Using simulation Technology to Analyze the COVID-19 Epidemic in Changsha, Hunan Province, China

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ABSTRACT

This study mainly uses simulation technology to simulate the COVID-19 epidemic in Changsha, Hunan Province, China, and analyze the impact of different prevention and control measures on the epidemic. we Collect the information of all COVID-19 patients in Changsha from January 21, 2020 to March 14, 2020 and relevant policies during the COVID-19 epidemic in Changsha. Established the SEIAR infectious disease dynamics model under natural conditions, and added isolation measures on this basis. Using Anylogic8.5, the COVID-19 epidemic in Changsha City was simulated under various conditions based on the established model. In this study we find that There were 242 COVID-19 patients in Changsha. including 121 males (50%) and 121 females (50%). Most cases occurred between February 6 and February 16. Through the calculation of the R_t during the epidemic in Changsha, it is found that it is reasonable to resume work on February 8, because the R_t value of Changsha dropped below 1 at this time. The simulation results show that reducing the contact rate of residents and reducing the success rate of virus transmission (wearing masks, disinfection, etc.) can effectively prevent the spread of COVID-19 and significantly reduce the number of peak patients. We believe that the disease is mainly spread by the respiratory tract. Therefore, the simulation results show that whether in the early or mid-stage of the epidemic, quarantining the names of residents or reducing the contact rate of residents is very effective in controlling the COVID-19 epidemic.

Keywords: SARS-CoV-2; COVID-19; Effective regeneration number (R_t); Simulation Technology;

BACKGROUND

COVID-19(Coronavirus disease 2019)is an emerging respiratory infectious disease caused by the severe acute respiratory syndrome coronavirus 2(SARS-CoV-2).The disease was discovered in Wuhan in December 2019. As of June 26, 2020, COVID-19 has caused a pandemic worldwide. It has affected most countries and regions, and has a very wide range[1].As of June 23, 2020 Beijing time, there were a total of 9081678 COVID-19 cases diagnosed worldwide, and 472649 deaths, affecting more than 200 countries and regions[2]. At present, most studies report the clinical characteristics of patients[3-6]. During the development of the epidemic in China, more studies have reported the expected end time and peak value of the epidemic. Evaluation of specific measures for epidemic prevention and control is still relatively rare.

The epidemic situation in China is gradually becoming clear, but the global epidemic situation cannot be ignored. Therefore, more research is needed to explain the specific prevention and control effects of various measures during the development of the epidemic situation, so as to provide specific reference for the policies of other countries and regions.

Changsha is the capital of Hunan Province, China, with a population of more than 8 million, and is the closest capital city to Wuhan (Figure 1). The first COVID-19 case in Changsha City was diagnosed on January 21, 2020. On January 24, the first-stage response to major public health emergencies was initiated and a series of preventive and control measures were taken, such as isolating patients. Screening of close contacts, Changsha achieved zero clearance of COVID-19 patients on March 14, and from March 14, 2020 to June 26, 2020, Changsha achieved the goal of zero to zero, including Media

promotion and health education, public places and traffic are closed, large gatherings and visits are prohibited, personal protection, etc. COVID-19 patients grow for 3 months, and strictly prevent and control foreign imports. This study describes the epidemiological characteristics of COVID-19 patients in Changsha City as of March 14, 2020, and compares the effective regeneration numbers in different periods based on key policies and interventions to evaluate various public health measures and epidemics. The relationship between development.

METHODS

Data source

The reported cases of COVID-19 in Changsha from January 21 to March 14, 2020 were collected from the Changsha City Health Commission [7]. The patient information collected includes: whether it is the input medical record, severity, date of onset (date of self-report of symptoms such as fever, cough or other respiratory symptoms), date of diagnosis (laboratory confirmation of SARS-COV-2 infection in biological samples Date), gender, residential area. All identifiable personal information is deleted to protect privacy.

Classification of 4 Time Periods

In order to better reflect the dynamics of the COVID-19 epidemic and the corresponding intervention measures, this study divided the entire epidemic in Changsha, Hunan Province into four periods. It is considered to be the first phase before January 24,

2020. At present, Changsha City has not implemented obvious preventive measures against COVID-19. This is the Spring Festival period in China. There is a large number of population movements and population aggregation. At this time, patients imported from Wuhan and incubation patients can infect a large number of Changsha residents. The second stage is from January 24, 2020 to February 8, 2020. During this period, Changsha City is believed to have taken obvious preventive measures against COVID-19 and has not resumed work. From January 24, 2020, Changsha City began to take strict prevention and control measures, strictly inspect entry vehicles, began to build the city's public health treatment center facilities, and strengthen the deployment of emergency medical supplies. Hubei immigrants were also subjected to unified medical observation and isolation, and 56 tourist attractions and all public places were closed. And on February 1st, a comprehensive treatment of COVID-19 patients began to ensure that each patient was treated correctly. The third phase is from February 8, 2020 to March 7, 2020. At this time, Changsha began to resume work gradually, and the flow of people gradually began to rise. At this time, Changsha gradually opened up various transportation hubs according to the number of daily patients, and gradually restored social order. While restoring production, conduct strict medical observations for migrant workers, implement necessary nucleic acid testing, strengthen volunteer services, and strictly grasp the diagnosis, symptoms, and discharge standards. And on February 29, 2020 COVID-19 nucleic acid detection point hospitals and third-party detection institutions were identified. From March 7, 2020 to March 14, 2020 is the fourth stage. At this time, the pressure of overseas imports began to appear, and Changsha began to establish a

working mechanism for the strict prevention of overseas epidemic imports, epidemic spread, and epidemic rebound, and strict inspection and quarantine and transshipment of foreign entry personnel.(Figure 2).

Models and statistical analysis

Estimated R_t

This study describes the age and gender distribution of COVID-19 cases in Changsha City.

According to an article published in the New England Journal of Medicine by the CDC team, the inter-generational time of COVID-19 conforms to the gamma distribution, with mean and standard deviations of 7.5 and 3.4[8], respectively, using R version 4.0.0. Based on the COVID-19 case data reported by Changsha City, calculate the change of R_t and its 95% confidence interval for the whole period of Changsha City. The effective reproduction number(R_t) is defined as the mean number of secondary cases generated by a typical primary case at time t in a population, calculated for the whole period over a 7-day moving average.

$$\tau(t_g) = \frac{\beta^\alpha}{\Gamma(\alpha)} t_g^{\alpha-1} e^{-\beta t_g} (t_g > 0) \quad (1)$$

In the formula, $\Gamma(\alpha)$ is the gamma function with the parameter α ; the shape parameter α and the inverse scale parameter β have the following simple relationship with the mean μ and Standard Deviation σ of the gamma distribution, which can be used

for calculation α and β :

$$\mu = \frac{\alpha}{\beta}, \sigma^2 = \frac{\alpha}{\beta^2} \quad (2)$$

Suppose we want to calculate the effective regeneration number at time t (unit: day), that is, to calculate the average number of infected people at time t . Considering the infected individual u , whose infection time $t_u = t$, it is necessary to investigate how likely the infected individual is to be infected by the patient u within t after $t_g^{\max}$ (the longest inter-generational time). This study considers that an individual v infected after u has an onset time of t_v . Now with v as the center, examine the individuals who developed within t_v before $t_g^{\max}$, and each of these individuals w may be infected with v , the probability of infection $\tau(t_v - t_w)$, therefore, the probability that patient u causes infection of patient v can be estimated as

$$P_{vu} = \frac{\tau(t_v - t_u)}{\sum_{w, t_v > t_w} \tau(t_v - t_w)} \quad (3)$$

According to (3), we can get:

$$\sum_{w, t_v > t_w} P_{vw} = 1 \quad (4)$$

For each patient infected at time t , such an expected value can be calculated, so the effective regeneration number at time t can be approximated as:

$$R_t = \frac{1}{|C_t|} \sum_{j \in C_t} E_j \quad (5)$$

In the formula, C_t is the set of all patients who have symptoms at time t . Assuming that each patient's infection ability and chance of infection are equal, then the effective reproduction number R_t at time t and the total number of individuals infected by any infected individual u on this day are expected to be equal, ie : $R_t = E_u(t = t_u)$. Further assume that the observed time window is $[0, T]$. For patients with symptoms on day t , if $t + t_g^{\max} \leq T$, then it is completely feasible to estimate the effective regeneration number R_t using the Willinge-Teunis method. However, if $t + t_g^{\max} > T$, then the patient with symptoms on day T may still be infected with a new individual after T , and the R_t obtained by the Willinge-Teunis method is too small. At this time, the formula needs to be corrected, namely:

$$R_t = \frac{R_t^-}{\sum_{w=0}^{T-1} \tau(w)} \quad (6)$$

In the formula, R_t^- represents the average number of infected individuals on day t before T and T , which can be estimated directly by the Willinge-Teunis method. Therefore, this study mainly uses formula (5) and formula (6) to calculate R_t .

SEIAR model

A SEIAR model was established to simulate the transmission of SARS-CoV-2 in Changsha. Population in this model was divided into five categories according to the disease status: susceptible (S), exposed (E), infected (I), asymptomatic (A) and recovered (R). The model was developed based on the following facts or assumptions,

which assumed that some individuals moved among categories because of infection or recovery: 1) Susceptible person (S) was assumed to have an equal infected rate (β_s) with the symptomatic infected person (I) and $\kappa\beta_s$ with asymptomatic infected person (A); 2) After infected, the exposed person (E) would turn to I or A after a certain exposed period ($1/\lambda$), the number of newly I and A per unit time was λE ; 3) γ meant the removal rate, $1/\gamma$ meant the infective period, the number of newly recovered individuals (R) per unit time was $(\gamma_1 A + \gamma_2 I)$; 4) The fatality rate of COVID-19 were ignored, because it was very low in Hunan.

The corresponding model equations were as follows, dS/dt , dE/dt , dI/dt , dA/dt and dR/dt denoted the number of individuals (n) at time t in the corresponding categories (Figure 3):

$$N(t) = S(t) + E(t) + I(t) + A(t) + R(t)$$

$$dS/dt = -\beta_s SI - \kappa\beta_s AS$$

$$dE/dt = \beta_s SI + \kappa\beta_s AS - \lambda(1-p)E - \lambda pE$$

$$dI/dt = \lambda(1-p)E - \gamma_2 I$$

$$dA/dt = p\lambda E - \gamma_1 A$$

$$dR/dt = \gamma_1 A + \gamma_2 I$$

After the isolation measures in Changsha City, the main framework of the model remains unchanged, and some parameters in the model are changed (Figure 4):

$$dS / dt = -\varepsilon S - \beta IS - \kappa \beta_s AS$$

$$ds / dt = \varepsilon S$$

$$dE / dt = \beta_s IS + -\varepsilon E - \lambda(1 - p)E - \lambda p E$$

$$de / dt = \varepsilon E$$

$$dI / dt = \lambda(1 - p)E - \gamma_2 I - \varepsilon I$$

$$di / dt = \varepsilon I$$

$$dA / dt = p \lambda E - \gamma_1 A - \varepsilon A$$

$$da / dt = \varepsilon A$$

In the equation, ε is the Isolation rate of residents in Hunan Province, s , e , i , and a are the isolated population of susceptible persons(s), the isolated population of patients in the incubation period(e), the isolated population of patients with clinical symptoms(i), and the isolated population of asymptomatic infected persons(a), respectively.

In order to show the actual effect of the measures taken by Changsha during the epidemic on the COVID-19 epidemic, we used Anylogic to simulate the COVID-19 epidemic in Changsha. The infection rate in the model is decomposed into the number of people who are infected daily and the efficiency of virus transmission.

$$\beta_s = \xi \varphi / N$$

ξ is the number of daily contacts of COVID-19 patients, φ is the efficiency of virus transmission. Assume that the maximum value of ξ is 10, the minimum value is 1, the maximum value of φ is 1, and the minimum value is 0.01. Adjust these two

parameters separately, and use AnyLogic8.5 software to simulate the number of COVID-19 patients in Hunan Province.

The model parameters are set as follows:

- a) The mean incubation period was 5.2 days (95% confidence interval [CI]: 4.1 –7.0) [8], so, the latency coefficient $\lambda = 1/5.2$.
- b) As of February 12, 2020, 972 cases with symptomatic infection and 121 cases with asymptomatic infection were reported in Hunan, so the the proportion of asymptomatic infection rate of people in our model was $P=121/(972+121)=11.1\%$.
- c) While once symptomatic infected person was diagnosed, they would be isolated, the $1/\gamma_2$ represented the time from onset to diagnosis of symptomatic infected person. From the actual data, we have calculated that the average time from onset to diagnosis was 3 days, so, the infectious period of I was $\gamma_2=1/3$; While those asymptomatic infected person would not be easily found and isolated, the recovery day was equal to 14 days [9], so, the infectious period of A was $\gamma_1=1/14$.
- d) ε is the isolation rate of residents in Hunan Province during the COVID-19 epidemic. This value cannot be accurately estimated, so use simulation to adjust.
- e) ξ is the number of daily contacts of COVID-19 patients. This value cannot be accurately estimated, so use simulation to adjust.
- f) φ is the efficiency of virus transmission. This value cannot be accurately estimated,

so use simulation to adjust.

RESULTS

Characteristics of Patients With COVID-19

This analysis included a total of 242 confirmed cases, including 121 males (50%) and 121 females (50%).(Table 1)The age of onset is mainly distributed in the 40-59 age group. According to the date of symptom onset and the key intervention diagram shown. Most cases occurred between February 6 and February 16, and peaked around February 10. After implementing obvious interventions in Changsha City, Hunan Province, the number of patients was effectively controlled and the number of cases Rapidly declined, and the number of patients was cleared on March 14.

Estimates of R_t

Figure 3 is a graph of R_t versus time. In the first stage, due to the influx of a large number of latent patients from Wuhan to Changsha, the number of patients in Changsha rose sharply, reaching a peak of 3.9 on January 18. After the implementation of disease prevention and control in the second phase, Changsha City entered a closed phase, isolated residents, isolated patients under centralized isolation and traffic control, and R_t began to decline significantly, and fell to less than 1 on February 6(Figure 5), The third stage is from February 8th, Changsha City began to restore normal social order and opened the transportation hub. At this time, there were 37,251 COVID-19 patients in China and 27,100 patients in Hubei Province (Figure 6), which shows that the situation

was not optimistic at that time. At this time, Changsha City's open traffic is undoubtedly under huge input pressure, but the R_t results show that under the implementation of various measures (concentrated treatment of patients, strict testing of migrant workers, etc.), the risk of COVID-19 epidemic in Changsha City There was no obvious rebound. The fourth stage is after March 8th, Changsha City is mainly subject to the risk of foreign COVID-19 epidemic imports. Through strict screening and epidemiological investigation of foreign immigrants, COVID-19 epidemic risk is also under control Inside. It can be seen that the prevention and control work during the entire COVID-19 epidemic in Changsha was very effective.

Simulation

After the implementation of isolation measures in Changsha, it can be considered that adopting comprehensive isolation measures for residents in Changsha can well avoid the development of the epidemic. According to the figure below, when the population isolation rate in Changsha was only 0.01, the peak of COVID-19 patients was significantly reduced. At this time, the peak of the number of COVID-19 patients is about 9,200. When the isolation rate was 0.02, the peak number of patients dropped to 34(Figure 7).

After decomposing the infection rate into the number of daily contacts of the sick and the success rate of infection, the daily number of contacts of the sick and the success rate of the infection are simulated to remove the isolation rate, and the number of daily contacts of the sick is used to reflect the impact of isolation measures . The figure below

is a graph of the number of patients under each number of contacts. Although there is no COVID-19 epidemic in Changsha City, when there is one exception to import cases, and the infection success rate is certain, the higher the number of daily contacts with patients, the higher the peak number of patients. It shows that the current input pressure of the epidemic still exists, and we cannot relax. Measures such as isolation and other measures to reduce the number of daily contacts of the sick must be taken to improve the situation of the COVID-19 epidemic.(Figure 8)

Under the circumstance that the daily number of people with the disease remains unchanged, the higher the efficiency of virus transmission, the higher the peak of COVID-19 patients. It shows that reducing the efficiency of virus transmission can also significantly improve the situation of COVID-19. The transmission of COVID-19 is mainly through the respiratory tract. Therefore, as long as measures such as wearing masks, maintaining contact distances, and proper ventilation, the epidemic can be effectively controlled.(Figure 9)

DISCUSSION

In this study, we found that the number of male patients was similar to female, which was different from the patients in Wuhan [5,6], but the same with the results of the whole country [10,11]. The possible reason is that Wuhan, as the birthplace of the pathogen, has extremely tight medical resources and a growing number of patients, which will inevitably lead to missed diagnosis and death omissions, so it may be different from other places, further studies are needed to find out whether there are

differences between men and women. People of all ages were generally susceptible to SARS-CoV-2, and the age of patients in various time periods is mainly concentrated in 40-59 years old, which is consistent with the results of other provinces in China[10,11]. This means that the epidemic is a major threat and challenge for all mankind and must be strictly controlled, especially for those who suffer from basic diseases of the elderly is the most important epidemic prevention. Since the sealed off Wuhan on January 23, according to Baidu's migration map, a few people have returned to Changsha for Spring Festival reasons and some early patients may have come from or contact with Wuhan or other areas in Hubei, but the latter patients were mostly local transmission patients. Since the first case of COVID-19 in Changsha was diagnosed on January 21, 2020, a series of preventive and control measures were taken to deal with it, most of the patients were found and diagnosed at an earlier time, which would reduce the proportion of severe patients and reduce the harm of this disease.

In the early stage of the outbreak, because Changsha City was not the place where the epidemic occurred, no corresponding disease control measures were taken, resulting in a large number of latent patients from Wuhan entering Changsha City, and due to the Spring Festival, a large number of people gathered, resulting in January 8 R_t rose sharply to a peak of 4.3 around the day. However, under the control of Changsha City's disease control efforts, in the second phase, R_t began to show a clear downward trend. During this period, Changsha City adopted traffic control, city blockade, residents' self-isolation, mandatory wearing of masks, and closing the city. Measures such as

public and entertainment venues, and issued corresponding prevention and control policies. It can be seen from the figure that the results of the relevant measures are quite remarkable, and R_t drops below 1 around February 6, indicating that Changsha City blocked the spread of the disease around February 24. According to Figure 1, on February 8th, Changsha City began to strengthen the treatment of patients, intensively treat patients, supplement medical resources, accelerate the healing cycle of patients, and completed the zeroing of the number of patients on March 14.

The results of this study show that the corresponding disease control measures have a significant effect on the prevention and control of COVID-19, mainly related to the city blockade and the independent isolation of residents. Without any obvious control conditions for the epidemic, the spread of the disease will proceed at a very fast rate, but after effective prevention and control measures are taken, the spread of the disease can be effectively blocked[12,13]. Take Changsha as an example, after the closure of the city on February 27, the spread of COVID-19 was effectively suppressed.

After simulating the COVID-19 epidemic in Changsha, it was found that reducing the contact rate of the population and the success rate of disease transmission can effectively prevent the spread of the disease. The main reason may be because the SARS-CoV-2 virus is mainly spread by the air, so by quarantining residents (reducing the rate of population contact) and wearing masks or maintaining ventilation (reducing the success rate of disease transmission) can be very good for residents. The protective effect.

In summary, prevention and control isolation and medical tracking isolation are important measures to effectively curb the spread of COVID-19 in large areas. The measures of prevention and control and isolation under the government's initiative have an important inhibitory effect on the spread of the epidemic in a large area, there is no deny that the strict medical tracking and isolation of the personnel contacted by the infected person has also effectively prevented the excessive growth of the epidemic situation. Concentrated treatment and other important measures have played a key role in the rapid decline of the peak number of infections, and have an important control effect on the development of the epidemic. Actually the promotion of personal safety protection measures will greatly curb the development of the epidemic, take strict self-protection measures, and play a role in curbing the excessive growth of infection. This is of great value to the prevention and control of the current global COVID-19 epidemic. Currently, many countries and regions are facing public health emergencies similar to those in Changsha from January to March. such as isolating cases, increasing social distance (such as less going to crowd gathering places, eliminating group activities, etc.), improving personal hygiene behavior (wearing masks, washing hands frequently)etc.

CONCLUSIONS

Through the analysis of related disease prevention measures, public health interventions in Changsha City, such as: blockade of cities, isolation of residents, closure of public places, etc., can effectively control the epidemic of COVID-19. These

findings can provide relevant references for the prevention and control of the public health policy of COVID-19, which is prevalent in other countries and the planet.

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Consent for publication

All authors agree to publish this article

Author's contributions

Guoqun LI and Nan Zhou has major contributions

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Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of

interest.

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Figures

Figure 1. Geographical location map of Changsha

Figure 1

Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2 Changes in number of COVID-19 patients in Changsha City and related policy changes

Figure 2

Figure 3 Changsha COVID-19 SEIAR model

Figure 3

Figure 4 Adjusted Changsha COVID-19 SEIAR model

Figure 4

Figure 5 Line chart of R_t over time in Changsha

Figure 5

Figure 6 China's COVID-19 epidemic situation on February 8

Figure 6

A

B

C

R is the isolation rate. Because the isolation rate has a greater impact on the number of COVID-19 patients, the number of patients corresponding to other IR values at IR=0.01 and IR=0.02 cannot be displayed. Therefore, IR=0.01 and IR=0.02 are separated separately, that is, A is the patient number curve with IR=0.01, B is the patient number curve with IR=0.02, and C is the patient number curve with IR=0.03 to IR=0.1.

Figure 7 The impact of the Isolation Rate on the COVID-19 epidemic in Changsha

Figure 7

A

B

C

CR is Contact Rate of COVID-19 patients(ξ), Each curve corresponds to the contact rate of different COVID-19 patients. The blue curve represents the curve of the number of COVID-19 patients corresponding to the selected CR. Figure B and Figure C respectively show the impact of two different CR on the number of COVID-19 patients. Because the number of patients with CR=1 to CR=5 is too low to be fully displayed on this picture, we just using CR=3 compare with the curve of CR=10.

Figure 8 The Impact of Contact Rate of patients(ξ) on the COVID-19 Epidemic in Changsha City

Figure 8

TR is the efficiency of virus transmission(φ),and each TR value corresponds to a blue curve (number of patients) in the Figure A-C,TR range is 1-0.1,with and interval of 0.1.In Figure D-F,TR range is 0.1-0.01,with an interval of 0.01.Because the peak of the curve of TR=0.01 to TR=0.05 is too low,in Figure D-F we just using TR=0.1 compare with TR=0.05.

Figure 9 The Impact of virus transmission efficiency (φ) on the COVID-19 epidemic in Changsha

Figure 9