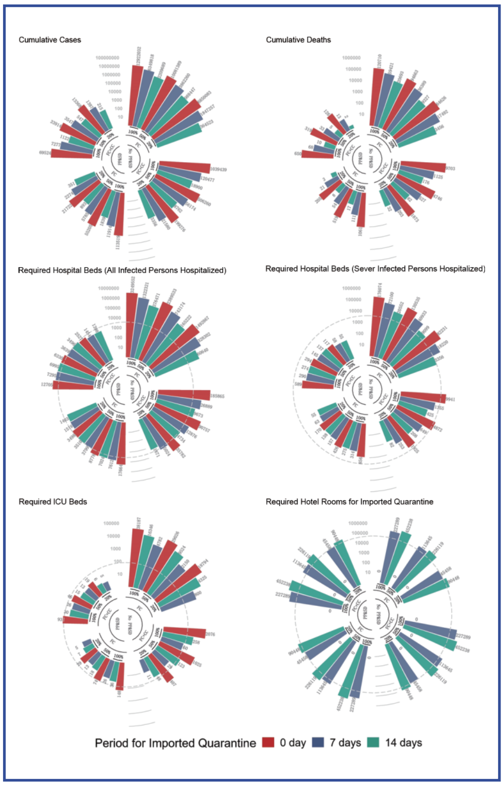
ISSN 2096-7071
CN 10-1629/R1

CHINA CDC WEEKLY

Vol. 4 No. 10 Mar. 11, 2022

CCDC weekly

中国疾病预防控制中心周报



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Cover Image: The estimated cumulative number of local COVID-19 cases and deaths, and the maximum required number of quarantine rooms, hospital beds, ICU beds, and hotel rooms under different scenarios (Source: Guanhao He et al.).

Commentary

Strengthening Community Defenses to Prevent and Control the Spread of COVID-19 in China

Xia Li[1,2]; Zhuona Zhang[1,2]; Keyang Lyu[1]; Dongqun Xu[1,#]

ABSTRACT

In light of the severity of coronavirus disease (COVID-19) around the world, it is an arduous task for China to prevent COVID-19 from being imported from abroad and proliferating domestically. The community is the first and most effective line of defense and can effectively cut off the channels of spread of the epidemic. In order to reduce risks of COVID-19 transmission in the community, it is necessary to sort out the loopholes in risk and management, as well as investigate previous epidemic transmission events in the community.

In the first week of 2022, more than 15 million new cases of coronavirus disease (COVID-19) were reported to the World Health Organization (WHO) from around the world (*1*). From December 2021 to January 2022, clusters of cases were reported in Shanxi, Henan, Tianjin, and Beijing. Currently, China's epidemic prevention focuses on people from overseas and domestic high-risk areas, as well as imports of cold-chain items. While vaccines remain highly effective at preventing severe disease and death (*2*–*3*), they do not fully prevent transmission (*4*). After the community finds a positive infected person, it is important to determine the close contacts and sub-close contacts as soon as possible and transfer them as soon as possible. Consolidating the defense line of the community prevention relies on a series of rapid, scientific, and precise prevention and control measures. As such, we made a series of these recommendations.

RISKS DURING NORMAL EPIDEMIC CONDITIONS

With the increase of e-commerce, more people buy foods that need cold chain transportation from overseas online shopping platforms. The epidemic situation abroad is serious, and it is difficult to avoid carrying the virus in the outer package of express delivery or even cold chain food (*5*). People working in the cold chain or receiving deliveries are at risk of infection. A previous study suggested that poor ventilation and insufficient hygiene facilities may increase the risks of infectious disease outbreaks (*6*). Supermarkets, shopping malls, restaurants, and other public places have a large flow of people, but code scanning and body temperature measurement under normal epidemic prevention and control conditions are not carefully implemented. During holidays, weddings, or funerals, it is traditional for Chinese families and friends to have dinner together, especially in rural areas. Once there is a source of infection, the epidemic will likely spread rapidly.

If community workers cannot conduct contact tracing accurately at the time of the outbreak, it is difficult to implement large-scale nucleic acid screening sampling without missing anyone. In addition, if close contacts failed to be transferred to quarantine as fast as possible, there would be risks of social transmission.

RISKS IN AN OUTBREAK

The complex rental housing structure along with an unclear number of tenants made nucleic acid screening and sampling difficult without missing someone. For example, if someone quarantined at home was not sampled for several days or large communities being unable to test all residents in one day, etc. In addition, some individual nucleic acid sampling methods were not standardized or reasonably laid out. Disinfection and medical evaluations were not performed in a timely manner after the confirmed COVID-19 patients were transferred, and most communities had incomplete preventive disinfection records. In some communities, medical waste and domestic waste were improperly mixed together.

In some areas, the health monitoring records were lacking or incomplete. Special groups such as the elderly and pregnant women in some communities had difficulties seeking medical treatment and purchasing medicine. In some control areas, low-income residents did not have basic living conditions and supplies guaranteed.

During the epidemic, basic medical care and other public health services could not be delivered in a timely and effective manner. There was no professional team for disinfection and effect evaluation. Urban villages have high house density, poor sanitary conditions, and arbitrarily modified sewage pipes and toilets — which do not meet the sanitation requirements. The complex composition of public health personnel further complicated the management of epidemic prevention. Close contacts of COVID-19 cases could not be accurately identified in some containment areas. Some groups in the containment area did not have independent bathrooms or kitchens, so it was difficult to truly isolate at home and there was a risk of cross-infection.

Larger-scale residential areas in cities have high population density, and the number of residents is not always clear. Elevator cars and buttons, stair handrails, unit door handles, and other high-frequency use and closed environment of public facilities were likely to cause virus transmission (*7–8*). It was difficult to control the flow of people in and out of commercial and residential buildings that faced the street. Some people stranded in the office areas stored food in advance and hid inside, unwilling to come out for nucleic acid testing. Stranded workers at construction sites with poor environmental conditions risked being part of a cluster infection of COVID-19 cases.

PREVENTION AND CONTROL MEASURES DURING NORMAL EPIDEMIC CONDITIONS

Regular nucleic acid testing should be carried out for cold-chain food and goods moving through airports, ports, transportation, storage, markets, and retail stores. We need to fully test, sterilize and trace the imported cargo and cold chain food. Also, personal protection and health management of key personnel must be strengthened. Daily random inspections of cold-chain food entering the customs at the port and in the market is recommended. Wholesale markets selling frozen, chilled, and fresh products should be operated in well-ventilated places, and the frequency of routine disinfection practices should be increased. Customers must validate their health code and get their temperature taken before entering. Wholesale and retail outlets should shift toward online shopping, contactless delivery, pickup, etc. Gatherings such as weddings and funerals need to be simple, with people wearing surgical masks and adhering to hand hygiene and social distance to avoid potential infection. Community (village) grid members should stay informed of the actual situation of COVID-19 infections within their village. Pharmacies are prohibited from selling medicines for symptoms related to COVID-19, and if someone bought one of these drugs, the health code would pop up, indicating that a nucleic acid test is needed as soon as possible.

PREVENTION AND CONTROL MEASURES IN CASE OF OUTBREAK

Community epidemic prevention and control needs to be carried out in three aspects: “containment, screening, and isolation.” Epidemiological investigations should be sped up and data should be immediately shared to identify the close contacts of COVID-19 cases and transfer those patients to centralized quarantined sites as soon as possible. In the containment area, sampling should be carried out directly at households to ensure that no one is missing. Nucleic acid sampling locations should be standardized: rational layout, single entry and single exit, with spacing greater than two meters between sampling stations. It is necessary to strengthen the training of nucleic acid sampling personnel, guarantee their protection and hand disinfection, increase sampling personnel and supplies, add sampling locations, transfer samples in accordance to the standard protocol, and release the test results as soon as possible. Health monitoring is carried out for all personnel every day in the containment and controlled areas.

After a confirmed COVID-19 case is transferred, a professional disinfection institution must be arranged to carry out terminal disinfection in accordance with “COVID-19 Prevention and Control Plan (Eighth Edition).” At the same time, the disease control institution should coordinate the processing and disinfection. In communities or villages where confirmed COVID-19 cases are found, disinfectants should be added to the septic tank and, only after passing a test, can the sewage be discharged into municipal pipelines. Fixed temporary storage points for medical waste should be set up and the frequency of disinfection should be increased so as to achieve "double bags, double seals, and double elimination." A roster of special personnel and a health service mechanism should be established to deal with this medical waste. The community should announce the channels for medical treatment to the public, including helping coordinate vehicles and contact medical institutions to ensure patients seek medical treatment in a timely fashion. A guarantee mechanism for the supply of basic living supplies should be established and distributed.

Improving the primary healthcare system and building healthcare capacity requires giving primary health institutions important roles in epidemic prevention and control. The district (county) CDC should set up a disinfection department to guide third-party disinfection institutions together with the health supervision center to carry out and evaluate the disinfection process and quality.

It is necessary to strengthen the supervision of housing construction in villages to avoid "illegal construction", especially the random modification of sanitary pipes. Through carrying out "knock-on" actions, the number of personnel was identified, and the personnel roster was established. The flow of people during the epidemic should be controlled, and those who do not have quarantined conditions at home need to be transferred to a centralized quarantined site. The roster of personnel in residential buildings should be established. Attention should be paid to the management and control of stranded people in commercial shops and construction projects. We should increase the number of inspections of commercial and residential buildings to keep track of the number of stranded personnel.

In order to adhere to precise scientific requirements, it is necessary to implement prevention and control measures with high standards and further reduce the risk of epidemic transmission in the community; control measures can be upgraded if necessary. The following conditions should be considered for expanding the scope of the containment and controlled areas: 1) the transmission chain is unclear and the source of infection is unknown; 2) infected persons have complex movement trajectories, and they have contact with other people at workplaces, activities, residences, etc., resulting in a high possibility of transmission; 3) there are multiple infected persons in different buildings in the community or residence community; 4) infection occurs among the staff involved in prevention and control in the community or residence community; 5) when the infected person or the close contact person is transported, the closed loop and protective measures are not strictly taken, which may increase the risk of transmission in the community; and 6) other situations that may cause the spillover of the epidemic in the community.

Scenarios to consider escalating controls: 1) it is difficult to track and determine close and sub-close contacts; 2) the close contacts and sub-close contacts quarantined at home and have not been transferred to the isolation point; 3) the communities have not taken sufficient technical defense for those quarantining at home to prevent them from going out; 4) there are phenomena such as irregular crowd protections, gatherings, frequent access to buildings (residences), etc.; 5) urban-rural junctions or rural areas with insufficient sanitary conditions, difficult management, and high risk of transmission; and 6) other situations that may cause the spread of the epidemic in the community.

In conclusion, a zero-COVID strategy is the current policy for the prevention and control of the epidemic in China (*9*). When local COVID-19 cases appear, comprehensive actions should be taken immediately to ensure timely detection, rapid disposal, precise control of spread, and effective treatment. Guiding the community to carry out epidemic management in a scientific and orderly manner can successfully curb the spread of COVID-19 in the community — one of the most effective ways to minimize the harm caused by the epidemic to people's health and livelihood.

Conflicts of interest: No conflicts of interest reported.

Acknowledgments: All experts from Community Prevention and Control Team of Xi'an Epidemic.

Funding: Supported by the Key Program of National Natural Science Foundation of China (No. 92043201).

doi: 10.46234/ccdcw2022.030

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Submitted: January 27, 2022; Accepted: February 20, 2022

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Preplanned Studies

Diagnostic Value of Neutrophil-Lymphocyte Ratio and Platelet-Lymphocyte Ratio in Patients with Severe COVID-19 — 7 PLADs, China, January 21–February 10, 2020

Yan Ma[1,&]; Dongshan Zhu[2,3,&]; Nannan Shi[4,&]; Lei Zhang[5]; Guangkun Chen[5]; Youwen Ge[1]; Zelei Zhang[4]; Renbo Chen[4]; Sihong Liu[5]; Yipin Fan[1]; Huamin Zhang[6,#]; Yanping Wang[4,#]

Summary

What is already known about this topic?

Coronavirus disease 2019 (COVID-19) causes symptoms ranging from mild to severe. Indicators for identifying severe COVID-19 infection have not been well identified, especially for young patients.

What is added by this report?

Both neutrophil-lymphocyte ratio (NLR) [area under curve (AUC): 0.80; the odds ratios (OR) and 95% confidence intervals (95% CI): 1.30 (1.13–1.50)] and platelet-lymphocyte ratio (PLR) [AUC: 0.87; OR (95% CI): 1.05 (1.01–1.09)] were determined to be indicators for recognition of patients with severe COVID-19 in young patients less than age 40.

What are the implications for public health practice?

NLR and PLR are useful indicators for identifying patients with severe COVID-19, especially in young patients less than age 40.

Novel coronavirus pneumonia (coronavirus disease 2019, COVID-19) can infect anyone and causes symptoms ranging from mild to severe. Previous studies demonstrated that severe COVID-19 had more unfavourable treatment outcomes compared to non-severe COVID-19 (*1–2*). Early diagnosis and timely treatment were essential to cure severe COVID-19 patients and curb the spread of disease. Yet, rapid and convenient inflammatory markers for identifying severe COVID-19 infection have not been well studied, especially for young patients. Evidence has shown that the lymphocytes count (especially the CD4+ and CD8+ T cell counts) decreased as infection progressed (*3*). Neutrophils and platelets were found to be important mediators of inflammation. In severe COVID-19 cases, neutrophil counts were increased (*4*), and platelet accumulation was common (*5*). Neutrophil-lymphocyte ratio (NLR) and platelet-lymphocyte ratio (PLR) have been used to evaluate systemic inflammation in neoplastic and cardiovascular diseases (*6–7*). Using data from 452 confirmed COVID-19 cases, we examined whether NLR and PLR values on admission may help us identify severe patients upon admission.

To better understand the association between NLR, PLR, and severity of patients with COVID-19, we conducted a multi-center observational study in 41 hospitals from 7 provincial-level administrative divisions (PLADs) of China, i.e., Shanxi, Hebei, Heilongjiang, Shaanxi, Anhui, Guangxi, and Sichuan between January 21, 2020 and February 10, 2020 (Supplementary Table S1, available in http://weekly.chinacdc.cn). The implementation sites of the 7 PLADs were selected based on the geographical distribution (namely Eastern, Western, and Central regions of China), and 41 hospitals from the 7 PLADs were chosen based on their willingness to participate. All of these hospitals were designated hospitals for treating COVID-19 patients.

In our study, all COVID-19 patients enrolled were confirmed by a laboratory test; the patients were excluded if core data such as routine blood laboratory data was incomplete at admission. Medical records of these patients were collected. The study was approved by the National Administration of Traditional Chinese Medicine and Institutional Review Board at each participating hospital. Due to the urgency in treating COVID-19 patients, the requirement for written informed consent from study participants was replaced by verbal consent. All data were supplied and analyzed in an anonymous format, without access to personal identifying information.

This study has been registered by the Chinese Clinical Trial Registry (Registration Number: ChiCTR2100042177) and approved by the Ethics Committee of the Institute of Clinical Basic Medicine of Chinese Medicine, China Academy of Chinese Medical Sciences (NO: P20009/PJ09).

De-identified demographic data [sex, age, body mass index (BMI), and comorbidity] and onset symptoms (fever, cough, dry cough, fatigue, shortness of breath, and diarrhea) were collected from patients' medical records. Results of complete blood count upon admission — including neutrophil count, platelet count, and lymphocyte count to calculate NLR and PLR — were collected.

Patients were divided into two groups of non-severe and severe based on their physician's clinical diagnosis after admission. Severe cases were defined as having any of the following: 1) respiratory distress; 2) pulse oxygen saturation ≤93%; or 3) arterial partial pressure of oxygen (PaO_2) / oxygen concentration ≤300 mmHg.

Multivariable logistic regression models were used to estimate the odds ratio (OR) and 95% confidence interval (95% CI) between NLR and PLR and patient's clinical severity of COVID-19. Receiver-operating characteristic (ROC) curves were used to assess the diagnostic value for identifying severe COVID-19 cases. In subgroup analyses, we stratified by sex and age (<40 years, 40–59 years, and ≥60 years).

A total of 452 patients were analyzed in our study between January 21, 2020 and February 10, 2020. The median age of patients was 45 years [interquartile range (IQR): 33.0, 57.0]; 50.9% of the participants were men; 33.8% had at least one comorbidity and the median BMI was 24.3 (IQR: 21.5, 26.4). Of 451 cases, 11.9% of severe and 4.0% of critical cases; 84.1% of non-severe cases including 41 mild cases and 339 moderate cases, respectively. The most common symptoms were cough (61.3%), fever (49.1%), and fatigue (37.6%), as seen in Table 1. The median (IQR, Q1–Q3) NLR and PLR in severe COVID-19 patients on admission were 5.4 (3.2–10.7) and 207 (160, 302), and in non-severe patients were 2.5 (1.7–3.8) and 149 (110–211), respectively.

Each one-unit (e.g., from 2 to 3) increase of NLR and each 10-unit increase of PLR was associated with 7% and 1% higher odds of being a severe patient, respectively (adjusted for age, sex, BMI, comorbidity, and onset symptoms, P<0.01). The odds ratios and 95% confidence intervals (OR, 95% CI) for being a severe patient in age groups of <40, 40–59, and ≥60 years were 1.30 (1.13–1.50), 1.04 (1.01–1.08), and 1.09 (0.99–1.20) for NLR, and 1.05 (1.01–1.09), 1.00 (1.00–1.01), and 1.01 (0.97–1.04) for PLR, respectively.

The area under curve (AUC) for predicting severe illness was 0.75 (95% CI: 0.69–0.82) for NLR and 0.67 (0.59–0.74) for PLR in all patients (Figure 1-A).

TABLE 1. Characteristics of the patients enrolled.

Characteristics	Patients (N=452)
Age (years)	
Median (IQR)	45.0 (33.0–57.0)
Distribution [n (%)]	
<40	166 (36.7)
40–59	192 (42.5)
≥60	94 (20.8)
Sex [n (%)]	
Male	230 (50.9)
Female	222 (49.1)
BMI (kg/m^2)	
Median (IQR)	24.3 (21.5–26.4)
Distribution [n/N (%)]	
<18.5	23/368 (6.3)
18.5–23.9	146/368 (39.7)
24–27.9	147/368 (39.9)
≥28	52 /368 (14.1)
Wuhan-related exposure [n (%)]	
Yes	134 (29.6)
Close history to COVID-19 cases [n (%)]	
Yes	285 (63.1)
Comorbidities [n (%)]	
Any	153 (33.8)
Hypertension	82 (18.1)
Diabetes	37 (8.2)
Cardiovascular disease	17 (3.8)
Stroke	13 (2.9)
Others	36 (23.6)
Clinical Classification [n (%)]	
Mild	41 (9.1)
Moderate	339 (75.0)
Severe	54 (11.9)
Critical	18 (4.0)
Signs and symptoms on admission [n (%)]	
Fever	170 (37.6)
Cough	277 (61.3)
Dry cough	156 (34.5)
Fatigue	170 (37.6)
Shortness of breath	63 (13.9)
Diarrhea	35 (7.7)

Note: Others of comorbidities included pulmonary tuberculosis, chronic bronchitis, emphysema, hepatitis, depression, etc.
Abbreviations: IQR=interquartile range; BMI=body mass index.

The AUCs in male and female were similar to that in all patients. After sub-analyses by age, the AUC in age groups of <40, 40-59, and ≥60 years were 0.80 (0.64–0.95), 0.75 (0.64–0.87), and 0.68 (0.56–0.80) for NLR, respectively, and 0.87 (0.78–0.86), 0.67 (0.56–0.79), and 0.54 (0.42–0.66) for PLR, respectively (Figure 1). The ideal cut-off values for predicting severe COVID-19 infection in patients less than age 40 for NLR and PLR were 3.1 and 192.

DISCUSSION

These findings indicate that both NLR and PLR were associated with clinical severity of COVID-19 infection. Higher NLR and PLR were useful predictors in diagnosis and early recognition of severe illness in younger patients of age <40 years. The benefits of using NLR and PLR measurements are because they are simple, rapid, and inexpensive, while also being associated with less patient discomfort, as only peripheral blood samples are required for testing. Furthermore, these values are easily evaluated in most hospital laboratories (*8*).

This study was subject to some limitations. Because we collected data from medical records, some demographic variables with missing values were not

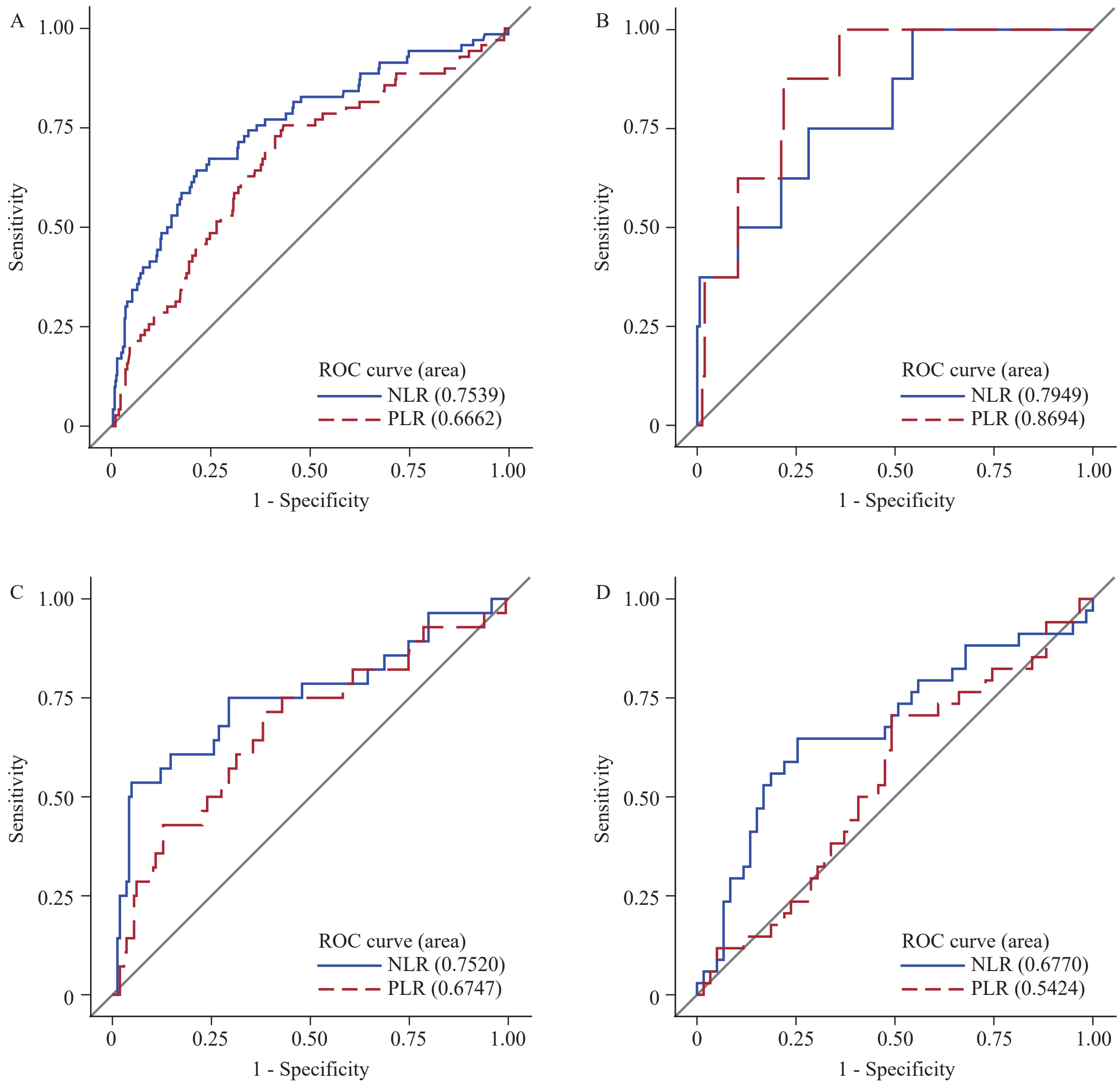

FIGURE 1. The area under curve for predicting severe COVID-19 infection for NLR and PLR in (A) all COVID-19 patients, (B) COVID-19 patients <40 years, (C) 40–59 year, and (D) ≥60 years.
Note: abbreviations: ROC=receiver operating characteristic; NLR=neutrophil-lymphocyte ratio; PLR=platelet-lymphocyte ratio. The blue curve represents the ROC of NLR and the red curve represents the ROC of PLR.

included, such as occupation, education level, and smoking status. This may cause some residual bias. Also, we only used the measurement of NLR and PLR upon admission. Thus, the trajectory of NLR and PLR and their association with clinical course could not be analyzed.

In conclusion, neutrophil, lymphocyte, and platelet counts are a part of routine blood tests, and NLR and PLR values can both be acquired in just five minutes. Because of this, NLR and PLR are recommended as indicators to identify severe COVID-19 patients, especially in young patients under 40 years old. This may help facilitate effective care and prioritize medical resources during a COVID-19 outbreak.

Conflicts of interest: No conflicts of interest reported.

Acknowledgments: All participants from 41 hospitals (Supplementary Table S1) in the study.

Funding: Supported by “CACMS Innovation Fund (CI2021A00704), COVID-19 Project of National Administration of Traditional Chinese Medicine (2020ZYLCYJ07-1), COVID-19 project of National Administration of Traditional Chinese Medicine (GZY-KJS-2021-007), the Fundamental Research Funds for the Central public welfare research institutes (Z-0696)”.

doi: 10.46234/ccdcw2022.047

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Submitted: April 28, 2021; Accepted: January 18, 2022

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SUPPLEMENTARY TABLE S1. List of 41 hospitals in the multi-center observational study.

Number	PLADs	List of hospitals
1	Shaanxi	Shangluo Central Hospital
2	Heilongjiang	The People’s Hospital of QiTaiHe
3	Shaanxi	Xianyang Central Hospital
4	Anhui	The First Affiliated Hospital of Anhui University of Traditional Chinese Medicine
5	Hebei	Langfang Hospital of Chinese Medicine
6	Hebei	Xingtai Hospital of Chinese Medicine
7	Guangxi	The People’s Hospital of GuangXi Zhuang Autonomous Region
8	Guangxi	The First People’s Hospital of Fangchenggang
9	Sichuan	Mianyang Hospital of Traditional Chinese Medicine
10	Guangxi	Liuzhou People’s Hospital
11	Sichuan	Affiliated Hospital of North Sichuan Medical College
12	Sichuan	The Public Health Clinical Center of Chengdu
13	Hebei	Shijiazhuang Fifth Hospital
14	Shanxi	The Fourth People’s Hospital of Taiyuan
15	Sichuan	The First Hospital of Suihua City
16	Shaanxi	Ankang Hospital of Traditional Chinese Medicine
17	Guangxi	Beihai Hospital of Chinese Medicine
18	Heilongjiang	Harbin Infectious Disease Hospital
19	Hebei	Chengde Hospital of Traditional Chinese Medicine
20	Shanxi	Datong Fourth Hospital
21	Sichuan	Suining Central Hospital
22	Shanxi	Jinzhong Infectious Disease Hospital
23	Shanxi	Jincheng People’s Hospital, Jincheng
24	Shaanxi	Hanzhong Central Hospital, Hanzhong,
25	Shanxi	Shuozhou People’s Hospital, Shuozhou
26	Heilongjiang	Mudanjiang Kangan Hospital, Mudanjiang
27	Shanxi	Xinzhou People’s Hospital,
28	Shanxi	Daqing Second Hospital
29	Heilongjiang	Jiamusi Infectious Disease Hospital
30	Shaanxi	Hanzhong Hospital for Infectious Diseases
31	Shaanxi	Shaanxi Infectious Disease Hospital
32	Shaanxi	Baoji Central Hospital
33	Shaanxi	Xi'an Chest Hospital
34	Heilongjiang	Qiqihar Institute for The Prevention and Treatment of Infectious Diseases
35	Shanxi	Fenyang Hospital of Shanxi Province
36	Heilongjiang	Shuangyashan People’s Hospital
37	Heilongjiang	The Greater Khingan Range People’s Hospital
38	Guangxi	The Fourth People’s Hospital of Nanning
39	Shanxi	The Third People’s Hospital of Linfen
40	Hebei	Hengshui Hospital of Chinese Medicine
41	Heilongjiang	The First Hospital of Qiqiha

Abbreviation: PLADs=provincial-level administrative divisions.

Methods and Applications

When and How to Adjust Non-Pharmacological Interventions Concurrent with Booster Vaccinations Against COVID-19 — Guangdong, China, 2022

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ABSTRACT

Introduction: With the large-scale roll-out of the coronavirus disease 2019 (COVID-19) booster vaccination effort (a vaccine dose given 6 months after completing primary vaccination) in China, we explore when and how China could lift non-pharmacological interventions (NPIs) against COVID-19 in 2022.

Methods: Using a modified susceptible-infectious-recovered (SIR) mathematical model, we projected the COVID-19 epidemic situation and required medical resources in Guangdong Province, China.

Results: If the number of people entering from overseas recovers to 20% of the number in 2019, the epidemic in 2022 could be controlled at a low level by a containment (215 local cases) or suppression strategy (1,397 local cases). A mitigation strategy would lead to 21,722 local cases. A coexistence strategy would lead to a large epidemic with 6,850,083 local cases that would overwhelm Guangdong's medical system. With 50% or 100% recovery of the 2019 level of travelers from overseas, the epidemic could also be controlled with containment or suppression, but enormous resources, including more hotel rooms for border quarantine, will be required. However, coexistence would lead to an uncontrollable epidemic with 12,922,032 local cases.

Discussion: With booster vaccinations, the number of travelers from overseas could increase slightly in 2022, but a suppression strategy would need to be maintained to ensure a controllable epidemic.

INTRODUCTION

Non-pharmacological interventions (NPIs) have contributed substantially to the control of coronavirus disease 2019 (COVID-19) (*1–2*) and have bought time for vaccine development and promotion. With increasing vaccine coverage, some countries have relaxed NPIs. However, breakthrough infections, especially from viral variants, caused significant rebounds of COVID-19 epidemics (*3*) that were unable to be controlled without re-tightening NPIs (*4*).

Despite the effectiveness of NPIs, they negatively impact daily life and the economy (*5*). Given the well-documented high efficacy of COVID-19 booster doses (a dose of COVID-19 vaccine 6 months after completing a primary series) (*6*), China initiated a booster vaccination campaign, with an expectation to return to normal life and lift NPIs (*7*). With booster vaccinations, it is a concern that when and how NPIs could be lifted without devastating the healthcare system. This includes questions of how many medical resources, such as hospital beds, intensive care unit (ICU) beds, and hotel rooms for border quarantine, are necessary as different levels of NPIs are lifted.

To address these critical questions, we used real-world data from multiple sources as input to a susceptible-infectious-recovered (SIR) model that we augmented with additional compartments to more accurately represent COVID-19 epidemiology and control policy in China. For 2022, we projected the magnitude of the COVID-19 epidemic in Guangdong Province under different NPI lifting policies, booster dose uptake, and overseas importation pressures.

METHODS

Model Structure

Starting with an SIR framework, we introduced additional compartments to model risks, factoring in people entering from overseas, border quarantine, and booster vaccination coverage (Figure 1). Details of the model are in the Supplementary Material (available in http://weekly.chinacdc.cn).

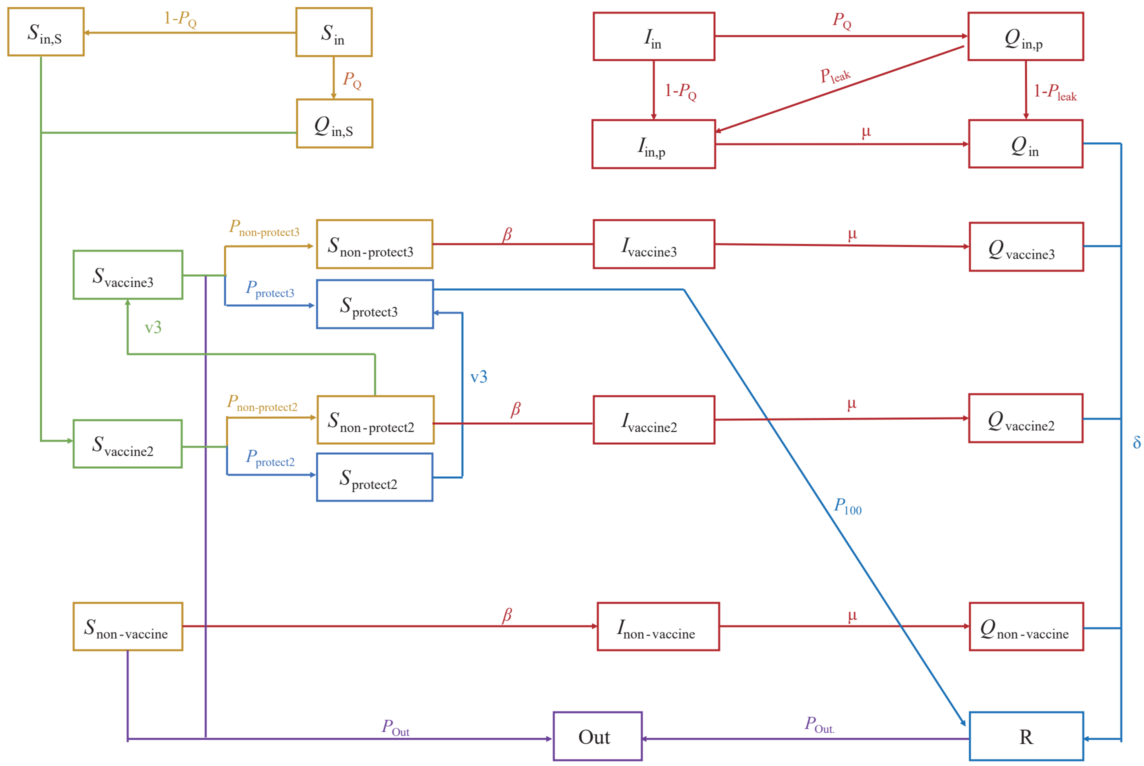

FIGURE 1. Conception model incorporating booster vaccination and NPIs.
Note: Details of the model are in the Supplementary Material (available in http://weekly.chinacdc.cn).
Abbreviation: NPIs=non-pharmacological interventions.

COVID-19 Risk from Overseas Importation

We estimated the number of infected people entering Guangdong from overseas as follow:

$$I_{in} = \sum Passenger_t \times 0.98\%$$

where $Passenger_t$ denotes the number of passengers from overseas at date *t*, which was obtained from flight data in VariFlight (https://www.variflight.com/en/). We used flight data from 2019 — the pre-pandemic level of passengers — to project flights in 2022 under various levels of restriction. We used the prevalence of COVID-19 cases imported from overseas to Guangdong from August 7, 2021 to November 14, 2021 (0.98%) to estimate the number of imported infections each day projected onto 2022 travel levels.

Vaccination Rate in 2022

Two scenarios for booster vaccination in 2022 were used for modeling. The first scenario was 60% of the population receiving a booster by June 30 and 85% receiving a booster by December 31. The second scenario was 50% and 75% booster vaccination by June 30 and December 31. Rationale for the scenarios is in the Supplementary Material (available in http://weekly.chinacdc.cn).

Vaccine Effectiveness

Inactivated COVID-19 vaccines have been the most widely used vaccines in China; their effectiveness against infection is 65.70% for fully vaccination (*8*). With a booster dose, vaccine effectiveness (VE) is 88.00% (*6*). Therefore, we used 65.70% and 88.00% for the VE parameters, $P_{protect2}$ and $P_{protect3}$.

Vaccination reduces hospital admission, severe illness, and death. Based on previous studies (*6,8–10*), we set the hospital admission rate, ICU admission rate, and fatality rate to 4.30%, 0.39%, and 0.80%, respectively, for fully vaccinated but infected individuals, and 0.30%, 0.03%, and 0.15%, respectively, for booster-vaccinated infected individuals.

Estimating the Effect of Local NPIs

Border Quarantine: We developed five scenarios of border quarantine of people coming from overseas to Guangdong in 2022: 1) no border quarantine; 2) 7 days of quarantine; 3) 14 days of quarantine; 4) 7 days of quarantine for those entering before July, but no quarantine for those entering after July; and 5) 14 days of quarantine before July but 7 days for those entering after July.

A certain proportion of cases from overseas may not be detected during quarantine. Based on real-world data from Guangdong, 1.04% and 0.16% of cases from overseas were not detected during 7- and 14-day quarantines. We used these values to represent residual importation risk after testing negative during quarantine.

Infection Detection Measures: In our model, μ denotes the rate of infected people being detected and quarantined. For different infection detection measures, the interval from infection to quarantine was obtained from real-world data in Guangdong (Supplementary Table S1, available in http://weekly.chinacdc.cn/).

Personal Protection and Social Distancing: A meta-analysis indicated that relative risk (RR) reduction from masks and social distancing were 0.47 and 0.75, respectively (*2*). Given that the combined effect of personal protection and social distancing was rarely reported, we used the lowest RR (0.47) to represent this combined effectiveness.

Four Strategies Against COVID-19

We modeled 4 strategies that differed by combination of NPIs: 1) *containment*: 14 days of border quarantine of incoming travelers; use of personal protection, social distancing, and use of sensitive measures for infection detection (fever monitoring and contact tracing); 2) *suppression*: 7 days border quarantine; use of personal protection, social distancing, and sensitive measures for infection detection; 3) *mitigation*: no border quarantine; use of personal protection, social distancing, and routine measures for infection detection (fever monitoring but no contact tracing); and 4) *coexistence*: no border quarantine, no personal protection, no social distancing, and only routine measures for infection detection.

Transmission Coefficient (Beta)

The transmission coefficient, β, was estimated using real-world data from a local epidemic triggered by imported cases from Africa in first half of 2020. The data indicated that the β with best fit was 0.14 (R^2=84.71%, Root Mean Square Error=3.61). During that outbreak, vaccination was unavailable, and therefore this β represents transmission with local NPIs and no vaccination. Given viral variants can have higher transmission rates (transmissibility of variants can reach 1.97 times non-variant transmission) (*11*), we set β as 0.14×1.97=0.27 to represent the transmission rate in 2022. We also set β as 0.27/0.47=0.57 to represent transmission without personal protection and social distancing.

Detailed definitions and values of compartments and parameters are presented in Supplementary Table S2 and Supplementary Table S3 (available in http://weekly.chinacdc.cn/). Statistical analyses were conducted with R software (version 3.6.2, R Foundation for Statistical Computing, Vienna, Austria). We used the R package “deSolve” for numerical treatment of our model’s system of differential equations in transmission dynamics analyses.

RESULTS

Travelers from Overseas and Imported Infections

From January 1 to November 14, 2021, 3,768 flights carried 349,987 people into Guangdong from overseas; 2,702 (0.77%) were infected. The percent was higher near the end of 2021 (0.98%). Using the percent infected as a multiplier, Figure 2 shows projected overseas travelers and numbers infected in 2022 under assumptions of 20%, 50%, and 100% of travelers from overseas compared with 2019.

Projected Epidemic in 2022 by COVID-19 Strategy

Modeling results were based on the percent of 2019 travel into Guangdong that occurs using the percent infected from real world data near the end of 2021 — 20%, 50%, and 100% of 2019 travel into Guangdong, called travel recovery.

Containment: With 2022 incoming travel at a 20% recovery of 2019 travel, a containment strategy controls the maximum number daily infections at low level (Figure 3), with annual cases and deaths of 215 and 2 (Figure 4). As booster dose coverage increases, daily cases become lower (Figure 3). With higher percentages recovery of 2019 travel, the epidemic is still controlled by containment.

Suppression: With 20% recovery of travel, a suppression strategy controls the maximum daily infections at 7 (Figure 3), with 1,397 total cases and 13 deaths (Figure 4). If booster dose uptake is 85%, the

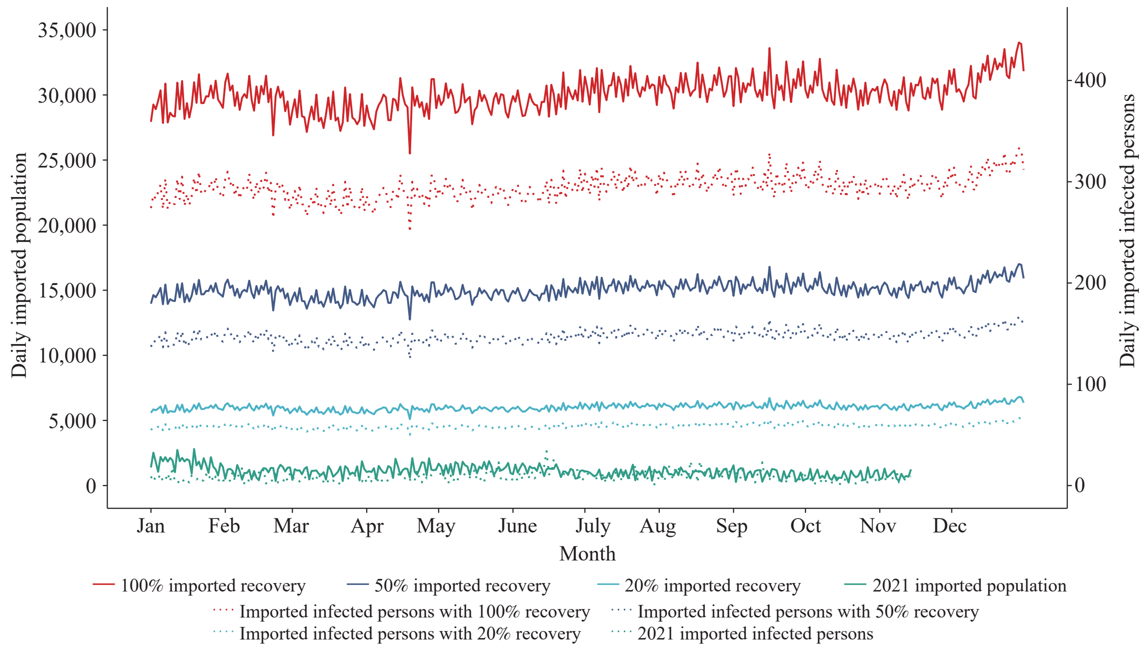

FIGURE 2. Projected daily incoming travelers and number infected in 2022 and actual figures for 2021.

maximum daily number of local infections decreases to 2. With 50% and 100% of travel recovery, the cumulative number of cases is projected to become 3,547 and 7,277.

Mitigation: With 20% recovery of travel, a mitigation strategy results in a maximum of 63 infections per day, with 21,722 total cases and 205 deaths. A booster dose coverage of 85% reduces the maximum daily infections to 22. However, 50% and 100% travel recovery yields 55,205 and 113,519 total cases in Guangdong.

Coexistence: If most NPIs are lifted, 20% travel recovery brings the projected daily maximum of cases to 75,716, with annual cases and deaths of 6,850,083 and 64,626. With 50% and 100% travel recovery, Guangdong would suffer 10,081,389 or 12,922,032 cases in 2022.

Projected Medical Resource Requirements by Strategy

Containment: At 20% travel recovery, at the peak of epidemic, 1,398 infected people, including locals and incoming travelers, will require quarantine and isolated treatment. Infected individuals are always hospitalized in China, implying the need for 1,398 hospital beds at epidemic peak. If only severe cases are hospitalized, 55 hospital beds and 5 ICU beds will be needed, but 90,448 hotel rooms will be needed for border quarantine. With 50% and 100% travel recovery, the peak needs for treatment will be 3,496 and 6,995 hospital beds and 226,119 and 452,238 quarantine rooms, respectively.

Suppression strategy: At 20% travel recovery, at the peak of the epidemic, 1,454 hospital beds will be needed. If only severe cases are hospitalized, 58 beds will be needed. Compared to containment, suppression requires fewer hotel rooms for imported quarantine (45,458), which is within Guangdong's capacity. With 50% and 100% travel recovery, 3,639 and 7,295 hospital rooms will be needed at epidemic peak, and 113,645 and 227,289 quarantine hotel rooms will be needed, respectively.

Mitigation: With 20% travel recovery, 3,498 hospital beds will be needed at peak if all infected individuals are hospitalized; 170 hospital beds will be needed if only severe cases are hospitalized. A peak of 29 ICU beds would be needed. With travel recovery of 50% and 100% levels, 8,778 and 17,664 hospital beds will be needed.

Coexistence: With 20% travel recovery, 1,492,867 hospital beds would be required at peak. If only severe cases are hospitalized, 82,231 hospital beds will be required. With 50% and 100% travel recovery, Guangdong would have to arrange 2,389,533 and 3,249,552 hospital beds for treatment of infected individuals.

As shown in Supplementary Table S4 (available in http://weekly.chinacdc.cn/), the epidemic would require more medical resources with slower booster

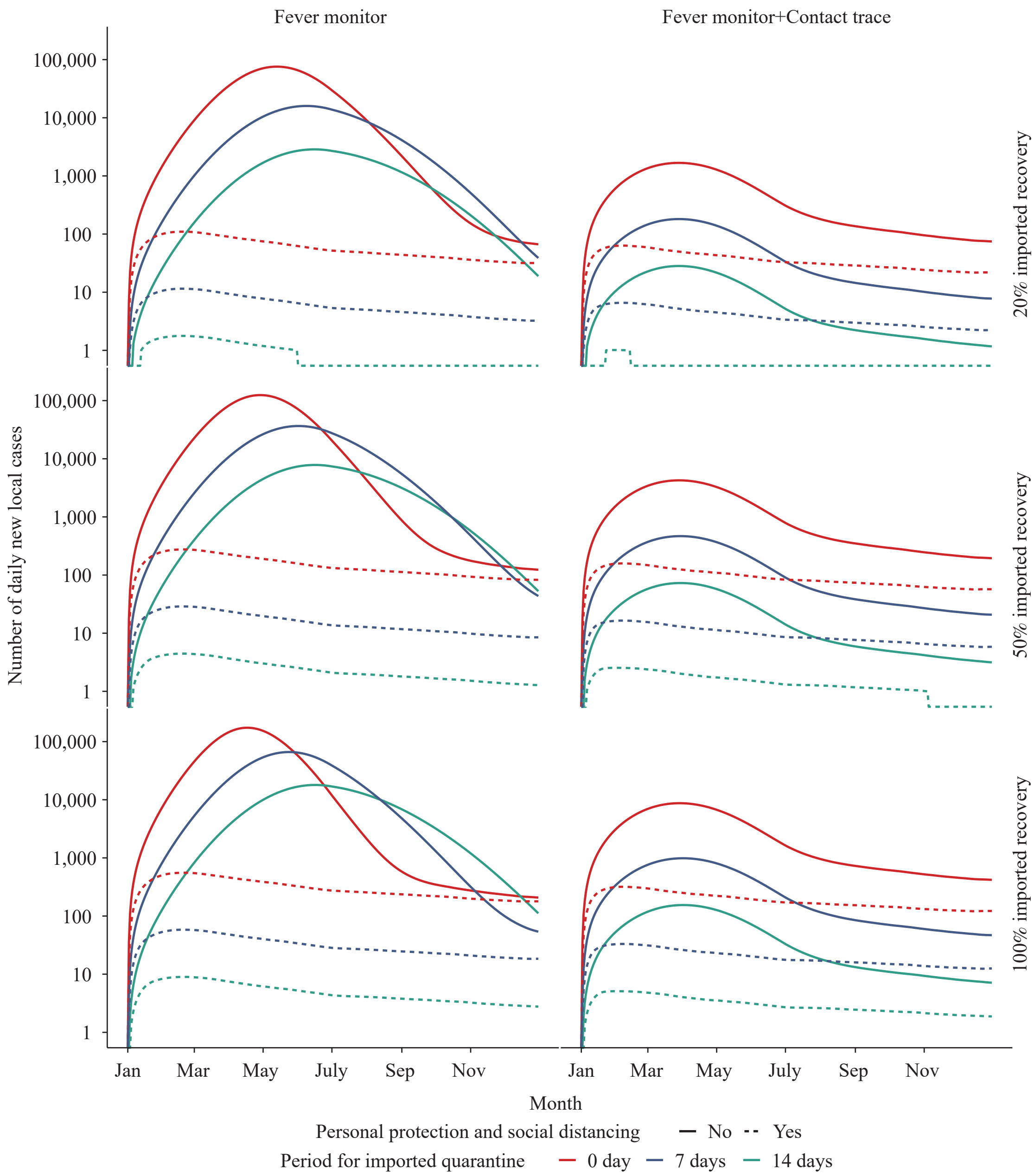

FIGURE 3. Projected daily new COVID-19 local cases under different NPI lifting scenarios in Guangdong Province in 2022.
Note: A log_{10} transformed y-axis was used in this figure. 1) containment strategy: 14 days border quarantine of incoming travelers, use of personal protection and social distancing, sensitive measures for infection detection (fever monitoring and contact tracing); 2) suppression: 7 days border quarantine, use of personal protection and social distancing, sensitive measures for infection detection; 3) mitigation: no border quarantine for travelers, use of personal protection and social distancing, routine measures for infected persons detection (fever monitor without contact tracing); 4) coexistence: no border quarantine, no personal protection, no social distancing, routine measure for infected persons detection (no contact tracing).
Abbreviations: COVID-19=coronavirus disease 2019; NPI=non-pharmacological interventions.

vaccination progress. More sensitive infection detection measures would slow the epidemic.

DISCUSSION

We developed dynamic severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission models to project the COVID-19 epidemic in Guangdong in 2022 under combinations of COVID-19 booster vaccination, increases of incoming international travel, and 4 NPI lifting strategies to identify appropriate NPI combinations that will keep

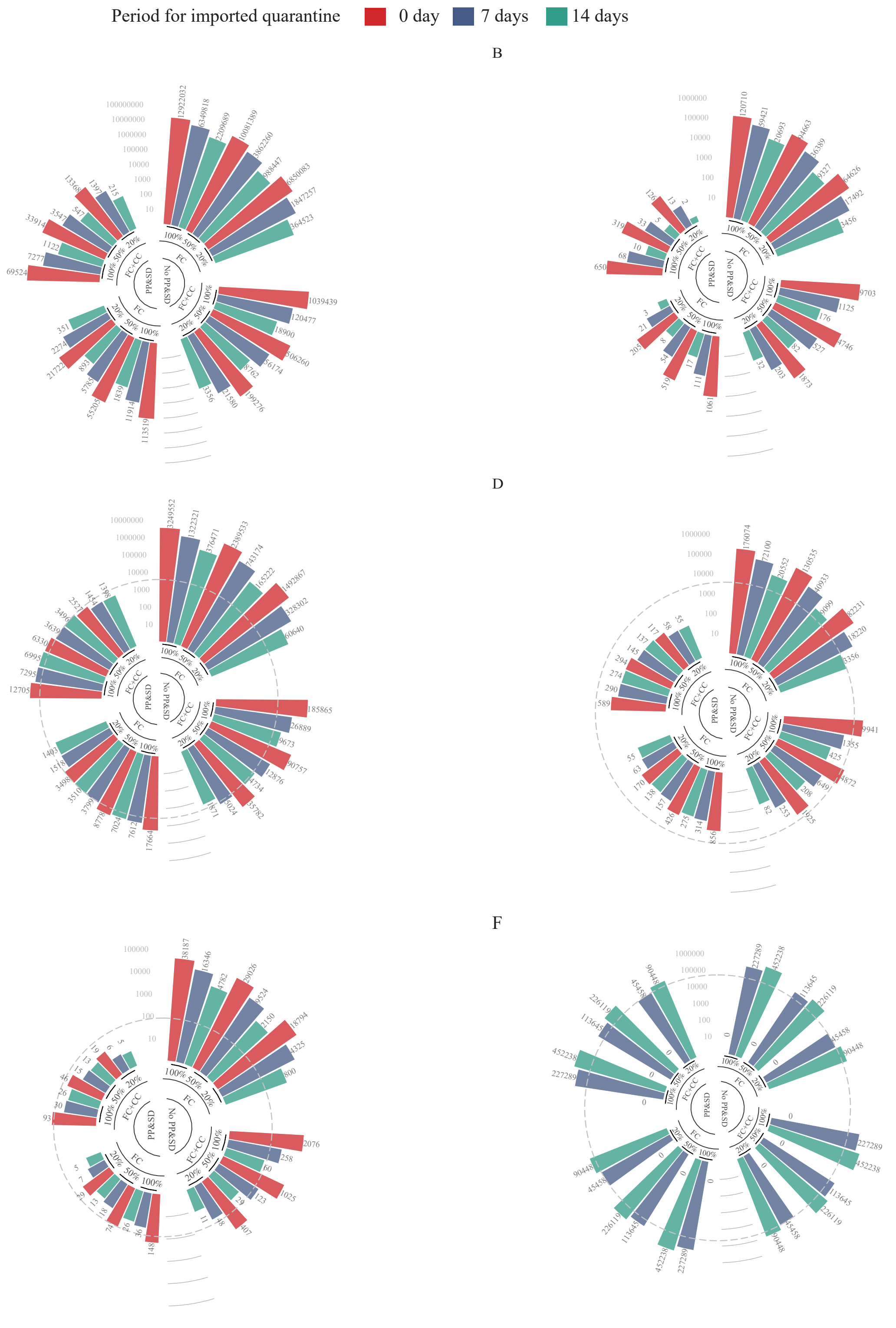

FIGURE 4. Cumulative number of local COVID-19 cases and deaths, and the maximum required number of hospital beds, ICU beds, and hotel rooms for border quarantine under different scenarios. (A) Cumulative cases; (B) Cumulative deaths; (C) Required hospital beds (all infected persons hospitalized); (D) Required hospital beds (severe infected persons hospitalized); (E) Required ICU beds; (F) Required hotel rooms for imported quarantine.

Note: The grey dashed lines refer to the current capacity of medical resources in Guangdong Province. PP&SD refer to personal protection and social distancing; FC refers to fever clinic monitor; CC refers to close contact tracing; 20%, 50% and 100% refer to 20%, 50% and 100% travel recovery compared with 2019 incoming overseas travel.

Abbreviations: COVID-19=coronavirus disease 2019; ICU=intensive care unit.

the COVID-19 epidemic under control and utilize affordable levels of medical resources.

If incoming international travel recovers to 20% of the level in 2019 and the infection rate of incoming travelers is the same as in 2021 in Guangdong, a suppression strategy may be considered in 2022. Suppression involves reducing incoming quarantine to 7 days, using personal protection and social distancing, and contact tracing during outbreaks. Under this scenario, the required medical resources will be within the current capacity of Guangdong. Our model also indicated that with increasing uptake of booster doses, the number of daily new infections decreased significantly. We project that a high booster dose vaccination rate of 85% will allow more incoming travel and decreased use of NPIs by the end of 2022.

Furthermore, several antiviral medicines against COVID-19 are being developed and some have been granted regulatory approval (*12–13*). Effective antivirals raise the possibility that infected people with mild symptomatic may be able to be safely treated at home, partially alleviating stress on the medical system.

This study was subject to several limitations. We assumed that reinfection would not occur. This assumption may cause the model to underestimate the epidemic magnitude and peak. We also did not consider the waning of booster-dose-induced immunity over time and assumed that the prevalence of imported COVID-19 in 2022 will be the same as it was in 2021. Additionally, we were under the assumption that the transmissibility of the virus in 2022 will be the same as the Delta variant. Given that the Omicron variant has higher transmissibility than Delta and that future variants may also have high transmissibility, our results may be underestimates. Our model used an SIR structure rather than an SEIR (susceptible, exposed, infectious, and recovered) structure for simulation. However, given that COVID-19 cases can transmit during the incubation period (*14*), SIR models have been used successfully (*15*) and we believe that an SIR structure reasonably simulates COVID-19 epidemics. Finally, our model did not consider vaccination effectiveness against SARS-CoV-2 infectiousness (VEI).

As booster vaccination increases in 2022, incoming international travel could increase slightly, but a suppression strategy should be maintained to ensure that the resulting COVID-19 epidemic can be maintained under control. High coverage of booster dose vaccinations along with the use of antiviral medicines and increasing the availability of medical resources, could allow for the possibility of lifting border restrictions and NPIs in the near future.

Conflicts of interest: No conflicts of interest.

Funding: Supported by National Key Research and Development Program of China (2021YFC2301604); Chinese Postdoctoral Science Foundation (2020T130020ZX); the Science and Technology Program of Guangzhou (202102021285); and Innovation and Development Project of China Meteorological Administration (CXFZ2021J045).

doi: 10.46234/ccdcw2022.048

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Submitted: February 16, 2022; Accepted: March 02, 2022

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SUPPLEMENTARY MATERIAL

Study Location

The study used Guangdong Province of China as an example to project the epidemic magnitude of coronavirus disease 2019 (COVID-19) from January 1, 2022, to December 31, 2022. Guangdong Province is located in the southeast coastal area of China and has frequent international exchange. Guangdong is the most populous province in China with 126,012,500 residents and is the most developed province with the highest gross domestic product (GDP) (*1–2*). Guangdong has the highest total export-import volume in China (*2*). For these reasons, Guangdong faces considerable risk of COVID-19 in the global pandemic.

Model Structure

Based on the susceptible-infectious-recovered (SIR) modeling framework, we introduced several compartments to include import risk from overseas, imported (border) quarantine, vaccination, and exiting population (Figure 1). Two compartments were added to describe the imported infectors (I_{in}) and imported susceptibles (S_{in}). I_{in} shunts into imported infectors with ($Q_{in,p}$) and without quarantine or leaked after quarantine ($I_{in,p}$). S_{in} shunts into imported susceptible with ($Q_{in,s}$) and without quarantine ($S_{in,s}$). We divided the S compartment into 3 sections: susceptible without vaccination ($S_{non\text{-}vaccine}$); susceptible with full vaccination ($S_{vaccine2}$); susceptible with booster dose vaccination ($S_{vaccine3}$). We further divided $S_{vaccine2}$/$S_{vaccine3}$ into 2 sections: vaccinated susceptible with immunity against COVID-19 ($S_{protect2}$, $S_{protect3}$); vaccinated susceptible without immunity against COVID-19 ($S_{non\text{-}protect2}$, $S_{non\text{-}protect3}$). $S_{non\text{-}protect}$, $S_{non\text{-}protect2}$, and $S_{non\text{-}protect3}$ would gradually become infectors and flow into $I_{non\text{-}vaccine}$, $I_{vaccine2}$, and $I_{vaccine3}$, respectively, which would be later detected, quarantined, and treated in $Q_{non\text{-}vaccine}$, $Q_{vaccine2}$, and $Q_{vaccine3}$, respectively. Then the recovered infectors would enter recovery compartment R. We introduced *Out* to describe the exported population from Guangdong.

Model Equations

The system of differential equations in the model is as follows:

$$\frac{dS_{non-vaccine}}{dt} = -\frac{\beta S_{non-vaccine}\left(I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p}\right)}{N} - S_{non-vaccine} \times P_{out}$$

$$\frac{dS_{vaccine2}}{dt} = S_{in,s} + Q_{in,S} - S_{vaccine2} \times P_{protect2} - S_{vaccine2} \times P_{non-protect2} - S_{vaccine2} \times P_{out}$$

$$\frac{dS_{protect2}}{dt} = S_{vaccine2} \times P_{protect2} - v_3 \times P_{protect2}$$

$$\frac{dS_{non-protect2}}{dt} = S_{vaccine2} \times P_{non-protect2} - v_3 \times P_{non-protect2} - \frac{\beta \times S_{non-protect2} \times (I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p})}{N}$$

$$\frac{dS_{vaccine3}}{dt} = v_3 \times P_{non-protect2} - S_{vaccine3} \times P_{protect3} - S_{vaccine3} \times P_{non-protect3} - S_{vaccine3} \times P_{out}$$

$$\frac{dS_{protect3}}{dt} = S_{vaccine3} \times P_{protect3} + v_3 \times P_{protect2} - S_{protect3}$$

$$\frac{dS_{non-protect3}}{dt} = S_{vaccine3} \times P_{non-protect3} - \frac{\beta \times S_{non-protect3} \times (I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p})}{N}$$

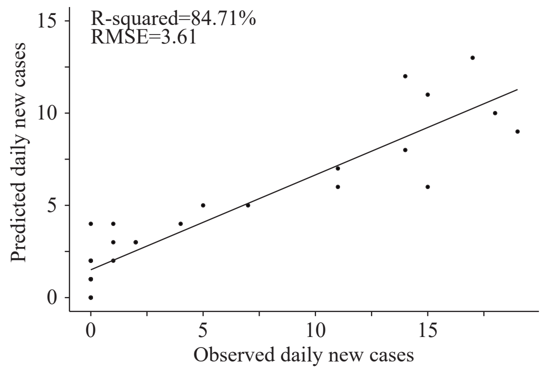
$$\frac{dI_{in,p}}{dt} = I_{in,p} \times \left(1 - P_Q\right) + Q_{in,p} \times P_{leak} - \mu \times I_p$$

$$\frac{dI_{non-vaccine}}{dt} = \frac{\beta S_{non-vaccine}(I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p})}{N} - \mu \times I_{non-vaccine}$$

$$\frac{dI_{vaccine2}}{dt} = \frac{\beta S_{non-protect2}(I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p})}{N} - \mu \times I_{vaccine2}$$

$$\frac{dI_{vaccine3}}{dt} = \frac{\beta S_{non-protect3}(I_{non-vaccine} + I_{vaccine2} + I_{vaccine3} + I_{in,p})}{N} - \mu \times I_{vaccine3}$$

$$\frac{dQ_{in}}{dt} = \mu \times I_{in,p} + Q_{in,p} \times (1 - P_{leak}) - Q_{in} \times \delta$$



SUPPLEMENTARY FIGURE S1. The association between observed daily new cases and the predicted daily new cases with beta= 0.14 (beta with best fitness)
Abbreviations: RMSE=root mean square error

SUPPLEMENTARY TABLE S1. Interval from infection to quarantine for different infection detected measures.

Infection detection measures	Median interval	μ
Fever monitor	6.5 days	1/6.5
Fever monitor + Contact trace	5 days	1/5
Fever monitor + Contact trace + High risk group trace	4.5 days	1/4.5
Fever monitor + Contact trace + High risk group trace + Community nucleic acid screening	4 days	1/4

SUPPLEMENTARY TABLE S2. Definitions and values of compartments in the transmission model.

Compartment	Definition	Value
I_{in}	Imported infected persons	Estimated from flight data and COVID-19 prevalence of imported population
S_{in}	Imported susceptible	Ditto
$I_{in,p}$	Imported infected persons without quarantine or leaked after quarantine	No imported quarantine: $I_{in,p} = I_{in}$ Imorted quarantine: $I_{in,p} = Q_{in,p} \times P_{leak}$
$Q_{in,p}$	Imported infected persons with quarantine	No imported quarantine: $Q_{in,p} = 0$ Imported quarantine: $Q_{in,p} = I_{in}$
$S_{in,s}$	Imported susceptible without quarantine	No imported quarantine: $S_{in,s} = S_{in}$ Imported quarantine: $S_{in,s} = 0$
$Q_{in,s}$	Imported susceptible with quarantine	No imported quarantine: $Q_{in,s} = 0$ Imported quarantine: $Q_{in,s} = Lag_{7/14}(S_{in})$
$S_{non\text{-}vaccine}$	Susceptible without vaccination	Initial value: 10%×126,012,500
$S_{vaccine2}$	Susceptible with full vaccination	Initial value: 90%×126,012,500−10,000,000
$S_{vaccine3}$	Susceptible with booster vaccination	Initial value: 10,000,000
$S_{protect2}$	Fully vaccinated susceptible with immunity	$S_{vaccine2} \times 65.70\%$
$S_{non\text{-}protect2}$	Fully vaccinated susceptible without immunity	$S_{vaccine2} - S_{vaccine2} \times 65.70\%$
$S_{protect3}$	Booster vaccinated susceptible with immunity	$S_{vaccine3} \times 88.00\%$
$S_{non\text{-}protect3}$	Booster vaccinated susceptible without immunity	$S_{vaccine3} - S_{vaccine3} \times 88.00\%$
$I_{non\text{-}vaccine}$	Infected persons without vaccination	Initial value: 0
$I_{vaccine2}$	Infected persons with full vaccination	Initial value: 0
$I_{vaccine3}$	Infected persons with booster vaccination	Initial value: 0
Q_{in}	Quarantined imported infected persons	Initial value: 0
$Q_{non\text{-}vaccine}$	Quarantined infected persons without vaccination	Initial value: 0
$Q_{vaccine2}$	Quarantined infected persons with full vaccination	Initial value: 0
$Q_{vaccine3}$	Quarantined infected persons with booster vaccination	Initial value: 0
R	Recovered population	Initial value: 0

SUPPLEMENTARY TABLE S3. Definitions and values of parameters in the transmission model.

Parameter	Definition	Scenario	Value
β	Transmission coefficient	With personal protection and social distance	0.14×1.97=0.27
		Without personal protection and social distance	0.27/0.47=0.57
μ	Rate from infected persons to quarantine	Fever monitor	1/6.5
		Fever monitor + contact trace	1/5
		Fever monitor + contact trace + high risk group trace	1/4.5
		Fever monitor + contact trace + high risk group trace + community nucleic acid screening	1/4
δ	Rate from quarantine to recovery	All	1/23
P_Q	Proportion of imported quarantine	No imported quarantine	0
		Imported quarantine	1
P_{leak}	Proportion of leaked infected persons under different imported quarantined period	7-day imported quarantine	1.04%
		14-day imported quarantine	0.16%
$P_{protect2}$	Vaccine efficacy for full vaccination	All	65.70%
$P_{protect3}$	Vaccine efficacy for booster vaccination	All	88.00%
P_{out}	Proportion of exported population	All	Imported population/Guangdong population

$$\frac{dQ_{non-vaccine}}{dt} = \mu \times I_{non-vaccine} - Q_{non-vaccine} \times \delta$$
$$\frac{dQ_{vaccine2}}{dt} = \mu \times I_{vaccine2} - Q_{vaccine2} \times \delta$$
$$\frac{dQ_{vaccine3}}{dt} = \mu \times I_{vaccine3} - Q_{vaccine3} \times \delta$$
$$\frac{dR}{dt} = (Q_{in} + Q_{non-vaccine} + Q_{vaccine2} + Q_{vaccine3}) \times \delta + S_{protect3} - R \times P_{out}$$

Estimation of Vaccination Rate

Guangdong Province has 126,012,500 residents (*1*). As of November 30, 2021, 86.67% residents in Guangdong were fully vaccinated. We assumed that the full vaccination (2 doses) rate could reach 90% by the beginning of 2022 in Guangdong. In the second half of 2021, full vaccination increased from 46.72% (on June 30) to 86.62% (on November 30). In other words, 46.72% and 86.62% of the population are eligible for booster doses on January 1 and June 1, 2022. In addition, 7.97 million people have received booster doses by November 30, and we predict that 10 million people could receive booster doses by January 1, 2022. As the roll-out of vaccination normally had a "fast, followed by slow, trend," we set high and low vaccination scenarios: 1) 60% population boosted by June 30, 2022 and 85% population boosted by December 31, 2022; 2) 50% population boosted by June 30, 2022 and 75% boosted by December 31, 2022.

Estimation of Vaccination Effectiveness

Inactivated COVID-19 vaccines were widely used in China, and their vaccine efficacy against infection was 65.70% for the fully vaccinated according to a recent meta-analysis (*3*). According to a recent publication, the efficacy for booster doses was 88.00% (*4*). Therefore, $P_{protect2}$ and $P_{protect3}$ were set to be 65.70% and 88.00%, respectively.

Vaccination reduces hospital admission, severe illness, and death. According to US CDC, for unvaccinated and fully vaccinated infected people, hospital admission rates were 9.00% and 3.90%; intensive care unit (ICU) admission rates were 3.12% and 0.36%; and the fatality rates were 1.40% and 0.70% (*5*). Given that inactivated vaccines have lower efficacy than mRNA vaccines, we adjusted these rates based on the ratio between the efficacy of inactive and mRNA vaccine (*3*,*6*). The hospital admission rate, ICU admission rate, and fatality rate were set to

SUPPLEMENTARY TABLE S4. Predicted epidemic magnitude and required medical resource under different scenarios in 2022 in Guangdong Province.

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
Booster vaccination rate=50% on June 30, 2022, Booster vaccination rate=75% on December 31, 2022.										
100%	0 day	No	A	17,057,217	158,898	245,140	4,488,007	241,854	51,011	0
100%	0 day	No	A+B	1,623,846	15,122	12,643	271,129	14,507	3,014	0
100%	0 day	No	A+B+C	603,404	5,618	4,112	91,869	4,841	967	0
100%	0 day	No	A+B+C+D	310,922	2,895	1,856	44,023	2,268	433	0
100%	7–0 days	No	A	11,767,643	109,710	136,895	2,653,201	143,601	31,342	211,576
100%	7–0 days	No	A+B	344,004	3,204	1,501	38,297	1,966	384	211,576
100%	7–0 days	No	A+B+C	167,251	1,558	793	23,683	1,185	238	211,576
100%	7–0 days	No	A+B+C+D	106,998	997	563	18,667	911	175	211,576
100%	7 days	No	A	11,682,121	108,912	136,895	2,653,201	143,601	31,342	227,289
100%	7 days	No	A+B	202,724	1,888	1,501	38,297	1,966	384	227,289
100%	7 days	No	A+B+C	66,087	615	446	15,719	750	126	227,289
100%	7 days	No	A+B+C+D	33,052	308	196	10,425	465	67	227,289
100%	14–7 days	No	A	7,162,142	66,787	63,596	1,313,897	71,355	16,076	421,820
100%	14–7 days	No	A+B	46,352	432	237	11,567	526	81	421,820
100%	14–7 days	No	A+B+C	20,287	189	84	8,684	366	47	421,820
100%	14–7 days	No	A+B+C+D	12,397	115	59	8,143	337	41	421,820
100%	14 days	No	A	7,145,332	66,631	63,596	1,313,232	71,317	16,066	452,238
100%	14 days	No	A+B	32,129	299	237	11,567	526	81	452,238
100%	14 days	No	A+B+C	10,277	96	70	7,908	330	39	452,238
100%	14 days	No	A+B+C+D	5,114	48	30	7,125	286	30	452,238
100%	0 day	Yes	A	130,757	1,218	584	18,433	896	155	0
100%	0 day	Yes	A+B	78,139	728	328	13,002	604	95	0
100%	0 day	Yes	A+B+C	65,496	610	269	11,790	539	82	0
100%	0 day	Yes	A+B+C+D	54,493	507	219	10,772	485	71	0
100%	7–0 days	Yes	A	54,658	509	296	13,239	615	106	211,576
100%	7–0 days	Yes	A+B	35,005	326	191	10,938	489	77	211,576
100%	7–0 days	Yes	A+B+C	29,855	278	163	10,337	456	69	211,576
100%	7–0 days	Yes	A+B+C+D	25,223	235	138	9,800	427	62	211,576
100%	7 days	Yes	A	13,718	128	61	7,707	319	37	227,289
100%	7 days	Yes	A+B	8,175	76	34	7,364	294	31	227,289
100%	7 days	Yes	A+B+C	6,848	64	28	7,300	290	30	227,289
100%	7 days	Yes	A+B+C+D	5,695	53	23	7,243	287	29	227,289
100%	14–7 days	Yes	A	6,138	57	31	7,595	306	33	421,820
100%	14–7 days	Yes	A+B	3,893	36	20	7,355	293	30	421,820
100%	14–7 days	Yes	A+B+C	3,313	31	17	7,293	290	30	421,820
100%	14–7 days	Yes	A+B+C+D	2,793	26	14	7,237	287	29	421,820
100%	14 days	Yes	A	2,117	20	9	7,044	276	26	452,238

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
100%	14 days	Yes	A+B	1,260	12	5	7,006	274	26	452,238
100%	14 days	Yes	A+B+C	1,056	10	4	6,996	274	26	452,238
100%	14 days	Yes	A+B+C+D	878	8	4	6,987	273	26	452,238
50%	0 day	No	A	14,593,265	136,568	195,326	3,655,505	198,408	42,742	0
50%	0 day	No	A+B	801,343	7,496	6,188	133,033	7,149	1,499	0
50%	0 day	No	A+B+C	290,695	2,719	2,007	44,833	2,369	476	0
50%	0 day	No	A+B+C+D	150,273	1,406	915	21,697	1,120	214	0
50%	7–0 days	No	A	8,932,401	83,812	93,142	1,846,408	100,932	22,654	105,788
50%	7–0 days	No	A+B	156,695	1,471	695	17,927	921	180	105,788
50%	7–0 days	No	A+B+C	77,912	732	370	11,232	565	115	105,788
50%	7–0 days	No	A+B+C+D	50,405	474	267	8,979	440	85	105,788
50%	7 days	No	A	8,878,596	83,303	93,142	1,846,527	100,941	22,655	113,645
50%	7 days	No	A+B	92,166	862	695	17,927	921	180	113,645
50%	7 days	No	A+B+C	31,220	292	215	7,682	366	61	113,645
50%	7 days	No	A+B+C+D	15,868	148	96	5,171	231	33	113,645
50%	14–7 days	No	A	4,392,446	41,293	34,343	727,727	39,987	9,268	210,910
50%	14–7 days	No	A+B	20,841	195	109	5,558	251	38	210,910
50%	14–7 days	No	A+B+C	9,440	89	39	4,274	180	23	210,910
50%	14–7 days	No	A+B+C+D	5846	55	28	4,033	167	20	210,910
50%	14 days	No	A	4,381,380	41,188	34,309	726,863	39,940	9,256	226,119
50%	14 days	No	A+B	14,440	135	109	5,558	251	38	226,119
50%	14 days	No	A+B+C	4,843	45	34	3,925	163	19	226,119
50%	14 days	No	A+B+C+D	2,453	23	15	3,556	143	15	226,119
50%	0 day	Yes	A	63,545	595	290	9,154	445	77	0
50%	0 day	Yes	A+B	38,124	357	163	6,477	301	47	0
50%	0 day	Yes	A+B+C	31,990	300	134	5,876	269	41	0
50%	0 day	Yes	A+B+C+D	26,642	250	109	5,372	242	35	0
50%	7–0 days	Yes	A	26,082	246	142	6,469	302	53	105,788
50%	7–0 days	Yes	A+B	16,814	158	92	5,388	242	38	105,788
50%	7–0 days	Yes	A+B+C	14,366	135	79	5,103	226	34	105,788
50%	7–0 days	Yes	A+B+C+D	12,158	114	67	4,847	212	31	105,788
50%	7 days	Yes	A	6,655	62	30	3,842	159	18	113,645
50%	7 days	Yes	A+B	3,985	37	17	3,673	147	15	113,645
50%	7 days	Yes	A+B+C	3,342	31	14	3,643	145	15	113,645
50%	7 days	Yes	A+B+C+D	2,783	26	11	3,616	143	14	113,645
50%	14–7 days	Yes	A	2,933	28	15	3,781	153	17	210,910
50%	14–7 days	Yes	A+B	1,872	18	10	3,669	146	15	210,910
50%	14–7 days	Yes	A+B+C	1,596	15	8	3,639	145	15	210,910
50%	14–7 days	Yes	A+B+C+D	1,348	13	7	3,613	143	14	210,910

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
50%	14 days	Yes	A	1,027	10	5	3,519	138	13	226,119
50%	14 days	Yes	A+B	614	6	3	3,501	137	13	226,119
50%	14 days	Yes	A+B+C	515	5	2	3,497	137	13	226,119
50%	14 days	Yes	A+B+C+D	429	4	2	3,493	137	13	226,119
20%	0 day	No	A	11,686,806	109,823	141,719	2,723,780	148,882	32,851	0
20%	0 day	No	A+B	317,808	2,981	2,442	52,585	2,834	598	0
20%	0 day	No	A+B+C	113,748	1,067	791	17,678	935	188	0
20%	0 day	No	A+B+C+D	58,924	553	363	8,606	444	85	0
20%	7–0 days	No	A	5,950,980	56,140	53,179	1,087,845	60,016	13,851	42,315
20%	7–0 days	No	A+B	59,386	560	266	6,907	355	70	42,315
20%	7–0 days	No	A+B+C	29,908	283	142	4,359	220	45	42,315
20%	7–0 days	No	A+B+C+D	19,470	184	103	3,512	173	34	42,315
20%	7 days	No	A	5,920,851	55,853	53,179	1,087,349	59,981	13,840	45,458
20%	7 days	No	A+B	34,910	327	266	6,907	355	70	45,458
20%	7 days	No	A+B+C	12,085	113	84	3,033	144	24	45,458
20%	7 days	No	A+B+C+D	6,199	58	38	2,059	92	13	45,458
20%	14–7 days	No	A	2,129,633	20,142	15,028	323,588	17,942	4,253	84,364
20%	14–7 days	No	A+B	7,849	74	42	2,176	98	15	84,364
20%	14–7 days	No	A+B+C	3,622	34	15	1,695	71	9	84,364
20%	14–7 days	No	A+B+C+D	2,260	21	11	1,605	66	8	84,364
20%	14 days	No	A	2,123,723	20,085	15,002	323,001	17,908	4,245	90,448
20%	14 days	No	A+B	5,438	51	42	2,176	98	15	90,448
20%	14 days	No	A+B+C	1,872	18	13	1,564	65	8	90,448
20%	14 days	No	A+B+C+D	958	9	6	1,421	57	6	90,448
20%	0 day	Yes	A	24,995	235	115	3,647	178	31	0
20%	0 day	Yes	A+B	15,029	141	65	2,585	120	19	0
20%	0 day	Yes	A+B+C	12,619	119	54	2,346	107	16	0
20%	0 day	Yes	A+B+C+D	10,515	99	44	2,146	97	14	0
20%	7–0 days	Yes	A	10,147	96	55	2,554	119	21	42,315
20%	7–0 days	Yes	A+B	6,566	62	36	2,136	96	15	42,315
20%	7–0 days	Yes	A+B+C	5,616	53	31	2,026	90	14	42,315
20%	7–0 days	Yes	A+B+C+D	4,757	45	26	1,926	84	12	42,315
20%	7 days	Yes	A	2,615	25	12	1,534	64	7	45,458
20%	7 days	Yes	A+B	1,570	15	7	1,467	59	6	45,458
20%	7 days	Yes	A+B+C	1,318	12	6	1,455	58	6	45,458
20%	7 days	Yes	A+B+C+D	1,098	10	5	1,445	57	6	45,458
20%	14–7 days	Yes	A	1,142	11	6	1,509	61	7	84,364
20%	14–7 days	Yes	A+B	732	7	4	1,465	58	6	84,364
20%	14–7 days	Yes	A+B+C	624	6	3	1,454	58	6	84,364

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
20%	14–7 days	Yes	A+B+C+D	528	5	3	1,444	57	6	84,364
20%	14 days	Yes	A	403	4	2	1,407	55	5	90,448
20%	14 days	Yes	A+B	242	2	1	1,400	55	5	90,448
20%	14 days	Yes	A+B+C	203	2	1	1,398	55	5	90,448
20%	14 days	Yes	A+B+C+D	169	2	1	1,397	55	5	90,448
Booster vaccination rate=60% on June 30, 2022, booster vaccination rate=85% on December 31, 2022										
100%	0 day	No	A	12,922,032	120,710	173,218	3,249,552	176,074	38,187	0
100%	0 day	No	A+B	1,039,439	9,703	8,723	185,865	9,941	2,076	0
100%	0 day	No	A+B+C	455,636	4,253	3,413	75,665	3,979	797	0
100%	0 day	No	A+B+C+D	255,103	2,382	1,684	39,865	2,049	392	0
100%	7–0 days	No	A	6,452,568	60,385	66,137	1,322,321	72,100	16,346	211,576
100%	7–0 days	No	A+B	216,215	2,022	986	26,889	1,355	258	211,576
100%	7–0 days	No	A+B+C	122,459	1,146	566	18,760	925	188	211,576
100%	7–0 days	No	A+B+C+D	83,289	780	427	15,746	758	146	211,576
100%	7 days	No	A	6,349,818	59,421	66,137	1,322,321	72,100	16,346	227,289
100%	7 days	No	A+B	120,477	1,125	986	26,889	1,355	258	227,289
100%	7 days	No	A+B+C	49,339	460	368	13,910	654	107	227,289
100%	7 days	No	A+B+C+D	27,072	253	178	9,977	442	62	227,289
100%	14–7 days	No	A	2,228,354	20,868	17,956	376,505	20,556	4,784	421,820
100%	14–7 days	No	A+B	28,421	266	155	9,673	425	60	421,820
100%	14–7 days	No	A+B+C	14,878	139	59	8,157	338	42	421,820
100%	14–7 days	No	A+B+C+D	9,720	91	45	7,835	321	38	421,820
100%	14 days	No	A	2,209,689	20,693	17,956	376,471	20,552	4,782	452,238
100%	14 days	No	A+B	18,900	176	155	9,673	425	60	452,238
100%	14 days	No	A+B+C	7,664	72	57	7,631	315	36	452,238
100%	14 days	No	A+B+C+D	4,189	39	28	7,079	283	29	452,238
100%	0 day	Yes	A	113,519	1,061	556	17,664	856	148	0
100%	0 day	Yes	A+B	69,524	650	319	12,705	589	93	0
100%	0 day	Yes	A+B+C	58,636	548	263	11,567	528	80	0
100%	0 day	Yes	A+B+C+D	49,054	458	215	10,604	477	70	0
100%	7–0 days	Yes	A	45,163	423	241	12,029	553	96	211,576
100%	7–0 days	Yes	A+B	29,724	278	161	10,279	456	72	211,576
100%	7–0 days	Yes	A+B+C	25,542	239	139	9,803	430	65	211,576
100%	7–0 days	Yes	A+B+C+D	21,727	203	118	9,370	405	59	211,576
100%	7 days	Yes	A	11,914	111	58	7,612	314	36	227,289
100%	7 days	Yes	A+B	7,277	68	33	7,295	290	30	227,289
100%	7 days	Yes	A+B+C	6,134	57	27	7,244	287	29	227,289
100%	7 days	Yes	A+B+C+D	5,129	48	22	7,198	285	29	227,289
100%	14–7 days	Yes	A	5,104	48	25	7,469	300	32	421,820

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
100%	14–7 days	Yes	A+B	3,325	31	17	7,287	290	30	421,820
100%	14–7 days	Yes	A+B+C	2,850	27	14	7,237	287	29	421,820
100%	14–7 days	Yes	A+B+C+D	2,419	23	12	7,193	285	29	421,820
100%	14 days	Yes	A	1,839	17	9	7,024	275	26	452,238
100%	14 days	Yes	A+B	1,122	10	5	6,995	274	26	452,238
100%	14 days	Yes	A+B+C	946	9	4	6,987	273	26	452,238
100%	14 days	Yes	A+B+C+D	791	7	4	6,980	273	26	452,238
50%	0 day	No	A	10,081,389	94,663	124,420	2,389,533	130,535	29,026	0
50%	0 day	No	A+B	506,260	4,746	4,254	90,757	4,872	1,025	0
50%	0 day	No	A+B+C	220,284	2,066	1,673	37,083	1,955	393	0
50%	0 day	No	A+B+C+D	123,644	1,161	832	19,689	1,013	194	0
50%	7–0 days	No	A	3,925,116	36,987	36,574	743,174	40,933	9,524	105,788
50%	7–0 days	No	A+B	100,174	945	467	12,876	649	123	105,788
50%	7–0 days	No	A+B+C	57,449	543	267	8,986	445	92	105,788
50%	7–0 days	No	A+B+C+D	39,347	372	203	7,618	369	72	105,788
50%	7 days	No	A	3,862,260	36,389	36,574	743,174	40,933	9,524	113,645
50%	7 days	No	A+B	56,174	527	467	12,876	649	123	113,645
50%	7 days	No	A+B+C	23,545	221	179	6,842	321	52	113,645
50%	7 days	No	A+B+C+D	13,054	123	88	4,957	219	31	113,645
50%	14–7 days	No	A	998,057	9,419	7,825	165,238	9,101	2,152	210,910
50%	14–7 days	No	A+B	13,104	123	73	4,734	208	29	210,910
50%	14–7 days	No	A+B+C	6,985	66	28	4,036	167	21	210,910
50%	14–7 days	No	A+B+C+D	4,601	43	21	3,890	159	19	210,910
50%	14 days	No	A	988,447	9,327	7,825	165,222	9,099	2,150	226,119
50%	14 days	No	A+B	8,762	82	73	4,734	208	29	226,119
50%	14 days	No	A+B+C	3,651	34	28	3,797	157	18	226,119
50%	14 days	No	A+B+C+D	2,019	19	14	3,535	141	15	226,119
50%	0 day	Yes	A	55,205	519	276	8,778	426	74	0
50%	0 day	Yes	A+B	33,914	319	159	6,330	294	46	0
50%	0 day	Yes	A+B+C	28,627	269	131	5,767	264	40	0
50%	0 day	Yes	A+B+C+D	23,968	226	107	5,290	238	35	0
50%	7–0 days	Yes	A	21,531	204	116	5,890	272	48	105,788
50%	7–0 days	Yes	A+B	14,248	135	78	5,068	226	36	105,788
50%	7–0 days	Yes	A+B+C	12,263	116	67	4,842	213	33	105,788
50%	7–0 days	Yes	A+B+C+D	10,446	99	57	4,636	201	30	105,788
50%	7 days	Yes	A	5,785	54	29	3,799	157	18	113,645
50%	7 days	Yes	A+B	3,547	33	16	3,639	145	15	113,645
50%	7 days	Yes	A+B+C	2,993	28	14	3,615	144	15	113,645
50%	7 days	Yes	A+B+C+D	2,505	24	11	3,594	142	14	113,645

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
50%	14–7 days	Yes	A	2,438	23	12	3,721	149	16	210,910
50%	14–7 days	Yes	A+B	1,596	15	8	3,636	145	15	210,910
50%	14–7 days	Yes	A+B+C	1,370	13	7	3,612	143	15	210,910
50%	14–7 days	Yes	A+B+C+D	1,165	11	6	3,591	142	14	210,910
50%	14 days	Yes	A	893	8	4	3,510	138	13	226,119
50%	14 days	Yes	A+B	547	5	3	3,496	137	13	226,119
50%	14 days	Yes	A+B+C	461	4	2	3,493	137	13	226,119
50%	14 days	Yes	A+B+C+D	386	4	2	3,489	136	13	226,119
20%	0 day	No	A	6,850,083	64,626	75,716	1,492,867	82,231	18,794	0
20%	0 day	No	A+B	199,276	1,873	1,676	35,782	1,925	407	0
20%	0 day	No	A+B+C	86,381	812	661	14,658	774	156	0
20%	0 day	No	A+B+C+D	48,561	457	330	7,819	403	77	0
20%	7–0 days	No	A	1,878,232	17,789	15,960	328,189	18,216	4,325	42,315
20%	7–0 days	No	A+B	38,329	363	181	5,024	253	48	42,315
20%	7–0 days	No	A+B+C	22,137	210	103	3,507	174	36	42,315
20%	7–0 days	No	A+B+C+D	15,221	145	79	2,990	145	29	42,315
20%	7 days	No	A	1,847,257	17,492	15,960	328,302	18,220	4,325	45,458
20%	7 days	No	A+B	21,580	203	181	5,024	253	48	45,458
20%	7 days	No	A+B+C	9,166	86	70	2,711	127	21	45,458
20%	7 days	No	A+B+C+D	5,112	48	35	1,976	87	12	45,458
20%	14–7 days	No	A	368,376	3,493	2,862	60,646	3,357	800	84,364
20%	14–7 days	No	A+B	5,002	47	28	1,871	82	11	84,364
20%	14–7 days	No	A+B+C	2,693	26	11	1,605	67	8	84,364
20%	14–7 days	No	A+B+C+D	1,782	17	8	1,550	63	7	84,364
20%	14 days	No	A	364,523	3,456	2,862	60,640	3,356	800	90,448
20%	14 days	No	A+B	3,356	32	28	1,871	82	11	90,448
20%	14 days	No	A+B+C	1,420	13	11	1,515	62	7	90,448
20%	14 days	No	A+B+C+D	790	7	5	1,413	56	6	90,448
20%	0 day	Yes	A	21,722	205	110	3,498	170	29	0
20%	0 day	Yes	A+B	13,368	126	63	2,527	117	19	0
20%	0 day	Yes	A+B+C	11,289	107	52	2,303	105	16	0
20%	0 day	Yes	A+B+C+D	9,456	89	43	2,113	95	14	0
20%	7–0 days	Yes	A	8,371	80	45	2,328	108	19	42,315
20%	7–0 days	Yes	A+B	5,557	53	30	2,010	90	14	42,315
20%	7–0 days	Yes	A+B+C	4,787	46	26	1,923	85	13	42,315
20%	7–0 days	Yes	A+B+C+D	4,081	39	22	1,843	80	12	42,315
20%	7 days	Yes	A	2,274	21	11	1,518	63	7	45,458
20%	7 days	Yes	A+B	1,397	13	7	1,454	58	6	45,458
20%	7 days	Yes	A+B+C	1,180	11	5	1,445	57	6	45,458

Continued

Recovery (%) of overseas incoming travel compared with 2019	Quarantine strategy	Personal protection	Case identification	Cumulative cases	Cumulative deaths	Maximum new cases	Maximum cases quarantined	Maximum hospital beds	Maximum ICU beds	Maximum hotel rooms for imported quarantine
20%	7 days	Yes	A+B+C+D	988	9	4	1,436	57	6	45,458
20%	14–7 days	Yes	A	949	9	5	1,485	60	6	84,364
20%	14–7 days	Yes	A+B	623	6	3	1,452	58	6	84,364
20%	14–7 days	Yes	A+B+C	535	5	3	1,443	57	6	84,364
20%	14–7 days	Yes	A+B+C+D	455	4	2	1,435	57	6	84,364
20%	14 days	Yes	A	351	3	2	1,403	55	5	90,448
20%	14 days	Yes	A+B	215	2	1	1,398	55	5	90,448
20%	14 days	Yes	A+B+C	182	2	1	1,397	55	5	90,448
20%	14 days	Yes	A+B+C+D	152	1	1	1,396	55	5	90,448

Note: A: Fever monitoring; B: Contact Tracing; C: Screening People at Risk ; D: Community-wide Screening.
Abbreviation: ICU=intensive care unit.

4.3%, 0.39%, and 0.80% for fully vaccinated infected people. A previous study demonstrated that risk of hospitalization, ICU admission, and death following booster doses were 6.50%, 8.10%, and 19.12% of full vaccination, respectively (*4*). Our study set hospital admission rate, ICU admission rate, and fatality rate as 0.30%, 0.03%, and 0.15% for booster vaccinated infected people, respectively.

Infection Detection Measures

In the dynamic transmission model, μ denotes the rate from infected persons to quarantine people. For assessing different local infection detection measures, we obtained information on the interval from infection to quarantine from real-world data in Guangdong Province.

Estimation of Transmission Coefficient (beta)

We collected real world time series data of imported and local infected persons in a Guangdong epidemic during March 15, 2020 to April 15, 2020. This epidemic was triggered by imported cases from Africa. Based on the real-world data, we conducted an SIR model to calculate a contact transmission coefficient β value with the best fit. Vaccination had not started during or prior to this outbreak. Its β value therefore represents the transmission rate with local non-pharmacological interventions (NPIs) but without vaccine-induced immunity. We found that the β with best fitness was 0.14 (R^2=84.71%, Root Mean Square Error=3.61).

Given viral variants could have higher transmission rates (transmissibility of variants could reach 1.97 times of non-variant) (*7*), we thus set β as 0.14×1.97=0.27 to represent the transmission rate in 2022.

A meta-analysis found that the relative risk (RR) reductions associated with mask wearing and social distancing were 0.47 and 0.75, respectively (*8*). Given that the effects of combinations of personal protection and social distancing were rarely reported, in our study we used the lowest risk reduction (RR=0.47) to represent the effectiveness of personal protection together with social distancing. We set β as 0.27/0.47=0.57 to represent the transmission rate without personal protection and social distancing.

Medical Resources Against COVID-19 in Guangdong Province

As of December 28, 2020, 7,091 hospital beds and 156 ICU beds (estimated by the number of total ICU beds multiplying by the proportion of infectious diseases) could be used for infectious disease cases in Guangdong Province (*9*). If 50% of these hospital beds could be used for COVID-19 treatment, 3,546 hospital beds and 78 ICU beds would be available. In addition, 419 hotels with 47,636 rooms could be used for quarantine of travelers.

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Outbreak Reports

A Limited Spreading Event of COVID-19 Caused by Delta Variant in a Cosmetic Hospital — Yantai City, Shandong Province, China, 2021

Yang Han[1]; Wenkui Sun[1]; Shengyang Zhang[1]; Bin Lin[1]; Jingyu Liu[2]; Runze Lu[3]; Xiaolin Jiang[1,#]; Jie Lei[1]

Summary

What is already known about this topic?

Coronavirus disease 2019 (COVID-19) outbreaks in the past were mostly caused by overseas transmission, but if control measures are not appropriately applied, domestic transmission could also cause large-scale local epidemics.

What is added by this report?

This report covers all information of epidemic investigation processes, epidemiological characteristics and exposure history, transmission chains, sequencing results as well as public health measures taken for the COVID-19 cluster epidemic caused by the Delta variant in a cosmetic hospital in Yantai City in August 2021.

What are the implications for public health practice?

The information provided in this report, including active case finding, community management, and mass testing, may assist public health professionals in dealing with local COVID-19 epidemics caused by domestic transmission.

As of September 18, 2021, more than 200 million people were confirmed as coronavirus disease 2019 (COVID-19) cases worldwide, including more than 4 million deaths, reported by the World Health Organization (WHO) (*1*). The Delta variant of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first identified in India in October 2020 (*2*) and had become the dominant variant globally. There is evidence showing that this variant is significantly more infectious (*3*). On July 20, 2021, Nanjing City reported 9 symptomatic and 2 asymptomatic cases of COVID-19, who were all cleaning staff of Nanjing Lukou Airport and detected by the latest weekly SARS-CoV-2 nucleic acid tests. In the next 10 days, more than 10 cities reported COVID-19 cases related to Nanjing Lukou Airport. On August 3, 2021, Yantai City reported 2 confirmed cases of COVID-19, who were both staff members of a cosmetic hospital and detected by the latest routine COVID-19 nucleic acid test, and finally led to a cluster of 10 cases.

INVESTIGATION AND RESULTS

We found 10 cases in this cluster, of which 8 were confirmed cases and 2 were asymptomatic cases (Table 1). Their median age was 28.5 years, and 4 were male. Overall, 9 of these cases worked in the operations department or aesthetic design department. The first 2 cases were found by routine COVID-19 nucleic acid test, while the rest were detected by close contact tracking and screening; these cases were reported on August 3 and 4, respectively. The most commonly reported symptoms were fever, cough, and pharyngalgia. Each of them was given 2 doses of SARS-CoV-2 inactivated vaccines, and vaccination was mainly completed in February, May, and June. After the first 2 cases were found by routine COVID-19 nucleic acid test, more than 1,000 people were isolated and tested as close contacts, and only 8 of them tested positive, all staff members of this cosmetic hospital. SARS-CoV-2 vaccination rate of close contacts in this cosmetic hospital (87.7%, 263/300) was higher than outside the cosmetic hospital (68.6%, 717/1,045), (χ^2=42.798, P<0.001).

The cosmetic hospital has 22 departments and 304 staff members. The index COVID-19 cases in the cosmetic hospital occurred in a 39-year-old female (Patient A), the director of the hospital, and a 28-year-old male (Patient B), the director of the plastic surgery marketing department. They were detected during the monthly SARS-CoV-2 nucleic acid test on August 2, 2021 and were diagnosed as confirmed cases of symptomatic COVID-19 on August 3.

The field epidemiological investigation found that Patient A flew to Guilin from Yantai on July 19, 2021,

TABLE 1. Clinical characteristics and vaccination history of COVID-19 patients.

Patient	Age (years)	Gender	Position	Case type	Discovery pathway	Symptoms*	Month of complete the whole process of SARS-CoV-2 vaccines
A	39	Female	Hospital director	Confirmed case	Routine COVID-19 nucleic acid test	2,4,8	June
B	28	Male	Director of plastic surgery marketing department	Confirmed case	Regular COVID-19 nucleic acid test	2,3,5,9,10	May
C	29	Male	Director of aesthetic design department	Confirmed case	Close contacts tracking and screening	1,4,7	February
D	38	Female	Staff of aesthetic design department	Confirmed case	Close contacts tracking and screening	4	February
E	26	Female	Assistant of the hospital deputy director	Confirmed case	Close contacts tracking and screening	1,2,5,6,7	May
F	33	Male	Director of receptionists	Asymptomatic case	Close contacts tracking and screening	−	June
G	26	Female	Assistant of operating room physician	Confirmed case	Close contacts tracking and screening	1,4,5	May
H	25	Male	Staff of electricity-network department	Confirmed case	Close contacts tracking and screening	1,4,7	May
I	28	Female	Staff of aesthetic design department	Confirmed case	Close contacts tracking and screening	1,4	May
J	33	Female	Staff of aesthetic design department	Asymptomatic case	Close contacts tracking and screening	−	May

Abbreviations: COVID-19=coronavirus disease 2019; SARS-CoV-2=severe acute respiratory syndrome coronavirus 2; CT=computed tomography.

* 1=fever; 2=cough; 3=expectoration; 4=pharyngalgia; 5=headache; 6=myalgia; 7=weakness; 8=vomiting; 9=ageusia; 10=CT findings of ground-glass opacities; − represented no symptom.

with a stopover of one hour at Nanjing Lukou Airport (the suspected source of COVID-19 outbreak in Nanjing City at that time), while Patient B did not leave Yantai during the latest 14 days. Patient A did not drink, eat, or have close contact with the airport staff, except going to the bathroom during the stop according to her description, but she experienced a cough the next day. She went back to Yantai on July 22 and took an intravenous drip and some cold pills during the next several days. Furthermore, after returning from Guilin, Patient A attended several morning briefings with more than 10 aesthetic design department staff members (including Patients B–F, I, and J). On July 31, Patient A organized a team-building activity for the cosmetic hospital staff and participated in a 10-person dinner (including Patients B, C, E, and F). Patient B had frequent contact with Patient A during work and coughed on July 30.

A total of 117 close contacts of Patient A were traced and quarantined, who were sampled and tested on the 1st, 3rd, 5th, 7th, 12th, and 13th day of centralized isolation. Overall, 3 confirmed cases and 1 asymptomatic case, Patients C–F, were identified during August 3 to 4 among these close contacts. In the same way, local CDCs traced and tested close contacts of Patients B–F, and 3 confirmed cases and 1 asymptomatic case, Patients G–J, were detected. In total, 10 confirmed or asymptomatic COVID-19 cases, Patients A–J, were identified in this cluster (Figure 1 and Table 1), who were all staff of the cosmetic hospital, and none of them had a history of travel to high risk areas 14 days before the onset of illness except Patient A.

Among the later identified 8 cases, Patient C, the director of aesthetic design department, and Patient D, a staff of aesthetic design department, also had frequent contact with Patient A during work. Patient B and C had frequent contact with many staff members, including Patients E, F, I, and J. Patient G only had contact with Patient B during work among the other 9 cases, while Patient H, a new employee in the cosmetic hospital, sat next to Patient B in the office. Furthermore, Patients B, E, F, and H were in the same office, and Patients C, I, and J often had lunch together.

Further investigation, including case interviews and examining the surveillance video, found that 9 of the 10 cases (except Patient G) were administrative staff, had separate office areas, and did not use the elevator for customers. Though most of the cosmetic hospital staff did not wear masks when they had contact with each other, they did wear masks strictly when contacting customers and after work. The usual work time of these 10 cases were 08:00 to 21:00, so they had little time to accompany their families.

From August 3 to 8, more than 30,000 people from the community where the cases resided and worked were screened with polymerase chain reaction (PCR) testing, and all Yantai City residents were eventually

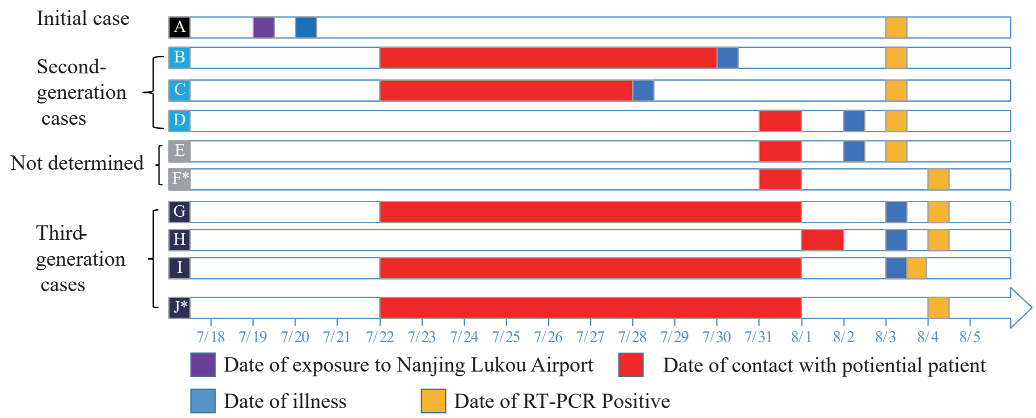

FIGURE 1. Cluster of COVID-19 cases associated with a cosmetic hospital in Yantai, Shandong province, China, 2021.
Abbreviations: COVID-19=coronavirus disease 2019; RT-PCR=reverse transcription-polymerase chain reaction.
* means asymptomatic case.

tested. No additional cases were found in the 6.5 million citizens.

Compared with the Wuhan reference strain (NC_045512) sequence, the COVID-19 genome sequence in Yantai cosmetic hospital belonged to the VOC/Delta variant (B.1.617.2 evolution branch). The 10 whole genome sequences shared 35 nucleotide mutation sites and 9 nucleotide deletion sites. On this basis, the genome sequence of Patient E added a mutation site (g27990t), and the homology between sequences was greater than 99.99%. It was located in the same branch and belonged to the same transmission chain in phylogenetic analysis. In the comparative analysis of the GISAID database (https://platform.epicov.org/), there were 34 nucleotide mutation sites consistent with the above sequence in the sample sequence collected by Russia on June 28, 2021, which had the parental sequence characteristics of the epidemic sequence, indicating that the epidemic may have been caused by overseas transmission (Figure 2).

According to the field epidemiological investigation and whole genome sequence traceability analysis, Patient A was likely the source of this COVID-19 cluster, Patients B–D were infected by Patient A, Patients G and H were infected by Patient B, and Patients I and J were infected by Patient C. The source of infection for Patients E and F could not be determined conclusively and may be due to transmission from Patients A–C. Therefore, there were 3 generations in this cluster.

DISCUSSION

This outbreak was likely a cluster infection related to Lukou Airport in Nanjing and was confined to a limited area — all cases occurred in the cosmetic hospital and did not spread outside this cosmetic hospital, indicating that the strategies used in Yantai City, including mass testing, active case finding, close contact and general contacts screening, and community management, were highly effective. Compared with the cluster of COVID-19 cases in other cities, which were also related to Lukou Airport in Nanjing, this cluster in Yantai was limited both in terms of infection scope and number of people infected for several reasons. First, SARS-CoV-2 vaccination rate in the cosmetic hospital and close contacts outside the hospital were higher than in other cities (*4–5*), as the inactivated SARS-CoV-2 vaccines against the Delta and other variant infections were still effective and protected other close contacts from infection (*6–7*). Second, the surveillance video confirmed that masks were worn regularly in the workplace. Because wearing masks was among the non-pharmaceutical intervention measures that could be effectively implemented at a minimal cost and without dramatically disrupting social practices (*8*), face mask use and other personal protections should be continued. Third, the surveillance video showed that 9 cases in this cluster worked at the auxiliary building and they seldom used elevators or other public spaces, so reducing exposure to contaminated environment can also protect other staff members from being infected.

Recommendations have been made to strengthen investigations of personnel coming to Shandong from the medium and high-risk areas and the prevention of nosocomial COVID-19 infections to prevent transmission at these medical institutions.

Funding: This work was supported by Shandong Medical and Health Science and Technology

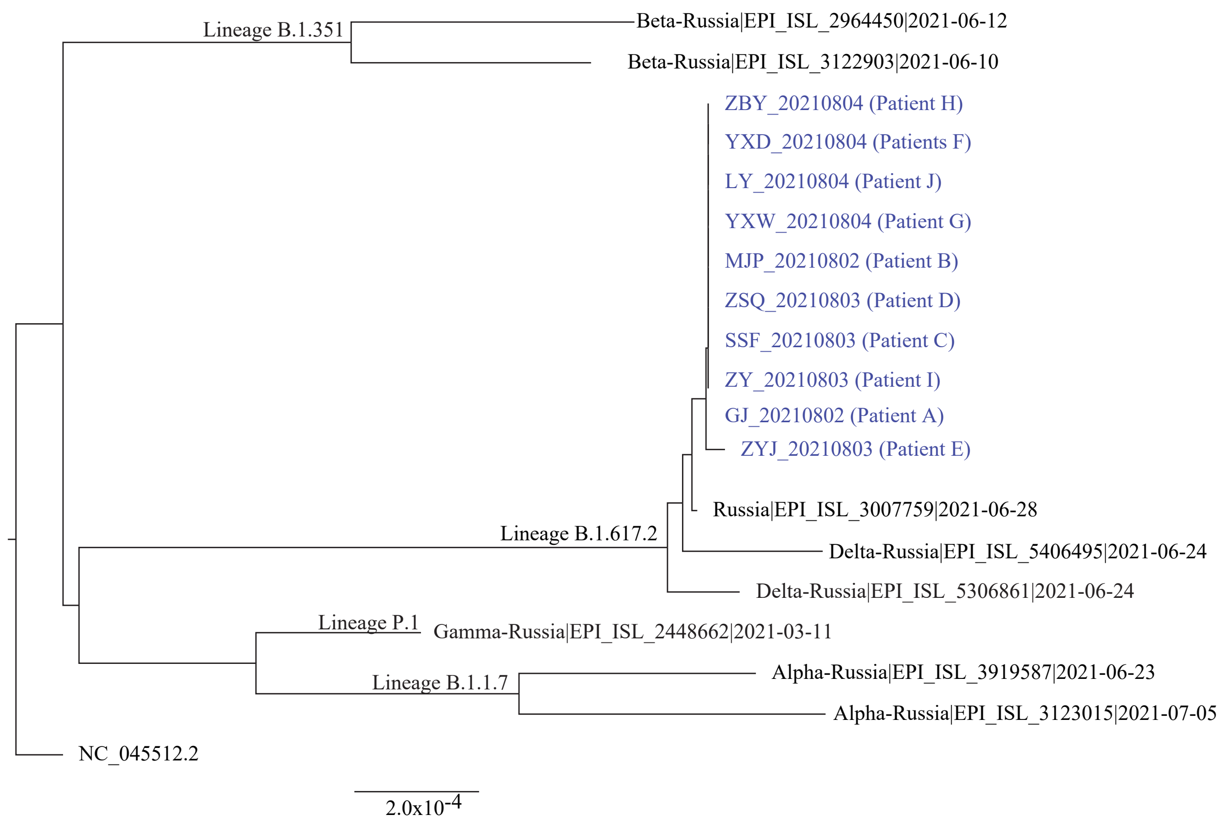

FIGURE 2. Phylogenetic tree based on the SARS-CoV-2 whole genome sequences in a cosmetic hospital of Yantai, 2021.
Notes: The Yantai cosmetic hospital VOC/Delta variant is marked in blue.The Wuhan reference strain (NC_045512.2) and other variants are marked in black.
Abbreviation: SARS-CoV-2=severe acute respiratory syndrome coronavirus 2.

Development Plan Project (Grant numbers: 202015021386); the Major Scientific and Technological Innovation Project in Shandong Province (Grant numbers: 2020SFXGFY02-1); Shandong Medical and Health Science and Technology Development Plan (Grant numbers: 2021RZA01021).

doi: 10.46234/ccdcw2022.033

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Submitted: September 23, 2021; Accepted: February 23, 2022

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Indexed by PubMed Central (PMC), Emerging Sources Citation Index (ESCI), and Chinese Scientific and Technical Papers and Citations

The inauguration of *China CDC Weekly* is in part supported by Project for Enhancing International Impact of China STM Journals Category D (PIIJ2-D-04-(2018)) of China Association for Science and Technology (CAST).

CCDC weekly

Vol. 4 No. 10 Mar. 11, 2022

Responsible Authority

National Health Commission of the People's Republic of China

Sponsor

Chinese Center for Disease Control and Prevention

Editing and Publishing

China CDC Weekly Editorial Office

No.155 Changbai Road, Changping District, Beijing, China

Tel: 86-10-63150501, 63150701

Email: weekly@chinacdc.cn

CSSN

ISSN 2096-7071

CN 10-1629/R1