimum.

In the proposed method, we calculate the death rate for each patient by using the Eq. (6). Later, we arrange these death rates in the descending order. The first *K* patients having the highest death rates will be tested for COVID-19. A pseudocode for the proposed method is given as follows:

1. Start with *P* (number of patients is *P*)
2. Check severity and age for each patient
3. Determine the severity stage, whether it is high, moderate, mild
4. Calculate death rate for the corresponding severity stage by using Eq. (5)
5. Calculate death rate for the age parameter by using Eq. (2)
6. Find the overall death rate for each patient by using Eq. (6)
7. Arrange the death rates in descending order
8. Keep the patient indexes in an array
9. Test first *K* patients in the array
10. End.

Results

In this section, we consider a group of 100 patients each one from age 1 to 100 years. The severity of the symptoms is divided into three groups: (i) highly severe, (ii) moderately severe, and (iii) mildly severe. The death rates for these three groups for unity severity hazard rate are calculated by using Eq. (5) and shown in Table 1. The death rates based on the age of patients are calculated by using Eq. (2). The overall death rate for each patient is calculated by using Eq. (6). Numerical results are plotted for *K* = 10, 20, 30, 40, 50, 60, 70, 80, and 90 testing kits. For a given number of kits, we first arrange the patients in a sequence as per their death rates, and the testing is performed only for those *K* patients who have the highest death rates in the sequence. There is also another trivial way of performing the test, which is called random testing – being usually followed everywhere. Here, a patient is randomly chosen for testing, and as the number of testing capability is less, other patients are left untested – few of them can have very high chances of death. There could be another possible way of just testing the old people and leave the young people untested. However, this method is also suboptimal as few of the young patients can have very severe symptoms. Other way could be to just test young patients, but this will also result in very high death rate like the other suboptimal approaches. There could be another way that the patients can be tested as per the severity of symptoms only. Hence, the patients with very severe symptoms will be tested before moderate or mild symptoms, and patients with moderate symptoms will be tested before those with mild symptoms. However, this approach will also result in high death rate as few patients with less severe symptoms may lie in high death rate regimen due to their age group.

A comparison of all these approaches is presented in Figure 2, where death rates versus number of testing kits plots are shown. It can be seen from Figure 2 that with increasing number of testing capabilities, the death rate keeps on reducing toward zero value. Further, it can be seen from the figure that the testing kits' allocation according to the proposed method offers a significant reduction in the death rate as compared to all other heuristic and random testing methods. For example, for *K* = 10, 20, and 30, it offers death rates of 0.56, 0.46, and 0.36 as compared to the random testing which provides death rates of 0.6, 0.54, and 0.49, respectively. Moreover, any method based on biased allocation (biased toward age or severity of symptoms) of testing capabilities provides higher death rates than the proposed method. Further, it can be seen

Table 1: Death rates for different severities of symptoms

Severity	High	Moderate	Mild
Death rate	1	0.9933	0.0067

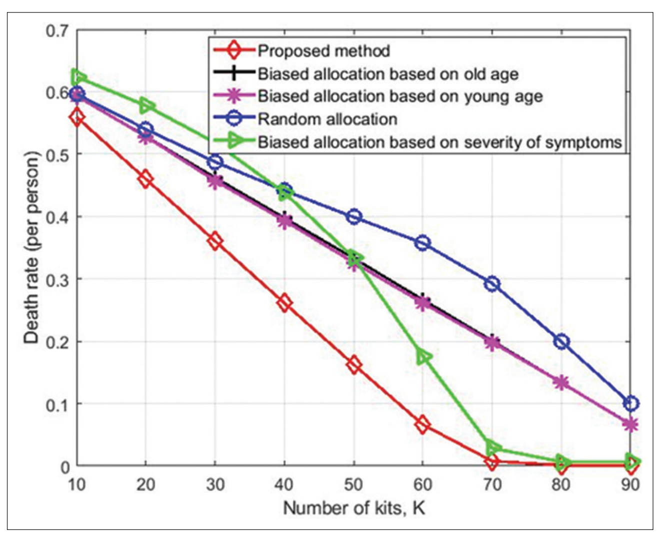

Figure 2: Death rate plots for different methods

from Figure 3 that the proposed method is able to reduce the death rate to almost close to zero with $K = 70$ kits, whereas other methods require more than 70 kits to achieve close to zero error rate. Furthermore, an interesting observation from the figure is that if testing is performed merely based on the severity of the symptom which is a usual customary in medical practice, then the death toll is even higher than the random testing, when the testing capabilities are significantly limited to 10%–40%. However, this method starts outperforming the other random and heuristic and random methods with enough testing capabilities, i.e., $K \geq 50$. Further, for abundant testing capabilities, i.e., $K \geq 80$, the symptom severity-based testing performs almost similar to the proposed testing method. Moreover, the following remarks can be deduced from the figure:

- For the scenario when limited testing capabilities are available, it is not recommended to use symptom-based testing as it may increase the death toll significantly. It is advisable to employ the proposed method to reduce the death toll for the limited testing capability scenario
- Random testing or age-based testing is mostly very much suboptimal and leads to high death toll with all testing capability situations
- The mortality rate keeps on reducing with increasing testing capabilities. It can be reduced to zero with abundant testing as seen from the figure. Specially, when the symptom-based testing or the proposed method is employed. This observation justifies the fact of reduction in deaths with increasing testing in countries like South Korea.

In Figure 3, we have plotted the curves between the total number of COVID-19 cases versus days (till March 29, 2020) in South Korea based on the actual data[4] and a recently proposed model.[5] Further, a plot with decreasing number of infection rate (r),[5] i.e., with decreasing number of hidden nodes, is also shown. It can be seen from the figure that the analytical plot approaches the actual plot from 1st day to 20th day with $r = 4.7$ and with $t = 1$. Then, because of increased testing, the infection rate decreases from $r = 4.7$ to $r = 0.5$; it can be noticed from the figure that the rate of increase of total cases decreases or it can be concluded that because of increasing testing, the disease can be controlled. Further, a plot with infection rate $r = -11$ is also shown in the figure with $t = 1$. It can be concluded from the figure that with decreasing number of infection rate (which is a consequence of increased testing capability), the total cases will be approaching toward zero. Therefore, it can be deduced from Figures 2 and 3 that increasing testing not only reduces the death rate but also spreads the disease in a society.

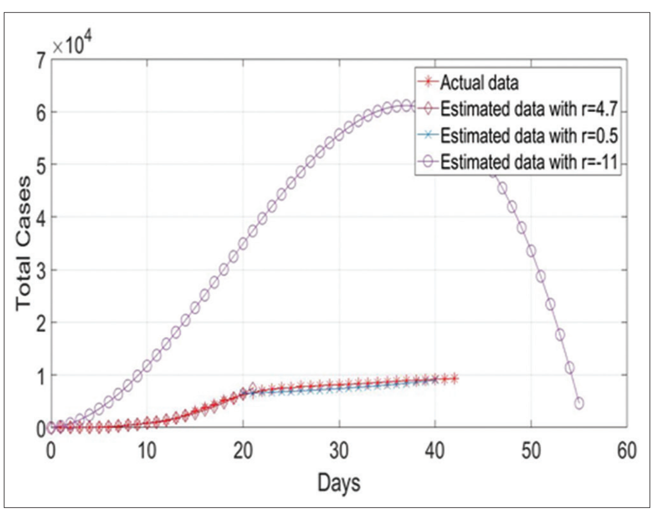

Figure 3: The actual and estimated spread of COVID-19 in South Korea[3]

Discussion

Results of the current study showed that the mortality rate of COVID-19 patients can be decreased by following the mathematical model of sampling proposed in this study. Assigning patients according to the age, severity of symptoms, and random method is less effective in reducing causality rate in comparison of mathematical model proposed by us. Findings of the current study is in agreement with the observations of previous studies of Dawson *et al*.[16] as they recorded that mathematical modeling has been found efficient in preventing the spread of infectious diseases.

Different mathematical models have successfully proved their relevance in preventing spread of various communicable diseases in diverse countries at dissimilar time and circumstances.[17]

It is shown by numerical results that if we use priority-based assignment of testing kits, then the death toll can be notably minimized. On the other hand, if testing kits are available in abundant numbers, then symptom-based assignment and priority-based assignment will show almost the same results. Further, it is also shown in a study that if the number of testing kits is appropriate, then hidden active nodes explained in the previous study[5] can also be deceased so that the spread of disease can be controlled.

Testing kits are not available in abundant throughout the world for this newly emerged pandemic. There are some studies that in Italy, the medical staff had to give more priority to the young subjects over the old persons, due to limited testing capabilities and limited availability of ventilators.[18,19]

Most of the countries of the world are currently struggling with the limitation of testing kits available for testing doubtful COVID-19 patients. A common practice adopted by the medical practitioners is to test the patients with severe symptoms related to COVID-19 disease. However, if the number of patients is very large than the number of testing kits, then medical staff may also decide to do random testing in such a scenario – under an impression that this random method can be more efficient that the symptom-based testing.

Further, the results of our study revealed that the present mathematical model was equally successful in decreasing the death from COVID-19 as it was recorded in original data of the South Korea, one of the countries relying upon the rapid testing for the prevention and control of the COVID-19.[4,5]

Mathematical modeling proposed in the present study may be helpful to decrease the rate of mortality and spread of COVID-19 in developing country like India with limited test kits; it has been suggested that a better understanding of mathematical modeling by clinicians may help in exact implication of results produced by mathematical model, which might help in decreasing the lethal effects and prompt management of the diseases.[20]

Conclusion

A simple method for improving the death rate of COVID-19 patients using limited testing capabilities has been discussed. Since the death rate of COVID-19 depends upon the age of the patients and severity of the symptoms as well, a new death rate function has been defined which depends upon both these parameters. It has been proposed to test the COVID-19 patients based on their death rates, which means that out of all patients showing the symptoms of corona disease only those patients with the highest death rates must be tested. The proposed method has shown to considerably improve the mortality rate due to COVID-19 disease as compared to the existing random testing and severity of symptoms-based testing methods, prevalent currently. It has been observed that if testing capabilities are extremely limited, then the proposed method is very useful all other existing methods increase the death toll significantly. However, if the testing capabilities are abundant, then symptom-based testing also keeps the death toll at low levels. Moreover, it has been revealed by the proposed study that how the country like South Korea is able to reduce the death toll by using an extensive COVID-19 testing over its population.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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