**Title:**

Assessment and forecasting the spread of SARS-CoV-2 outbreak in Changsha, China: Based on a SEIAR Dynamic Model

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## ABSTRACT

**Background:** A new human coronavirus named SARS-CoV-2 emerged during December 2019 in Wuhan, China. Cases have been exported to other Chinese cities and abroad, which may cause the global outbreak. Chang Sha is the nearest provincial capital city to Wuhan, the first case of COVID-19 in Changsha was diagnosed on January 21, 2020. Estimating the transmissibility and forecasting the trend of the outbreak of SARS-CoV-2 under the prevention and control measures in Changsha could inform evidence based decisions to policy makers.

**Methods :** Data were collected from the Health Commission of Changsha and Hunan Center for Disease Control and Prevention. A Susceptible-exposed-infections/ asymptomatic- removed (SEIAR) model was established to simulate the transmission of SARS-CoV-2 in Changsha. Berkeley Madonna 8.3.18 were employed for the model simulation and prediction, while the curve fitting problem was solved by the Runge-Kutta fourth-order method, with a tolerance of 0.001.

**Results:** In this study, we found that Rt was 2.05 from January 21 to 27 and reduced to 0.2 after January 27, 2020 in Changsha. The prediction results showed that when no obvious prevention and control measures were applied, the total number of patients in Changsha would reach the maximum (2.27 million) on the 79th day after the outbreak, and end in about 240 days; When measures have not been fully launched, the total number of patients would reach the maximum (1.60 million) on the 28th day after the outbreak, and end in about 110 days; When measures have been fully launched, the total number of patients would reach the maximum (234) on the 23rd day after the outbreak,

and end in about 60 days.

**Conclusions:** Outbreak of SARS-CoV-2 in Changsha is in a controllable stage under current prevention and control measures, it is predicted that the cumulative patients would reach the maximum of 234 on February 12, and the outbreak would be over on 20 March in Changsha. With the fully implementation of prevention and control measures, it could effectively reduce the peak value, short the time to peak and duration of the outbreak.

**Keywords:** SARS-CoV-2; COVID-19; SEIAR model; Effective regeneration number (Rt); Forecast

## BACKGROUND

A new human coronavirus, named as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by International Committee on Taxonomy of Viruses on February 11, 2020, emerged during December 2019 in Wuhan, the capital of Hubei province in China [1]. On January 31, 2020, the world health organization (WHO) suggested that there was possible sustained human-to-human transmission of SARS-CoV-2, and announced that this outbreak in China became an Public health emergencies of international concern (PHEIC), which may cause the global outbreak [2]. As of February 17, 2020 (Beijing time), 72528 cases of SARS-CoV-2, which have been named as Coronavirus disease 2019 (COVID-19) have been reported in China, including 1870 deaths, and cases have been detected in at least 25 regions or countries

outside China, including Japan (n=520), Singapore (n=77), Thailand(n=35), South Korea (n=29), Malaysia (n=22) and so on [3]. Data is growing day by day, public health concerns are being paid globally on this outbreak of SARS-CoV-2.

Changsha, the provincial capital of Hunan in China, with more than 8 million residents, which is the nearest provincial capital city to Wuhan (Figure 1). The first case of COVID-19 in Changsha was diagnosed on January 21, 2020, the first level response to major public health emergencies was launched on January 24, and a series of preventive and control measures like isolation of patients, screening of close contacts, media publicity and health education, closure of public places and transportation, prohibiting big parties and visits, personal protection and so on were taken to deal with it. Up to now, the cumulative case of COVID-19 in Changsha was 241, ranking the 7th in cities of China except Hubei province [3].

The genetic features and some clinical findings of the infection in Wuhan have been reported recently [4-7]. It's been a month since the first patient of COVID-19 was reported in Changsha, however, the effect of preventive and control measures, the future epidemic trend in Changsha were unclear. In this study, we analysed the epidemiological characteristics of patients, developed a Susceptible-exposed-infections/asymptomatic-removed (SEIAR) dynamic model to estimate the transmissibility and dynamic of the transmission of the virus, evaluate the effect of the prevention and control measures, and forecast the trend of the epidemic situation of SARS-CoV-2 in Changsha, in order to inform evidence based decisions to health decision and policy makers.

## METHODS

### Data source

The reported case of COVID-19 from January 21 to February 17, 2020 in Changsha were collected from the Health Commission of Changsha [8]. The proportion of recessive infection in Hunan were collected from the Hunan Center for Disease Control and Prevention. The onset date of the first case was on January 21, 2020, and the epidemic curve from January 21 to February 17, 2020 was collected for our study, the simulation time step was one day.

### Models and statistical analysis

### 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 (Figure 2): 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) The population was defined as closed and stable; 2) Susceptible person (S) was assumed to have an equal infected rate ($\beta$) with the symptomatic infected person (I) and $\kappa\beta$ with asymptomatic infected person (A); 3) After infected, the exposed person (E) would turn to I or A after a certain exposed period ($1/\omega$), the number of newly I and A per unit time was $\omega$E; 4) $\gamma$ meant the removal rate, the number of newly recovered individuals (R) per unit time was ($\gamma_1$A+$\gamma_2$I); 5) The fatality rate were

ignored, because it was very low in Changsha.

The corresponding model equations were as follows, $d$S/$d$t, $d$E/$d$t, $d$I/$d$t, $d$A/$d$t and $d$R/$d$t denoted the number of individuals (n) at time t in the corresponding categories:

$$\begin{cases} dS/dt = -\beta SI - \kappa\beta SA \\ dE/dt = \beta SI + \kappa\beta SA - pwE - (1-p)wE \\ dA/dt = pwE - \gamma_1 A \\ dI/dt = (1-p)wE - \gamma_2 I \\ dR/dt = \gamma_1 A + \gamma_2 I \end{cases} \quad (1)$$

The effective regeneration number (Rt) was calculated by the following formula according to the model:

$$Rt = \beta S_t \left(\frac{1-p}{\gamma_2} + \frac{\kappa p}{\gamma_1}\right) \quad (2)$$

**Parameter estimation**

There were six parameters in all models in this study, which were infection rate ($\beta$), the ratio of transmission probability of A to I ($\kappa$), the proportion of asymptomatic infection rate of people ($P$), latency coefficient ($\omega$), removal rate of A ($\gamma_1$) and removal rate of I ($\gamma_2$), all parameters and initial values of each categorie were list in Table 1.

a) As of February 12, 2020, 972 cases with COVID-19 and 121 cases with asymptomatic infection were reported in Hunan province, Changsha is the provincial capital of Hunan, so the the proportion of asymptomatic infection rate of people in our model was $P$=121/(972+121)=11%.

b) The mean incubation period was 5.2 days (95% confidence interval [$CI$]: 4.1 –7.0) [4], we set the same value (5.2 days) of the incubation period in our study, so,

$\omega$=1/5.2.

c) $\gamma$ meant the removal rate, $1/\gamma$ meant the infective period. 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, $\gamma_2$=1/3.

d) While those asymptomatic infected person would not be easily found and isolated, the recovery day was equal to 14 days [9], so, the infective period of asymptomatic infection was $\gamma_1$=1/14.

**Simulation methods**

Considering the implementation degree of the prevention and control measures, we divided the time into two periods based on the measures in Changsha. The first period was from January 21 to 27, 2020, when the prevention and control measures have not been fully launched, the second period was from January 28 to February 17, 2020, when the prevention and control measures have been fully launched.

We fitted the data from the outbreak of SARS-CoV-2 in Changsha to a SEIAR model curve to estimate $\beta$ and $\kappa$ in these two periods respectively. Berkeley Madonna 8.3.18 and Microsoft Office Excel 2010 software were employed for the model simulation and data management, respectively. Graphpad prism 5 was used for the figure development, while the curve fitting problem was solved by the Runge-Kutta fourth-order method, with a tolerance of 0.001. A Goodness of fit test ($\chi^2$ test) was performed using the IBM-SPSS software, in which the significance level was $\alpha = 0.05$.

**Forecast**

153 Three prediction models based on different parameters were established, Berkeley
154 Madonna 8.3.18 was used for model forecast, the peaks and duration of the epidemic in
155 three models were compared.
156 a) The first prediction model was to forecast the epidemic situation in Changsha based
157 on the parameters in the early stage of Wuhan ($R_0$=2.68) [10], that was, the
158 parameters when almost no prevention andcontrol measures were taken.
159 b) The second prediction model was to forecast the epidemic situation in Changsha
160 according to the parameters obtained by model fitting from January 21 to 27, 2020,
161 when the prevention and control measures have not been fully launched.
162 c) The third prediction model was to forecast the epidemic situation in Changsha
163 according to the parameters obtained by model fitting from January 28 to February
164 17, 2020, when the prevention and control measures have been fully launched.
165
166 **RESULTS**
167 **Epidemiological features of the outbreak of SARS-CoV-2 in Changsha**
168 From January 21 to February 17 in the year 2020, 241 patients of COVID-19 in
169 Changsha were reported. The sex ratio of men to women was 120:121, the oldest and
170 youngest were 84 and 3 years old, respectively, the median age was 45 years old. 40
171 people were from Wuhan or other areas in Hubei, accounting for 16.6%. The median
172 time of patients from onset to diagnosis in Changsha was 3 days, and 217 patients just
173 had mild symptoms at the time of diagnosis, which accounting for 90.0%. Among the
174 eight districts under the jurisdiction of Changsha, Furong, Kafu and Yulu district
175 reported the largest number of patients, a total of 166 cases, which accounting for 68.9%.

As of February 17, 2020, 92 patients were discharged from hospital, 2 died, 147 patients were in hospital now, 10 of them were serious. The distribution of time among patients was shown in Figure 3.

**The effect of prevention and control measures in Changsha at different time**

We divided the time into two periods based on the prevention and control measures in Changsha, which was from January 21 to 27, and from January 28 to February 17, 2020. The results of curve fitting of the outbreak data in Changsha and SEIAR model showed that the simulated result agreed well with the reported data when $\beta 1$ equal to $5.02\times10^{-7}$, $R_1$ equal to 2.05 , $\kappa_1$ equal to 0.93 from January 21 to 27, 2020, and $\beta 2$ equal to $6.00\times10^{-8}$, $R_2$ equal to 0.20, $\kappa_2$ equal to 0.95 from January 27 to February 17, 2020 ($R^2$=0.97, $P$<0.001). The model fitting diagram was shown in Figure 4.

**Forecast of the outbreak of SARS-CoV-2 in Changsha**

The prediction results showed that when no obvious measures were applied, the total number of patients in Changsha would reach the maximum on the 79th day after the outbreak, which was 2.27 million patients, and the outbreak would end in about 240 days; When prevention and control measures have not been fully launched, the total number of patients in Changsha would reach the maximum on the 28th day after the outbreak, which was 1.60 million patients, and the outbreak would end in about 110 days; When prevention and control measures have been fully launched, the total number of patients in Changsha would reach the maximum on the 16th day after the fully intervention, that is, on the 23rd day after the outbreak (February 12, 2020), which was 234 patients, and the outbreak would end in about 60 days (March 20, 2020). The

forecast results were shown in Figure 5.

## 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 [11,12], which may be due to the different study sites and the number of cases, 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 median age of patients were 45 years old, which is consistent with the results of other provinces in China [11,12]. 16.6% patients were from Wuhan or other areas in Hubei, 90.0% patients just had mild symptoms at the time of diagnosis. Since the sealed off Wuhan on January 23, there have been few, almost none people from Wuhan to Changsha, so, 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.

The proportion of asymptomatic infection of SARS-CoV-2 was low, just accounting for 11.1%, which was higher than Severe acute respiratory syndrome (SARS) and Middle east respiratory syndrome (MERS) [13,14], but lower than influenza [15]. The probability of transmission in asymptomatic infected patients were not very different

222 from that of symptomatic infected patients ($\kappa$=0.93 to 0.95), which is what we need to
223 pay attention to. So, in the later stage, we should carry out nucleic acid testing to find
224 out more asymptomatic infected people, especially from the key groups, such as close
225 contacters of patients, medical workers, employees returning to enterprise and students
226 returning to school from Wuhan or other areas of Hubei, to reduce the impact of
227 asymptomatic infection on the re-outbreak or epidemic of SARS-CoV-2.

228 To control the transmission of virus, it is important to decrease $R_t$. Due to the
229 different research places and time, the $R_0$ or $R_t$ obtained by scholars were quite different,
230 which ranged from1.10 to 6.47 in China [16-19]. The number of patients is changing
231 rapidly, the measures taken in different places and time are not all the same, so, it is
232 necessary to adjust the model and parameters according to different situations of
233 different regions. In this study, we found that Rt was 2.05 from January 21 to 27 in
234 Changsha, which was lower than the $R_0$ in Wuhan at the early time, and Rt reduced to
235 0.2, lower than 1 after January 27, 2020, which meant that the SARS-CoV-2 in
236 Changsha was in a controllable stage under current prevention and control measures.

237 The prediction results of the model showed that the cumulative patients of
238 COVID-19 in Changsha would reach the maximum value of 234 on February 12, which
239 was fitting well to the actual situation, and the outbreak of SARS-CoV-2 in Changsha
240 would end around March 20. Compared with no or initial measures, with the fully
241 implementation of the epidemic prevention and control measures in Changsha, it could
242 effectively reduce the peak value, short the time to peak and duration of the outbreak,
243 reduce the harm brought by the epidemic. Scientific and effective prevention and control

provides a reference for dealing with new infectious diseases in the future.

The actual situation was complex and changeable, differences remained between the simulation and the actual outbreak, which is the limitation in our study. After February 17, the resumption of work in enterprises and schools may have some impact on the development of the epidemic, so the model and parameters need to be adjusted according to the actual situation.

## CONCLUSIONS

The proportion of asymptomatic infections of SARS-CoV-2 in Changsha was low, but the probability of transmission was not very different from that of patients; Outbreak of SARS-CoV-2 in Changsha is in a controllable stage under current prevention and control measures, it is predicted that the cumulative patients would reach the maximum of 234 on February 12, and the outbreak would be over on March 20 in Changsha. With the fully implementation of prevention and control measures, it could effectively reduce the peak value, short the time to peak and duration of the outbreak.

## List of abbreviations

1. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)
2. World health organization (WHO)
3. Public health emergencies of international concern (PHEIC)
4. Coronavirus disease 2019 (COVID-19)
5. Susceptible-exposed-infections/asymptomatic- removed (SEIAR)

6. Regeneration number (Rt)
7. Confidence interval (*CI*)
8. Severe acute respiratory syndrome (SARS)
9. Middle east respiratory syndrome (MERS)

## Declarations

### Ethics approval and consent to participate

Not applicable

### Consent for publication

Not applicable

### Availability of data and materials

All data and material in our study were availability

The reported case of COVID-19 in Changsha were collected from the Health Commission of Changsha. http://wsjkw. changsha.gov.cn/ztzl_1/fkxxgzbd/index.html. The proportion of recessive infection in Hunan were collected from the Hunan Center for Disease Control and Prevention.

### Competing interests

The authors declare that they have no competing interests.

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**Authors' contributions**

W Z and N Z mainly responsible for the data analysis, model building and drafting of article;

G L and W L mainly responsible for the chart making;

H Z, S Z, M C and R F mainly responsible for the collection of data and searching for relevant parameters;

T L mainly responsible for the correction of English;

Y L mainly responsible for sponsorship of funds and final review of the article.

All authors read and approved the final manuscript.

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**Tables and Figures**