2019 in Jilin Province, China

Running title: Assessing countermeasures to control COVID-19

Qinglong Zhao#, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China. Email: jlcdczql@126.com

Yao Wang#, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: 812304436@qq.com

Meng Yang#, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: yangmeng0531@163.com

Meina Li, The first Hospital of Jilin University, Changchun 130021, Jilin Province, People's Republic of China; Email: lmn_1982@yeah.net

Zeyu Zhao, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: 381597586@qq.com

Xinrong Lu, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China. Email: luxr78@foxmail.com

Bo Shen, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China; Email: 76000471@qq.com

Bo Luan, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China; Email: 443023974@qq.com

Yifei Zhao, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China; Email: 1741153413@qq.com

Bonan Cao, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China; Email: cbnanys@163.com

Laishun Yao, Jilin Provincial Center for Disease Control and Prevention, Changchun, 130062, Jilin Province, People's Republic of China; Email: yls@jlcdc.com.cn

Benhua Zhao, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: benhuazhao@163.com

Yanhua Su*, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: suyanhua813@xmu.edu.cn

Tianmu Chen*, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University, Xiamen City 361102, Fujian Province, People's Republic of China; Email: 13698665@qq.com

[#]These authors contributed equally to this study.

***Correspondence:**

Tianmu Chen

State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University

4221-117 South Xiang'an Road, Xiang'an District, Xiamen City, Fujian Province, People's Republic of China

Email: chentianmu@xmu.edu.cn, 13698665@qq.com

Yanhua Su,

State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, School of Public Health, Xiamen University

4221-117 South Xiang'an Road, Xiang'an District, Xiamen City, Fujian Province, People's Republic of China

Email: suyanhua813@xmu.edu.cn

Abstract

Objective: This study aimed to calculate the transmissibility of coronavirus disease 2019 (COVID-19), and to evaluate the effectiveness of countermeasures to control the disease in Jilin Province, China.

Methods: The data of reported COVID-19 cases were collected, including imported and local cases from Jilin Province as of March 14, 2019. A Susceptible–Exposed–Infectious–Asymptomatic–Recovered (SEIAR) model was developed to fit the data, and the effective reproduction number (R_{eff}) was calculated at different stages in the province. Finally, the effectiveness of the countermeasures was assessed.

Results: A total of 97 COVID-19 infections were reported in Jilin Province, among which 45 were imported infections (including one asymptomatic infection) and 52 were local infections (including three asymptomatic infections). The model fit well with the reported data (R^2 = 0.593, P < 0.001). The R_{eff} of COVID-19 before and after February 1, 2020 was 1.64 and 0.05, respectively. Without the intervention taken on February 1, 2020, the predicted cases would reach a peak of 177011 on October 22, 2020 (384 days from the first case), and 17129367 cases would be reported until the end of the outbreak (on October 9, 2021), with a total attack rate of 63.66%. These results revealed that the interventions implemented in Jilin Province had reduced more than 99.99% cases.

Conclusions: COVID-19 has a moderate transmissibility in Jilin Province, China. The interventions implemented in the province had great effectiveness.

Keywords: COVID-19, China, epidemic, disease countermeasures, disease transmissibility

Background

Coronavirus disease 2019 (COVID-19) is caused by the novel coronavirus with typical symptoms of fever, dry cough, shortness of breath, and fatigue[1, 2]. The incubation period of COVID-19 was reported to be 3-7 days, with a minimum of one day and a maximum of 14 days. Nucleic acid detection and genome sequencing have commonly been conducted with pharyngeal swabs, sputum, alveolar lavage fluid, feces, and other samples from patients to detect COVID-19 virus[3-7]. It has been reported that COVID-19 can be transmitted person-to-person, with the main transmission methods being air transmission and contact transmission[8-12]. Therefore, persons can be infected by exposure to the outside environment and the virus can be spread by inhaling COVID-19 droplets or aerosols that are exhaled into the air by the source of the infection, or people can be infected by contact with virus-contaminated items.

Due to its diverse transmission routes and strong transmissibility, COVID-19 has become a global epidemic in a short period of time. The World Health Organization (WHO) announced that this epidemic was a public health emergency of international concern. As of April 8th, more than 200 countries and regions have experienced COVID-19 outbreaks Furthermore, the number of confirmed cases worldwide has become as high as 1,353,361 and there have been 79,235 cumulative deaths[13]. According to the report of the Chinese Health Commission, as of April 9, a total of 81,865 confirmed cases and a total of 3,335 deaths in China have been reported[14]. According to data from the Jilin Provincial Center for Disease Control and Prevention, a total of 98 cases with one death were reported[15]. On January 25, Jilin Province launched the Public health events level I emergency response, and took measures to control the non-resident population, such as isolation and observation at home, disinfection and sterilization, temperature measurement screening, wearing masks, etc.[16]. Since then, the epidemic situation in Jilin Province has been checked. Although the severity of the domestic epidemic has declined, the problems of imported cases and asymptomatic cases have still been very serious.

At present, several studies of COVID-19 transmission models have been reported to evaluate the transmissibility of COVID-19 virus and predict the future epidemic situation[8, 17-19]. However, the more important issue at present is to consider asymptomatic infections when designing models. Asymptomatic infection refers to cases who tested positive for COVID-19 in the laboratory tests, yet had mild or even no symptoms. Asymptomatic cases can potentially transmit the virus to others. It is predicted that at least 59% of infectious cases have not been tested[20]. Therefore, ignorance of asymptomatic infections may have a greater impact on the effectiveness of the model, while at the same time, traditional infectious disease models were built under the condition that the disease is allowed to develop[2, 8, 17, 18, 21-25]. However, China declared a first-level health emergency in the early stage of the outbreak, and with a strict supervision system and the high degree of cooperation of the people, a series of prevention and control measures, such as wearing masks, restricting travel, and suspending work and school were implemented. In this study, our COVID-19 model was established with comprehensive consideration of most of the possibilities of comprehensive prevention and control measures that exist. Moreover, there is no domestic province that can be used to construct a dynamic model of the spread of COVID-19 according to the local population characteristics and epidemic distribution. Hence, the transmissibility of COVID-19 in Jilin Province is still unclear and the effect of current prevention and control measures on the epidemic still needs to be explored. This study focused on the susceptible–exposed–infectious–asymptomatic–recovered (SEIAR) model based on the distribution of outbreaks in Jilin Province. The various parameters in the model were calculated based on the actual cases obtained, so it is closer to the real situation; the fit of the model to the actual data was explored, the effectiveness of current prevention and control measures was evaluated, and the progress of the epidemic without measures was predicted.

Methods

Data collection

The case information collected in this article was provided by the Jilin Provincial Center for Disease Control and Prevention, including onset date, diagnosis date, date of contact with related cases, disease severity, and laboratory diagnosis of different case types. In addition, the permanent population of Jilin Province comes from the "Jilin Statistical Yearbook."

Transmission model

According to the COVID-19 propagation dynamic model that this team has built[26], the SEIAR model of "person-to-person,," secondary cases of COVID-19 were only prevalent in Jilin Province for 27 days. The natural birth rate and mortality rate of the population during this period were negligible. Therefore, on this basis, we have improved the model by excluding the natural birth and natural death of various populations to construct a SEIAR model of COVID-19 in Jilin Province. The model is based on the following assumptions:

（1）The model divides the population into five categories: susceptible (S), exposed (E), infectious (I), asymptomatic (A), and removed (R).

（2）Both I and A are infectious, and A's transmissibility is k times that of I ($0 < k < 1$). S may be infected when exposed to I and A, and the infection rate coefficient is β. Therefore, at time t, the infected S is $\beta S(I + A)$.

（3）Among E, the proportion of those who develop asymptomatic infections is p, the incubation period is $1/\omega$, and the incubation period is $1/\omega'$. Then at time t, there is $p\omega' E$ persons in E who develops into A, and $(1-p)\omega E$ persons become I.

（4） I from the onset to admission is $1/\gamma$ days, that is, there are γI admitted to the hospital in unit time. Therefore, at time t, there are γI people in I who change to movers. The case fatality rate of I is f, so at time t, fI people die in I.

（5）A has an infectious period of $1/\gamma'$, that is, γ' persons in A escape from the infectious period in unit time. Therefore, at time t, there are $\gamma' A$ people in A who are transformed into movers.

Therefore, the framework of the SEIAR model with the natural birth rate and mortality rate of the population removed is shown in Figure 1. The differential equations of the model are as follows:

$$
\begin{aligned}
&dS/dt = -\beta S(I + kA) \\
&dE/dt = \beta S(I + kA) - p\omega' E - (1-p)\omega E \\
&dI/dt = np + (1-p)\omega E - \gamma I \\
&dA/dt = p\omega' E - \gamma' A \\
&dR/dt = \gamma I + \gamma' A
\end{aligned}
$$

Parameter estimation

The total number of susceptible people comes from the number of permanent residents in Jilin

Province recorded in the Jilin Statistical Yearbook. According to the actual incidence characteristics of COVID-19 in Jilin Province, the cases were divided into two types: imported cases as the source of infection and secondary cases used as the actual data to fit the model. According to the trend of the secondary cases over time, using February 1 as the cut-off point, the time distribution curve of the continuation of cases was divided into two sections and fitted by the model separately, and the β value in different time periods were obtained (β_1 and β_2).

According to previous research by our team, the transmissibility of asymptomatic infections is the same as for infections, $k = 1$. There were four asymptomatic infections among 97 cases in Jilin Province, that is, the proportion of asymptomatic infections was 0.04. To calculate the time interval from infection to symptom onset in all cases in Jilin Province, except for asymptomatic infections, the median was calculated as 10. Checking the previous literature showed that the COVID-19 incubation period of asymptomatic infections is the same as that of infections[26], therefore, $\omega = \omega' = 0.1$. The time interval from the onset to admission of infectious cases in Jilin Province was calculated, and the median was 3. Because asymptomatic infections are mostly admitted to hospital for isolation treatment for intensive contacts the infections, and the proportion of asymptomatic infections in Jilin Province is small, the period of infection of asymptomatic infections is similar to that of infections. Therefore, $\gamma = \gamma' = 0.33$. According to the statistics of COVID-19 in Jilin Province, there was only one death in all patients, so in the COVID-19 model in Jilin Province, the mortality rate f was negligible, that is, $f = 0$. The model parameter values and methods are shown in Table 1.

Transmissibility of COVID-19

Under ideal circumstances, the basic reproduction number (R_0) can be used to quantify the transmissibility of COVID-19[26-29], R_0 is the number of cases where the source of infection directly spread during the infection period. Comparing the R_0 value with 1 can be used as an index to evaluate whether the disease is prevalent. If the evaluated disease does not spread in a natural state, such as the application of isolation, vaccines, and other interventions, R_0 cannot reflect the actual spread of the disease. At this time, an effective reproduction number (R_{eff}) is needed to represent transmissibility. Based on previous research[30-32], R_{eff} can be expressed by the following equation:

$$\lim_{dr\to\infty} R_{eff} = \beta S\left(\frac{1-p}{\gamma+f}+\frac{\kappa p}{\gamma'}\right)$$

At the same time, because the mortality rate of COVID-19 in Jilin Province is close to 0, the equation can be simplified to:

$$R_{eff} = \beta S\left(\frac{1-p}{\gamma}+\frac{\kappa p}{\gamma'}\right)$$

Simulation method and statistical analysis

The software Berkeley Madonna 8.3.18 was used to model the actual cases, and the fourth-order Runge-Kutta method was used to solve the differential equations. Curve estimation in SPSS 20.0 was used to compare the fitted data with the actual data, and observe the P and R^2 values to judge the goodness of fit.

Results

Epidemiological characteristics

As of March 14, a total of 97 COVID-19 infections, including 45 imported infections (including one asymptomatic infection) and 52 secondary infections (including three asymptomatic infections), were reported. The first case in Jilin Province was an imported case whose onset date was January 12, 2020, while the latest case was a secondary case whose onset date was February 9, 2020. The peak date of the incidence of imported cases was January 22, and the peak of local cases was February 1. The stacked histogram of changes is shown in Figure 2.

Regarding the gender breakdown (Figure 3), there were 56 males and 41 females. Among male and female cases, normal cases predominated, accounting for 54% and 49% of all case types, respectively. In descending order, these were followed by mild, severe, and critical cases.

The proportion of disease severity of different age groups was analyzed (Figure 4). The age of onset was concentrated between 20-59 years, accounting for about 80.41% of the total number of patients. Among them, the proportion of mild cases in the 40-49 age group was 56%, the proportion of normal cases in the 30-39 age group was 73.33%, and the proportion of severe cases in the 80-89 age group was 33.33%, the proportion of critical cases in the 70-79 age group was up to 20%. The proportion of normal cases was highest in different age groups, and the number of cases decreased as the severity of the disease increased.

Model fitting and calculation of transmissibility

According to the comparison between the model fitting curve and the actual secondary cases curve (Figure 5), the degree of fitness was good. At the same time, the goodness-of-fit test results showed that the difference between secondary cases fitted by the model and the actual secondary cases was statistically significant ($R^2 = 0.593$, $P < 0.001$). The values of β_1 and β_2 obtained by the model fitting were brought into the formula of the effective reproduction number; the effective reproduction number of COVID-19 in Jilin Province before February 1 was 1.64, the effective reproduction number of COVID-19 in Jilin Province after February 1 was 0.05, and the transmissibility decreased by 96.95%.

It is known that after February 1, the incidence of COVID-19 showed a downward trend, and the last case occurred on February 19 (Figure 2). If no intervention measures had been taken after the onset of new coronary pneumonia, the model can fit the curve of the future incidence in this scenario (Figure 6). Therefore, if no measures had been taken, the model predicted that the incidence on February 19 would have been 13 cases, while the actual incidence on that date was one case. Therefore, the comprehensive interventions reduced the incidence by 92.31%. If the epidemic situation had been allowed to continue, the incidence curve would resemble a bell shape, and it would reach a peak of incidence on October 22, 2020 (284 days from the first case), with 177011 cases on that day, and the epidemic would last for 22 months. At the same time, the forecast can also predict the condition of onset at the end of each month in the near future (Table 2). Without intervention taken on February 1, 2020, a total of 17,129,367 cases would have been reported until the end of the outbreak (on October 9, 2021), with a total attack rate of 63.66%. These results revealed that the interventions implemented in Jilin Province reduced the number of cases by more than 99.99%.

In addition, this study predicts the epidemic curve and peak incidence of COVID-19 after taking measures at different time points (Figure 7). The following figure shows the future incidence curve when the number of days from the first case varies (175 days, 200 days, 225 days, 250 days, 275 days, 300 days, 325 days, 350 days, 375 day). The trend turns into a gradual decline in the curve fitting figure. The prevalence of measures taken at different time points shows that the sooner measures are taken, the more easily the epidemic can be controlled, the lower the peak number of outbreaks, the earlier the end of the outbreak, and the lower the cumulative number of outbreaks (Table 3).

Discussion

Based on the epidemic situation of COVID-19 in Jilin Province, we constructed a transmission dynamics model that accords with the population characteristics of Jilin province. Furthermore, based on the collection of 97 cases as of March 14, the true parameters of Jilin Province were calculated. Using imported cases as the source of infection, the model calculates fitted secondary cases based on local secondary cases. Therefore, from the design of the model, the calculation of parameters and the fitting of data, it is more in line with the actual situation of Jilin Province, and the transmissibility index is more real.

According to the temporal distribution of COVID-19 in Jilin Province (Figure 2), the imported cases in Jilin reached a peak on January 22nd, and decreased after January 23rd. Since January 31st, the imported cases have remained at a low level. On January 23, the city was closed in Wuhan. At the same time, Jilin Province implemented measures of screening and isolation for outsiders. This time coincided with the period of decline in imported cases, indicating that the above interventions had obvious effects. On January 31st 2020, the measures of having a flexible working system and fewer meetings were implemented. Personnel were required to wear masks when entering or leaving public places. From Figure 2, we can see that since February 1st, the number of secondary cases and daily actual incidence has been decreasing. Since January 31, 2020, the implementation time of intervention measures such as reducing travel and wearing masks has been consistent with the incidence decline time. This shows that the above intervention measures were effective in this period.

The clinical disease types of COVID-19 in Jilin are the most common cases[33], and are consistent with the distribution of clinical types in the whole country. This shows that most cases are mild and easily treated by patients as common influenza. For this reason, it has not been easy to investigate who infected persons have had close contact with. Therefore, a large number of sources of infection were not effectively isolated in the external environment at the early stage of the disease and at the early stage of the epidemic, which was the main reason for the public response delay in the early stage of the outbreak.

The age of onset of COVID-19 in Jilin was mainly between 20-59 years old. Among these cases, people aged 30-49 years most commonly had mild and normal cases[34]. Therefore, in young adults, the prognosis of the disease is better and mortality is low.

In this study, according to the time distribution characteristics of the epidemic curve of COVID-19 in Jilin Province, taking February 1st as the time cut-off point, the data were divided into two sections to fit the secondary cases, and the fitting effect was better (R^2 = 0.593, P<0.001). According to the fitting results, the effective reproduction number of the first stage (before February 1st) was 1.64, indicating that the infection source of COVID-19 could infect about two people during the infectious period. If intervention had not been taken in time to allow the disease to progress naturally, COVID-19 in Jilin would have continued to spread widely. The effective reproduction number in the second stage (after February 1st) was 0.05, that is, the infection source of a new coronavirus could infect 0.05 people during the infectious period, meaning that the epidemic situation had been controlled by this stage. The comprehensive intervention measures in Jilin Province reduced the transmissibility of COVID-19 by

96.95%.

Combined with a series of related measures since the outbreak of the epidemic in Jilin Province, a series of related measures were launched on January 23rd, including closing tourist spots, suspending business operations, ensuring good disinfection and ventilation in public places, and banning wild animal trade. On January 25th, 2020, the Jilin provincial government launched a public health events level I emergency response, strengthened the investigation of non-native people and isolated non-native people at home, strengthened body temperature testing, implemented disinfection and sterilization measures, encouraged wearing of masks, and strengthened the management of large scale activities. From January 31, 2020, the unit flexible working system was implemented to reduce the number of meetings and personnel input. The above measures were effective in the second stage of COVID-19, and transmissibility was reduced by 96.95%. Additionally, by the deadline (February 19), the actual number of secondary cases had been reduced by 92.31%, so that the epidemic could be controlled. If Jilin had not taken measures and had allowed the disease to develop before February 1st, the prevalence of COVID-19 would have continued to spread in the province. The peak would have been reached by October 22, 2020, with the number of cases on that day being 177011. The epidemic would have continued to be prevalent for 22 months, with a cumulative number of 17129367 cases, and an attack rate during the epidemic of 63.66%. Therefore, a series of prevention and control measures formulated and implemented in Jilin Province effectively controlled the progress of the COVID-19 epidemic, and, as much as possible, helped avoid an interpersonal epidemic.

Limitations

The parameters in this research model were calculated based on the actual data of Jilin Province, so the quality of the data is high. However, the small number of actual illnesses in Jilin Province would have had a certain impact on the calculation of the model. There were only four asymptomatic infections in the data obtained, which reduced the reliability of the proportion estimation of asymptomatic infections in Jilin Province. At present, studies have shown that asymptomatic infections also have transmissibility, and they are not easy to find and isolate, which promotes the spread of disease and the epidemic. This model takes into account the effect of asymptomatic infection in the population. Therefore, error in the proportion of asymptomatic infections may cause the prediction results to deviate from the actual situation.

In this study, the reciprocal of the incubation period calculated using the actual data of the COVID-19 in Jilin Province was a parameter in the model, so the accuracy of the incubation period calculation can also affect the model's prediction. The incubation period of COVID-19 is 3-7 days[35], and the incubation period of the disease calculated in this study was 10 days in Jilin Province. The reason may be that the time of contact with the first case is uncertain, and there are some cases with unclear contact time, such as repeated or continuous contact. Therefore, it is necessary to clarify the activity trajectory of secondary cases, or how long susceptible persons have the ability to infect others after being exposed to the source of infection. This is also a direction for exploration in future research.

In accordance with the epidemic trend of the disease, this study fitted the actual number of secondary cases in two stages. Additionally, the transmissibility of COVID-19 after February 1 was evaluated, and the effectiveness of preventive measures was verified. However, this article evaluated comprehensive prevention and control measures, and did not evaluate certain specific measures. It is not possible to determine which specific measure produced an effect. To solve this problem, it will be necessary to establish a model that considers separate prevention and control measures. However, the specific implementation time and completion status of each measure are difficult to determine, so this situation is difficult to achieve.

Conclusions

COVID-19 had moderate transmissibility in Jilin Province, China. The interventions implemented in the province had great effectiveness.

Abbreviations

COVID-19: coronavirus disease 2019; SEIAR: susceptible – exposed – infectious – asymptomatic – recovered.

Ethics approval and consent to participate

This effort of disease control was part of CDC's routine responsibility in Jilin Province, China. Therefore, institutional review and informed consent were waived by the Ethics Committee of Jilin Provincial Center for Disease Control and Prevention. All data analyzed were anonymized.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from Dr. Qinglong Zhao (jlcdczql@126.com) on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was partly supported by the Bill & Melinda Gates Foundation (INV-005834), the Science and Technology Program of Fujian Province (No: 2020Y0002), and the Xiamen New Coronavirus Prevention and Control Emergency Tackling Special Topic Program (No: 3502Z2020YJ03).

Authors' contributions

TC, QL, and YS designed research; QZ, ML, XL, BS, BL, YZ, BC, and LY collected the data; YW, MY, ZZ, BZ, YS and TC analyzed the data; TC, YW, MY, and QZ wrote the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

References:

1. Hui DS, E IA, Madani TA, Ntoumi F, Kock R, Dar O, Ippolito G, McHugh TD, Memish ZA, Drosten C, Zumla A, Petersen E: **The continuing 2019-nCoV epidemic threat of novel**

coronaviruses to global health - The latest 2019 novel coronavirus outbreak in Wuhan, China. *International journal of infectious diseases : IJID : official publication of the International Society for Infectious Diseases* 2020, **91**:264-266.

2. Read JM, Bridgen JRE, Cummings DAT, Ho A, Jewell CP: **Novel coronavirus 2019-nCoV: early estimation of epidemiological parameters and epidemic predictions**. *medRxiv,* 2020.

3. Benvenuto D, Giovanetti M, Ciccozzi A, Spoto S, Angeletti S, Ciccozzi M: **The 2019-new coronavirus epidemic: Evidence for virus evolution**. *Journal of medical virology* 2020, **92**(4):455-459.

4. Dong N, Yang X, Ye L, Chen K, Chan EW-C, Yang M, Chen S: **Genomic and protein structure modelling analysis depicts the origin and infectivity of 2019-nCoV, a new coronavirus which caused a pneumonia outbreak in Wuhan, China.** . *bioRvix* 2020.

5. The L: **Emerging understandings of 2019-nCoV**. *Lancet (London, England)* 2020, **395**(10221):311.

6. Zhou P, Yang X-L, Wang X-G, Hu B, Zhang L, Zhang W, Si H-R, Zhu Y, Li B, Huang C-L, Chen H-D, Chen J, Luo Y, Guo H, Jiang R-D, Liu M-Q, Chen Y, Shen X-R, Wang X, Zheng X-S, Zhao K, Chen Q-J, Deng F, Liu L-L, Yan B, Zhan F-X, Wang Y-Y, Xiao G-F, Shi Z-L: **Discovery of a novel coronavirus associated with the recent pneumonia outbreak in humans and its potential bat origin**. *bioRvix* 2020.

7. Wu F, Zhao S, Yu B, Chen Y-M, Wang W, Hu Y, Song Z-G, Tao Z-W, Tian J-H, Pei Y-Y, Yuan M-L, Zhang Y-L, Dai F-H, Liu Y, Wang Q-M, Zheng J-J, Xu L, Holmes EC, Zhang Y-Z:

Complete genome characterization of a novel coronavirus associated with severe human respiratory disease in Wuhan, China. *bioRvix* 2020.

8. Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, Ren R, Leung KSM, Lau EHY, Wong JY, Xing X, Xiang N, Wu Y, Li C, Chen Q, Li D, Liu T, Zhao J, Liu M, Tu W, Chen C, Jin L, Yang R, Wang Q, Zhou S, Wang R, Liu H, Luo Y, Liu Y, Shao G, Li H, Tao Z, Yang Y, Deng Z, Liu B, Ma Z, Zhang Y, Shi G, Lam TTY, Wu JT, Gao GF, Cowling BJ, Yang B, Leung GM, Feng Z: **Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia**. *The New England journal of medicine* 2020, **382**(13):1199-1207.

9. Tang JW, Tambyah PA, Hui DSC: **Emergence of a novel coronavirus causing respiratory illness from Wuhan, China**. *The Journal of infection* 2020, **80**(3):350-371.

10. Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y, Xia J, Yu T, Zhang X, Zhang L: **Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study**. *Lancet (London, England)* 2020, **395**(10223):507-513.

11. Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, Zhao X, Huang B, Shi W, Lu R, Niu P, Zhan F, Ma X, Wang D, Xu W, Wu G, Gao GF, Tan W: **A Novel Coronavirus from Patients with Pneumonia in China, 2019**. *The New England journal of medicine* 2020, **382**(8):727-733.

12. Lai CC, Shih TP, Ko WC, Tang HJ, Hsueh PR: **Severe acute respiratory syndrome coronavirus 2 (COVID-19) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges**. *International journal of antimicrobial agents* 2020, **55**(3):105924.

13. **Coronavirus disease 2019 (COVID-19) Situation Report – 79** [https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200408-sitrep-79-covid-19.pdf?sfvrsn=4796b143_6]

14. [http://www.nhc.gov.cn/xcs/yqtb/202004/fa7bb40a7fbf4b2c8f3989d512fe5b77.shtml]

15. [http://www.jl.gov.cn/szfzt/jlzxd/yqtb/202004/t20200409_7064800.html]

16. [https://baijiahao.baidu.com/s?id=1656717951737450858&wfr=spider&for=pc]

17. Zhao S, Musa SS, Lin Q, Ran J, Yang G, Wang W, Lou Y, Yang L, Gao D, He D, Wang MH: **Estimating the Unreported Number of Novel Coronavirus (2019-nCoV) Cases in China in the First Half of January 2020: A Data-Driven Modelling Analysis of the Early Outbreak**. *Journal of clinical medicine* 2020, **9**(2).

18. Wu JT, Leung K, Leung GM: **Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study**. *Lancet (London, England)* 2020, **395**(10225):689-697.

19. Zhao S, Lin Q, Ran J, Musa SS, Yang G, Wang W, Lou Y, Gao D, Yang L, He D, Wang MH: **Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China, from 2019 to 2020: A data-driven analysis in the early phase of the outbreak**. *International journal of infectious diseases : IJID : official publication of the International Society for Infectious Diseases* 2020, **92**:214-217.

20. Qiu J: **Covert coronavirus infections could be seeding new outbreaks**. *Nature* 2020.

21. Tang B, Wang X, Li Q, Bragazzi NL, Tang S, Xiao Y, Wu J: **Estimation of the Transmission**

Risk of the 2019-nCoV and Its Implication for Public Health Interventions. *Journal of clinical medicine* 2020, **9**(2).

22. Zhang C, Wang M: **MRCA time and epidemic dynamics of the 2019 novel coronavirus**. *bioRvix* 2020.

23. Li X, Wang W, Zhao X, Zai J, Zhao Q, Li Y, Chaillon A: **Transmission dynamics and evolutionary history of 2019-nCoV**. *Journal of medical virology* 2020, **92**(5):501-511.

24. Shao P, Shan Y: **Beware of asymptomatic transmission: Study on 2019-nCoV prevention and control measures based on extended SEIR model**. *bioRvix* 2020.

25. Ming W-K, Huang J, Zhang CJP: **Breaking down of healthcare system: Mathematical modelling for controlling the novel coronavirus (2019-nCoV) outbreak in Wuhan, China**. 2020.

26. Chen TM, Rui J, Wang QP, Zhao ZY, Cui JA, Yin L: **A mathematical model for simulating the phase-based transmissibility of a novel coronavirus**. *Infectious diseases of poverty* 2020, **9**(1):24.

27. Chen T, Gu H, Leung RK, Liu R, Chen Q, Wu Y, Li Y: **Evidence-Based interventions of Norovirus outbreaks in China**. *BMC Public Health* 2016, **16**(1):1072.

28. Chen T, Ka-Kit Leung R, Liu R, Chen F, Zhang X, Zhao J, Chen S: **Risk of imported Ebola virus disease in China**. *Travel medicine and infectious disease* 2014, **12**(6 Pt A):650-658.

29. Cui J-A, Zhao S, Guo S, Bai Y, Wang X, Chen T: **Global dynamics of an epidemiological model with acute and chronic HCV infections**. *Applied Mathematics Letters* 2020, **103**.

30. Zhao S, Ran J, Yang G, Cao P: **Attach importance to the procedure of deriving reproduction numbers from compartmental models: Letter to the editor in response to 'Seasonality of the transmissibility of hand, foot and mouth disease: a modelling study in Xiamen City, China'**. *Epidemiology and infection* 2020, **148**:e62.

31. Huang Z, Wang M, Qiu L, Wang N, Zhao Z, Rui J, Wang Y, Liu X, Hannah MN, Zhao B, Su Y, Zhao B, Chen T: **Letter to the editor in response to 'Seasonality of the transmissibility of hand, foot and mouth disease: a modelling study in Xiamen City, China'**. *Epidemiology and infection* 2020, **148**:e61.

32. Huang Z, Wang M, Qiu L, Wang N, Zhao Z, Rui J, Wang Y, Liu X, Hannah MN, Zhao B, Su Y, Zhao B, Chen T: **Seasonality of the transmissibility of hand, foot and mouth disease: a modelling study in Xiamen City, China**. *Epidemiology and infection* 2019, **147**:e327.

33. Wang Y, Wang Y, Chen Y, Qin Q: **Unique epidemiological and clinical features of the emerging 2019 novel coronavirus pneumonia (COVID-19) implicate special control measures**. *Journal of medical virology* 2020.

34. Novel Coronavirus Pneumonia Emergency Response Epidemiology T: **[The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) in China]**. *Zhonghua liu xing bing xue za zhi = Zhonghua liuxingbingxue zazhi* 2020, **41**(2):145-151.

35. Yang Y, Lu Q, Liu M, Wang Y, Zhang A, Jalali N, Dean N, Longini I, Halloran ME, Xu B, Zhang X, Wang L, Liu W, Fang L: **Epidemiological and clinical features of the 2019 novel coronavirus outbreak in China**. 2020.

Figure legends

Figure 1 SEIAR model for simulating COVID-19

Figure 2 Temporal distribution of COVID-19 in Jilin Province, China

Figure 3 The proportion of disease severity according to gender in Jilin Province, China

Figure 4 The proportion of disease severity in different age groups in Jilin Province, China

Figure 5 The fitting results of the SEIAR model and the data of the actual secondary cases of COVID-19 cases in Jilin Province, China

Figure 6 Simulation results of the SEIAR model without intervention and the data of the actual secondary cases of COVID-19 cases in Jilin Province, China

Figure 7 COVID-19 prevalence curve and peak incidence after taking measures at different time points in Jilin Province, China

Tables

Table 1 The definition and values of parameters in SEIAR model of COVID-19 in Jilin Province, China

Parameter	Description	Unit	Value	Parameter source
β_1	Infection rate coefficient (before February 19)	$\text{Person}^{-1}\cdot\text{day}^{-1}$	6.7865×10^{-9}	Curve Fitting
β_2	Infection rate coefficient (after February 19)	$\text{Person}^{-1}\cdot\text{day}^{-1}$	2.0519×10^{-10}	Curve Fitting
k	Coefficient of Transmissibility of A relative to I	1	1	literature[26]
p	Proportion of asymptomatic infections	1	0.04	Actual data
ω	Relative rate of incubation period of I	day^{-1}	0.1	Actual data
ω'	Relative rate of incubation period of A	day^{-1}	0.1	literature[26]
γ	Coefficient of time between onset and admission	day^{-1}	0.33	Actual data

γ'	Infection period coefficient	day^{-1}	0.33	literature[26]
f	Fatality rate	1	0	Actual data

Table 2 Prediction of short-term onset of COVID-19 without intervention

Date	Number of cases	Cumulative number of cases	Attack rate
Feb. 29	20	356	1.32E-05
Mar. 31	82	1755	6.52E-05
Apr. 30	313	7033	2.61E-04
May.31	1250	28485	1.06E-03
Jun.30	4742	108914	4.05E-03
Jul.31	18217	427535	1.59E-02

Table 3 Prevalence of COVID-19 after comprehensive intervention at different time points

Time for comprehensive intervention	Cumulative number of cases	Attack rate	Peak date	Peak incidence	Outbreak duration
D175	170197	0.63%	Jul. 5	5911	8 month
D200	510848	1.90%	Jul. 30	17462	9 month
D225	1471201	5.47%	Aug. 24	48043	10 month
D250	3805023	14.14%	Sept. 18	109787	11 month
D275	7892257	29.33%	Oct. 13	171253	12 month
D300	12193645	45.32%	Oct. 22	177011	13 month
D325	14939812	55.52%	Oct. 22	177011	14 month
D350	16235738	60.34%	Oct. 22	177011	15 month
D375	16775568	62.35%	Oct. 22	177011	16 month
D650	17129367	63.66%	Oct. 22	177011	22 month