



Prediction of the Epidemic of COVID-19 Based on Quarantined Surveillance in China

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Abstract

Background and Objective: To predict the epidemic of COVID-19 based on quarantined surveillance from real world in China by modified SEIR model different from the previous simply mathematical model.

Design and Methods: We forecasted the epidemic of COVID-19 based on current clinical and epidemiological data and built a modified SEIR model to consider both the infectivity during incubation period and the influence on the epidemic from strict quarantined measures.

Results: The peak time of the curve for the infected newly diagnosed as COVID-19 should substantially present on Feb 5, 2020 (in non-Hubei areas) and Feb 19, 2020 (in Hubei). It is estimated that the peak of the curve of the cumulative confirmed cases will appear in non-Hubei areas on Mar 3, 2020 and in Hubei province on Mar 10, 2020, and the total number of the patients diagnosed as COVID-19 is 18,000 in non-Hubei areas and 78,000-96,000 in Hubei. The Chinese COVID-19 epidemic can be completely controlled in May, 2020.

Conclusions: COVID-19 is only a local outbreak in Hubei Province, China. It can be probably avoided the pandemic of global SARS-CoV-2 cases rise with the great efforts by Chinese government and its people.

Keywords

COVID-19; SARS-CoV-2; Quarantined surveillance; Modified SEIR model; China

Introduction

The first case of pneumonia of unknown aetiology was reported in Wuhan, Hubei Province in China on Dec 8, 2019, and the epidemic spread rapidly in Wuhan, Hubei Province and the surrounding areas of Hubei Province [1,2]. A novel coronavirus was identified as the causative agent by the Chinese authorities on Jan 7, 2020, and World Health Organization (WHO) designated the novel coronavirus as 2019-nCoV on Jan 10, 2020. Later, WHO defined the pneumonia as COVID-19 associated with infecting SARS-CoV-2.

According to the statistics of National Health Commission of People's Republic of China (www.nhc.gov.cn), by at 12:00 on Feb 17, 2020, a total of 441 individuals, including 137 individuals in Singapore and Japan together, were diagnosed as COVID-19 outside of China, and a total of 70,639 infected cases in mainland China (with a total population of 1400.05 million), including 58,182 infected cases were diagnosed as COVID-19 associated with SARS-CoV-2 in Hubei Province (with a total population of 59.4 million, accounting for 4.2% of the total population in mainland China), accounting for 82.4% of the total count of the infected individuals in China, and including 41,152 cases in Wuhan (with a total population of 11.08 million), accounting for 70.7% of the total number of the infected individuals in Hubei Province (accounting for 18.7% of the total population in Hubei Province). There were 9 cities in Hubei Province, such as Xiaogan (with a total population of 5 million), Huanggang (with a total population of 7 million), Jingzhou, Suizhou, Xiangyang, Ezhou, Huangshi, Jingmen and Yichang, with more than 1,000 infected patients respectively.

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And outside of Hubei Province, there were 6 provinces, including Guangdong, Henan, Zhejiang, Hunan, Anhui and Jiangxi, with more than 900 infected patients respectively. The total infected patients in these six provinces accounted for 53.4% of the total infected individuals outside of Hubei Province, particularly in Wenzhou and Shenzhen, the mere two cities, with a total of more than 400 infected persons outside of Hubei Province.

After Wuhan was sealed off on Jan 23, 2020, other cities in Hubei Province successively started to isolate residential quarters and villages and shut off the traffic to halt the migration both in urban and in rural regions. According to Tencent's big data (<https://heat.qq.com/>) and Location Intelligence (www.wayhe.com), from Jan 1, 2020 to Jan 24, 2020, the population outflow from Wuhan was about 5 million, with 65% of the outflow into other cities in Hubei Province, such as Huanggang and Xiaogan (accounting for 27.0% together), and with 55% of the outflow outside of Hubei Province, including Henan, Guangdong, Zhejiang, Hunan, Jiangxi and Anhui together. The remainder population was 9 million in Wuhan, which was the most severe epidemic region. The strictly blocked and isolated measures had been taken in other cities in Hubei before the local outbreak of SARS-CoV-2, which had not caused fulminating infection similar to Wuhan. In Hubei and other areas with serious epidemic situation, Chinese government had taken the strictly blocked and isolated control, including the infected, the suspiciously infected individuals and the susceptible intimately contacted with the infected and the suspiciously infected individuals, involved the independent community buildings and villages, which were separated and quarantined in a unified way. On Jan 28, 2020, JAMA magazine interviewed Professor NIH of the United States, and affirmed that the Chinese government adopted the strategy of closure and quarantine against the epidemic.

Many academics tried to estimate key epidemiological characteristics and possible outcomes of the epidemic by means of transmission model mathematically. On Jan 24, 2020, Jonathan M. Read [3] estimated the basic reproduction index (R_0) for SARS-CoV-2 to be between 3.6 and 4.0, then and COVID-19 would outbreak further both in other Chinese cities and in international travel destinations such as Thailand, Japan, Taiwan, Hong Kong and South Korea at an sharply increasing rate [3]. According to his model, he predicted the number of infected individuals in Wuhan to be greater than 190 thousand by Feb 14, 2020 although with a 99% effective reduction as a result of travel restrictions, the size of the epidemic outside of Wuhan might only be reduced by 24.9%. His model suggested that travel limitation from and to Wuhan city were unlikely to be effective in halting transmission across China.

Professor Joseph T Wu considered R_0 of SARS-CoV-2 as 2.68 by MCMC method and SEIR model [4], and forecast that COVID-19 was no longer contained within Wuhan, other major Chinese cities (Chongqing, Beijing, Shanghai, Guangzhou and Shenzhen) were probably sustained localised outbreaks, including large cities overseas with close transport links to China. However, there were some deficiencies in his study: underestimating the strength of the strictly isolated measures and the initial and maintaining time by Chinese government and neglecting the significant difference about R_0 between in Hubei and in non-Hubei areas [5].

The above data from real world in China threw a hit on their predictions on the COVID-19 epidemic simply taking advantage of epidemiological model but ignoring quarantined measures and different R_0 .

Design and Methods

There was no quarantined measure in the early stage of the epidemic, so R_0 , as the basic reproductive index, was often high for SARS-CoV-2 [6,7], and there was a significant difference between in Hubei and in non-Hubei areas, but both decreased gradually with the strengthening of isolated measures [8,9].

We forecast the epidemic of COVID-19 by modified SEIR model

[10,11] and current clinical and epidemiological data on COVID-19, involved in two practical factors to correct the model: 1) considering the infectivity during incubation period [12]; 2) considering the influence on the epidemic from strictly quarantined measures. It had been confirmed that both the latent and the infected are infectious. We assumed that both were with the same infectivity. According to the epidemic data before Feb 1, 2020, it indicated that the probability from the exposed to the infected was 1.7% [13,14], and the average incubation period was 7 days, and the average hospital stay was 14 days [15,16]. The average daily contact rate of the infected was 6, referring to the statistical data from CCDC in the early stage of SARS epidemic in 2003 [17-19]. However, the population density in Hubei Province was 2.3 times the national average, so the daily contact rate in Hubei was 13.8, and the average daily contact rate of the latent was twice as the infected. The calculation method was $R_0 = \text{average daily contact rate} \times \text{probability of the exposed to the infected} \times \text{infection period}$. The average infection period was 21 days. Therefore, R_0 was 4.9-9.9 in Hubei, but 2.5-4.8 in non-Hubei areas. However, R_0 would gradually decrease with the progress of the epidemic for the sake of strengthened isolation and blocking measures [20]. The median value of R_0 was 7.5 in Hubei. According to the statistical data from Hubei Provincial Center for Disease Control and Prevention (<http://wjw.hubei.gov.cn/>), there were 27 patients diagnosed as COVID-19 and 0 death in Wuhan on Dec 31, 2019. Since nobody approached to obtain the quantity of the latent during epidemic period early [21], we had to deduce the quantity of the latent by the subsequent epidemiological data, the probability from the latent to the infected, which was 14.0%. Consequently, the possible quantity of the latent was 208 individuals in Hubei on Dec 31, 2019. Assuming that there was only one hidden infected individual with COVID-19 in non-Hubei area at that time, the quantity of the latents was 8 individuals in non-Hubei areas.

We forecast the epidemic of COVID-19 both in Hubei and in non-Hubei areas by modified SEIR model by the software K-SEIR simulator (v1.0) [22], combined with the epidemic data of the last 45 days, and aimed to obtain the possible total number of the infected individuals diagnosed as COVID-19 in Hubei and in non-Hubei areas and the time eliminating the epidemic of SARS-CoV-2 in Hubei and in non-Hubei areas. The modified SEIR model was as listed below. S, E, I, R, S_m, E_m represent the susceptible individuals, exposed individuals, infected individuals, resistant individuals, susceptible individuals quarantined for being observed medically and the exposed individuals quarantined respectively. The conversion speed rate of E, S_m, E_m is $c\beta$ ($1-q$), cq ($1-\beta$) and cq respectively. According to MCMC and CCDC, we estimated the mean value for the parameters of COVID-19 (Table 1).

$$\frac{dS}{dt} = -[c\beta + cq(1-\beta)]S(I+E) + v_1S_m$$

$$\frac{dE}{dt} = c\beta(1-q)S(I+E) - v_2E$$

$$\frac{dI}{dt} = v_2E - (v_3 + \mu + \gamma_1)I$$

$$\frac{dR}{dt} = \gamma_1I + \gamma_2E_m$$

$$\frac{dS_m}{dt} = cq(1-\beta)S(I+E) - v_1S_m$$

$$\frac{dE_m}{dt} = c\beta q(I+E)S(I+E) - v_2S_m$$

Results

The quarantined efficiency depended on the occasion and strength of blocking and isolation [23,24]. The strength of blocking and isolation included the intensity and scope of containment. The lower c value signifies stern surveillance and better halting transmission.

Nevertheless, the lower q value indicates deficient quarantine on the infected and exposed individuals giving rise to increased total number of COVID-19. Theoretically, the maximal reducing number of the possible infected individuals could be calculated by the formula [25]: $1 - 1/R (1 - 1/7.5) \times 100\%$, about 86.7%. In China, in the early stage of COVID-19 epidemic, the most severe isolated measures had been taken in the areas where epidemic was likely to be serious according to the population outflow from Wuhan. Both the occasion and intensity of quarantined measures were far greater than that during influenza outbreak in the United States in 1918. In this study, it was proved to be 90% efficacy in halting transmission by the blocked and isolated measures, so the size of the epidemic could be reduced by $87.0\% \times 90\%$, about 78.0%.

The ultimate population outflow from Wuhan on Jan. 23, 2020 was the most source of transmission, based on the incubation period of 1-14 days, so the peak time of the curve for the infected newly diagnosed as COVID-19 should substantially present on Feb 5, 2020 (in non-Hubei areas) and Feb 19, 2020 (in Hubei) for the intensive blocked and isolated measures resulting in population mobility accessible to zero during the Spring Festival. It is estimated that the peak of the curve of the cumulative confirmed cases will appear in non-Hubei areas on Mar.3, 2020 and in Hubei province on Mar 10, 2020, and the total number of the patients diagnosed as COVID-19 is 18,000 in non-Hubei areas and 78,000-96,000 in Hubei. The Chinese COVID-19 epidemic can be completely controlled in May, 2020.

Discussion

From the above, it could be seen that our study was principally based on the epidemiological characteristics of the COVID-19 in recent 45 days and modified SEIR model, which was quite different from other absolutely theoretical models, mainly as follows:

1. Our study was based on the epidemiological characteristics of the COVID-19 according to epidemic situation, considering that the incubation period was still infectious;
2. Evaluating R_0 was on the basis of the big data of epidemic situation, R_0 was 4.9-9.9 (the median R_0 7.5) in Hubei, but 2.5-4.8 (the median R_0 3.7) in non-Hubei areas;
3. The occasion and intensity of the blocked and isolated measures by Chinese government were unprecedented and efficient in scale, which prevented SARS-CoV-2 out breaking in non-Hubei area;
4. In scale, the COVID-19 epidemic was currently a local public health emergency in Hubei Province in China;
5. Our insufficiency:
 - i. whether there was a significant difference in infectivity between the latent and the infected and it required to be further confirmed in clinical practice;
 - ii. the blocked and isolated measures had been implemented differently in different areas due to different economic, cultural and management levels;
 - iii. the maintaining time of the blocked and isolated measures is still in suspense;
 - iv. whether the epidemic will relapse owing to the surveillance paralysis and the complicated population migration caused by returning to work in a large number of enterprises;
 - v. for SEIR model by itself, the limitations on considering little on other vital factors, such as the improvement of prevention, treatment experience and control measures, the advent of new medication, building new hospitals to shorten waiting time in hospital, are not considered, in addition, the setting of each coefficient is still subjective based on clinical practice.

Substantially, COVID-19 is only a local outbreak in Hubei Province, China, on the basis of the big data of epidemic situation and different R_0 value between Hubei Province and non-Hubei areas.

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