Real-time assessment of COVID-19 epidemic in Guangdong Province, China using mathematical models

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Abstract: China government has relaxed the response measures of COVID-19 in early December 2022. In this report, we assessed the number of infections, the number of severe cases based on the current epidemic trend (October 22, 2022 to November 30, 2022) using a transmission dynamics model, called modified susceptible-exposed-infectious-removed (SEIR) to provide valuable information to ensure the medical operation of the healthcare system under the new situation. Our model showed that the present outbreak in Guangdong Province peaked during December 21, 2022 to December 25, 2022 with about 14.98 million new infections (95% CI: 14.23–15.73 million). The cumulative number of infections will reach about 70% of the province's population from December 24, 2022 to December 26, 2022. The number of existing severe cases is expected to peak during January 1, 2023 to January 5, 2023 with a peak number of approximately 101.45 thousand (95% CI: 96.38–106.52 thousand). In addition, the epidemic in Guangzhou which is the capital city of Guangdong Province is expected to have peaked around December 22, 2022 to December 23, 2022 with the number of new infections at the peak being about 2.45 million (95% CI: 2.33–2.57 million). The cumulative number of infected people will reach about 70% of the city's population from December 24, 2022 to December 25, 2022 and the number of existing severe cases is expected to peak around January 4, 2023 to January 6, 2023 with the number of existing severe cases at the peak being about 6.32 thousand (95% CI: 6.00–6.64 thousand). Predicted results enable the government to prepare medically and plan for potential risks in advance.

Keywords: Coronavirus disease 2019 (COVID-19); susceptible-exposed-infectious-removed (SEIR); prediction; potential risks

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Introduction

From the end of December 2019 to December 2022, the spread of COVID-19 in China could be summarized into three stages, namely, the stage of the wild strain found in Wuhan, the stage of the delta variant found in India and the stage of the Omicron variant in South Africa. In the first stage, we incorporated population migration data as well as the latest epidemiological data from COVID-19 into a susceptible-exposed-infected-removed (SEIR) model to obtain epidemic transmission curves. We also used an artificial intelligence (AI) approach, trained on 2003 SARS data, to predict the epidemic. The predicted results suggest that control measures are essential to reduce the size of the eventual COVID-19 outbreak (1). In the second stage, with stronger spread of Delta subtype, under the measure of "dynamic clearing" and strict control, our team combined the modified SEIR model and autoregressive integrated moving average (ARIMA) model to make predictions. The ARIMA model evaluates the R_t values and plays an important role in the correction of SEIR model results. In the third stage, the Omicron variant has presented its enhancement on transmission and the reduction on pathogenesis. It has grown rapidly to be the main virus strain on the world since November 2021. Most countries encounter one or more peak after deregulation. For instance, Thailand and Japan were deregulated at December 2021 and March 2022 separately. After that, Thailand met with a peak at March 2022 while Japan met two at August 2022 and January 2023. Since more people are infected by the SARS-CoV-2 virus, more people are die because of the disease. Meanwhile, they both encounter an increment on excess mortality. However, the case fatality rate did not increase in Japan. Omicron virus propagation was dominant while the Chinese government successively took a dynamic clearance and optimized control measures. Before the optimization of the epidemic control measures, we used a combination of Empirical Mode Decomposition and Long Short-Term Memory methods to forecast. After the relaxation of control, as the most populous country in the world, China may face the risk of a continuous increase in the number of infections and a lack of medical resources in the future. Therefore, the study used the modified SEIR transmission dynamics model to forecast the epidemic trend for Guangdong Province and Guangzhou City under the recent measures to offer support for the properly operation of the medical system.

Methods

In this section, we briefly introduce data sources, the modified SEIR model and estimation of parameters in the model.

Data sources and premises

The epidemiological data we used in this study is based on the daily COVID-19 infective numbers reported by the National Health Commission of China from October 22 to November 30, 2022 since the relaxation response measures were released at the beginning of December, 2022 (2). The total population of Guangdong Province and Guangzhou City are found in Guangdong statistical yearbook (3). The transmission parameters of Omicron BA.5.2 will be used for calculations in the experiments (4). It is assumed that the rate of severe case is constant when overwhelming the medical capacity (4,5).

Modified SEIR model

We modified the SEIR commonly used in epidemiological analysis by adding critical/severe and death population compartment (short for C and D in *Figure 1*).

In this five compartmental model, let S(t), E(t), I(t), R(t), C(t) and D(t) denote the number of individuals in the susceptible, exposed, infectious, recovered critical and death class at time t respectively. Taking all the above considerations into account we are led to the following dynamical system:

$$\frac{dS(t)}{dt} = -\frac{\beta S(t) I(t)}{N} \quad [1]$$

$$\frac{dE(t)}{dt} = \frac{\beta S(t) I(t)}{N} - \sigma E(t) \quad [2]$$

$$\frac{dI(t)}{dt} = \sigma E(t) - \gamma_I I(t) - \lambda I(t) - \xi I(t) \quad [3]$$

$$\frac{dR(t)}{dt} = \gamma_I I(t) + \gamma_C C(t) \quad [4]$$

$$\frac{dC(t)}{dt} = \lambda I(t) - \gamma_C C(t) \quad [5]$$

$$\frac{dD(t)}{dt} = \xi I(t) \quad [6]$$

with the initial conditions $S(0) = S_0$, $E(0) = E_0$, $I(0) = I_0$, $R(0) = R_0$, $C(0) = C_0$, $D(0)=D_0$, where

S_0: The number of susceptible people in Guangdong

Province and Guangzhou City whose data are found in Guangdong statistical yearbook.

$E_0=R_0=C_0=D_0=0$,

I_0: The number of infected people in December 1, 2022.

Model parameters

We used the expert consultation method [Delphi method (6)] to estimate the severe rate, consulting experts from the study group of senior researchers who are experts in the fields of public health, biology, and mathematical modeling. Combining statistics from mainland China, Taiwan, Hong Kong, and neighboring countries, including Japan, and Singapore, we estimated the rate of severe disease in COVID-19 infection to be about 0.2% (4). The predicted outcome of this report is the number of infections, including the number of confirmed cases and the number of asymptomatic infections; therefore, we used the number of infections as the denominator for both the rate of severe and death cases. The detailed of parameters can be described in *Table 1*.

Considering the small number of severe patients and the fact that they generally stay at hospital and do not cause transmission in the community, β was calculated using γ_I, that is, $\beta=Re*\gamma_I$, where Re represents effective reproduction number which is computed by R Programming Language with EpiEstim package base on the infective data from October 22 to November 30, 2022. According to the reference (7) we assume that the incubation rate is 2. It follows that the probability of recovery for general infections γ_I is 5.2 due to the equation: Generation time = The incubation rate + The probability of recovery for general infections/2, where the generation time is obtained by the reference (7). According to the hospital, there are not many severe patients in COVID-19, and the severity rate depends on the basic diseases of patients. Thus we take the same value on γ_C with γ_I. For high-risk groups, such as the elderly, more care is usually taken to prevent infection at home. Moreover, after infection, the course of the disease progresses to severe disease in about 3–4 days (8). Thus severe disease will be one to two weeks later than the peak of infection. Under the assumption of 7 days the severe rate equals to 0.2%. It was concluded that the ratio of severe case to death rate was about 1 to 0.1818, so the final estimated rate of death (death rate of the number of infected) was 0.036%.

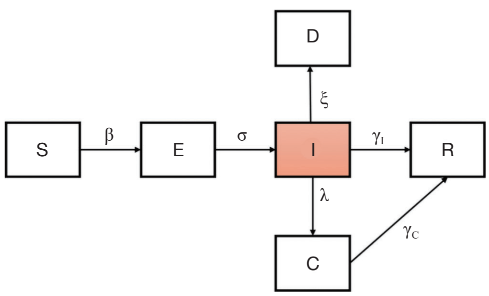

Figure 1 The SEIR-CD model. SEIR, susceptible-exposed-infectious-recovered model; CD, critical/severe and death population.

Results

Based on the number of infections in the first 40 days of the optimization measures, i.e., from October 22, 2022 to November 30, 2022, we predicted the epidemic in Guangdong Province and Guangzhou City using the SEIR-CD model. The predicted time range was from December 1, 2022 to March 1, 2023.

Guangdong Province

Starting from December 1, 2022, the prediction under

Table 1 The parameters in SEIR-CD model

Parameters	Description	Values	Source
β	The rate of transmission for the susceptible to exposed	89%	R Programming Language with EpiEstim package
σ	The incubation rate	50%	Leung K, Leung GM, Wu J (7)
γ_I	The probability of recovery for general infections	19%	Leung K, Leung GM, Wu J (7)
γ_C	The probability of recovery for severe infections	19%	Leung K, Leung GM, Wu J (7)
λ	The severe rate	0.2%	Huang Z, Xu S, Liu J, *et al.* (5)
ξ	The death rate	0.036%	Huang Z, Xu S, Liu J, *et al.* (5)

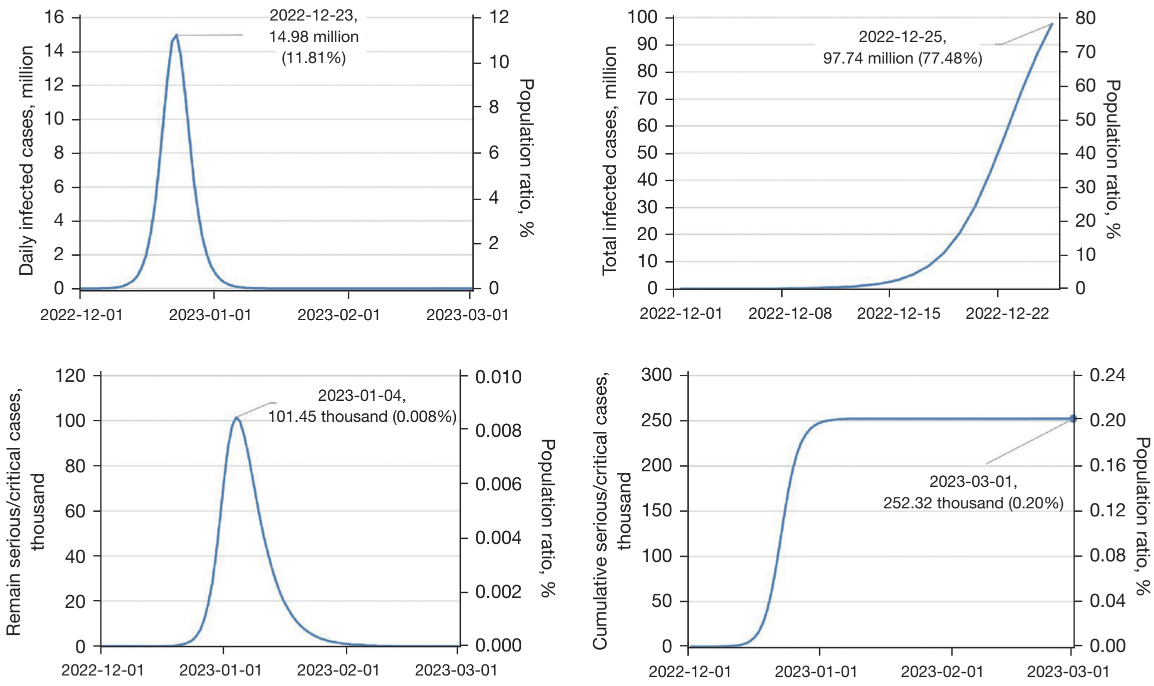

Figure 2 Prediction of Guangdong Province.

the relaxation of control measures across the country are shown in *Figure 2*. The current round of the epidemic in the province is expected to reach its peak around December 21, 2022 to December 25, 2022 with about 14.98 million infections (95% CI: 14.23–15.73 million). The cumulative number of infected people will reach about 70% of the province's population from December 24, 2022 to December 26, 2022. The number of existing severe cases is expected to peak around January 1, 2023 to January 5, 2023. At the peak, the number of severe cases is about 101.45 thousand (95% CI: 96.38–106.53 thousand). The cumulative number of severe cases is expected to reach about 252.32 thousand (95% CI: 239.70–264.94 thousand).

Guangzhou City

The results of Guangzhou City were shown in *Figure 3*. The current round of epidemic in Guangzhou is expected to have peaked around December 22, 2022 to December 23, 2022 with the number of new infections at the peak being about 2.45 million (95% CI: 2.33–2.57 million). The cumulative number of infected people will reach about 70% of the city's population from December 24, 2022 to December 25, 2022. The number of existing severe cases is expected to peak around January 4, 2023 to January 6, 2023 with the number of existing severe cases at the peak being about 6.32 thousand (95% CI: 6.00–6.64 thousand). The cumulative number of severe cases is expected to reach about 15.05 thousand (95% CI: 14.30–15.80 thousand).

Discussion

Despite the weakened pathogenicity of the Omicron variant, increased vaccination rates, accumulated experience in prevention and control, and changes in the global epidemic, the epidemic risk in China remains critical due to a huge population base, uneven development between east and west and urban and rural areas, low and uneven distribution of healthcare resources per capita, and insufficient vaccination rates for the elderly.

Our model predicted the cumulative number of infected people in Guangdong Province will reach about 70% of the province's population by December 25, 2022, while December 23, 2022 in Guangzhou. Guangdong Province faces a major public health challenge because of its dense population of 12.7×10^6 residents. Although we don't have real data to show, our peak forecast time should also be earlier than other cities in our country according to Chinese center for disease control and prevention.

The current global COVID-19 is still in an epidemic and

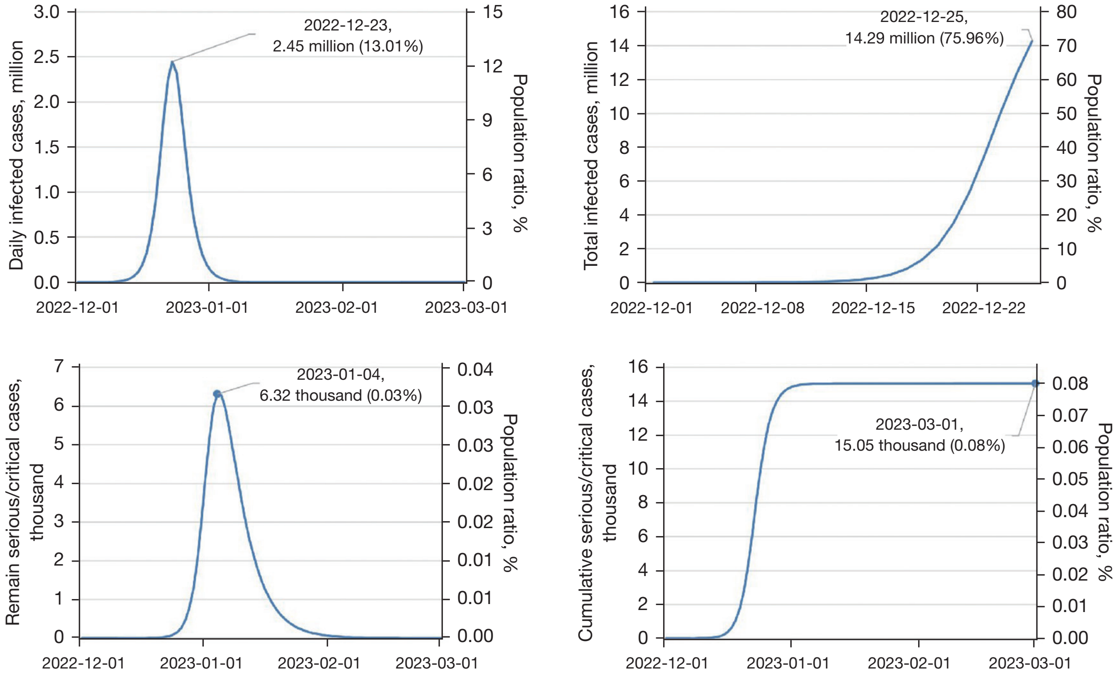

Figure 3 Prediction of Guangzhou City.

mutated situation. Although the pathogenicity of Omicron is weakened, the transmission is significantly enhanced by the winter and spring climate and other factors. It can be seen that the epidemic is inevitably growing in a big scale of transmission.

Therefore, prevention of severe cases and avoidance of overwhelming of the medical capacity are key to future epidemic control, especially during the peak of a pandemic. Regarding the new situation of epidemic control, the current focus point is shifting from control of infection to prevention of severe cases, strengthening avoidance against secondary infection is the next key step. Our team provides the government with reliable information that helps in the early preparation and rational allocation of medical resources.

In order to study whether the next large-scale COVID-19 epidemic is likely to occur, the arrival time and the number of infected people, we checked the information of COVID-19 epidemic in 22 developed countries or regions in 2022 on Our world in data website (https://ourworldindata.org/coronavirus). According to statistics, the average period between the two infection peaks in these countries or regions is 149.35 days (median: 161 days), and the average number of new cases in the second peak of infection is 48.61% (median: 41.72%) of the first peak. These may be attributed to the decaying effect of antibodies, and we speculate that the next phase of epidemic may be in May, 2023 and requires attention.

Conclusions

The modified SEIR model can effectively predict the peak and scale of the SARS-CoV-2 outbreak under the relaxation of control measures. The evaluations are required to help visualize social and public health measures and to minimize the mortality risk of SARS-CoV-2 on the daily life.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-47/coif). The series "Current Status of Diagnosis and Forecast of COVID-19" was commissioned by the editorial office without any funding or sponsorship. ZY and WG served as the unpaid Guest Editors of the series. JH serves as Executive Editor-in-Chief of *Journal of Thoracic Disease*. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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