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Preplanned Studies

Field Simulation of Aerosol Transmission of SARS-CoV-2 in a Special Building Layout — Guangdong Province, China, 2021

Zhuona Zhang¹; Xia Li¹; Qin Wang¹; Jin Xu²; Qinqin Jiang³; Sili Jiang³; Jiayun Lyu³; Shiqiang Liu³; Ling Ye⁴; Jun Yuan³; Wenru Feng³; Dongqun Xu^{1, #}

Summary

What is already known on this topic?

Aerosol transmission was one route for the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and usually occurred in confined spaces.

What is added by this report?

Aerosol transmission was found to exist between handshake buildings, i.e., buildings with extremely close proximity that formed relatively enclosed spaces. Transmission was mainly affected by the airflow layout caused by switching air conditioners on and off as well as opening and closing doors and windows.

What are the implications for public health practice?

Centralized isolation and home isolation in handshake buildings creates a risk of SARS-CoV-2 aerosol transmission under certain conditions. Attention should be paid to the influence of air distribution layout on aerosol diffusion in isolation wards, and disinfection of isolation venues should be strengthened.

Transmission of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), by aerosol has been confirmed in many studies (1–4), but transmission usually occurs in a confined space. In the epidemic that occurred in Guangzhou City of Guangdong Province in May 2021 (5), the index case and a close contact (later diagnosed as infected) arrived on international flights and were located in 2 different buildings in the hospital at the same time before diagnosis. The buildings were close to each other and formed a relatively enclosed space due to the exterior ceiling between the two buildings; buildings in this layout are sometimes informally referred to as handshake buildings due to their extremely close proximity—in this case, approximately 50 cm separated the handshake buildings.

Epidemiological investigation and viral gene

sequencing showed that there was a temporal and spatial crossover between the two individuals and their genetic sequences were highly homologous, so aerosol transmission may be likely. We used fluorescence microspheres with similar aerodynamic characteristics to the SARS-CoV-2 spike pseudovirus to investigate the transmission path and influencing factors of the virus aerosol through field experiment simulation. The results showed that there was clear aerosol transmission path from the location of the close contact and the index case, and its transmission was mainly affected by the airflow layout that resulted from switching the air conditioner on and off as well as opening and closing doors and windows. In the future, more attention should be paid to the risk of aerosol transmission in close-proximity buildings and to the influence of air distribution layout on aerosol diffusion in isolation wards.

We investigated the hospital and selected 6 sites for the field experiment (Figure 1). Site 1 and 2 were in the fever clinic building. Site 1 was the isolation ward where the infected person stayed; Site 2 was the corridor with windows that could open to an enclosed space, and each window faced the windows of a corresponding room in the clinic building; Sites 3–6 were in the routine clinic building opposite the fever clinic building. Site 3 was a traditional Chinese medicine clinic where the index case saw the doctor and its window was opened; Site 4 was a waiting area for patients with an opened window; Sites 5 and 6 were a doctor's office and a consulting room, respectively, with closed windows. Considering the influence of the airflow layout, 6 simulation scenarios were set according to switching on and off the air conditioner (A) of Ward 1, (B) the opening and closing door of Ward 1, and (C) the window of Corridor 2 (Supplementary Table S1, available in <http://weekly.chinacdc.cn/>). Polystyrene fluorescent microspheres (supplied by the Beijing Institute of Metrology) with similar aerodynamic characteristics as

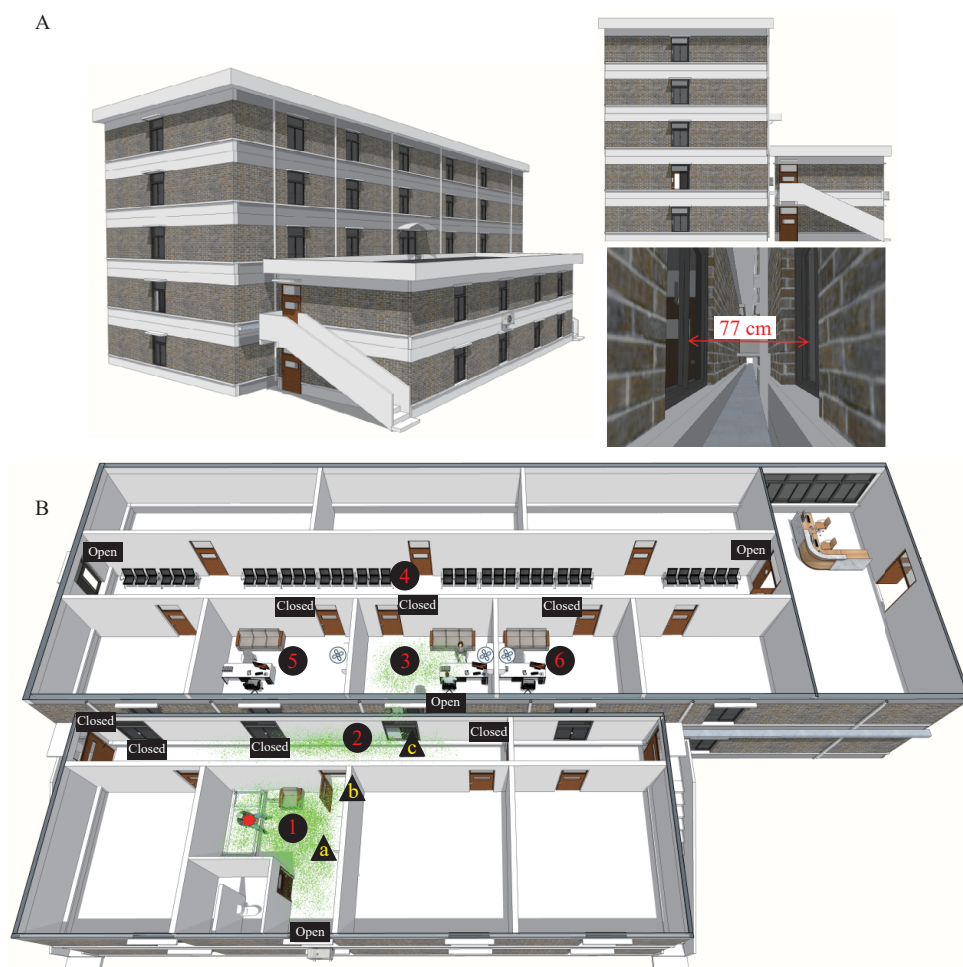


FIGURE 1. Exterior and interior layout of the fever clinic building and the routine clinic building. (A) Exterior layout of the buildings. (B) Interior room layout of the buildings.

Note: In the exterior layout of the buildings, the two-storied building was the fever clinic building, and the five-storied building was the routine clinic building. The distance between the external walls of the 2 buildings is 51 cm. The corridor window had a distance of 77 cm from the window of the opposing traditional Chinese medicine clinic. The isolation area on the second floor and the traditional Chinese medicine clinic on the opposite side formed a relatively enclosed space through the exterior ceiling between the two buildings. In the interior room layout of the buildings, Sites 1–6 were where field experiments were conducted. Triangles (a–c) were influencing factors on airflow distribution: (a) an air conditioner; (b) a door; (c) a window. Red dot was where the Collision Nebulizer was located. Fan symbol (⊗) showed the air conditioner was switched on. Green particles were fluorescent microspheres to simulate exhaled virus aerosol of the imported infected person and transmission diffusion path.

SARS-CoV-2 spike pseudovirus were selected. The Collision Nebulizer (BGI, INC.) was used at Ward 1 to simulate the respiration of the infected person for 1–1.5 hours (exhalation of fluorescent microspheres was 10^{12} – 10^{13} /hour), cough or sneeze (exhalation of fluorescent microspheres was 10^{11} – 10^{12} each cough or sneeze) (6–7). Meanwhile, the concentration of different particle sizes and some meteorological conditions were monitored at 6 sites every 10 minutes. PM_{10} samplers and bioaerosol samplers were used to collect aerosol samples, and samples of sedimentation were collected with cotton swabs. After the field

experiment, the yellow and green fluorescent particles in different samples were observed by fluorescence microscope (Nikon DS-RI) in the laboratory, and the data directly read from the field were analyzed by OriginPro 8 SR3 (OriginLab Company, Northampton, United States).

A total of 7,411 data from the field and 304 samples were obtained in the simulation experiment, including 210 cotton swab samples for wiping the object surface, 54 aerosol liquid samples, 40 aerosol filter membrane samples. In Ward 1, aerosolized fluorescent microspheres were used to simulate the respiration of

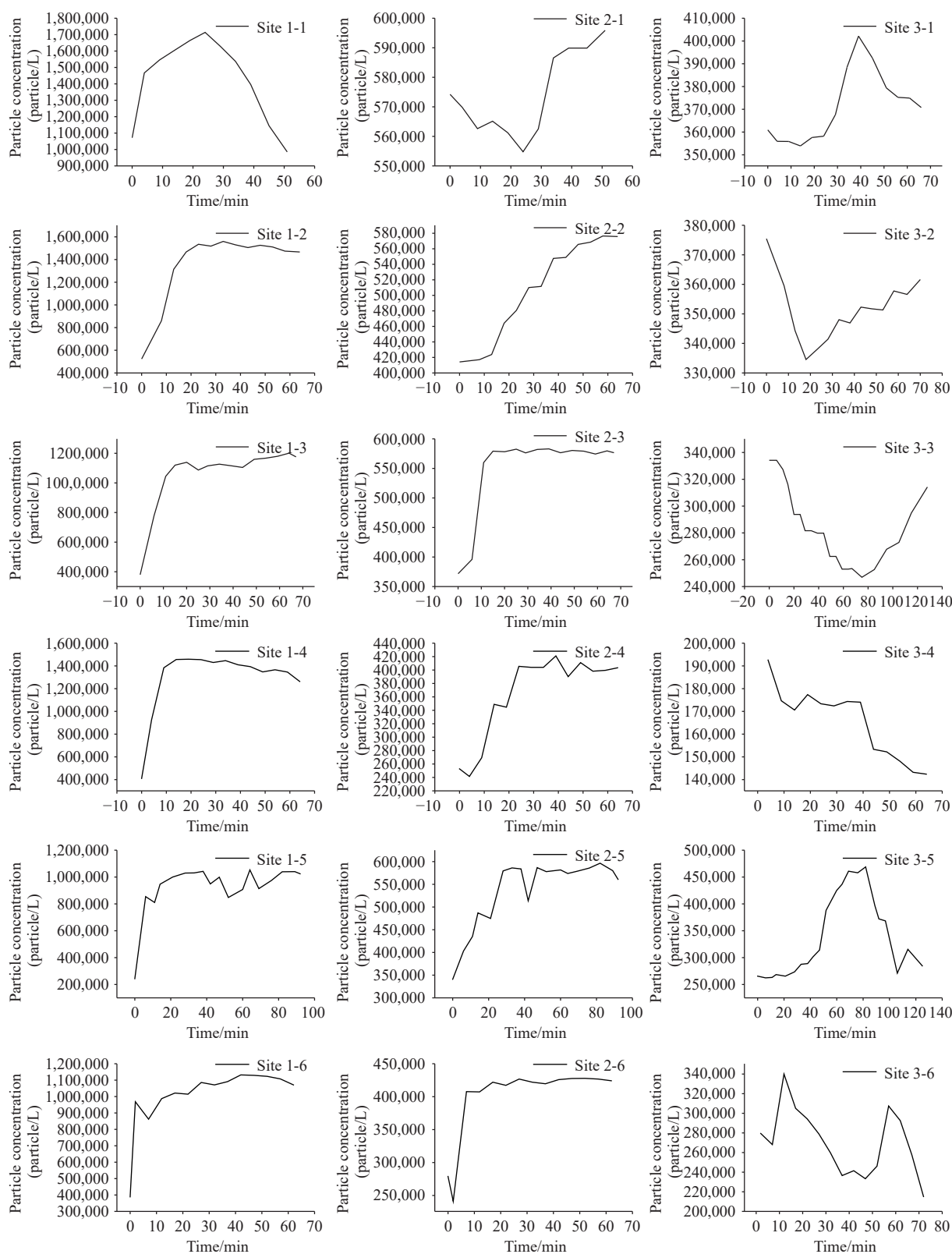


FIGURE 2. The changes of particle concentration over time at 0.3 μm in 6 different scenarios at different sites (Site 1, Site 2, and Site 3).

Note: The abscissa axis represents time (minutes); the ordinate axis represents the particle concentration (particle/L); the number behind the dash represents different simulation scenarios, i.e., Site 1-1 refers to the changes of particle concentration in 0.3 μm with time at Site 1 in Scenario 1.

the infected person and observe the diffusion in Corridor 2 and the opposite of Room 3 through the variation in concentration of aerosol particles, the results were shown in Figure 2. In Ward 1, the concentration of particles in 0.3 μm increased significantly and remained stable after rising to the highest level as well as particles in 0.5, 1, 2.5, 5, and 10 μm . After aerosolization of fluorescent microspheres, the concentration of particles in the Corridor began to rise immediately and remained unchanged after reaching its highest value. Compared with the change at Ward 1, the peak time of particle concentration was relatively delayed. For the opposite of Room 3, particle concentration began to rise 20–40 minutes after aerosolization of fluorescent microspheres. During the monitoring time, only the peak concentration was detected, but no plateau of high concentration was detected. In some scenarios, particle concentration did not change significantly in Room 3. At the same time, fluorescent microspheres were detected in aerosol filter membrane samples, aerosol liquid samples, and swab samples that were collected at the above 3 sites (Figure 3). The results showed that the complete aerosol transmission chain could be obtained from Ward 1 to the Corridor to the opposite of Room 3.

The effects of (A) air conditioners, (B) doors, and (C) windows on aerosol transmission was investigated through 6 different scenarios. The results showed that under the conditions that air conditioners, doors, and windows were all switched off or closed, no fluorescent microspheres were found in the air filter membrane samples and liquid samples collected in Room 3 after aerosolization of fluorescent microspheres in Ward 1. This showed that when airflow was poor, fluorescent microspheres were not easily to spread to Room 3.

When air conditioners, doors, and windows were all switched on or opened, fluorescent microspheres quickly spread to Room 3. As long as air conditioners were switched on, the air current circulated in the ward and the particle concentration in the Corridor and Room 3 rose slowly even if doors and windows were closed. Once a door was opened, particles in the Corridor could rise to the highest concentration in 5 minutes, but the change of particle concentration in Room 3 was less affected. Once a window was opened, particle concentration in Room 3 changed rapidly and significantly even if the door was closed.

In addition, the influence of doors, windows, and personnel movement on aerosol transmission to Office 5 and Room 6 which were adjacent to Room 3 was investigated under the condition that air conditioner was switched on. During the experiment, people left Room 3 and entered the Waiting Area and Room 6 every 10 minutes. The results showed that no fluorescent microspheres were detected in aerosol filter membrane samples and liquid samples collected in the Waiting Area, Office 5, and Room 6 when window was closed. Once a window was opened, fluorescent microspheres were detected in the samples in the Waiting Area and Room 6, but no fluorescent microspheres were detected in Office 5 because no personnel enter and exit from Office 5. It can be found that the risk of aerosol transmission was low when the opposing window of the handshake building was closed.

DISCUSSION

Aerosol field simulation experiments can observe the concentration change of aerosol particle in air in real time to determine the transmission path of aerosol.

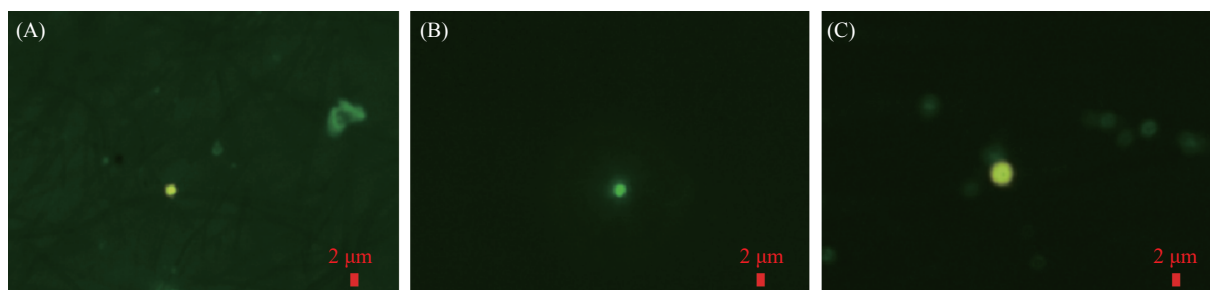


FIGURE 3. Representative photos of fluorescent microspheres tracked by different sampling methods in different sites. After the aerosolization of fluorescent microspheres at Site 1, fluorescent microspheres (yellow and green) were detected in (A) the aerosol filter membrane sample using PM_{10} samplers (100 L/min) under fluorescence microscopy; (B) the aerosol liquid sample using biological aerosol samplers (100 L/min) under fluorescence microscopy; and (C) an air sample using natural sedimentation on table, door handle, windowsill, chair, etc., under fluorescence microscopy.

Through the settings of different scenes, the influencing factors of transmission can be determined. In addition, when people walked around, they will influence the airflow and spread fluorescent microspheres to other places. It has also been confirmed that human activities can affect bacteria-carrying particles in a study (8). After simulating breathing and coughing or sneezing of infected persons, fluorescent microspheres can persist in the air and the particle sizes were mainly between 0.3 μm and 0.5 μm . Under a certain air distribution layout, they can spread to handshake buildings in 20–40 minutes. The better the ventilation, the faster the transmission. Some fluorescent microspheres can settle to the surface of tables, windowsills, and other objects after coagulation. Presently, the research on SARS-CoV-2 transmission usually focused on the simulation cabin experiment or computational fluid dynamic model (9–10). This result provided a basis for epidemic prevention and control and experimental support for future research.

Although some results were obtained, this study was subject to some limitations. First, real SARS-CoV-2 could not be used in real environments due to hazardous risk, so the virus aerosol could not be properly quantified. Second, there was no way to recover the meteorological conditions when the index case stayed in the hospital, so the analysis may be subject to some biases.

The above aerosol simulation experiments for tracing the index case not only supported aerosol transmission but also found key factors affecting transmission. Therefore, adequate space should be maintained between isolation wards and routine outpatient areas in hospitals, and air distribution layouts should be examined in isolation wards. Furthermore, disinfections in the isolation area need be strengthened. COVID-19 aerosol transmission risk exists in many handshake buildings in Guangzhou due to centralized isolation and home isolation and is highly concerning.

Conflicts of interest: No conflicts of interest.

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SUPPLEMENTARY TABLE S1. The six ventilation layout scenarios according to the air conditioner, door, and window status.

Scenario	Site 1		Site 2
	Air conditioner	Door	Window
1	×	×	×
2	√	×	×
3	√	√	×
4	√	×	√
5	×	√	√
6	√	√	√

Note: √: open or switch on; ×: close or switch off.

Methods and Applications

Modelling the Emerging COVID-19 Epidemic and Estimating Intervention Effectiveness — Taiwan, China, 2021

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ABSTRACT

Introduction: The coronavirus disease 2019 (COVID-19) pandemic recently affected Taiwan, China. This study aimed to calculate the transmissibility of COVID-19 to predict trends and evaluate the effects of interventions.

Methods: The data of reported COVID-19 cases was collected from April 20 to May 26, 2021, which included daily reported data (Scenario I) and reported data after adjustment (Scenario II). A susceptible-exposed-symptomatic-asymptomatic-recovered model was developed to fit the data. The effective reproductive number (R_{eff}) was used to estimate the transmissibility of COVID-19.

Results: A total of 4,854 cases were collected for the modelling. In Scenario I, the intervention has already taken some effects from May 17 to May 26 (the R_{eff} reduced to 2.1). When the R_{eff} was set as 0.1, the epidemic was projected to end on July 4, and a total of 1,997 cases and 855 asymptomatic individuals would have been reported. In Scenario II, the interventions were projected as having been effective from May 24 to May 26 (the R_{eff} reduced to 0.4). When the R_{eff} was set as 0.1, the epidemic was projected to end on July 1, and a total of 1,482 cases and 635 asymptomatic individuals would have been reported.

Conclusion: The epidemic of COVID-19 was projected to end after at least one month, even if the most effective interventions were applied in Taiwan, China. Although there were some positive effects of intervention in Taiwan, China.

INTRODUCTION

Recently, a coronavirus disease 2019 (COVID-19) epidemic emerged in Taiwan, China, although local authorities announced the epidemic had been controlled since early 2021 (1). An average of 414 daily

confirmed cases were reported from May 18 to May 24 in Taiwan, China (2). The epidemic was potentially traced to gatherings of local citizens (3). Furthermore, the epidemic's accelerated spread might also be related to the Alpha variant (B.1.1.7) of COVID-19 (1). Facing this situation, Taiwan, China moved urgently to implement a series of control measures to respond to the epidemic.

Dynamics models have played important roles in analyzing emerging infectious disease such as dengue fever (4). It might also have applications in analyzing COVID-19, including estimating transmissibility, predicting trends, and evaluating the effects of interventions (5). Differing from statistical models, these dynamics models could better explain transmission mechanisms. The dynamics models that are commonly used in COVID-19 are the susceptible-infectious-recovered and susceptible-exposed-infectious-recovered models (6). However, these models could not capture the influence of asymptomatic infections. Therefore, we developed a susceptible-exposed-symptomatic-asymptomatic-recovered (SEIAR) model that considered transmission via asymptomatic infections. The SEIAR model had been applied in Hunan Province and Jilin Province in China (7–8). In this study, the SEIAR was further applied to analyze COVID-19 transmission in Taiwan, China and to evaluate the effects of some interventions for controlling COVID-19.

METHODS

Data Collection

The daily reported data of COVID-19 from April 20 to May 26, 2021 was collected from the website of Taiwan Affairs Office of the State Council (<http://www.gwytb.gov.cn>). The demographic data was collected from the Chinese National Bureau of Statistics (<http://www.stats.gov.cn/>).

Model Development

The total population was divided into five categories, including susceptible (S), exposed (E), infectious (I), asymptomatic (A), and recovered/removed individuals (R) (Figure 1). The model was based on the following assumptions: 1) susceptible individuals could be infected via contact with symptomatic and asymptomatic individuals, and the transmission rate was defined as β ; 2) the incubation period of symptomatic individuals and the latent period of asymptomatic individuals were $1/\omega$ and $1/\omega'$, respectively; the proportion of asymptomatic infection was defined as p (where $0 \leq p \leq 1$); exposed individuals would become asymptomatic individuals at a rate of $p\omega E$ or become infectious individuals at a rate of $(1-p)\omega'E$; and 3) infectious individuals and asymptomatic individuals would become recovered individuals (R) after an infectious period of $1/\gamma$ and $1/\gamma'$, respectively. The infectious individuals died due to illness at a rate of f .

The equations for SEIAR model were as follows:

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

In this model, the definitions of the parameters were sourced from previous studies (7–8). Combined with previous studies (6–7), the value of parameter κ was set as 0.7, p was set as 0.3, ω was set as 0.3333, ω' was set as 0.2, γ was set as 0.2, and γ' was set as 0.1. According to extracted data, the total population was set at 23,561,236, and the case-fatality rate f was set as 0.005.

Because the basic reproductive number (R_0) was difficult to quantify when coupled with the interventions, we used an effective reproductive

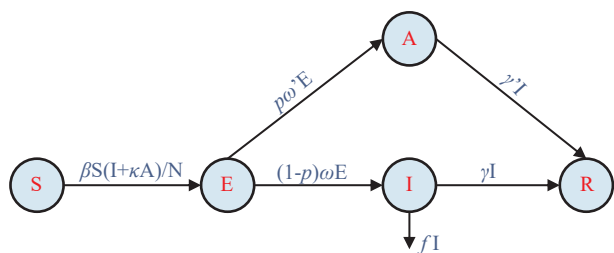


FIGURE 1. The framework of susceptible-exposed-symptomatic-asymptomatic-recovered model.

number (R_{eff}) to estimate COVID-19 transmissibility. The equation was as follows:

$$R_{eff} = \beta \left(\frac{1-p}{f+\gamma} + \frac{\kappa p}{\gamma'} \right) \quad (2)$$

The effectiveness of the interventions was evaluated by examining the decreasing value of R_{eff} . In Jinlin and Zhejiang Province, R_{eff} dropped below one after the implementation of strict interventions from the national government (8–9). Therefore, the interventions in Taiwan, China could also decrease the value of R_{eff} .

Statistics Analysis

The calibration between reported data and the SEIAR model was performed using the least squares method. The coefficient of determination (R^2) was used to evaluate the goodness of fit. We calibrated the data according to the increasing and decreasing trends of reported data. Two scenarios were used to model the data: Scenario I used daily reported data, and Scenario II used daily reported data after correction. The correction was implemented by adjusting daily totals to account for missed cases or delays in reporting or diagnosis.

RESULTS

A total of 4,854 cases were reported in Taiwan, China from April 20 to May 26, 2021. In addition, over 100 cases were reported daily after May 15 (Figure 2).

In Scenario I (Figure 2A), the model appeared to have a relatively good fit with the data ($R^2=0.951$, $P<0.001$). The results showed a total of 4,948 cases and 2,120 asymptomatic individuals before May 26, and the R_{eff} of the 3 segments were 4.5 (April 20 to May 15), 5.6 (May 15 to May 17), and 2.1 (May 17 to May 26), respectively. The interventions already showed some effects from May 17 to May 26 as the R_{eff} reduced to 2.1. Based on the above situation, the government was assumed to impose more interventions after May 26 and simulate the sub-scenarios of interventions as follows: 1) if $R_{eff}=1$, the number of daily reported cases would slowly decrease; a total of 3.2 million cases would be reported from May 26 to August 29, and the epidemic would be not over; 2) if $R_{eff}=0.5$, the number of daily reported cases would decrease, and the epidemic would end on August 29 and report a total of 0.5 million cases from May 26 to August 29; and 3) if $R_{eff}=0.1$, the number of daily

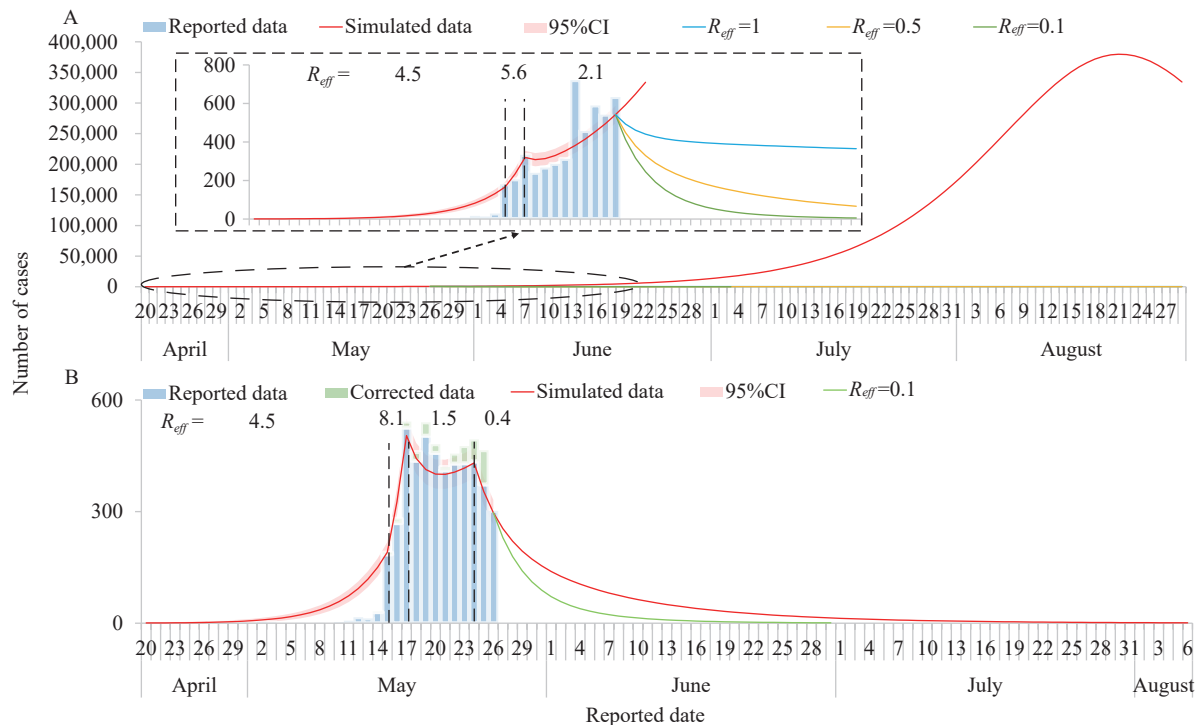


FIGURE 2. The simulation results of epidemic trends based on the different value of R_{eff} in Taiwan, China, 2021, according to two types of report data. (A) Scenario I; (B) Scenario II.

Note: In scenario I, the daily reported data was directly simulated in the model, and the curve was divided into 3 segments (from April 20 to May 15, from May 15 to May 17, from May 17 to May 26) based on the heterogeneity of the epidemic trends and the best goodness-of-fit of the model. We modeled the data according to trends from May 17 to May 26 and estimated the effects of interventions after May 26 by setting R_{eff} to 1, 0.5, and 0.1. In scenario II, the daily reported data after adjustment was simulated in the model, the calibration of curve was divided into four segments (from April 20 to May 15, from May 15 to May 17, from May 17 to May 24, from May 24 to May 26) according to the heterogeneity of the epidemic trends and the best goodness-of-fit of the model. We predicted the data according to the trend from May 24 to May 26, and performed intervention after May 26 when setting R_{eff} to 0.1.

reported cases would quickly decrease, a total of 1,997 cases and 855 asymptomatic individuals would be reported from May 26 to July 4, and the epidemic would end on July 4.

In Scenario II (Figure 2B), the model fitted the data ($R^2=0.968$, $P<0.001$) from April 20 to May 26 after regression correction. There were 4,847 confirmed cases after regression correction. A total of 5,293 cases and 2,268 asymptomatic individuals were simulated in our model before May 26, and the R_{eff} of 4 segments were 4.5 (April 20 to May 15), 8.1 (May 15 to May 17), 1.5 (May 17 to May 24), and 0.4 (May 24 to May 26), respectively. The interventions had already shown effectiveness from May 24 to May 26, with the R_{eff} decreasing to 0.4. A total of 2,758 cases and 1,182 asymptomatic individuals would be reported from May 26 to August 7, and the epidemic would end on August 7. Furthermore, if the government imposed more interventions after May 26 and a sub-scenario of $R_{eff}=0.1$ was simulated, the epidemic would end on

July 1 with a total of 1,482 cases and 635 asymptomatic individuals from May 26 to July 1.

DISCUSSION

In this study, the SEIAR model was used to calculate the transmissibility of COVID-19 to predict the development trends and evaluate the effectiveness of interventions in Taiwan, China. The results showed that the R_{eff} of the first segment was 4.5, and the second segment was 5.6. Further interventions are suggested to be implemented to control the epidemic.

The transmissibility in the first stage of the epidemic (April 20 to May 15) in Taiwan, China was 4.4 or 4.5, which suggested that one of the infectious or asymptomatic individuals could infect 4.4 to 4.5 susceptible individuals after contact if no interventions were adopted. A study reported that the alpha variant of COVID-19 (B.1.1.7) had a 43% to 90% higher reproductive number than preexisting variants (10).

Therefore, imported cases might have had the alpha variant and led to the epidemic in Taiwan, China (1). Furthermore, large gatherings were also potential factors accelerating the epidemic. Increased contact frequency also heightened the risk of transmission for COVID-19.

Several interventions have already been implemented for the epidemic. For example, the local authorities announced an upgraded alert for epidemic prevention and control to the third level in Taipei City and Xinbei City on May 15. There are 4 levels of alert, and a larger number means stricter measures. Taiwan, China have also suspended entry of foreigners and stopped passengers from transferring on flights since May 19. A reduction in the value of R_{eff} had already been observed, but the local authorities should further strengthen interventions to accelerate the end of the COVID-19 epidemic, which was projected to end after at least one additional month with effective interventions ($R_{eff}=0.1$). Therefore, the following measures are suggested for implementation or strengthening: 1) strictly tracing close contacts and enhancing testing of symptomatic and asymptomatic individuals; 2) treat cases according to severity; 3) employing community management measures and maintaining social distancing, and; 4) administering vaccinations as soon as possible and improving the vaccine coverage (11).

This study was subject to at least 3 limitations. First, the parameters of the model were not calculated from first-hand data in Taiwan, China, which might lead to some uncertainty of the simulated results. Second, we did not add the effect of vaccination into the prediction of the model. Third, the effectiveness of each intervention could not be quantified in this model due to limits in the data.

Conflicts of interest: No conflicts of interest were reported.

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Methods and Applications

Vaccination Vehicles for COVID-19 Immunization — China, 2021

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ABSTRACT

Background: Recently, developed vaccination vehicles were repurposed and deployed for coronavirus disease 2019 (COVID-19) vaccination in China. We described the vehicles and reported an evaluation of vaccination throughput of these vehicles for COVID-19 vaccination in China.

Methods: We obtained daily reports of COVID-19 vaccine doses administered in vehicles in Hubei Province between March 16 and 29 of 2021. We determined the rate of COVID-19 vaccines given and evaluated the applicability of vaccination vehicles for COVID-19 vaccination.

Results: Vehicles with 2 vaccination stations are suitable for several real-world scenarios. Vehicles administered an average of 72 COVID-19 vaccine doses per hour, with an upper limit of 145 doses per hour.

Conclusion: Vaccination vehicles can save human and financial resources and provide high quality, effective, convenient, and rapid on-site vaccination services; they can increase the pace of COVID-19 vaccination.

INTRODUCTION

The global coronavirus disease 2019 (COVID-19) pandemic continues to be severe. Some of the emerging severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) variants of concern have shown increased transmissibility, challenging epidemic control and adding urgency to the deployment of COVID-19 vaccines. To rapidly build an immune barrier against SARS-CoV-2, many countries, including France (1), England (2), the United States (3), India (4), and China (5), are increasing the number of vaccination sites and building COVID-19 vaccination centers. However, building new vaccination centers is expensive and takes time. In China, in addition to using temporary vaccination clinics, specialized vaccination vehicles are being used

to accelerate vaccination in communities, colleges, marketplaces, and companies.

China CDC proposed the development of vaccination vehicles in 2018. After completion of the design, production began in 2019, and in April 2020, the first vaccination vehicle was formally approved. The vehicles were developed to improve convenience, accessibility, and equity of access to vaccination services and promote timely information reporting from remote mountainous areas, settings that serve migrant children, and areas experiencing natural disasters.

In September 2020, an evaluation was conducted in 8 villages in Henan Province to assess the usefulness of vaccination vehicles for routine immunization of children in rural areas. The evaluation included questionnaire-based surveys for vaccination managers, staff, and parents, which measured their satisfaction with the vehicles. The evaluation showed that although some design features of the vehicles needed to be improved, such as the length of vaccination desks and the location of the refrigerator, the vehicle was well received by managers, staff, and parents and was useful for providing routine immunization services to rural children (6). A similar evaluation was conducted in Shandong Province in September and November of 2020 that showed that most adults were satisfied with the vaccination vehicle and thought it was very convenient (7).

As a result of the evaluations, the vehicles were improved by resizing vaccination desks and relocating the cold chain refrigerator. During the evaluations, several vaccination vehicles were beginning to be used for COVID-19 vaccination, including in settings that included government facilities, CDCs, harbors, prisons, and businesses in the provincial-level administrative divisions (PLADs) of Shandong, Shaanxi, Ningxia, and Xinjiang (8).

We conducted an evaluation of the vaccination vehicles for COVID-19 vaccination in several of these settings and report results of our evaluation.

METHODS

Vaccination Vehicle Description

Vaccination vehicles are specialized vehicles equipped for storing, handling, administering vaccines, and treating immediate adverse reactions (e.g., allergic shock) following vaccination; they can be used for program and non-program vaccines. The vehicles have information systems that provide end-to-end data management. The information systems manage patient flow and support pre-inspection and registration of vaccinees, electronic notification, vaccine barcode-scanning, recipient verification and confirmation, record of vaccine type, voucher-printing, and record of adverse reaction treatment (9).

The vehicles are 9.0 meters long, 2.5 meters wide, 3.7 meters high, and have 2 doors. They are decorated with green cartoon patterns and a tagline that highlights the National Immunization Program. A television and display screen are installed on the outside of the vehicle to show educational videos and to announce next persons to be served. The top of the vehicle is equipped with a collapsible 6 meters by 2.5 meters awning to shelter people from rain and sun. Vehicles are also equipped with solar panels that generate electricity for cold chain and vaccination refrigerators (Figure 1).

The vehicle's interior is two meters high with a registration area, two vaccination stations, a cold chain section, and an adverse reaction treatment area. The registration area is near the front door and has a desk with an electronic screen. A comfortable waiting bench with room for three people is attached to the registration desk. The cold chain area is located near the second door; the solar powered refrigerator is

secured to the floor, which has a capacity of 100 liters and can maintain a temperature of 2 °C–8 °C for 7 days without external electrical power. The two vaccination stations are opposite the second door and the cold chain area; each has a vaccination desk and a countertop refrigerator. Countertop refrigerators store 200 vaccine vials or syringes in 8 drawers that open automatically via computer control and relay vaccine data to the data management system. The refrigerator displays vaccine storage temperature in real time and sends alarms for temperature excursions. The stations are equipped with printers, a medical waste disposal box, and a display screen for vaccination information. The adverse reaction treatment area is near the back of the vehicle and is equipped with a bed, an oxygen cylinder, a first-aid kit, and a privacy curtain. Each vehicle has an air conditioner, ultraviolet disinfection lamps, cameras, and a 5G network for connectivity. All devices can be controlled by speech (Figure 2).

Vehicles in Use

Vaccination vehicles are used by immunization clinics to conduct onsite vaccination in their respective jurisdictions. Vehicles are parked in accessible locations and vaccination workers from an immunization clinic can rapidly start providing services. People seeking vaccination scan a Quick Response (QR) code to get a wait-list number. All vaccination data are recorded in the Immunization Information System of the local immunization clinic and are submitted to the Immunization Information System of the provincial CDC and relayed to the National Immunization Information System of China CDC — all in near real time. After vaccination, there is a required 30-minute observation period outside of the vehicle, after which



FIGURE 1. The exterior of a vaccination vehicle.

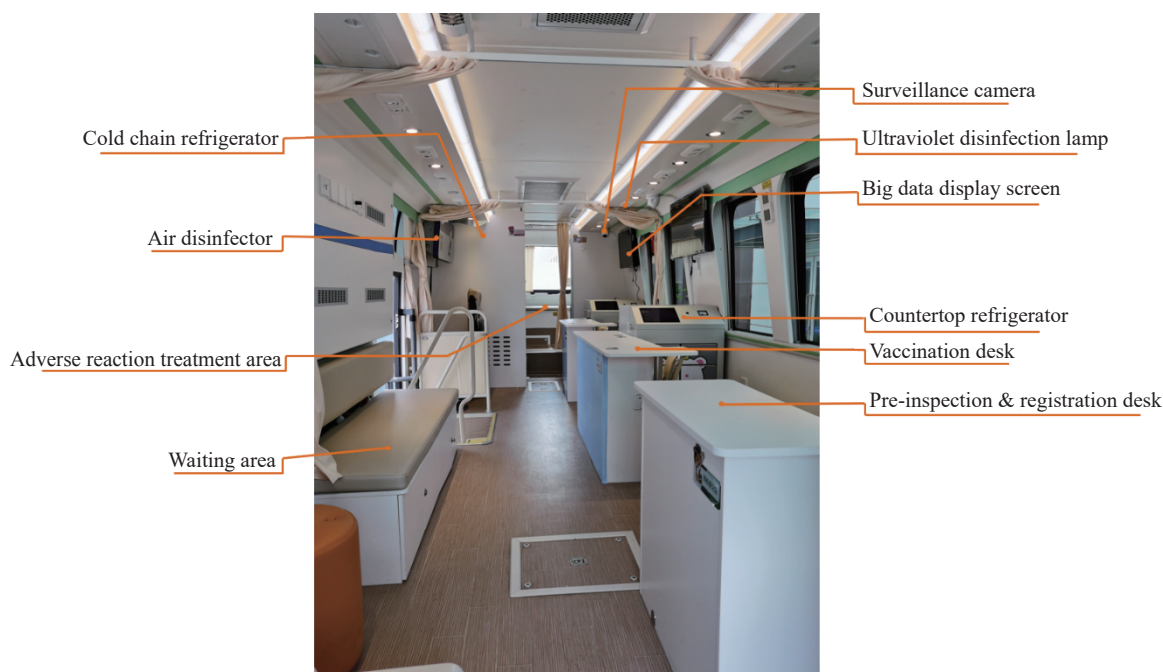


FIGURE 2. Design and layout of the vaccination vehicles.

Note: The vehicles have an air filtration unit and an ultraviolet disinfection lamp to keep the air clean. A display screen shows the vehicle's operating condition in real time. When an individual's turn for vaccination arrives, they enter one door, are registered and vaccinated, and they exit through the second door. In case of an adverse reaction, treatments can be provided in the vehicle while waiting for an ambulance.

time the vaccinated person can leave.

Data Collection and Analysis

In March 2021, Wuhan City of Hubei Province rented several vaccination vehicles to offer free COVID-19 vaccines in colleges, governments, prisons, businesses, and communities (10). We obtained daily reports of COVID-19 vaccination in vaccination vehicles in Hubei from March 16 to 29 of 2021; we used Microsoft Excel (version 2019, MS, Redmond, USA) to calculate the rate of vaccination.

RESULTS

During the study period, district CDCs and immunization clinics in Hubei Province rented 4 vaccination vehicles to provide vaccination services to adults in companies, hospitals, colleges, gymnasias, hotels, residential districts, public squares, and scenic spots. Staff in the vehicles administered 23,000 doses of COVID-19 vaccine; no serious adverse events occurred. Vehicle-1 was used for 8 days and had a daily average vaccination rate that ranged from 30 doses an hour to 133 doses an hour; Vehicle-2 was used 11 days (28 to 117 doses per hour); Vehicle-3 was used 11 days

(19 to 114 doses per hour); and Vehicle 4 was used for 10 days (31 to 145 doses per hour) (Figure 3). The daily average vaccination rate across all vehicles was 72 doses per hour per vehicle, with a maximum of 145 doses per hour.

DISCUSSION

Our evaluation showed that one vaccination vehicle can provide up to 145 doses of COVID-19 vaccine in an hour. If this rate was sustained throughout the day, a single vehicle could potentially vaccinate up to 1,160 people in an eight-hour day. Based on this maximal throughput, the vehicles could be utilized more. Integrating the vehicles as outreach from immunization clinics and programs can promote progress on COVID-19 vaccination.

Vaccination vehicles represent a new service mode that complements fixed vaccination clinics. It can vaccinate in accordance with the Basic Functional Standards for Digital Vaccination Clinics, the Vaccination Work Specification, and the Vaccine Administration Law of the People's Republic of China. Vaccination vehicles are in mass production for deployment in China. Through early June of 2021,

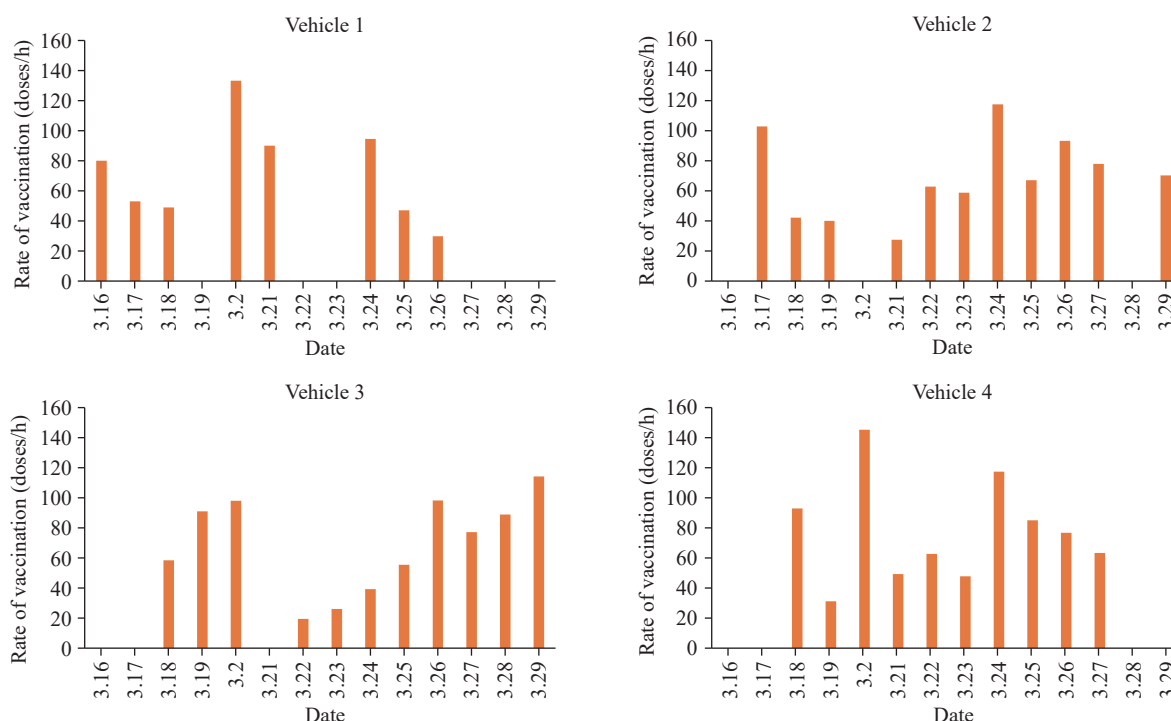


FIGURE 3. COVID-19 vaccine doses administered per day in vaccination vehicles 1–4, Hubei Province, March 16 to 29, 2021.

140 vaccination vehicles were distributed around 21 PLADs and have collectively administrated 1 million doses of the COVID-19 vaccine. The Basic Guideline of the Function for Vaccination Vehicle was published in June 2021 (9) to ensure standardized production and use of the vehicles.

Vaccination vehicles improve convenience and timeliness of COVID-19 vaccination. They can be used in a variety of settings, including companies, markets, communities, and schools. For example, by bringing vaccinations to companies, people only need to step outside of the workplace and can quickly return to work after the 30 minutes observation period. By not having enclosed waiting rooms, vaccination vehicles may reduce the risk of respiratory infection. Onsite vaccination, with its greater convenience, may improve people's enthusiasm for vaccination and facilitate the vaccination effort.

Vaccination vehicles improve equity of access to COVID-19 vaccines and support timely data reporting. The new design and equipment are more advanced than many immunization clinics. Real-time data transmission and sharing allows every level of CDC to monitor progress in COVID-19 vaccination.

This study was subject to at least two limitations. First, the evaluation was conducted over a short time and the use of vaccination vehicles was still in their

initial stages; further evaluation is warranted. Second, we only evaluated the rate of vaccination in the vehicles; a more comprehensive evaluation should be conducted.

Vaccination vehicles can save labor, material, and cost, while providing effective and equitable access to high quality immunization services in a variety of settings suitable for different populations and geographical conditions. Vaccination vehicles are important assets for COVID-19 vaccination in China and are contributing to the massive vaccination campaign in China. Other countries may want to use such vehicles in their COVID-19 campaigns.

Conflicts of interest: Authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Notes from the Field

The First Case of COVID-19 by an A.27 Lineage Variant Detected in a Returning Employee — Sichuan Province, China, January 7, 2021

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On January 7, 2021, a 32-year-old returning employee arrived in Chengdu from Algeria via airplane and tested positive for coronavirus disease 2019 (COVID-19) by nucleic acid tests. He was transferred to the designated hospital for further diagnosis and treatment. The patient was diagnosed as a mild COVID-19 case on January 16. After medical treatment, this patient recovered and left the hospital on February 18.

According to the manufacturer's instruction, Viral RNA from the patient's specimen was extracted using the QIAamp[®] Viral RNA Mini Kit (Qiagen, Valencia, CA, USA). Amplicon-based enrichment and sequencing approach were applied. The viral genome was reverse-transcribed and amplified using ULSEN[®] 2019-nCoV Whole Genome Kit (Micro Future). The sequencing libraries were prepared using the Illumina Nextera[®] XT Library Prep Kit. The final viral-enriched libraries were sequenced using the Illumina MiSeq platform. The whole genome sequence of this COVID-19 virus strain, designated SCSR-455, was assembled and obtained using Geneious v11.0.3 (<https://www.geneious.com>). The published genomes from the Global Initiative on Sharing All Influenza Data (GISAID) and the genome of SCSR-455 were aligned with the reference genome (Wuhan-Hu-1, Genbank: NC_045512, GISAID: EPI_ISL_402125) (1) using MAFFT v7.4 (<https://mafft.cbrc.jp/alignment/software/>) (2). The maximum likelihood (ML) phylogeny was estimated with IQ-TREE v1.6.12 (3) with 1000 bootstraps and the best-fit model autodetected.

The genomes of SCSR-455 had the single nucleotide polymorphisms (SNPs) 8782T and 28144C, which represent the Pangolin A lineage (4). The A lineage was prevalent during the early stage of the COVID-19 epidemic in China (5). So far, however, it has been less frequently detected than the B lineage. Phylogenetic analysis revealed that SCSR-455

was located in the Pangolin lineage A.27 which was designated in February 2021. This lineage of COVID-19 viruses was first detected in Denmark on December 14, 2020, and then transmitted to several other countries, including Belgium, France, the Netherlands, Nigeria, Rwanda, Switzerland, the United Kingdom (UK), and Turkey (Figure 1). Apart from 8782T and 28144C, viruses in the A.27 lineage had 21 SNPs (A361G, C1122T, C2509T, A9204G, A11217G, C16466T, A18366G, A20262G, C21614T, G22468T, T22917G, A23063T, C23520T, C23525T, G23948T, G25218T, T25541C, C27247T, A28273T, G28878A, and G29742A) compared with the Wuhan-Hu-1 reference sequence. The genomes of SCSR-455 shared all these lineage-defining SNPs with the A.27 lineage strains and also had another 6 SNPs, including C3096T, C5974T, C12241T, C16293T, C19895T, and C21658T. The genomes of 4 strains of the A.27 lineage, collected in France (EPI_ISL_934974), Rwanda (EPI_ISL_1020288), and the UK (EPI_ISL_769875 and EPI_ISL_769876), respectively, shared 26 SNPs with SCSR-455. These 4 strains were phylogenetically most closely related to SCSR-455 within the A.27 lineage (Figure 1).

A total of 7 amino acid mutation sites (L18F, L452R, N501Y, A653V, H655Y, D796Y, and G1219V) that correspond to the features of the A.27 lineage were detected in the spike protein of SCSR-455. The A.27 is the first sub-lineage of the A lineage that evolved to obtain N501Y mutation in the spike protein, despite the amino acid mutation D614G, which might increase viral transmissibility (6) not being identified. Residue 501 is a key contact residue within the receptor-binding domain (RBD), and the N501Y mutation has been shown to enhance binding affinity to human and murine hACE2 (7–8). N501Y has been associated with some faster-growing COVID-19 virus lineages throughout the world (e.g.,

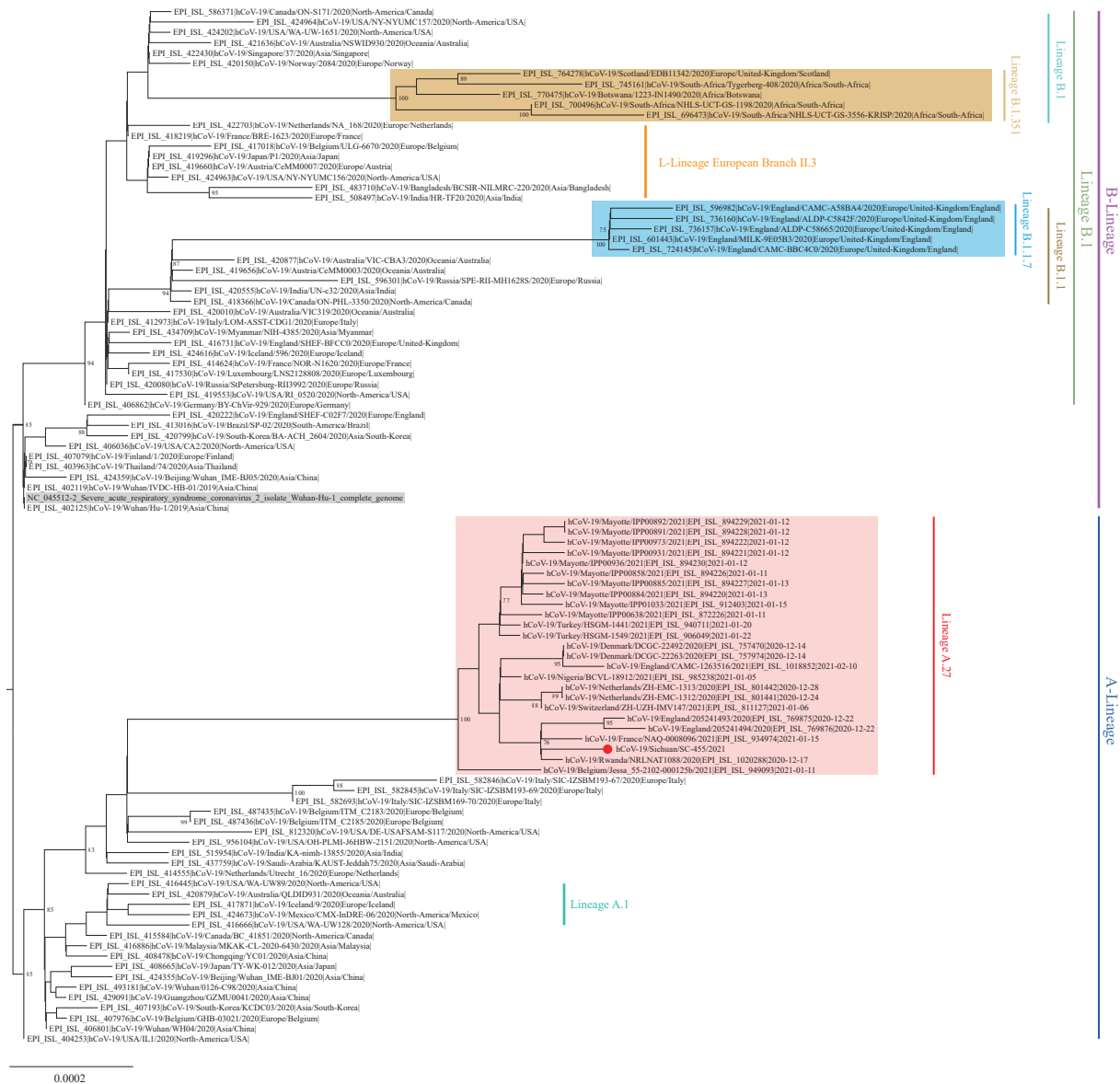


FIGURE 1. The maximum likelihood (ML) phylogenetic tree is based on the genome sequences of the COVID-19 virus. Note: The A.27 variants are highlighted in red, and the Sichuan imported A.27 variant is marked with a red dot. The Wuhan reference strain is shaded in gray. The A or B-lineage and sub-lineages of the COVID-19 virus were marked and colored on the right. All labeled clades are supported by ML bootstrap values >75%.

the UK lineage B.1.1.7, also known as the 501Y.V1; and the South African lineage B.1.351, also known as the 501Y.V2). The A.27 lineage shared only one amino acid mutation, N501Y, with the B.1.1.7 and the B.1.351 lineage. In Addition, the A.27 lineage obtained the L452R mutation, which might alter the antibody recognition sites, and D796Y, which might be associated with changes in ligand binding surface.

The strain SCSR-455 is the first imported A.27 lineage variant in China. Previous investigations showed that the A lineage was less prevalent than the B lineage. Given the importance of N501Y in the

sustained human-to-human transmission of COVID-19, ongoing epidemiological and genomic surveillance are needed to monitor the potential expanded transmission of the A lineage. Further laboratory investigations are required to test the efficiency of the existing vaccines against this newly described A.27 lineage.

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Commentary

Guangdong's Study of the Effectiveness of China's Inactivated Vaccines Against the SARS-CoV-2 B.1.617.2 (Delta) Variant

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Hui Zheng¹; Qianqian Liu¹; George F. Gao¹; Zundong Yin^{1,*}

Guangdong CDC published in preprint a critically important study of the effectiveness of China's inactivated vaccines against the B.1.617.2 (Delta) variant of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) — a strain of the virus that causes coronavirus disease 2019 (COVID-19) and is circulating globally (1–2). The Delta variant managed to get through China's strong international border quarantine protection and spark an outbreak in Guangdong Province in May–June 2021. While the outbreak was being stopped using guidance of the *Protocol for Prevention and Control of COVID-19* (3), the investigators took advantage of provisions in the Protocol that identified close contacts of anyone infected with SARS-CoV-2, quarantined the close contacts, and tested them for infection while in managed quarantine. Guangdong CDC determined the vaccination status of these close contacts and which of the close contacts became infected, allowing an estimate of the effectiveness of the vaccines used in Guangdong against COVID-19 caused by the Delta variant. The study design was elegant, as the investigators were able to evaluate vaccine effectiveness (VE) in the population with the highest force of infection in the outbreak area, maximizing the possibility of making an accurate estimate of VE.

THE FINDINGS

The investigators found that the inactivated vaccines provide excellent protection from pneumonia and severe illness caused by the Delta variant — results that are consistent with the Phase III efficacy clinical trials against the original SARS-CoV-2 prototype. Unadjusted and adjusted VE estimates for full vaccination (14 days after the second dose with a 21+ day interval between two doses) against pneumonia among individuals 18 years and above were 78% [95% confidence interval (CI): 45%–91%] and 70% (95%

CI: 43%–96%), respectively, with 100% VE against severe illness. Partial vaccination, in contrast, showed little effectiveness against pneumonia — unadjusted and adjusted VEs of partial vaccination were 1.4% and 8.4%, respectively. Importantly, there were no severe or critical breakthrough cases, while unvaccinated close contacts had 19 severe or critical cases.

IMPORTANCE OF THE STUDY

As the COVID-19 pandemic continues, SARS-CoV-2 evolves in unpredictable directions, with emerging variants that differ in transmissibility, infectiousness by age group, and severity of illness. Since vaccines are essential tools for pandemic control, it is vital that their performance is continuously assessed. Guangdong CDC's study is an excellent example of extracting valuable information on the real-world performance of the China-produced inactivated COVID-19 vaccines. It is the first real-world VE study of inactivated vaccines against the Delta variant. Their study shows the feasibility of monitoring VE against incoming variants, even though the number of infections in China remains extremely low. Since the two most prominent inactivated COVID-19 vaccines used in China are approved and recommended for emergency use by the World Health Organization (WHO) and are in widespread use globally, this study provides some assurance to the global scientific community that the vaccines hold up against the Delta variant.

RELEVANCE TO CHINA'S COVID-19 VACCINATION STRATEGY

Guangdong's VE study provides some assurance that China's current COVID-19 vaccination strategy remains on track. The current phase of the strategy

includes vaccination of older people, who have the highest risk of severe illness from SARS-CoV-2 infection. Since there is an ever-present risk of importation, it is useful to know that the vaccines reduce risk severe illness and death. Knowing that the vaccines retain effectiveness against the current variant provides some confidence for expanding vaccinations to adolescents, 12–17 years of age, to help build whole-population immunity. Guangdong's study serves as a good example for other researchers in China to conduct VE evaluations when managing a local epidemic. A growing evidence base will help keep the strategy on track.

The study reinforces that it takes two doses of the inactivated vaccines to protect. Individuals who completed the first dose should receive their second dose as soon as possible, in accordance with technical vaccination recommendations for COVID-19 vaccines in China.

VACCINATION PROGRESS

To date, COVID-19 vaccines from 7 manufacturers have been approved for conditional marketing or emergency use in China. From Phase III clinical trials of the 3 conditionally approved inactivated vaccines and the adenovirus vectored vaccine, we know that protective efficacy ranges from 50% to 78%. The other 3 COVID-19 vaccines are approved for emergency use, and include a recombinant subunit vaccine [made with Chinese hamster ovary (CHO) cells] and 2 inactivated vaccines. These three have shown good immunogenicity and safety based on the Phase II clinical trial results and emergency-use adverse event following immunization (AEFI) surveillance.

China's COVID-19 vaccination campaign was officially launched on December 15, 2020, with the initial target population of 18–59 years old in occupations at high risk of infection, subsequently expanding to everyone 18 years and older. As of August 11, 2021, more than 1.82 billion doses of COVID-19 vaccines have been administered in China. Almost 770 million people are fully vaccinated, achieving a national coverage rate of 55%, on par with high- or middle-income countries such as Chile, Canada, Germany, Italy, the United Kingdom, and the United States that have full-vaccination population coverage levels between 50% and 68% (4).

LOOKING FORWARD

From the very beginning of this pandemic, research and evaluation have been critically important to understand and control the disease (5). The Guangdong VE study is reassuring, but it is only one of hundreds to thousands of evaluations needed to monitor and adjust pandemic control strategies. Vaccination strategy is complex and necessarily dynamic because of continuous virus evolution and changes in COVID-19 epidemiology. As new vaccines are developed and new variants emerge, real world vaccine performance must be monitored. The most commonly used COVID-19 vaccines globally are inactivated, mRNA, and adenovirus-vectored vaccines. The effectiveness rates of BNT162b2 and ChAdOx1 CoVID-19 vaccine (after two doses for both vaccines) were 88.0% (95% CI: 85.3 to 90.1) and 67.0% (95% CI: 61.3 to 71.8), respectively, among those with the Delta variant (6). Thus far, and with the Guangdong study included, they are all showing high effectiveness against the Delta variant.

Immunization programs have considerable experience monitoring vaccine coverage and uptake, vaccine safety, confidence in vaccines and immunization, and vaccine effectiveness. All of the assets of China's immunization programs, national and provincial, in collaboration with immunization programs in other countries and international organizations like the WHO, United Nations Children's Fund (UNICEF), The Global Alliance for Vaccines and Immunisation (GAVI), and Coalition for Epidemic Preparedness Innovations (CEPI), will be needed to manage this unpredictable pandemic.

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