Investigating the effect of health measures and social restrictions on the COVID-19 epidemic based on the SIQR mathematical model

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Abstract

Background & Aims: COVID-19 pandemic is a serious concern of the World Health Organization and is considered the most important global health challenge. This study aimed to study the effect of health measures and social restrictions on the COVID-19 epidemic based on the susceptible-infectious-quarantine-recovered (SIQR) mathematical model.

Materials & Methods: Using the SIQR model, we assessed the effect of health measures and social restrictions on the COVID-19 epidemic by considering different values for the reproductive rate parameter and constant values for the recovery rate and quarantined rate (or disease detection rate).

Results: The results indicated that with increasing the level of social restrictions and health measures equivalent to 20, 40, 60, and 80%, the reproductive rate of the COVID-19 reduced from 2.5 to 2, 1.5, 1, and 0.5, respectively. Also, with increasing the levels of social restrictions and health measures, a smaller percentage of people in the community became infected. Considering the level of social restrictions equal to 20, 40, 60, and 80% during the COVID-19 epidemic, about 60, 50, 35, and 10% of the individuals were infected with COVID-19, respectively.

Original Article

Conclusion: The study of the impact of health measures and social restrictions on the COVID-19 epidemic will provide appropriate information on how the disease spreads and also help researchers select the proper level of these measures and restrictions to prevent further spread of COVID-19 disease.

Introduction

COVID-19 has been spreading from Wuhan, China, since December 2019 and is growing rapidly, leading to an epidemic in China and eventually a pandemic in other parts of the world (1, 2). To date, more than 10 million people worldwide have been diagnosed with COVID-19, and this trend is increasing (3). The spread of the COVID-19 virus is currently the most important global health challenge. Coronavirus includes a large family of viruses, consisting of seven different species, which are commonly found in both humans and animals (4). Some types of coronavirus, such as the virus causes COVID-19, can infect humans through animals and spread through human-to-human transmissions (5). Although this virus is less dangerous in terms of mortality than other emerging viruses of the corona family such as SARS and MERS, it has shown rapid spread and special pathogenic behaviors that make its control very difficult (6-8). The most common and severe manifestation of COVID-19 infection is pneumonia. Patients who suffer from COVID-19 often develop symptoms, on average, five days after the onset of the disease (9, 10). About 85% of these patients experience mild to moderate and approximately 15% have severe symptoms (10, 11). While some medications and treatments have been proposed for COVID-19, they are still in the experimental phase. Moreover, the efficacy of drugs for the treatment of patients with COVID-19 is

unknown (12-15). Given the importance of COVID-19 from various aspects of personal and social health, the World Health Organization has recommended attention to health measures at the individual and community level and application of social restrictions by governments as the only appropriate strategy for COVID-19 epidemic control (5, 10). However, the effectiveness of these health measures and social restrictions in controlling the COVID-19 epidemic is unclear.

So far, no comprehensive study has been conducted to determine what level of health measures and social restrictions are needed to control, and how these measures will affect this epidemic. Simulation is an approach helps understand how the disease spreads and also study the impact of health measures and social restrictions on its control (8). In fact, simulation is a method that uses mathematical models to study the behavior of disease under different conditions (16). There are several mathematical models to simulate the COVID-19 epidemic pattern (17, 18). However, as the susceptible-infectious-quarantine-recovered (SIQR) model divides patients in the community into quarantined patients (Q) and unidentified patients (I), it is able to create a better understanding of this epidemic and also show more compatibility with the reality of the disease in the community (19). The SIQR model is one of the most common models for studying and simulating the epidemic of infectious diseases. In this

model, people in the community are divided into four categories: people at risk (S), unidentified patients (I), quarantined patients (Q), and people who have recovered or died from the disease (R) (19). The model also assumes that everyone in the community is susceptible to and can suffer from the disease. Any infected person can infect the susceptible people, and after the susceptible person becomes infected, this person places into two categories of unidentified patients or quarantined patients. Any infected person (whether unidentified or quarantined) will be transferred to the recovered (R) group if they recover or die. This model contains four basic components, as follows:

• S: Number of susceptible people

• I: Number of infected and unidentified patients

• Q: Number of infected and quarantined patients

• R: Number of people who have recovered or died from the disease

Therefore, if we consider "N" the total population, "S" the population at risk, "I" the unidentified patients, "Q" the quarantined patients, and "R" the population who were recovered or dead, the simple formula for this model is as follows:

$$N = S + I + Q + R$$

The SIQR model is suitable for predicting infectious diseases transmitted from human to human, as well as recovering patients who are resistant to re-infection.
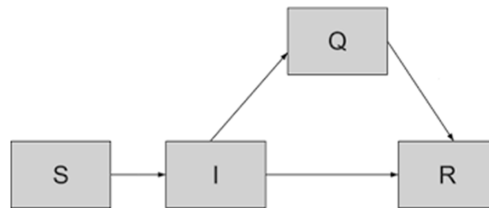

Fig. 1. Schematic of the SIQR mathematical model for COVID-19.

The SIQR model consists of three basic parameters, r, γ, and β, which need to be determined according to the type of disease and the different scenarios that the researcher considers for the disease. The parameter r is the reproductive rate of the disease and is related to the pathogenicity of the infectious agent. This parameter is strongly influenced by health measures and social restrictions; in other words, it is related to the incidence rate. The parameter γ determines the recovery rate of the disease and is influenced by treatment measures and vaccines. The parameter β determines the quarantine rate or disease detection rate, which is affected by the ability of the health care system to identify patients. The disease prevalence, reproduction rate, recovery rate, and disease detection rate or quarantine is important determining factors. Each disease has its own reproductive rate, which, apparently, this parameter in COVID-19 is a large number of about 2.2 to 2.5 (10). The values of this

parameter can be controlled by applying social restrictions and quarantine. If α is considered the extent of social and health restrictions for disease control, the reproductive rate can be controlled as r (1- α). In this regard, $\alpha = 1$ denotes the application of 100% restrictions in society, and $\alpha = 0$ means no health measures are taken, and no social restrictions are imposed on disease control.

Due to the fact that there is no specific treatment and vaccine are available for COVID-19, the parameter of the recovery rate (γ) was considered constant, and based on the ability of the health system of countries was assumed about 0.5 to 0.7 (20, 21). The parameter of quarantine or disease detection rate (β) is more related to the medical system. Since the actual number of patients in the community is 10 to 20 times higher than the official statistics, this parameter was considered constant and about 0.1 to 0.2 (16, 21). Therefore, in the study of the COVID-19 epidemic,

reproductive rate (r) is the only parameter that changes under the influence of health measures and social restrictions. The changes or dynamics of the number of people in each group can be expressed over time using differential equations mathematically, and the status of the disease can be assessed using simulations. This study aimed to investigate the impact of health measures by the people and social restrictions by the government on the COVID-19 epidemic, based on the SIQR model.

Materials & Methods

In this study, the effect of health measures and social restrictions on the COVID-19 epidemic was investigated based on the SIQR mathematical model. The present study hypothesized that the recovery and quarantine rates (or the detection rate) was constant because the values of these two parameters depended on the ability of the health care system to treat COVID-19 and identify patients (especially asymptomatic patients, and patients with mild to moderate symptoms), as well as vaccine discovery. Given that the reproductive rate is the only parameter in the SIQR model that was dependent on the health measures and social restrictions, the role of health measures and social constraints on the COVID-19 epidemic was investigated based on changes of this parameter.

To estimate the parameters of SIQR model, we used the information of COVID-19 patients who referred to Dr. Masih Daneshvari Hospital in Tehran (Iran) during the epidemic of the disease, statistics and daily information on COVID-19 epidemic reported by the Iran's Ministry of Health and Medical Education, and the results of other studies related to COVID-19. It should be noted that the population considered in this study was about 100 million people. MATLAB software was used to study the effect of health measures and social restrictions on the COVID-19 epidemic.

Results

Given that the reproduction rate (r) is the only parameter depending on health measures and social restrictions in the SIQR model, the parameters recovery rate (γ) and quarantine or disease detection rate (β) were considered constant and equal to 0.7 and 0. 2, respectively.

Based on the level of health measures and also social restrictions equivalent to 80, 60, 40, and 20%, the reproductive rate parameter reduced from 2.5 to 0.5, 1, 1.5, and 2, respectively (Figure 1). The results of the SIQR model indicated a level of 20% for both health measures and social restrictions and the rate of 2 for COVID-19 reproduction. According to the results of this simulation, the disease reached its peak 20 days from the start of the epidemic, and nearly 60% of the population (60 million people) was affected by this disease (Figure 2). Also, the number of identified (or quarantined) patients was very different from the number of real patients in the community. As the results of this study showed, all people in the community were exposed to this disease until the end of the initial phase of the COVID-19 epidemic.

With the increased level of health measures and social restrictions to 40%, the rate of reproduction of COVID-19 reached 1.5. In this case, it reached its peak in about 25 days from the beginning of the epidemic, and about 50% of the population (50 million people) was affected (Figure 2). At this level of health measures and social restrictions, the number of identified (or quarantined) patients was still very different from the number of real patients in the community, and by the end of the initial phase of the COVID-19 epidemic, all the members of the community were exposed to this disease.

With an increase in the level of health measures and social restrictions to 60%, the rate of reproduction of COVID-19 decreased to 1, which in this case, it reached the peak after 40-45 days from the beginning of the epidemic, and about 35% of the community (35 million people) was affected (Figure 2). At this level of health measures and social restrictions, the number of identified (or quarantined) patients was closer to the number of real patients in the community, and by the end of the initial phase of the COVID-19 epidemic, about 95% of the population was at risk. In other

words, according to the results of the SIQR model, about 5% of the population was not affected by the disease.

According to the increased level of health measures and social restrictions to 80%, the rate of reproduction of COVID-19 reached 0.5. However, after 120 to 125 days from the beginning of the epidemic, the peak of the disease epidemic was about 10% of the population

(10 million people) (Figure 2). At this level of health measures and social restrictions, the number of identified (or quarantined) patients was very close to the number of real patients in the community, and by the end of the initial phase of the COVID-19 epidemic, about 75% of the population was exposed to the diseases. In other words, about 35% of the population was affected by COVID-19.
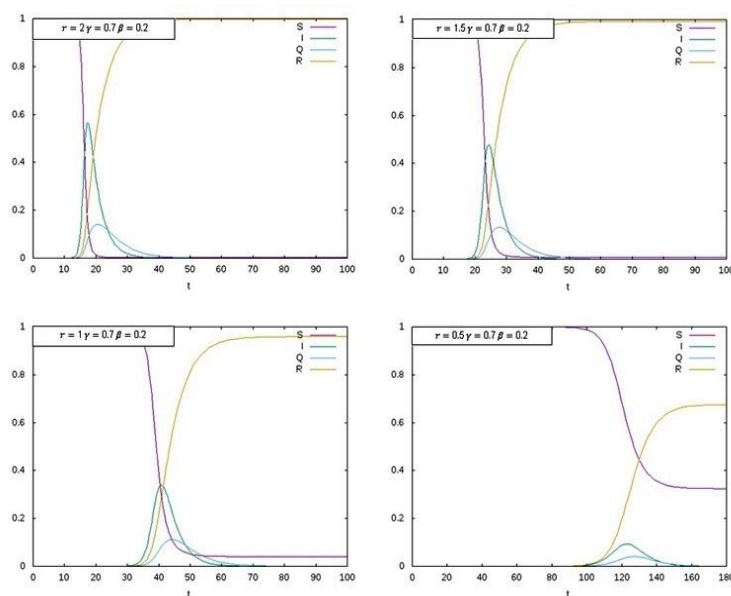

Fig. 2. Effect of the health measures and social restrictions on the COVID-19 epidemic based on the SIQR model by considering the reproductive rate (r), constant values for the recovery rate (γ), and quarantine or disease detection rate (β).

Discussion

The outbreak of COVID-19 in China and the spread of the disease worldwide have posed a significant international challenge (5). The United States has suffered the most in this epidemic, with a quarter of all cases and a third of the mortality rate in the world (22). Russia, Brazil, and the United Kingdom are also the second to fourth countries affected by the COVID-19 epidemic (3, 23), and Spain, Italy, and Germany fifth to eighth, respectively (3, 22). Countries are trying to control the prevalence of the COVID-19 epidemic by observing health measures and imposing widespread social restrictions, as well as by different studies on

medicines, treatment, and vaccines against the disease, to achieve effective methods for the treatment and prevention of COVID-19 (9-10, 12, 24).

So far, a specific treatment and medication have not been provided for this disease, and the only way to control this epidemic is to pay attention to health measures and social restrictions (5, 10, 14, 25). What level of health measures and social restrictions are needed to control the COVID-19 epidemic is a matter of the economic and social structure of each country. However, the positive role of health measures and social restrictions in controlling the COVID-19 epidemic needs to be emphasized (25, 26). Given that

many aspects of COVID-19 (both the source of the disease and its treatment) are still unknown, simulation based on the mathematical models is the best way to understand the role of health measures and social restrictions on the outbreak of COVID-19 (17, 19-21). In this study, based on the SIQR mathematical model, the effect of different levels of health measures and social restrictions on the prevalence of the COVID-19 was investigated. Based on the results of this study, two points are very important. The first point is that with increasing the level of health measures and social restrictions, the rate of COVID-19 decreases. In this condition, fewer people in the community will be infected during the epidemic, and the number of identified (or quarantined) patients will be closer to the actual number of patients in the community. Also, as the epidemic time lengthens, and the number of infected patients decreases, there will be a good opportunity for researchers to find the time and money needed for clinical research to discover effective drugs or to produce a COVID-19 vaccine. Conversely, as the level of health measures and social restrictions decreases, the reproductive rate of COVID-19 will increase. In this case, more people in the community will be infected during the epidemic, and the number of identified (or quarantined) patients will be very different from the actual number of patients in the community. Following the shortening of the epidemic time and the increase in the morbidity and mortality rate of the COVID-19, the socio-economic structure and also the health care system of the country will face a crisis.

The second point that can be deduced from the results of this study is that with increasing the level of health measures and social restrictions, although the epidemic period increases, due to the presence of a small number of COVID-19 patients in the community, the disease will be controlled in the first phase. Moreover, the possibility of the second phase of this epidemic is very low and unlikely. However, with the reduction of health measures and social restrictions, while the duration of the epidemic period will be shorter, due to the large number of patients in the community, the epidemic of COVID-19 will not be controlled in the first phase, and the possibility of the second phase will be very high and probable. Therefore, the epidemic of COVID-19 can be controlled, and the recurrence of the disease and the formation of the second phase can be prevented by application of health measures by people in the community (e.g. wearing masks and gloves, and regular handwashing) and the application of social restrictions by governments (e.g. social distancing, closure of educational, cultural, and religious centers, and reduction of urban and interurban traffic). Of course, each country can choose the appropriate level of health measures and social restrictions to control COVID-19, depending on its economic strength, social structure, and the ability of its health care system. To achieve the desired result, there must be health and social restrictions to reduce the reproductive rate of COVID-19 to less than one.

Conclusion

The study of the impact of health measures and social restrictions on the COVID-19 epidemic using mathematical models such as the SIQR model will provide appropriate information on the disease spread. Also, it will help researchers select the appropriate level of these health measures and social restrictions to prevent the further spread of COVID-19.

Acknowledgments

Conflict of interest

The authors have no conflict of interest in this study.

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Data availability

The raw data supporting the conclusions of this article are available from the authors upon reasonable request.

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