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Analysis of the effect of PCR testing and antigen testing on controlling the transmission for Omicron based on different scenarios

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A B S T R A C T

After the policy adjustment, China no longer carries out COVID-19 PCR testing for all people, and antigen testing has become the main way to detect and manage infectious sources. We developed a dynamic model to evaluate and compare the effects between PCR and antigen testing for controlling the pandemic. Due to the increase of contact degree, the peak reduction effect of PCR testing in population is lower than that of antigen testing. Even if it was only 20% of people isolated at home after antigen testing, the peak of the epidemic could be reduced by 9.46%. If the proportion of antigen testing is further increased to 80%, the peak of the pandemic can be reduced by 31.41%. Antigen testing performed better effects in school (reduction proportion 29.27%) and community (29.34%) than in workplace (27.75%). Therefore, we recommend that antigen testing in the population should be encouraged during the pandemic, and home isolation of infected persons should be advocated, especially in crowded places. To improve the availability of antigen, the testing proportion should be further enhanced.

1. Introduction

Ever since the outbreak of COVID-19 caused by SARS-CoV-2 was characterized as a pandemic on March 11, 2020, the WHO Emergency Use Listing (EUL) has given a high priority to the application for SARS-CoV-2 antigen detection tests and nucleic acid detection tests (Extranet, 2023). From December 7, 2022, China has announced to optimize the disease control strategies for COVID-19 (Xinwen, 2022). There are three main detection tests of SARS-CoV-2, namely a) the viral gene detection, also known as the nucleic acid tests at the molecular level b) rapid viral antigen tests and c) human antibody tests based on

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immunology, among which the viral gene detection by RT-PCR (Real-Time Reverse Transcription Polymerase Chain Reaction) has been found as the most available technique (Yüce et al., 2020). And RT-PCR is the gold standard for SARS-Cov-2 detection due to its capacity to directly measure the viral genomic parts rather than the secondary biomarkers such as antigens or antibodies (Schmitz et al., 2022).

Nevertheless, there are some differences in sensitivity and specificity in theses testing methods. And there have been discussions on which one of these tests are optimized in the current stage of the pandemic. A study of the epidemic in Hong Kong in February 2022 analyzed the impact of rapid antigen tests on SARS-CoV-2 in this epidemic and concluded that antigen tests has a sensitivity of 20% on the 5th days and 80% on the 8th day after infection, while high-quality RT-PCR is 80% on the 4th day and molecular point-of-care (POC) test is of high sensitivity of 100% on the 3rd day after infection (Du et al., 2022). The study of Hong Kong also revealed that testing an infected individual with two or three kinds of tests together at the same time could result in a high sensitivity close to 80% at least after the 4th day post infection (Du et al., 2022). One research in France says that antigen test has a good sensitivity (75.5%; 95% CI: 69.5–81.5) only for samples with Ct value lower than 25 (Fenollar et al.). Researchers in Thailand also calculated that the antigen tests showed comparable sensitivity (98.33%; 95% CI, 91.06–99.6) and specificity (98.73%; 95% CI, 97.06–99.59%) with real-time RT-PCR (Chaimayo et al.). Besides, an evaluation of antigen test for diagnosing SARS-CoV-2 during the COVID-19 epidemic in Taiwan concluded that antigen test was effective and essential for early diagnosis (Cheng et al.).

Before the refinement of the COVID-19 policy, nucleic acid tests were the main tests used in China and were one of the standard criteria for confirming COVID-19 cases. However, nucleic acid testing has some disadvantages: it requires a high condition for conducting the test, besides it takes time to collect nucleic acid samples, which could easily cause the spread of the high-infectious disease when implementing massive testing. After the new policy, antigen testing is now being widely used in detecting SARS-CoV-2 infections. Though antigen testing is less sensitive than nucleic acid testing due to limitations in methodology and testing principles, and there is a high probability in false negatives, while it doses have advantages in detecting cases in a short period of time when the regions with relatively high epidemic levels, and therefore could not only reduce medical burden but avoid cross-infection. Now that the mass nucleic acid testing has been canceled, antigen testing is now playing a role in the early detection of COVID-19 cases, and is used for home screening of positive cases during mass infections.

Currently, in the context of China's effort to optimize the COVID-19 strategies, antigen tests are gradually replacing nucleic acid tests as the primary virus detection method. Considering the respective advantages and disadvantages of antigen tests and nucleic acid tests, it is necessary to conduct a study on the impact of these testing methods on the trend of an epidemic. In this study, we explored the advantages that antigen tests can play on disease transmission through a multi-group transmission dynamics model. We aim that the result of our study may provide basis for early control of the peak of the pandemic in China.

2. Methods

2.1. Study design and model development

The study aimed to compare the spread of SARS-CoV-2 between scenarios where nucleic acid tests, or PCR tests was performed and scenarios where antigen tests was implemented during the pandemic phase in China by means of a multi-group dynamics model (Fig. 1). Before building the model, we had set two important conditions for the model scenarios: one is that PCR testing would increase contact degree, but antigen testing would not increase it; the other was that it had been

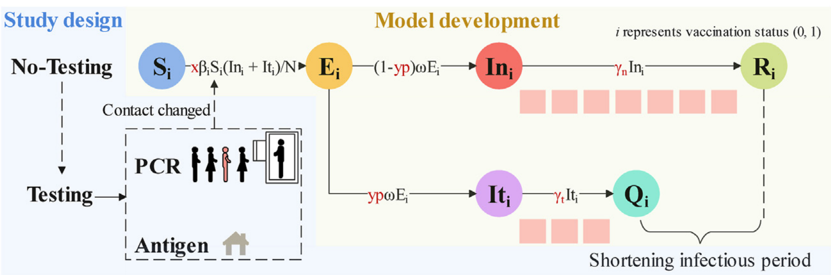

Fig. 1. Study design and framework of model. This is a multi-group Susceptible-Exposed-Infected with no testing-Removed-Infected with testing-Isolated (SEI_nR-I_tQ) dynamics model. Subscript i represents the vaccination status of the individuals, for vaccinated ($i = 0$) and unvaccinated ($i = 1$). The susceptible individuals experience either testing or not testing for SARS-CoV-2, which increases their contact degree by a ratio of x relative to baseline. However, the individuals could either test for the pathogen by PCR or rapid antigen tests. The proportion of testing infections was defined as p. The relative ratio of sensitivity between PCR testing and antigen testing was defined as y. The red square between I_{ni} and R_i, as well as I_{ti} and Q_i represent average infectious periods for testing and no-testing individuals, for the infectious period of the disease was 5–9 days, we made it 7 squares for average in the figure, while average duration of home isolation after testing positive was set as 0–8 days, the infectious period for tested individuals was 1–5 days, therefore we made it 3 squares for average in the figure.

assumed that people who tested positive could consciously perform self-quarantine at home. Accordingly, we built a multi-group Susceptible-Exposed-Infected with no testing-Removed-Infected with testing-Isolated (SEI_nR-I_tQ) model (Fig. 1). The model was built based on the following assumptions:

a) Susceptible individuals were divided into two groups, including vaccinated ($i = 0$) and unvaccinated ($i = 1$). Unvaccinated people would be infected by contacting with infected people with a transmission relative rate β and it will reduced by (1-VE) times after vaccination.
b) PCR testing increases contact degree by a ratio of x relative to baseline.
c) The proportion of testing infections was defined as p. The relative ratio of sensitivity between PCR testing and antigen testing was defined as y. The exposed individuals would become infectious after an incubation period ($1/\omega$).
d) The non-testing and testing cases would flow into recovered/isolated individuals after an infectious period of $1/\gamma_n$ and $1/\gamma_t$, respectively.

The equations of the model are:

$$i = 0, 1$$

$$\frac{dS_i}{dt} = -x\beta_i S_i(In_i + It_i)$$

$$\frac{dE_i}{dt} = x\beta_i S_i(In_i + It_i) - \omega E_i$$

$$\frac{dIn_i}{dt} = (1 - yp)\omega E_i - \gamma_n In_i$$

$$\frac{dIt_i}{dt} = yp\omega E_i - \gamma_t It_i$$

$$\frac{dR_i}{dt} = \gamma_n In_i$$

$$\frac{dQ_i}{dt} = \gamma_t It_i$$

$$N = S_i + E_i + I_{ni} + I_{ti} + A_i + R_i + Q_i$$

The left side of the differential equations was showed the instantaneous change rate of S, E, I_n, I_t, R and Q at time t.

2.2. Parameter estimation

Several studies described the transmissibility of Omicron through the basic reproduction number (R_0), which is often ranged from 8 to 12 in some studies (Estimating global, 2021; Dong et al.; Du et al.). As of June 23, 2022, 90% of the people in China have completed vaccination (News, 2022). However, effectiveness of the vaccine (inactivated vaccine and Ad-5-vectored vaccine) in preventing infection is very low, with a reported VE of inactivated vaccine was only 16.3% (15.4–17.2%) and of Ad-5-vectored vaccine was 13.2% (10.9–15.5%) based on real-world data from Shanghai, China (Huang et al., 2022). In this study 10%–30% of VE is used for Monte Carlo simulation in the model. A study reported that the average contact degree in Wuhan City was 14.6, Shanghai was 18.8, Shenzhen was 7.9 and Changsha was 9.5 (Zhang et al.). Average contact degree (c) of China was set as 13 in the model. Usually, the incubation period ($1/\omega$) of the Omicron strain is very short ranged from 3 to 5 days (Backer et al., 2021; Del Águila-Mejía et al.; Song Js Fau - Lee et al., 2021). A study recommended 10-day isolation after first contact with an infectious case (CDC, 2022). In the model, we set the infectious period ($1/\gamma_n$) as 5–9 days for Monte Carlo simulation. In this study, we assumed that the infected persons would be spontaneously isolated at home after tested positive. The average duration of home isolation was set as 0–8 days ($1/\gamma_n - 1/\gamma_t$). At the same time, we assumed that PCR testing could increase contact degree by 1.1–1.3 times (x). In addition, we assume that the Relative rate between PCR and antigen testing (y) is 1 (Table 1). Finally, as the parameters, the vaccine coverage (VC), contact degree increased by testing and the relative ratio y of sensitivity between PCR testing and antigen testing are obtained from assumption but Monte Carlo simulation, therefore, sensitivity analysis for them are of necessity.

2.3. Statistical analysis

We developed four scenarios to evaluate the effects of antigen testing, including Scenario I: Comparison of Antigen and PCR effects with different testing proportions (20%, 50% and 80%) during pandemic of China. Scenario II: Effect of different proportions on antigen testing of outbreaks in work place. Scenario III: Effect of different proportions on antigen testing of

Table 1
Source of parameters of SEInR-ItQ Model.

Parameters	Definition	Value	Range	Distribution	Source
R_0	Basic reproduction number	10	8–12	Uniform	Reference
β	Transmission relative rate	–	–	–	–
VC	Vaccine coverage	0.9		–	Reference
VE	Vaccine efficacy	–	0.1–0.3	Uniform	Reference
c	Contact degree	13	–	–	Reference
q	Single infectious probability per contact	–	–	–	–
ω	Incubation period	–	1–3	Uniform	Reference
γ_n	Infectious period of non-testing people	–	5–9	Uniform	Reference
γ_t	Infectious period of testing people	–	1–5	Uniform	Assumption
x	Relative rate of contact degree between PCR testing and baseline	–	1.1–1.3	–	Assumption
y	Relative rate between PCR and antigen testing	1	–	–	Assumption
p	Testing proportion	0.2, 0.5, 0.8	–	–	Assumption

outbreaks in school. Scenario IV: Effect of different proportions on antigen testing of outbreaks in community. Differences in workplaces, schools, and communities are mainly reflected in differences in contact degree (c) and total population (N). Based on the actual situation of China, we assume that the parameters of the above three places are shown in Table 2. Model simulation was performed by *Anylogic 8.7.0* (Personal) Statistical analysis and figure drawn were performed in Python matplotlib and seaborn.

3. Results

3.1. Comparison effects between PCR and antigen testing

We observed that if there were only 20% of the people that carried out PCR testing, although they will be isolated at home for an average of 4 days, the peak of infection, which is 61.7 million (95% CI: 58.5–64.9 million), will be 5.72% higher than that of control group, whose peak of infection is 57.9 million (95% CI: 54.2–61.5 million), as the contact degree increases by an average of 20% (Fig. 2A). Meanwhile, when taking PCR testing, the pandemic peak can be advanced 25 days due to an average 20% increase in contact degree. While taking strategy of antigen testing, the peak, 57.7 million (95% CI: 54.6–60.8 million), can be reduced by 4.28% compared to the control group and 9.46% compared to the PCR testing group (Fig. 2E).

If we further increase the testing proportion, the difference in the peak of the pandemic has been increased. For example, in the condition of increasing the testing population to 50% of the population, the peak value by PCR testing was basically the same as the control group, and the peak value of pandemic can be reduced to 19.81% compared to the control group by antigen testing. Compared with PCR testing, the peak value can be reduced to 19.73% by antigen testing, and for the peak infections of control group, PCR group and antigen group are 57.9 million (95% CI: 54.2–61.5 million), 56.4 million (95% CI: 53.2–59.6 million), 47.8 million (95% CI: 45.0–50.5 million), respectively (Fig. 2B, F).

If we increase the proportion of screening to 80% of the total population, then antigen testing can reduce the daily infection by 31.41%, and PCR testing lowered the daily infection by 4.28% compared to the control group, respectively. And for the peak infections of control group, PCR group and antigen group are 57.9 million (95% CI: 54.2–61.5 million), 50.1 million (95% CI: 46.7–53.4 million), 42.8 million (95% CI: 40.2–45.4 million), respectively (Fig. 2C, G).

3.2. Effects of antigen testing in different outbreak sites

Antigen testing is effective for SARS-CoV-2 outbreaks in local sites, including school, work place, and community. Antigen testing performed better in school and community than that in workplace after six months' simulation. In workplace, the epidemic peak and total infection can be reduced by 27.75% compared to baseline scenarios that each person had been tested for antigen (Fig. 3A, E). However, the epidemic peak and total infection can be reduced by 29.27% (Fig. 3B, F) in school and reduced by 29.34% in community (Fig. 3C, G) compared to baseline scenarios that each person had been tested for antigen.

Table 2
Parameters of three scenarios.

Parameters	School	Work place	Community
N	3000	1000	10,000
c	18	15	13

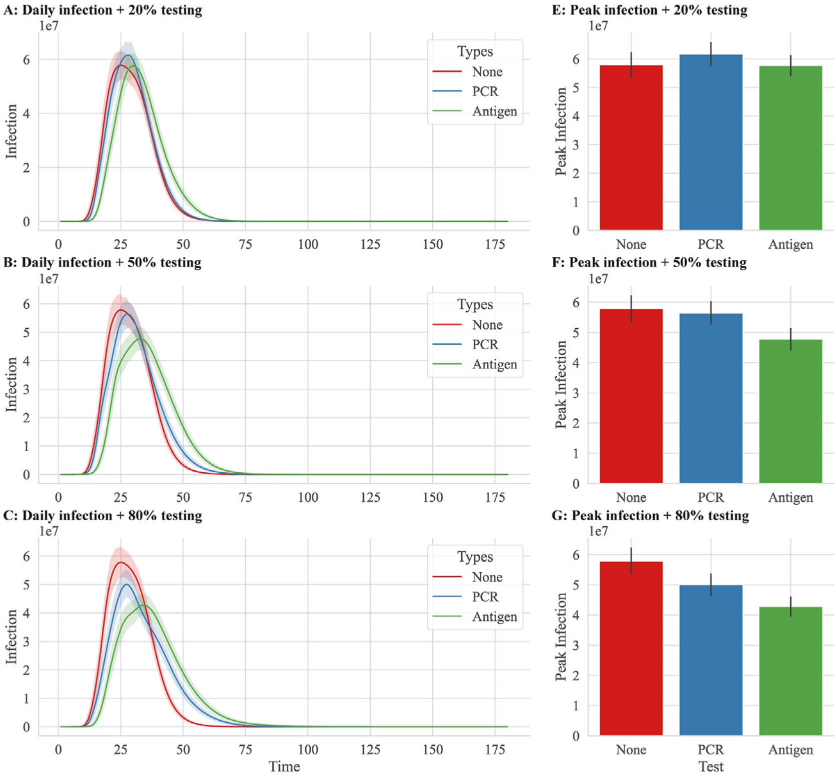

Fig. 2. Pandemic stage of scenario I under six months' simulation. A, B and C represent pandemic wave of simulation. In figure A, B and C, x-axis is the simulated time in days in this study, while y-axis is about the infection number. The red line is the scenario of no-testing, and blue is for PCR testing, green is for antigen testing. For plots A, B and C, they demonstrate the circumstances under daily infection with various proportion of testing. The plots E, F and G represent peak value of pandemic. The x-axis for them are three different situations, and the y-axis is about the peak infection number of each scenario.

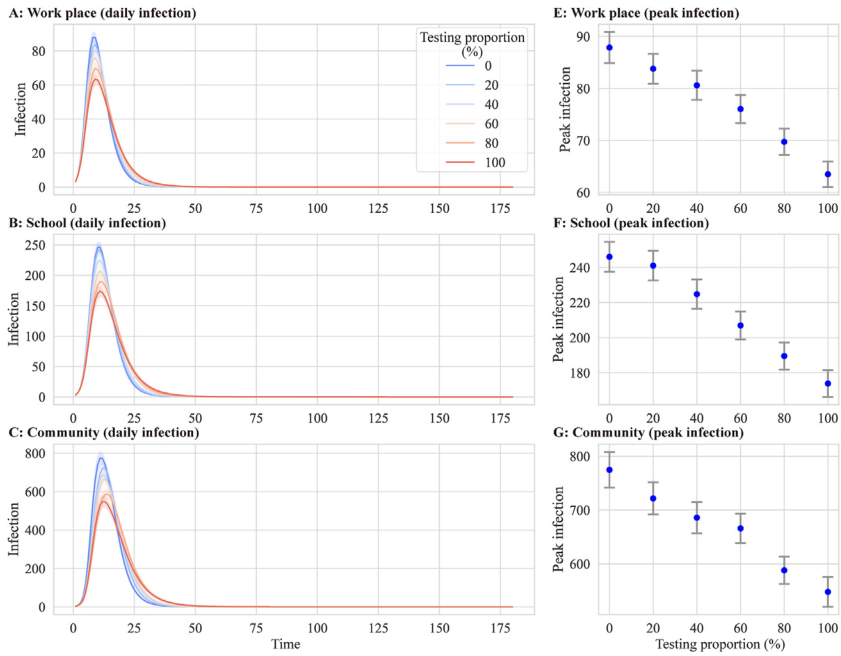

Fig. 3. Outbreak of three scenarios after six months' simulation. A, B and C represent outbreak wave of simulation; E, F and G represent peak value of three scenarios. The x-axis for plots A, B and C is the simulation time, and for plots E, F and G is the testing proportions. The y-axis for each plot is the infection numbers.

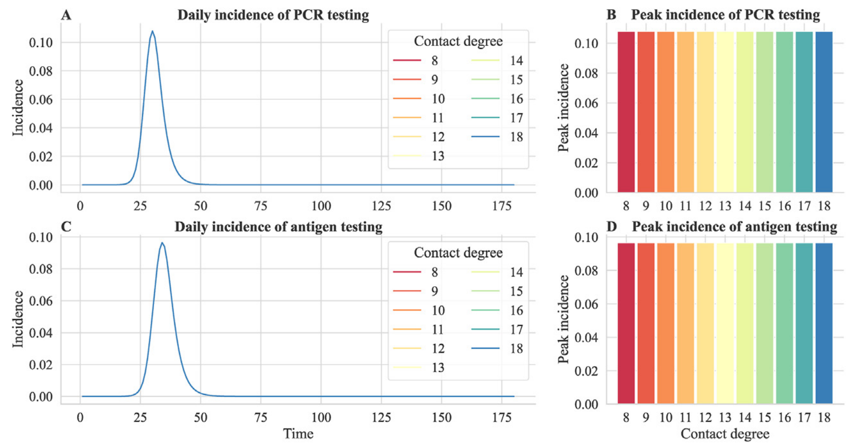

Fig. 4. Sensitivity analysis for contact degree increased by testing. Plot A and B are about the sensitivity analysis for contact degree when the population take PCR testing and plot C and D are showing that in antigen testing. The x-axis for plot A and C is the simulation days, while for plot B and D is different contact degrees. It has presented in the figure that the parameter of contact degree increased by testing is not sensitive.

3.3. Sensitivity analyses

In the sensitivity analysis for contact degree changed by PCR and antigen testing, it has been found that there is not significant impact of changing contact degree on the model simulation, which is not sensitive (Fig. 4).

For the sensitivity analysis for different vaccine coverage, there do have slight differences about the peak indigence of PCR testing and antigen testing, however, the differences are not significant enough to prove that this parameter is able to affect the accuracy of the model simulation (Fig. 5).

It has showed that the parameter, the relative ratio of sensitivity between PCR testing and antigen testing, could affect the model significantly. Under different relative ratios, the model simulation had been influenced. Therefore, a further investigation on this parameter is needed and to refine the model simulation (Fig. 6).

4. Discussion

The COVID-19 pandemic has lasted for three years, and how to control local clusters or regional epidemics rapidly has always been a hot topic. For the prevention and control of infectious diseases, the three links and two factors, i.e., the infectious source, transmission route, susceptible population, and environmental and social factors, are keys to implement disease control strategies. For the COVID-19 pandemic, it is of great significance to detect the infections. The nucleic acid tests and antigen tests are the main methods to detect the infections worldwide.

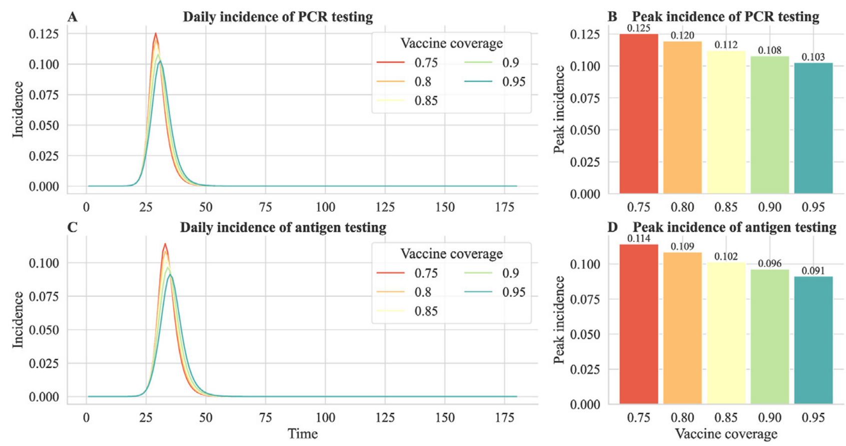

Fig. 5. Sensitivity analysis for vaccine coverage. Plot A and B are about the sensitivity analysis for vaccine coverage when the population take PCR testing and plot C and D are showing that in antigen testing. The x-axis for plot A and C is the simulation days, while for plot B and D is different vaccine coverage. It has presented in the figure that the parameter of vaccine coverage is not sensitive.

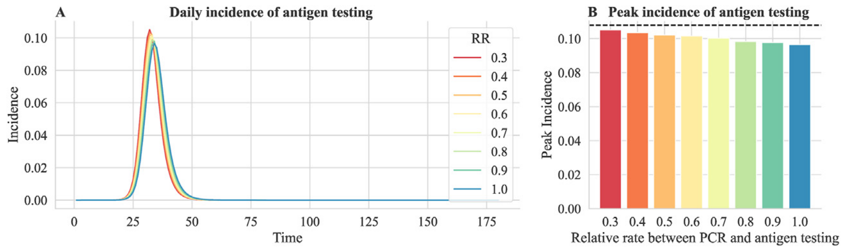

Fig. 6. Sensitivity analysis for the relative ratio of sensitivity between PCR testing and antigen testing. Plot A is about the sensitivity analysis for the relative ratio of sensitivity between PCR testing and antigen testing and plot B is the specification of the peak incidence. The x-axis for plot A is the simulation days, while for plot B is the relative rate between PCR and antigen testing. The black dot line in plot B represents maximum daily incidence simulated in the PCR scenario. It has presented in the figure that the parameter of the relative ratio of sensitivity between PCR testing and antigen testing is sensitive.

However, there are differences in the detecting abilities of these two tests. And several researches were carried out in the aim of comparing the discrepancies. Studies about the fifth wave of the epidemic in Hong Kong, 2022 said that antigen tests played vital role in detecting infections along with PCR tests, resulting in a low case fatality ratio (CFR) and a decrease in real-time reproduction number, so the epidemic was under control (Du et al., 2022). And there are also studies proved that the antigen test is more advantageous since it has a comparable sensitivity and specificity with PCR and do not increase contact degree as mass PCR tests (Fenollar et al.; Chaimayo et al.; Cheng et al.; Qi et al.). In our study, our results show that 50% antibody testing in total population can reduce the peak of pandemic by nearly 20%. In that case, antigen testing demonstrates its advantages in detecting infectious sources. Effects of antigen testing could be affected by number of basic population and contact degree. It is necessary that performed antigen testing in local sites for controlling outbreak, especially should promote antigen testing and isolation in crowded places like school and work place. Although promotion of antigen testing in the community will also has good effects, it may be more difficult to promote antigen testing in the community than in school and work place.

In order to further optimize the COVID-19 testing strategies and guide the personnel in need of independent and standardized SARS-CoV-2 antigen testing, on December 7 the Chinese government which responds to the epidemic joint prevention and control mechanism comprehensive group issued the “Notice on the Issuance of the SARS-CoV-2 Antigen Testing Application Program” (Xinwen, 2022). For regions with relatively high epidemic levels, it is assumed that positive infections with symptoms as fever and cough are infectious all the way to the fever clinic for PCR tests, then medical institutions will spend a lot of medical resource in order to eliminate the virus and need to be sealed for control, which will cause inconvenience to other patients in need. In contrast, antigen testing can be done at home, positive tests are reported according to procedures, and home isolation and precautions are taken to avoid the possible spread of disease and to reduce the scope for close contact caused by the infections.

At present, Chinese domestic manufacturers have the relevant technology and a large production capacity to produce antigen testing kits, and some provinces and cities have developed smartphone applications or platforms for antigen-positive self-testing. The testing capacity and technical platform to carry out antigen self-testing are now available. Simultaneously, due to the abolition of the mass nucleic acid testing, it is impossible to grasp the scale of infections in the population in a timely manner, while antigen self-testing and reporting can partially make up for the lack of population screening after the adjustment of nucleic acid testing, thus being able to quickly grasp the infection status of the population.

5. Limitation

This study was based on two major hypotheses. The first one is that the contact degree could increase when implementing PCR testing in an epidemic, and the second is that antigen testing has the similar effect with PCR testing. In this research, we can solve this problem to some extent by preliminary Monte Carlo simulation, but further in-depth analysis such as sensitivity analysis is still needed to analyze the above hypothesizes. We still have some limitations in the modelling process when it comes to the natural mortality and the fatality of the diseases. Now that in the scenario simulated in this study, only the infection was taken into consideration and we omitted the death rate, therefore, we did not include either the natural mortality or the fatality of the disease in our model.

6. Conclusion

Under the pressure of the COVID-19 pandemic, it is of significance to be able to fully exploit the ability to detect cases so that the epidemic could be controlled. Since PCR testing increases contact degree and antigen testing has the similar testing effectiveness, antigen testing should be preferred, especially performed antigen testing in school and work place. Increasing the mass of antigen testing while advocating home isolation among population can be effective in suppressing peaks and mitigating the epidemic.

Authors' contributions

Tianmu Chen, Wentao Song, Buasiyamu Abudunaibi, Zeyu Zhao and Xiaolan Wang, designed research; Wentao Song, Zeyu Zhao analyzed data; Tianmu Chen, Xiaolan Wang, Wentao Song, Buasiyamu Abudunaibi, Zeyu Zhao, Weikang Liu, conducted the research and analyzed the results; Wentao Song, Buasiyamu Abudunaibi, Zeyu Zhao, Weikang Liu wrote the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The data in this study were all simulated by the model and no actual data were applied.

Ethics approval and consent to participate

The data in this study were all simulated by the model and no actual data were applied. Neither medical intervention nor biological samples were involved. Study procedures and results did not affect the clinical management of patients.

Declaration of competing interest

The 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.

Abbreviations

COVID-19 Coronavirus disease 2019
PCR Polymerase Chain Reaction
$SEI_nR\text{-}I_tQ$ Susceptible-Exposed-Infected with no testing-Removed-Infected with testing-Isolated
WHO World Health Organization

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