Original Article

Simulation of COVID-19 disease epidemic in Iran based on SIR model

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Abstract

Background & Aims: The spread of the COVID-19 virus is currently considered the most important global health challenge. Therefore, it is very important to study and simulate the patterns of spread of this disease based on mathematical models. This study aimed to simulate the COVID-19 epidemic based on the SIR model, in Iran.

Materials & Methods: In this study, the COVID-19 epidemic was simulated based on the susceptible-infected-recovered (SIR) mathematical model. According to the parameters of this model, different scenarios for this disease were examined. Finally, the simulation of the COVID-19 epidemic based on the values of these parameters was presented for Iran.

Results: According to the results of this study, with increasing the level of social restrictions and health measures, the reproductive rate of COVID-19 decreased, and also with access to effective medicines and vaccines, the recovery rate of this disease increased, and fewer people became infected. Moreover, results showed that with the continuation of social restrictions and attention to health issues by the people in Iran, the peak of COVID-19 is seen within 50 days from the beginning of the epidemic also about 5% of the population is affected by this disease. The end of the initial wave of the disease was predicted at least 100 days after the onset of the epidemic.

Conclusion: A simulation study to evaluate the prevalence of COVID-19 will provide comprehensive and complete information about the role of health care measures and social restrictions to prevent the spread of this disease to health researchers.

Keywords: COVID-19, Simulation, Mathematical modeling, SIR model, Epidemic, Prediction

Introduction

Coronavirus includes a large family of viruses that are commonly found in both humans and animals. This family consists of 7 different species (1). Sometimes types of coronavirus can infect humans through animals and spread through human-to-human transmissions, such as the virus that causes Coronavirus disease-2019 (COVID-19) (2). As of December 2019, this new coronavirus has been identified as the cause of upper and lower respiratory tract infections. The virus spread rapidly, leading to an epidemic in China and eventually in other countries around the world, and led to a pandemic (3). People have been infected with the virus in almost every part of the world except Antarctica (2).

The spread of COVID-19 is currently the most important global health challenge which has caused economic, social, cultural, and even political damage (3). Although the virus is less deadly than other emerging viruses of the Corona family, such as SARS and MERS, it has spread rapidly and exhibited special pathogenic behaviors that have made it very difficult to control (4-6). The pandemic caused by the spread of this virus has caused each country to adopt policies by their conditions. China, as the first country to face it, was very strict to control the virus quickly and tried to control the leaps of growth of the disease with severe travel restrictions in Wuhan and other infected areas (5, 7). Although this policy was somewhat successful, it did not prevent COVID-19 from spreading to other parts of China and the world, especially since the virus had spread to the vast network of global communications before these restrictions were imposed (2, 5).

There are a lot of unknowns about this virus and many aspects of this disease have not been identified yet (6). Therefore, one of the ways to know how this disease spreads in a country and also in the world is to use simulation (8-9). Simulation is a method that uses mathematical models to study the behavior of disease under different conditions. Numerous models are considered to simulate the pattern of infectious diseases such as COVID-19 (10). The susceptible-infected-recovered (SIR) mathematical model is one of the common models for simulating infectious diseases such as measles and mumps, and many other types of models are derived from this basic model (8, 11). In this model, people in the community are divided into three categories: people at risk (susceptible), infected or suffering people, and recovered people. The model also assumes that everyone in the community is susceptible to the disease or capable of being infected. Any infected person can infect susceptible people, and after a susceptible person becomes infected, this person falls into the category of infected people. Any infected person will be shifted to the recovered group if they recover (Figure 1). This model contains three basic components that are stated below:

- **S**: Number of people at risk (susceptible)
- **I**: Number of people affected (infected)
- **R**: Number of people improved (recovered)

According to this model, if we consider N as the whole population, S as the population that can get sick, I as the sick population, and R as the improved or dead population, the following simple formula for this model is:

N=S+I+R

The SIR model is well suited for predicting infectious diseases that are transmitted from human to human and whose recovering individuals are resistant to re-infection.

Fig 1. Schematic of the SIR model for infectious diseases such as COVID-19

The SIR model consists of two basic parameters of r and γ that need to be determined according to the type of disease and the different scenarios that the researcher considers for the disease. Parameter "r" indicates the speed at which a disease is capable of spreading (reproductive rate) and is related to the pathogenicity of the infectious agent. This parameter is strongly influenced by health and prevention measures, in other words, it is related to the incidence rate. Another parameter, γ, determines the speed of treatment and recovery, which is influenced by therapeutic and vaccination measures and is related to the rate of disease recovery. In the epidemic of a disease, the reproduction rate (r) and the recovery rate (γ) are important determining factors. Each disease has its reproductive rate, which is a large number about 2.5 in COVID-19 (12). The values of the reproductive rate parameter can be controlled by applying government lockdowns, social restrictions, and quarantine. If α is considered as the extent of social and health restrictions for disease control, the reproductive rate can be controlled as r (1-α). In this regard, $\alpha = 1$ means the application of 100% restrictions in society, and $\alpha = 0$ means that no health measures are taken and no social restrictions are imposed on disease control.

Using differential equations, the changes or dynamics of the number of people can be expressed in each group over time mathematically and using simulations, it will be possible to assess the disease status. The differential equations of variation in the number of people at risk, the number of people affected, and the number of people recovering from the disease per unit of time are as follows:

$$\frac{dS}{dt} = -r(1-\alpha)\frac{SI}{N}$$
$$\frac{dI}{dt} = r(1-\alpha)\frac{SI}{N} - I\gamma$$
$$\frac{dR}{dt} = I\gamma$$

These three equations represent the differential equations of the number of people at risk, the number of people affected and the number of people improved,

respectively, and examine how a person in the population can shift between the different categories over time as shown in Figure 1. The SIR model can study the epidemic of COVID-19, the impact of health and preventive measures such as quarantining, social distancing, restriction of unnecessary urban and interurban traveling, and mask-wearing, as well as the impact of treatment and clinical measures such as effective medicines and vaccines. It allows researchers to gain insight into how the disease spreads by considering different scenarios. Hence, this study aimed to simulate the COVID-19 epidemic based on the SIR model, in Iran.

Materials & Methods

In this study, COVID-19 epidemic simulations were performed based on the SIR mathematical model. According to the parameters of the SIR model, different scenarios for COVID-19 were examined. To estimate the parameters of the model, the information was collected by daily statistics and information from the Iran Ministry of Health and Medical Education, and also from patients with COVID-19 who were referred to Dr. Masih Daneshvari Hospital in Tehran from early March 2020 to late April 2020. This hospital is a university-affiliated and selected referral center for COVID-19 patients in Tehran, Iran. In this study, two different scenarios were considered to simulate COVID-19. In the first scenario, the role of health measures and social restrictions in the spread of the COVID-19 epidemic was investigated. In the second scenario, the role of therapeutic and clinical measures on the spread and prevalence of this disease was examined. Finally, the COVID-19 epidemic simulation was determined for Iran based on the values of these parameters. It should be noted that in this study, the population of Iran was considered to be about 82 million people and COVID-19 was simulated using MATLAB mathematical software.

Results

Based on two different scenarios, the prevalence of the COVID-19 epidemic was simulated according to the

role of health measures by the people and social restrictions by the government, as well as the role of treatment and clinical measures at the time of the disease epidemic.

In the first scenario, the role of health measures and social restrictions was investigated in the prevalence of the COVID-19 epidemic. In this scenario, assuming that the recovery rate (γ) was constantly equal to 0.25 and the level of social restrictions was applied at about 75, 50, and 25 percent, the reproduction rate (r) would be considered 0.625, 1.25, and 1.875, respectively (Figure 2). According to the results of this simulation, with the application of 75% of social restrictions, the reproduction rate of COVID-19 would be 0.625, and

also about 80 days after the start of the epidemic, the disease would reach its peak and 20% of the population would become infected (Figure 2A). By reducing the level of social restrictions to 50%, the reproduction rate of this infection would reach 1.25, in which case the disease would reach its peak within 30 to 35 days from the beginning of the epidemic, and about 40 to 50% of people in the community would be affected (Figure 2B). With the reduction again of the level of social restrictions, the reproduction rate of COVID-19 would be increased to 1.875, and the peak of the epidemic would be after 20 to 25 days from the onset of the epidemic, and near 60% of the population would be infected (Figure 2C).
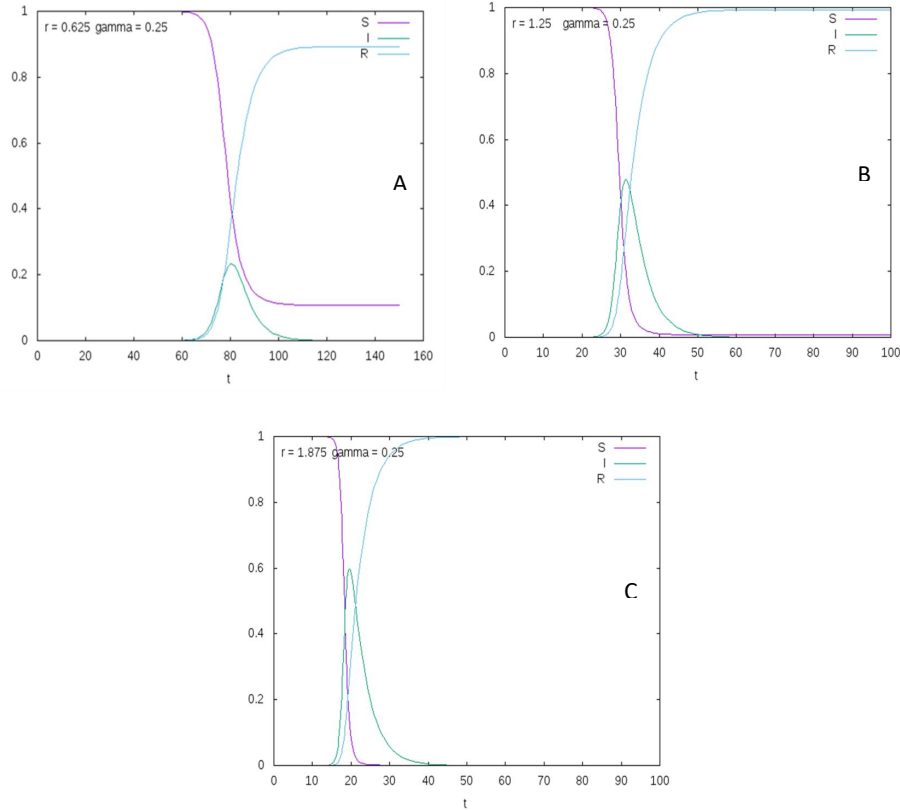

Fig 2. Simulation of the impact of health measures and social constraints on the COVID-19 epidemic by considering different rates of reproductive and assuming a constant recovery rate

In the second scenario, assuming that the level of social restrictions was constantly equal to 50%, and the

reproduction rate (r) of the disease was considered 1.25, the role of the therapeutic and clinical measures was

assessed in the epidemic of COVID-19 by changing the recovery rate parameter (γ) to 0.25, 0.50, and 0.75, respectively (Figure 3). Based on the results of this simulation, by considering the recovery rate parameter (γ) equal to 0.25, the peak of COVID-19 disease would be about 30 to 35 days from the onset of the disease, and at this time about 40 to 50% of the population would become infected (Figure 3A). With increasing the

recovery rate parameter to 0.50, the peak of the disease would be appeared 40 days after the onset of the epidemic, in which case about 20% of the population would be affected (Figure 3B). By increasing the rate of recovery to 0.75, the peak of the disease epidemic would be 60 days from the onset of the disease and less than 10% of the population will be infected with the disease (Figure 3C).
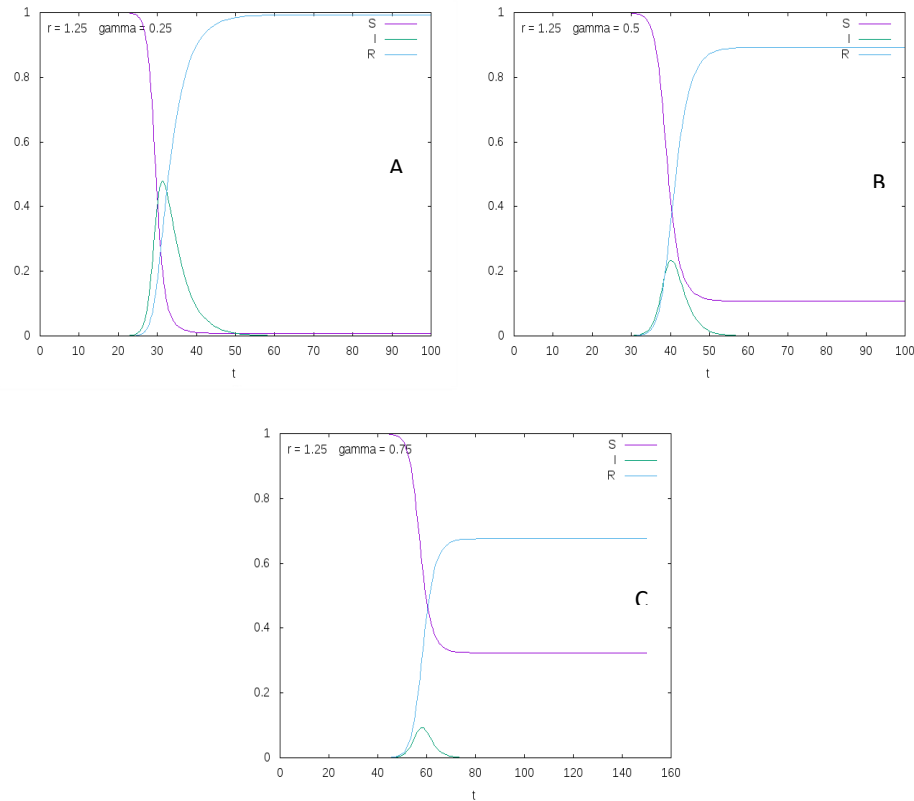

Fig 3. Simulation of the effect of therapeutic and clinical measures in the epidemic of COVID-19 by considering the constant rate of reproduction and different rates of recovery

Based on these results, by applying social restrictions as well as appropriate therapeutic measures such as the discovery of vaccines and effective medicines for this disease, fundamental changes will be observed in the epidemiology of this disease in society. Although no effective medicine or vaccine has been discovered for this disease so far, the recovery rate of

COVID-19 patients is high and according to official statistics, about 70% of patients with COVID-19 have improved in Iran. Therefore, to simulate the COVID-19 epidemic in Iran, the parameter of recovery rate (γ) was equal to 0.70, and assuming the application of 60% of social restrictions in Iran, the reproduction rate (r) was considered to be about one (Figure 4).
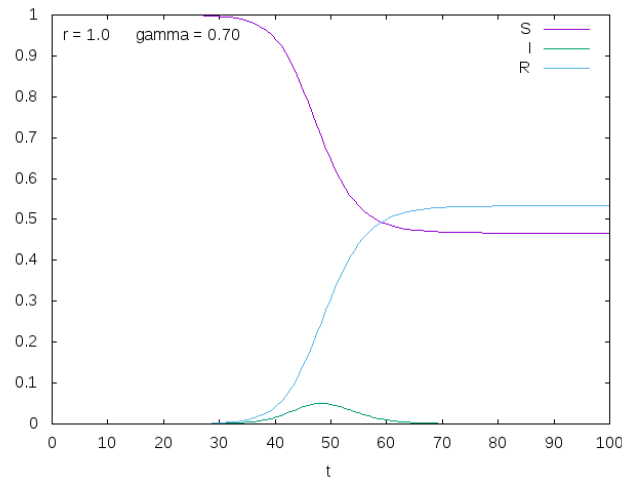
Fig 4. Simulation of COVID-19 epidemic for Iran

According to the results of this simulation, by applying 60% of social restrictions in Iran, the number of cases of COVID-19 would increase in about 35 days from the onset of the epidemic and the peak of the COVID-19 epidemic would occur within 50 days from the onset of the epidemic. At this point, about 5% of people in the community would infect. The simulation also predicted that about 65 days after the onset of the epidemic, there would be a significant reduction in the number of cases (Figure 4). But this was not the end of the initial outbreak of the COVID-19 epidemic in Iran, because it would take at least about 100 days from the onset of the outbreak to zero.

Discussion

The high prevalence and mortality rate of COVID-19 in different countries has caused a significant challenge worldwide (2). Although the prevalence of this disease was thought to be less than 5%, with the spread of this disease in other countries of the world, the mortality rate has reached more than 10% (5-6, 13 -14). Different countries are trying to control the prevalence of the COVID-19 epidemic by taking health measures and imposing widespread social restrictions, and are also attempting to find therapeutic methods, medicines, and effective vaccines to treat COVID-19 (12, 15-17).

Given that many aspects of COVID-19 are still unknown, the best way to understand the role of health measures and social restrictions, as well as the impact of treatment and health measures on the outbreak of COVID-19, is to simulate mathematical models. (8-9, 18).

The SIR model is one of the most common models for simulating infectious diseases and can make predictions for infectious diseases that are transmitted from human to human (11, 19-22). So far, many simulations have been performed based on mathematical models for Covid-19, including the SIR model, in different countries (8, 10, 18, 23). In this study, the simulation of the COVID-19 epidemic was investigated based on the SIR model for Iran. In this way; two different scenarios, the role of health measures and social restrictions as well as the role of treatment and clinical measures on the prevalence of the COVID-19 epidemic was examined.

In the first scenario, the role of health measures and social restrictions was investigated in the prevalence of COVID-19 by considering the constant rate of the recovery parameter (γ) of the disease (Figure 2). According to the results of this study, with the increase of social restrictions and health measures by people in the community, the reproduction rate (r) of COVID-19

decreases, and this causes that a long time from the beginning of the epidemic, the disease reaches its peak and a lower percentage of people in the community be infected (Figure 2A). With the reduction of social restrictions and lack of attention to health measures by people in the community, the disease will reach its peak in a short time from the beginning of the epidemic and a high percentage of people in the community will be affected (Figure 2B, C). Therefore, paying attention to health measures by people in the community such as wearing masks and gloves, regular handwashing, observing social distance, and imposing social restrictions such as closing educational, cultural, and religious centers, reducing urban and intercity traffic can reduce the reproduction rate of the COVID-19 and affect a smaller percentage of the population at the highest peak of the epidemic.

In the second scenario, the effect of therapeutic and clinical measures in controlling the epidemic of COVID-19 was investigated by considering the constant rate of the reproductive parameter (r) (Figure 3). According to the results of this scenario, with the increased recovery rate of this disease, it takes a longer time for the onset of the disease to reach its peak and will also affect a very small percentage of people in the community (Figure 3C). Conversely, by slowing the recovery rate of COVID-19, the disease will reach its peak in a shorter period and a higher percentage of people in the community will be infected with the disease (Charts 3A, B). Therefore, increasing the rate of recovery of COVID-19 is strongly related to the discovery of vaccines, medicines, and effective therapeutic methods for this disease. For this reason, since the beginning of the epidemic, researchers have used a wide range of medicines and therapies to treat COVID-19 (15, 24-26).

In scientific studies, researchers have concluded that anti-HIV drugs are useful in treating and preventing the progression of COVID-19 and that many patients have survived through the use of these medicines, and overall evidence has shown that antiviral drugs have been able to save the lives of many people with COVID-19 (15, 26). Currently, another method to save people with

Covid-19 is to use the blood plasma of those who have been cured of the disease (27). In this method, by transferring the plasma of patients who have recovered from Covid-19 to patients who are still in critical condition, they can use the protective shield produced by the recovered patients' immune system against COVID-19 to help the current patients recover (24-25). Despite the therapies and medicines that have been used to treat patients with COVID-19 so far, as well as the high rate of improved patients, high values can be expected for the recovery rate of this disease.

Although the medicines and treatment methods available for COVID-19 are still in the experimental phase and their effectiveness has not been recognized in most cases by the World Health Organization (WHO), these methods have been able to save the lives of many patients with COVID-19 (15, 24, 26-27). Therefore, in this study, for the simulation of COVID-19 in Iran; the parameter of the recovery rate of this disease was considered 0.70. Due to the implementation of social restrictions and health measures from the beginning of the COVID-19 epidemic in Iran, the simulation was performed by considering the value of one for the rate of reproductive of the disease (Figure 4). In the COVID-19 simulation, the disease would reach its peak about 50 days after the onset of the disease epidemic, and nearly 5% of the population would be infected (Figure 4). Given that COVID-19 is mild in 80% of patients (15-16), many patients will not notice the disease and will not go to medical centers (12), the official incidence of patients with COVID-19- 19 much less than this estimate will be recorded. About 65 days from the beginning of the epidemic, gradually a significant decrease would observe in the number of patients, but this time is not the end of the initial outbreak of COVID-19 in Iran, at least it takes 100 days from the onset of the outbreak to the zero.

Of course, this figure is strongly influenced by the attention of people in the community to health measures, the continuation of social restrictions, and also the discovery of vaccines or effective medicines in the treatment of COVID-19 (28-29). It should be noted that this simulation will be for the first wave of COVID-19,

and issues such as the genetic mutation of the virus, the early reduction of social restrictions, and the lack of attention of community members to health measures and social distance can lead to the second wave of COVID-19 epidemic or cause a re-emergence of the disease and even prolong the end of the COVID-19 epidemic much longer than predicted in this study.

Conclusion

Finally, it should be noted that the study and simulation of COVID-19 using mathematical models such as the SIR model reveals how the disease behaves and spreads in different conditions. Therefore, considering different scenarios can be emphasized the role of health care to prevent the spread of this disease and more effective decisions can be made to control and treat COVID-19.

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Conflict of interest

The authors have no conflict of interest in this study.

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