Research on the Impacts of Different Model Parameters on the Trends of Infectious Diseases Based on Improved SEIR Model

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Abstract. In this research, the infectious disease studied by the authors takes coronavirus disease 2019 as an example. The source of data for research is from Health Commission of Hubei Province during Wuhan epidemic in 2020. The specific time is from January 25, 2020 to April 26, 2020. Set different values for the relevant parameters in the modified SEIR model constructed in Reference 1 to simulate the intensities change of the corresponding prevention and control measures, respectively calculate the results of the model when the relevant parameters are different values, and comparative analysis to find essential and quantitative associations between prevention and control measures in various levels and the epidemic trends. The comparative analysis of results shows that community isolation, travel restriction, compulsory wearing protective equipment, medical isolation and other measures effectively inhibit the rapid spread of the epidemic in a short time; shelter treatment, rapid construction of hospitals, mobilization of medical resources and other measures can reduce the peak of the epidemic and make it fall back quickly. The results show that: in order to maintain the people's life safety, the Central People's Government of our country takes various epidemic prevention and control measures in Wuhan just like a strong "national vaccine", which helps Wuhan to quickly achieve the victory of the battle against the epidemic in 2020.

Keywords: Improved SEIR Model, Parameter Settings, Intensities of Prevention and Control Measures, Trends Comparison

1. Introduction

Taking the Wuhan epidemic in early 2020 as the research object, this paper quantitatively analyzes the inhibitory effect of different intensities of prevention and control measures on the development trends of the novel coronavirus from the perspective of data simulation. From the outbreak of the epidemic on January 23, 2020 to the elimination of number of confirmed on April 26, 2020, Wuhan achieves this crucial victory in less than 100 days, which is closely related to the multiple prevention and control measures by Chinese government, and it is particularly necessary to

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quantitatively study the impact of different prevention and control measures on the trends of the epidemic. However, the improved SEIR model established in Reference 1 has a good simulation effect on the epidemic. Therefore, the intensities change of a certain prevention and control measure can be simulated by adjusting the relevant parameter in the model, so as to realize the quantitative analysis of the essential associations between the intensities of prevention and control measures and the trends of the epidemic.

2. The Modified SEIR Model

The traditional SEIR model is equivalent to the Markov chain that includes the four states: S(Susceptible), persons who have no immunity to the virus and are not yet infected, and if they contact with someone who is already infected, they may be infected; E(Exposed), persons who have been infected but have no corresponding symptoms, and they are temporarily not contagious; I(Infected), persons who are already infected and there are corresponding symptoms with them, and they are contagious; R(Removed), persons who have dropped out of the model, which included two parts: those who are successfully cured and return to normal, and those who are dead after treatment failure. At present, many scholars have simulated and analyzed the novel coronavirus epidemic through SEIR model and its derivative models [2-9]. According to Reference 1 [1], the mathematical expression of the modified SEIR model is shown in Equation 1.

$$\begin{aligned}
\frac{dS_1}{dt} &= p_4 S_2 - p_1 p_2 (1-p_3) S_1 (I_1 + E_1) - p_1 p_3 S_1 \\
\frac{dS_2}{dt} &= p_1 p_3 S_1 - p_4 S_2 - p_1 p_2 p_3 S_1 \\
\frac{dE_1}{dt} &= p_1 p_2 (1-p_3) S_1 E_1 - p_5 E_1 \\
\frac{dI_1}{dt} &= p_1 p_2 (1-p_3) S_1 I_1 + p_5 E_1 - p_6 I_1 - p_7 I_1 \\
\frac{dE_2}{dt} &= p_1 p_2 p_3 S_1 - p_8 E_2 \\
\frac{dI_2}{dt} &= p_8 E_2 + p_6 I_1 - p_9 I_2 - p_{10} I_2 \\
\frac{dH}{dt} &= p_7 I_1 + p_9 I_2 - p_{11} H \\
\frac{dD}{dt} &= p_{10} I_2 \\
\frac{dS_{N1}}{dt} &= p_{11} H
\end{aligned} \tag{1}$$

In the above formula, susceptible persons (S) split to unconstrained susceptible (S_1) and isolated susceptible (S_2). Exposed persons (E) split to unconstrained exposed (E_1) and mild isolated (E_2). Infected persons (I) split to unconstrained infected (I_1) and non-mild isolated (I_2). Suppose the virus can't transmit from one isolated state to another isolated state, it can transmit from one unconstrained state to another unconstrained state only. Because in the latent period, the virus is also contagious, and not only it can transmit from unconstrained infected (I_1) to unconstrained susceptible (S_1), but also from unconstrained exposed (E_1) to unconstrained susceptible (S_1). Since the COVID-19 mortality rate is high (4%), the deceased persons (D) can be divided from the removed (R), and the deceased persons (D) only comes from the non-mild isolated (I_2). The rest of the removed (R) is the recovered (H). It is uncertain that the infected ones will gain perpetual immunity after recovery or not, so the new unconstrained susceptible (S_{N1}) can be an independent part in the SEIR model, which comes from the recovered (H) [10].

The transition probabilities between each state in equation(1) are as follows: The average daily contact number of E_1 or I_1 is p_1. The infection rate of the virus is p_2. The rate of medical isolation of S_1 is p_3. The de-isolation rate of S_2 is p_4. The conversion rate from E_1 to I_1 is p_5. The isolation rate of I_1 is p_6. The recovery rate of I_1 is p_7. The conversion rate of E_2 to I_2 is p_8. The successful and failed rates of treatments to I_2 are p_9 and p_{10}, respectively. The rate of H becoming susceptible again is p_{11}. The initial values are from the Health Commission of Hubei Province. The parameters such as transition probabilities are estimated by Reference 8 & 10 and MCMC.

Table 1. Transition probabilities of the modified SEIR model

Name	Value	Source
p_1	2	Reference 8
p_2	0.01	Parameter analysis
p_3	2 %	Parameter analysis
p_4	0.0714	Reference 10
p_5	0.2	Reference 10
p_6	0.1259	Parameter analysis
p_7	0.3303	Parameter analysis
p_8	3%	Actual analysis
p_9	10%	Actual analysis
p_{10}	0.0003	Actual analysis
p_{11}	0.0008	Parameter analysis

3. Analysis of the Impacts of Different Intensities of Prevention and Control Measures on the Trends of the Epidemic

The model parameters in Table 1 are divided into two types: Parameters that are closely related to individual immunity and parameters that are closely related to relevant prevention and control measures in various levels. Based on the actual situation, the following parameters are determined as the second type: The average daily contact number of E_1 or I_1 (p_1); The infection rate of the novel coronavirus (p_2); The rate of medical isolation of S_1 (p_3); The conversion rate of E_2 to I_2 (p_8); The successful rates of treatments to I_2 (p_9).

3.1 Analysis of the Impact of Model Parameter P1 on the Trends of the Epidemic

In the beginning, Chinese government takes measures such as community isolation, restricting residents' travel within the city, closing all non-essential public places, and stopping all mass gathering activities. Essentially, it greatly reduces the average daily contact number of E_1 or I_1 (p_1). If the intensity of corresponding prevention and control measures weakens, the value of p_1 will rapidly increase. The authors simulate the trends of the epidemic by calculating the peak and peak time of the existing confirmed cases in the improved SEIR model within 60 days after January 25th (p_1=2, p_1=5, p_1=10), and analyze the impact of the average daily contact number of E_1 or I_1 (p_1) on the trends of the epidemic. In Figure 1, the horizontal axis represents time (unit: day) and the vertical axis represents the number of confirmed cases (unit: person). Figures 2 to 4 are the same.

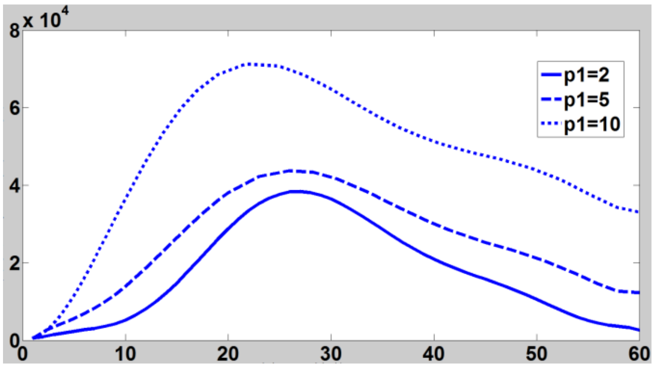

Fig.1 Comparison of epidemic trends with different values of p1

As shown in Figure 1, when p_1=2, the model reaches its peak on the 26th day (38073 cases); When p_1=5, the model reaches its peak on the 25th day (43882 cases); When p_1=10, the model reaches its peak on the 22nd day (71226 cases). The data shows that if the relevant epidemic prevention and control measures are weaker than the actual situation, that is, the average daily contact number increases, the number of confirmed cases will also increase, and the time for the model to reach its peak will also be shortened. And compared to the increase speed and magnitude of p_1, the increase speed and magnitude of the confirmed cases are more intense. Therefore, in the beginning, the different prevention and control measures form Chinese Government to reduce the average daily contact number are extremely effective and necessary.

3.2 Analysis of the Impact of Model Parameter p2 on the Trends of the Epidemic

P_2 is the infection rate of the novel coronavirus, indicating the probability of S_1 being infected after contact with E_1 or I_1. Although the value of p_2 is related to the self-infectivity of the novel coronavirus, the virus is mainly transmitted through respiratory droplets or contact transmission, and the value of p_2 can also be reduced by paying attention to personal protection. In the beginning, Chinese Government takes the prevention and control measures of compulsory wearing medical masks and other personal protective equipment in public places, which block the transmission path of the virus as much as possible and greatly reduce the infection rate of the novel coronavirus (p_2). The authors simulate the trends of the epidemic by calculating the peak and peak time of the existing confirmed cases in the improved SEIR model within 60 days after January 25th (p_2=0.01, p_2=0.1, p_2=0.3), and analyze the impact of the infection rate of the novel coronavirus (p_2) on the trends of the epidemic.

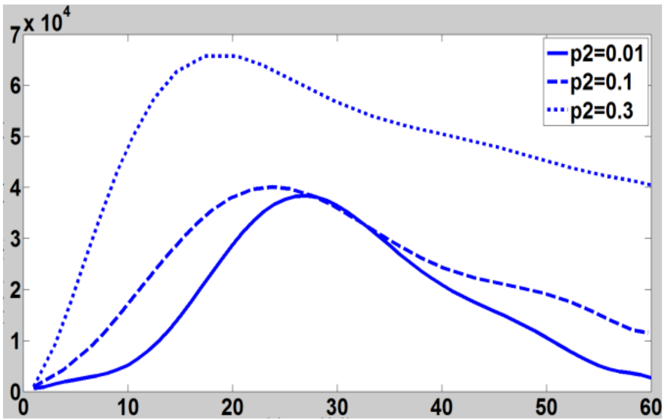

Fig.2 Comparison of epidemic trends with different values of p2

As shown in Figure 2, when p_2=0.1, the model reaches its peak on the 24th day (40157 cases); When p_2=0.3, the model reaches its peak on the 18th day (65985 cases). The data shows that if the relevant epidemic prevention and control measures are weaker than the actual situation, that is, not wearing personal protective equipment such as medical masks required by the government, the infection rate will increase, and the confirmed quantity will also increase, and the time for the model to reach its peak will also be shortened. Similar to parameter p_1, as p_2 increases, the speed and magnitude of the corresponding increase in the confirmed quantity will become more intense. Therefore, in the beginning, the prevention and control measures from Chinese Government to reduce the infection rate, such as compulsory wearing medical masks and other personal protective equipment in public places, are based on scientific evidence.

3.3 Analysis of the Impact of Model Parameter p3 on the Trends of the Epidemic

P_3 is the rate of medical isolation of S_1. In the latent period, COVID-19 also has strong transmissibility, it is necessary to screen S_2 among unconstrained susceptible for medical isolation. In the beginning, Chinese Government takes strong screening and medical isolation measures in accordance with the requirements of experts in NHC, to avoid potential or infected individuals becoming unconstrained. The authors simulate the trends of the epidemic by calculating the peak and peak time of the existing confirmed cases in the improved SEIR model within 60 days after January

25th (p_3=2%, p_3=1.5%, p_3=1%), and analyze the impact of the rate of medical isolation of S_1 (p_3) on the trends of the epidemic.

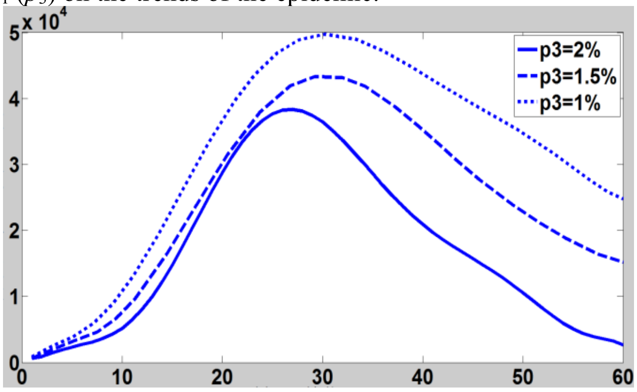

Fig.3 Comparison of epidemic trends with different values of p3

As shown in Figure 3, when p_3=1.5%, the model reaches its peak on the 30th day (43646 cases); When p_3=1%, the model reaches its peak on the 30th day (49703 cases). The data shows that if the screening and medical isolation measures are weaker than the actual situation, the number of confirmed cases will also increase. Although the speed and magnitude of the increase in the number of confirmed cases in the model do not change significantly compared to actual data when the values of p_3 are different in the early time, and there is no significant impact on the trends of the epidemic as the model parameters p_1 and p_2. However, due to the weakening of screening and medical isolation measures, as more first-generation and second-generation unconstrained exposed pass the incubation period, that is, after 30 days (about two incubation periods), the model will quickly reach its peak, which may cause more serious social panic. Therefore, in the early stage of the epidemic, it is necessary and foreseeable for the Central People's Government to take screening and medical isolation measures in accordance with the requirements of experts from the National Health Commission.

3.4 Analysis of the Impact of Model Parameter p8 on the Trends of the Epidemic

P_8 is the conversion rate of mild isolated (E_2) to non-mild isolated (I_2). Compared with I_2, E_2 has milder symptoms and almost no clinical symptoms, so it requires fewer medical resources. If p_8 is maintained at a lower value, it is more conducive to concentrate superior medical resources to treat I_2 with more severe symptoms, so as to better control the epidemic. According to the suggestion of experts from the National Health Commission, the Central People's Government has quickly built a number of shelter hospitals to treat E_2, effectively reducing the value of parameter p_8. The authors simulate the trends of the epidemic by calculating the peak and peak time of the existing confirmed cases in the improved SEIR model within 60 days after January 25th (p_8=3%, p_8=10%, p_8=15%), and analyze the impact of parameter p_8 on the trends of the epidemic.

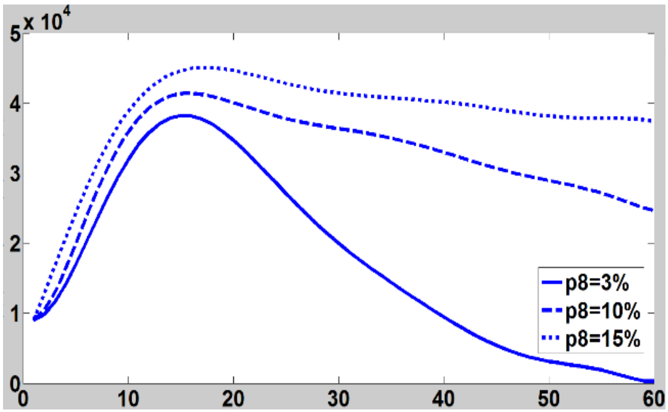

Fig.4 Comparison of epidemic trends with different values of p8

As shown in Figure 4, when p_8=3%, the model reaches its peak on the 15th day (38073 cases) and decreases to only 577 cases on the 60th day; When p_8=10%, the model reaches its peak on the 16th day (41582 cases) and remains at 24720 cases on the 60th day; When p_8=15%, the model reaches its peak on the 17th day (45329 cases) and remains at 37449 cases on the 60th day. The data shows that establishing shelter hospitals can not only reduce the peak number of confirmed cases, but also significantly improve the cure rate of patients. Because the shelter hospitals can cure mild isolated (E_2) with relatively fewer medical resources in a short period of time, avoiding their conversion into non-mild isolated (I_2) who require more medical resources, thus saving valuable medical resources and facilitating the treatment of I_2. It can be seen that the Central People's Government establishes shelter hospitals to receive and treat mild illness patients in accordance with the suggestion of experts from NHC, which has changed the relatively passive situation in the beginning and played a role in reversing the situation.

3.5 Analysis of the Impact of Model Parameter p9 on the Trends of the Epidemic

Improving the cure rate p_9 is fundamental to overcoming the epidemic, and its impact on the trends of the epidemic is particularly important. In the beginning, Chinese Government takes multiple measures to improve the cure rate: it only takes about 10 days to build two high standard infectious disease hospitals, Huoshenshan and Leishenshan hospitals; Mobilize advantageous medical resources from various provinces across the country to support Wuhan, including tens of thousands of medical workers and a large amount of medical equipment and protective equipment. The authors simulate the trends of the epidemic by calculating the peak and peak time of the existing confirmed cases in the improved SEIR model within 60 days after January 25th (p_9=10%, p_9=5%, p_9=2%), and analyze the impact of parameter p_9 on the trends of the epidemic.

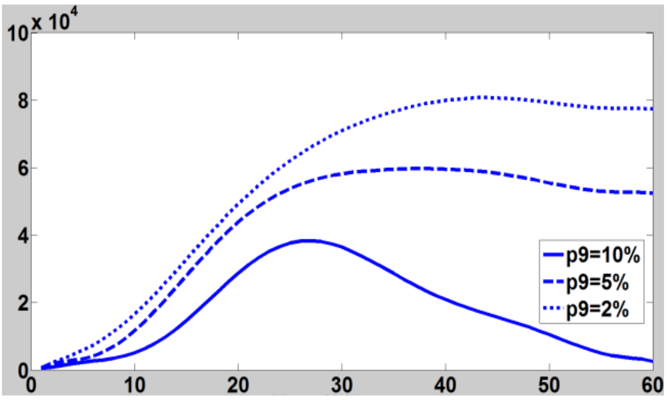

Fig.5 Comparison of epidemic trends with different values of p9

As shown in Figure 5, when p_9=5%, the model reaches its peak on the 38th day (59727 cases), and on the 60th day, there are still 52743 cases; When p_9=2%, the model reaches its peak on the 45th day (80761 cases), and on the 60th day, there are still 77620 cases. The data shows that compared to other parameters, p_9 has the most severe impact on the trends of the epidemic. If the Central People's Government does not take corresponding measures to increase the cure rate, the number of confirmed cases will significantly increase and cause serious medical runs, resulting in more patients unable to be cured and discharged in a short period of time. This vicious cycle is extremely unfavorable for epidemic prevention and control. Therefore, the prevention and control measures adopted by Chinese Government "at all costs", such as rapid construction of hospitals and mobilization of medical resources, are the key to the final victory of the battle against the epidemic in Wuhan in 2020.

3.6 Discussion of Results

In this paper, the number of confirmed cases under different values of parameters p_1, p_2, p_3, p_8 and p_9 is calculated by the modified SEIR model to explore the impact of different intensities of prevention and control measures on the trends of the epidemic. The results indicate that the strong prevention and control measures from Chinese Government have effectively suppressed the spread of the COVID-19 and protected the lives of people.

Since the comprehensive blockade of Wuhan on January 23, 2020, the Central People's Government has taken a series of prevention and control measures: community isolation, restrictions on residents' travel within the city, closure of all non-essential public places, and cessation of all mass gathering activities. The above measures have effectively reduced the average daily contact number of E_1 or I_1 (p_1). If the corresponding prevention and control measures weaken, it will lead to an increase in p_1, which will greatly accelerate the development speed of the epidemic. The results indicate that when p_1 increases to 5 or 10, the number of confirmed cases of the epidemic will reach its peak 1 day or 4 days earlier than the actual value, with an increase of 16.23% or 88.66%, respectively. That is to say, as p_1 increases, the number of confirmed cases of the epidemic will reach a higher peak in a shorter period of time. At the same time, the Central People's Government has taken the prevention and control measures of compulsory wearing personal protective equipment such as medical masks in public places, which have reduced the infection rate of the novel coronavirus (p_2). The results indicate that it is similar to the impact of p_1 on epidemic trends. When p_2 increases to 0.1 or 0.3, the number of confirmed cases of the epidemic will reach its peak 2 or 8 days earlier than the actual value, with increases of 6.36% or 74.78%, respectively. It can be seen that the relevant prevention and control measures from Chinese Government to reduce p_1 and p_2 have prevented the large-scale spread of the epidemic in a short period of time, and have bought valuable time for the smooth and efficient implementation of other prevention and control measures. Subsequently, in the process of prevention and control on COVID-19, Chinese Government adopts the suggestion of experts from NHC and takes measures such as medical screening, isolation, and the establishment of shelter hospitals. The former effectively improves p_3, allowing more unconstrained exposed (E_1) to be controlled, and weakening the uncertainty and momentum of the epidemic development; The latter effectively reduces p_8, enabling more mild isolated (E_2) to be quickly cured, saving valuable medical resources, and reversing the critical situation of the epidemic spread with a approach of "zero infection, zero death, and zero recurrence". In addition, increasing the cure rate (p_9) is one of the most important measures in any epidemic prevention and control. In the beginning, Chinese Government's "at all costs" measures such as rapid construction of hospitals and dispatch of medical teams have greatly increased the cure rate. The results indicate that when the cure rate p_9 decreases to 5% or 2% respectively, the number of confirmed cases of the epidemic will increase by 58.20% or 113.91% compared to the actual value. And if p_9 decreases, it will cause a series of adverse effects such as medical runs, which is extremely unfavorable for the continuous and rapid decline of the epidemic trends.

The fact that Wuhan is able to achieve a zero number of current confirmed and no recurrence within less than 100 days (April 26, 2020) is a miracle. At the same time, the results of the model prove that the powerful epidemic prevention and control measures from Chinese Government, in order to protect a massive amount of lives, are the fundamental reason for the rapid victory of the battle against the epidemic in Wuhan in 2020.

4. Conclusions

Strong prevention and control measures are the key to overcoming the epidemic, and exploring the inherent correlation between prevention and control measures in various levels and the trends of the epidemic is of great significance. The authors use Wuhan related epidemic information as the data source and select the improved SEIR model constructed in Reference 1 to simulate the epidemic trends. After analysis, the parameters p_1, p_2, p_3, p_8 and p_9 in the model can respectively simulate the changes in the intensities of relevant infectious diseases' prevention and control methods. By calculating and comparing the model results when the above parameters are different values, the impacts of prevention and control measures in various levels on the trends of the epidemic are quantitatively analyzed. The research content of this paper can give certain data assistance for the formulation of prevention and control measures of other infectious diseases. At the same time, due to the constraints of a variety of uncertain interference factors, no model can fully match the actual situation, resulting in some deviation in the simulation results of this paper.

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