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ORIGINAL RESEARCH

Evaluating the Demand for Nucleic Acid Testing in Different Scenarios of COVID-19 Transmission: A Simulation Study

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ABSTRACT

Introduction: The 2019 novel coronavirus (COVID-19) has been recognized as the most severe human infectious disease pandemic in the past century. To enhance our ability to control potential infectious diseases in the future, this study simulated the influence of nucleic acid testing on the transmission of COVID-19 across varied scenarios. Additionally, it assessed the demand for nucleic acid testing under different circumstances, aiming to furnish a decision-making foundation for the implementation of nucleic acid screening measures, the provision of emergency materials, and the allocation of human resources.

Methods: Considering the transmission dynamics of COVID-19 and the preventive measures implemented by countries, we explored three distinct levels of epidemic intensity: community transmission, outbreak, and sporadic cases. Integrating the theory of scenario analysis, we formulated six hypothetical epidemic scenarios, each corresponding to possible occurrences during different phases of the pandemic. We developed an improved SEIR model, validated its accuracy using real-world data, and conducted a comprehensive analysis and prediction of COVID-19 infections under these six scenarios. Simultaneously, we assessed the testing resource requirements associated with each scenario.

Results: We compared the predicted number of infections simulated by the modified SEIR model with the actual reported cases in Israel to validate the model. The root mean square error (RMSE) was 350.09, and the *R*-squared (R^2) was 0.99, indicating a well-fitted model. Scenario 4 demonstrated the most effective prevention and control outcomes. Strengthening

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non-pharmaceutical interventions and increasing nucleic acid testing frequency, even under low testing capacity, resulted in a delayed epidemic peak by 78 days. The proportion of undetected cases decreased from 77.83% to 31.21%, and the overall testing demand significantly decreased, meeting maximum demand even with low testing capacity. The initiation of testing influenced case detection probability. Under high testing capacity, increasing testing frequency elevated the detection rate from 36.40% to 77.83%. Nucleic acid screening proved effective in reducing the demand for testing resources under diverse epidemic prevention and control strategies. While effective interventions and nucleic acid screening measures substantially diminished the demand for testing-related resources, varying degrees of insufficient testing capacity may still persist.

Conclusions: The nucleic acid detection strategy proves effective in promptly identifying and isolating infected individuals, thereby mitigating the infection peak and extending the time to peak. In situations with constrained testing capacity, implementing more stringent measures can notably decrease the number of infections and alleviate resource demands. The improved SEIR model demonstrates proficiency in predicting both reported and unreported cases, offering valuable insights for future infection risk assessments. Rapid evaluations of testing requirements across diverse scenarios can aptly address resource limitations in specific regions, offering substantial evidence for the formulation of future infectious disease testing strategies.

Keywords: COVID-19; Nucleic acid screening; Dynamical model of infectious disease; Demand assessment

Key Summary Points

Nucleic acid testing, as a crucial component of precision prevention and control, plays a pivotal role in promptly screening and isolating infected individuals, thereby contributing to a reduction in the overall number of infections.

Many health facilities in various regions have faced challenges due to resource constraints during the battle against the outbreak. Testing capacity stands as a vital metric, reflecting the maximum number of nucleic acid tests achievable in a region under varying degrees of resource constraints. This capacity significantly influences the sustainability of nucleic acid testing strategies. Upon reviewing the trajectory of infectious disease pandemics, it has been observed that numerous regions in China faced shortages in resources for nucleic acid testing.

This study considers the willingness of residents to choose nucleic acid testing and the accuracy of nucleic acid laboratory testing techniques, aiming to develop a mathematical model to predict the number of infections in real situations. According to the predicted number of infections, the demand for nucleic acid testing and the effectiveness of prevention and control strategies were evaluated.

In different scenarios with the same initial infected person, the scale of infection after 200 days of epidemic simulation follows the order scenario 4, scenario 3, scenario 5, scenario 2, scenario 6, and scenario 1. In scenario 4, with improved nucleic acid testing capacity compared to scenario 3, the number of undetected cases and test-negative cases decreased, and the proportion of undetected cases was 22.14%.

In situations with constrained testing capacity, implementing more stringent measures can notably decrease the number of infections and alleviate resource demands. The improved SEIR model demonstrates proficiency in predicting both reported and unreported cases, offering valuable insights for future infection risk assessments.

INTRODUCTION

Infectious diseases are one of the most important threats to human survival and health and hinder social and economic development. The 2019 novel coronavirus (COVID-19) is the most serious human infectious disease pandemic in the past century [1]. To curb the transmission of SARS-CoV-2, countries have implemented a diverse array of prevention and control measures, primarily encompassing non-pharmaceutical interventions and vaccination efforts [2]. Following the onset of COVID-19 in early 2020, China swiftly implemented the initial lockdown and control measures. While these actions effectively curtailed the epidemic's spread, they also had significant repercussions on social production and people's daily lives. Consequently, starting in April 2020, China initiated a shift from comprehensive prevention and control to precision-based strategies, aiming to strike a balance between curbing the virus's impact and minimizing disruptions to societal functions [3]. Nucleic acid testing, as a crucial component of precision prevention and control, plays a pivotal role in promptly screening and isolating infected individuals, thereby contributing to a reduction in the overall number of infections [4, 5].

However, the surge in asymptomatic infections during the circulation of the Omicron strain has posed challenges to the swift identification of infected individuals through rapid screening [6]. Furthermore, the impact of false negative results in the laboratory testing process and the ongoing mutation of the strain underscore the need to intensify detection efforts within the population to promptly identify infected individuals. Many health facilities in various regions have faced challenges due to resource constraints during the battle against the outbreak [7]. Testing capacity stands as a vital metric, reflecting the maximum number of nucleic acid tests achievable in a region under varying degrees of resource constraints. This capacity significantly influences the sustainability of nucleic acid testing strategies [8].

Upon reviewing the trajectory of infectious disease pandemics, it has been observed that numerous regions in China faced shortages in resources for nucleic acid testing. Conducting a needs assessment emerges as an effective strategy to streamline resource allocation. By gauging anticipated medical and health requirements, a timely resource allocation plan can be devised to prevent the misuse or scarcity of resources [9]. Nevertheless, the fluctuation of virus strains and the adjustment of prevention and control strategies will impact the incidence of infections, subsequently influencing the demand for resources [10]. Therefore, the demand for nucleic acid testing under varying circumstances remains uncertain, with the question of whether it will surpass nucleic acid testing capacity is yet to be determined.

Previous studies have shown that the SEIR model can effectively simulate the development trend of the COVID-19 epidemic, evaluate the demand for laboratory testing resources, and optimizes resource allocation [11–13]. A study conducted in the UK utilized the SEIR-D model to forecast the number of infections in local areas, gauge healthcare requirements, and anticipate needs and isolation capacity within regional hospitals [14]. Cui et al. [15] employed an improved SEIR model to accurately simulate and predict the transmission dynamics of COVID-19 in two low-income countries, namely Kazakhstan and Pakistan. Their findings offer valuable insights, serving as a reference for low-income countries in formulating effective prevention and control strategies. In India, a study utilized the SEIR model in conjunction with sociodemographic variables to guide the development of a prioritized testing strategy for infectious disease control. This approach not only reduced the utilization of testing resources but also minimized the scale of infections and shortened outbreak durations compared to traditional testing models [16]. However, existing studies frequently rely on the number of infections to validate models, often overlooking the impact of the false negative rate in virus detection. This oversight may result in an imprecise modeling of COVID-19 transmission dynamics based solely on the reported "cases." Moreover, the emphasis tends to be on evaluating the effectiveness of prevention and control measures, such as vaccines and quarantine, with less attention given to resource constraints.

In this study, we consider the false negative rate of SARS-CoV-2 testing and address the selection bias resulting from testing priority, acknowledging the potential bias in validating the model solely based on reported cases. Consequently, we established an infectious disease model based on testing outcomes to analyze the effects of varying testing resources and the intensity of prevention and control measures on the epidemic trajectory. The aim is to offer insights and guidance for the development of resource allocation plans in future public health emergencies.

METHODS

This study considers the willingness of residents to choose nucleic acid testing and the accuracy of nucleic acid laboratory testing techniques, aiming to develop a mathematical model to predict the number of infections in real situations. According to the predicted number of infections, the demand for nucleic acid testing and the effectiveness of prevention and control strategies were evaluated.

Data Collection

To enhance the reliability of model simulation results and considering the backdrop of the epidemic, Haifa, Israel, characterized by high vaccine coverage and a relatively severe outbreak, was chosen as the focal point of this research. A comparative analysis was conducted by juxtaposing the predicted number of individuals within a specific period with the actual count. Real-time data, including confirmed cases, vaccinated individuals, and detected cases, from December 25, 2021 to April 29, 2022, were sourced from the official website of the Israeli Ministry of Health. Following the determination of model parameters, the infectious disease model's validity was assessed by contrasting simulation outcomes with actual data (Table 1). Ethics approval and consent to participate in this study are not applicable.

Establishment of Infectious Disease Model

We formulated an improved SEIR model to simulate the epidemic's developmental trajectory (Fig. 1). Unlike the traditional SEIR model, which categorizes the study population into four states (S, E, I, and R) based on different stages of the infectious disease course, and assumes the total population in the area as N (i.e., $N = S + E + I + R$), our improved model introduces considerations for the protective impact of vaccines and virus detection measures. Specifically, we modified the SEIR model to account for whether testing was conducted and whether the infected person was detected. Compartment I was subdivided into untested infected individuals (U), tested positive infected individuals (P), and tested negative infected individuals (F).

Model assumptions:

1. The floating population in the study area remained in equilibrium throughout the research period, with the total population remaining constant. This implies that the birth rate equals the mortality rate, and the immigration rate equals the emigration rate.
2. As a result of the continuous mutation of the virus, immunity acquired through previous infection does not shield susceptible individuals from new strain infections. Therefore, the population is considered generally susceptible, and all individuals are at risk of infection.
3. Patients who recovered from COVID-19 attain temporary immunity and are not susceptible to reinfection.
4. The level of vaccine protection does not diminish over the study period after vaccination.

Table 1 Initial parameter settings and values

Parameter	Orientation questions	Value	Source
a	Vaccine protection rate	0.14	Reference [17]
W	Daily vaccination rate	0.02	Parameter estimation
f	Probability of false negative detection (PCR detection)	0.23	Reference [18]
r	Probability of detection	0.24	Parameter estimation
De	Latent period	5.50	Reference [19]
Dr	Recovery period (positive patients)	22.14	Reference [20]
β	Transmission rate of infection in false-negative individuals	0.50	Parameter estimation
α_p	Transmission rate of patients who test positive relative to those who test false negative	0.80	Expert opinion
α_u	Transmission rate of untested positive patients relative to false negative patients	1.10	Expert opinion
λ_u	Recovery rate of undetected positive patients compared to those who tested positive	1.20	Expert opinion
λ_f	Recovery rate of false-negative patients compared to those who tested positive	1.10	Expert opinion

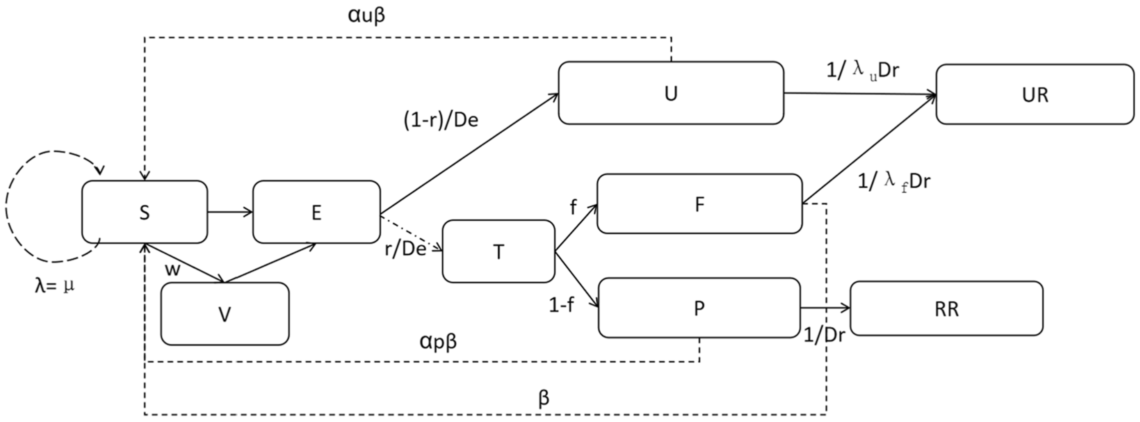

Fig. 1 Architecture diagram of the improved SEIR model

Differential equation:

$$dS = -\beta S\left(\alpha_p P + \alpha_u U + F\right)/N - Sw$$

$$dE = \beta S\left(\alpha_p P + \alpha_u U + F\right)/N + \beta V(1-a)\left(\alpha_p P + \alpha_u U + F\right)/N - E/De$$

$$dV = Sw - \beta V\left(\alpha_p P + \alpha_u U + F\right)(1-a)$$

$$dT = rE/De - r\left(1-f\right)T/De - rfT$$

$$dU = (1-r)E/De - U/(\lambda_u Dr)$$

$$dP = r(1 - f)E/De - P/Dr$$

$$dF = rfE/De - F/(\lambda_f Dr)$$

$$\mathrm{d}RR = P/Dr$$

$$dUR = U/(\lambda_u Dr) + F/(\lambda_f Dr)$$

Definition of Nucleic Acid Testing Capacity and Demand

Testing capacity was stipulated as 50% (125,000) of the total population tested daily with high testing capacity and 25% (62,500) of the total population tested daily with low testing capacity. The demand for nucleic acid testing primarily comprises the quantity of tests utilized and the potential testing demand. "Used test quantity" refers to the total number of individuals tested throughout the outbreak. The "potential demand for testing" encompasses individuals requiring retesting because of exposure or those who have not been identified as infected.

Scenario Setting

To assess the trajectory of the COVID-19 epidemic under various testing capabilities, three epidemic intensities were established: community transmission, outbreak, and sporadic. The transmission of COVID-19 was simulated under different testing strategies. Drawing on scenario construction theory, epidemic scenarios with distinct testing capabilities and strategies were crafted through expert consultation and group discussion. The retrospective summary of the epidemic's development characteristics both domestically and internationally during scenario construction is detailed as follows:

Scenario 1: Baseline scenario, assuming no intervention is implemented, and the initial exposure is 5% of the total population, portraying a natural progression independent of testing capacity.

Scenario 2: Disease outbreak scenario with numerous imported cases at the initial stage. The initial exposure population was set at 2% of the total population. As a result of low COVID-19 vaccination coverage in the initial epidemic stage, the government did not rigorously implement non-pharmaceutical prevention and control measures (50%). Additionally, nucleic acid detection capacity in this region was low, with a 3-day duration from sampling to result reporting and a high false-negative rate. The initial input quantitation was set at 10 cases, including 5 undetected infected patients, 2 patients testing positive, and 3 patients testing undetected (Table 2). All individuals were infectious with no reported deaths or recoveries.

Scenario 3: Building upon scenario 2, it was a community-based cluster outbreak with a 20% reduction in the initial exposed population. The local government prioritized prevention and control, implementing strict non-pharmaceutical measures, and tested infected individuals 1 day after detection. The remaining elements were consistent with scenario 2.

Scenario 4: Based on scenario 3, this scenario increased the initial exposed population by 50%. The vaccination level of residents in the area was high, and the testing ability was robust, allowing quick reporting of test results and minimizing the probability of false negatives.

Scenario 5: Building upon scenario 4, the initial exposed population was reduced by 50%, residents received voluntary testing, and all other elements remained consistent with scenario 4.

Scenario 6: Building upon scenario 2, the initial exposed population increased by 50%. Considering social and economic benefits, the government did not enforce strict prevention and control measures, and residents underwent voluntary testing. However, the vaccination level remained high, and other factors were consistent with scenario 2.

Model Calibration and Verification

Israel boasts one of the highest vaccination rates globally and has been significantly impacted by the current Omicron outbreak. With 1892 cases per million people during the Omicron epidemic, Israel leads the world in

Table 2 Setting of initial values of scenario simulation

Meaning	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total number of the model (N)	250,000	250,000	250,000	250,000	250,000	250,000
Initial susceptible population (S_0)	237,490	144,990	145,990	66,990	70,990	64,990
Number of initial vaccinations (V_0)	0	100,000	100,000	175,000	175,000	175,000
Number of initial exposure (E_0)	12,500	5000	4000	8000	4000	10,000
Number of initial untested (U_0)	10	5	5	5	5	5
Number of initial tested positive (P_0)	0	2	2	2	2	2
Number of initial tested false negative (F_0)	0	3	3	3	3	3

case numbers, surpassing second-place Mongolia's 1119 cases. Given the relatively comprehensive data on confirmed cases reported in Israel compared to other regions during the same period, this study validated the model by comparing the predicted number of infections simulated by the improved SEIR model with the actual number of reported cases in Israel. The root mean square error (RMSE) was 350.09, and the R-squared (R^2) was 0.99, indicating a robust fitting effect. The simulated curve closely aligned with the epidemic data from Haifa City, Israel, as retrieved from the official source (https://data.gov.il/dataset/covid-19, December 20, 2023) (Fig. 2).

RESULTS

On the basis of the improved SEIR model, we simulated the trajectory of infected cases in various outbreak scenarios under nucleic acid detection measures and estimated the nucleic acid detection quantity based on the model simulation results. This information is valuable for adjusting strategies according to the available detection capacity.

In different scenarios with the same initial infected person, the scale of infection after 200 days of epidemic simulation follows this order: scenario 4, scenario 3, scenario 5, scenario 2, scenario 6, scenario 1 (Table 3).

Scenario 1

In the scenario without any interventions, the outbreak peaks at approximately 30 days, with 143,195 people infected, constituting 57.28% of the total population (Fig. 3a) All the infected cases were untested (Fig. 4a). As a result of the lack of intervention, there is a potential demand of 187,148, far exceeding the set nucleic acid detection capacity (Table 4).

Scenario 2

Under a scenario with relaxed containment measures and low testing capacity, the epidemic peaks at about 44 days, with 115,419 people infected (Fig. 3b) Among them, 83,518 are undiagnosed cases, 25,589 are positive cases, and 6312 are negative cases (Fig. 4b). Undetected cases account for 77.83% of the total cases. The total demand reaches a peak of 121,201 on the 41st day, surpassing the capacity when testing is low (Table 4).

Scenario 3

In a scenario with low testing capacity but strengthened non-pharmaceutical prevention and control measures, the epidemic peaks at 122 days, with 21,096 infected people (Fig. 3c) Among them, 2875 are undetected, 14,511 are positive, and 3710 are negative. Undetected cases account for 31.21% of the total cases (Fig. 4c). The total demand peaks at 11,739 on

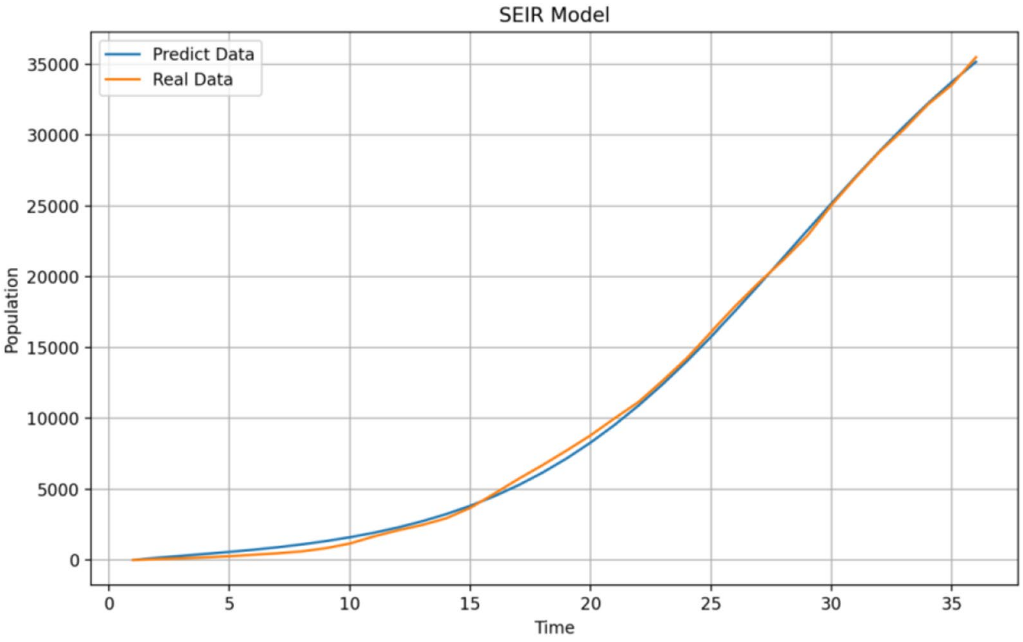

Fig. 2 Improved SEIR model prediction data and real data validation

Table 3 Peak values and time to peak for all types of infected persons under scenarios 1–6

Scenario	Untested (U)		Tested positive (P)		Tested false negative (F)		Total number of infections	
	Peak value (cases)	Time to peak (days)	Peak value (cases)	Time to peak (days)	Peak value (cases)	Time to peak (days)	Peak value (cases)	Time to peak (days)
1	143,195	30	–	–	–	–	143,195	30
2	83,561	45	25,589	44	6312	44	115,419	44
3	2878	125	14,511	122	3711	123	21,096	122
4	2659	111	15,024	107	1622	109	19,303	108
5	18,473	126	11,267	123	1212	125	30,942	125
6	102,870	39	13,062	38	3219	38	119,103	39

the 115th day, and the demand can be met even with low detection capacity (Table 4).

Scenario 4

With increased testing capacity, intensified non-pharmaceutical prevention and control measures, and vaccination, the epidemic peaks at 108 days, with 19,303 infected people (Fig. 3d). Among them, 2657 are undetected, 15,024 are positive, and 1622 are negative. Undetected cases account for 22.17% of the total cases (Fig. 4d). The total demand peaks at 12,884 on the 97th day, and both high and low detection capabilities can meet the demand at this time (Table 4).

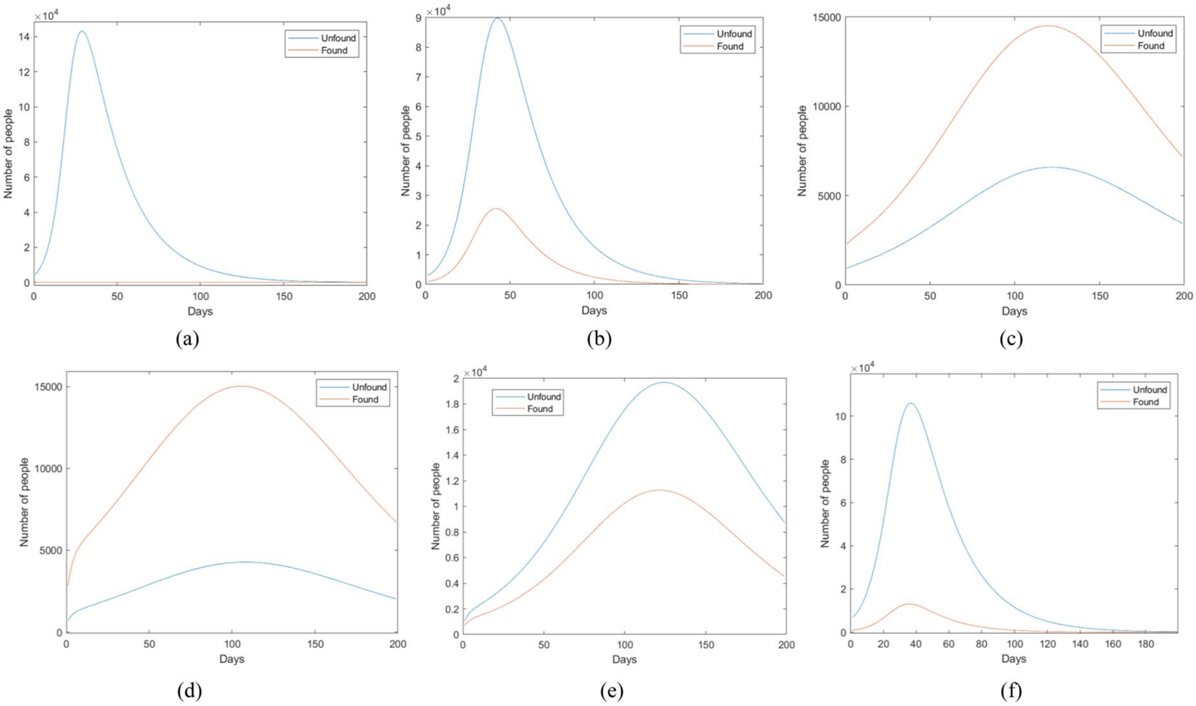

Fig. 3 The change trend of undetected and detected infected persons under scenarios 1–6 (**a**–**f**)

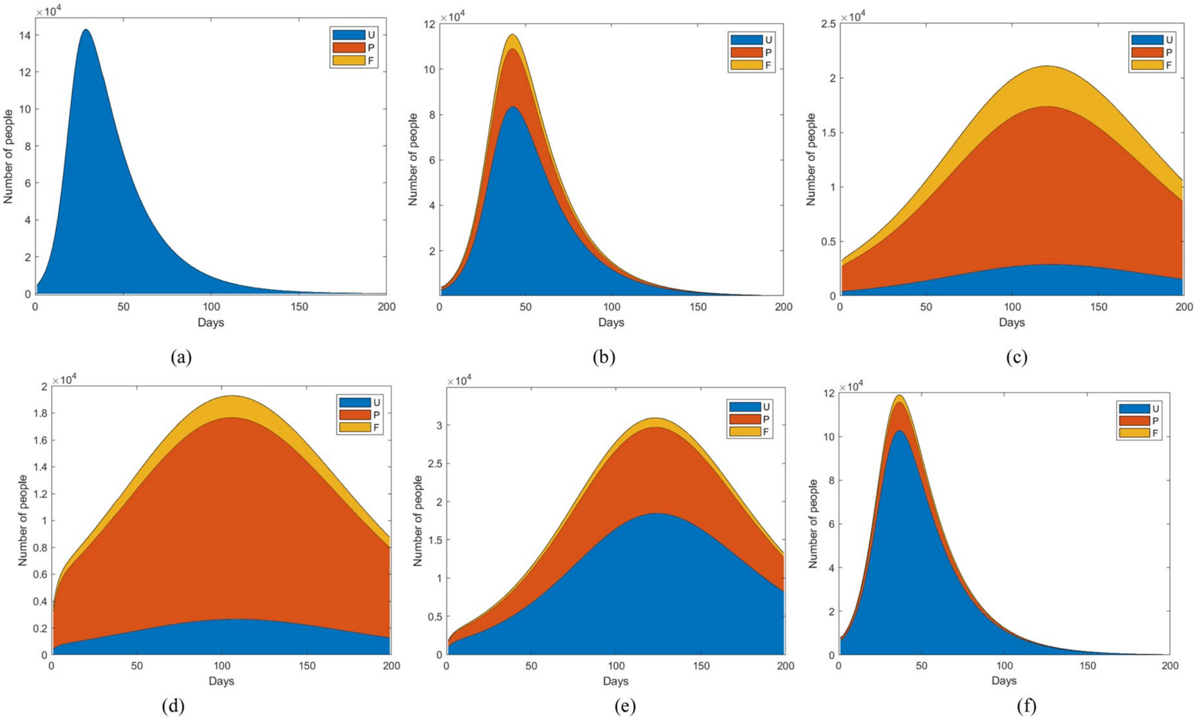

Fig. 4 Changes in the proportion of different types of infected persons under scenarios 1–6 (**a**–**f**)

Table 4 Results of test demand estimation under scenarios 1–6

Scenario	Number of tests used		Potential demand for testing		Total demand for testing	
	Peak value (cases)	Time to peak (days)	Peak value (cases)	Time to peak (days)	Peak value (cases)	Time to peak (days)
1	–	–	187,149	26	187,149	26
2	17,999	40	103,358	42	121,202	41
3	2656	106	9125	117	11,739	115
4	4358	94	8534	99	12,884	97
5	6599	117	25,965	120	32,537	119
6	14,707	37	119,647	36	134,320	36

Scenario 5

Under strict prevention and control measures and robust testing capacity, the epidemic peaks at 125 days, with 30,942 infected people (Fig. 3e). Among them, 18,468 are undetected, 11,262 are positive, and 1212 are negative. Undetected cases account for 63.60% of the total cases (Fig. 4e). The total demand peaks at 32,537 on the 119th day, and both high and low detection capabilities can meet the demand at this time (Table 4).

Scenario 6

In a scenario of high vaccination efficiency and low testing capacity with relaxed prevention and control measures, the epidemic peaks at about 39 days, with 119,103 infected people (Fig. 3f). Among them, 102,870 are undetected, 13,018 are positive, and 3215 are negative. Undetected cases account for 89.07% of the total cases (Fig. 4f). The total demand peaks at 134,320 on the 36th day, and neither high nor low detection capabilities can meet the demand at this time (Table 4).

Comparative Analysis Result

There were significant differences in the total demand for testing under different scenarios (Fig. 5).

Compared with no prevention and control measures, relatively lenient prevention and control measures can reduce the infection peak and prolong the epidemic's peak time. Building upon the implementation of scenario 1, scenario 2 introduced non-pharmaceutical interventions, vaccination, nucleic acid testing, and other measures, resulting in a reduction of 27,776 infections and 65,947 in total testing demand. By intensifying non-pharmaceutical interventions and increasing the frequency of nucleic acid testing in scenario 3, even under low testing capacity, the epidemic's peak time was delayed by 78 days. The proportion of undetected cases decreased from 77.83% to 31.21%, and the total demand for testing was significantly reduced, meeting the maximum demand under low testing capacity.

In scenario 4, with improved nucleic acid testing capacity compared to scenario 3, the number of undetected cases and test-negative cases decreased, and the proportion of undetected cases was 22.17%. However, the total demand for testing increased in this scenario. Scenario 5 transitioned from universal testing to voluntary testing on the basis of scenario 4, resulting in a 44% decrease in residents' willingness to test. Consequently, the number of infected patients increased by 11,640, the proportion of undetected cases surged to 63.60%, and the total demand rose by 2.5 times, surpassing the set capacity of nucleic acid testing.

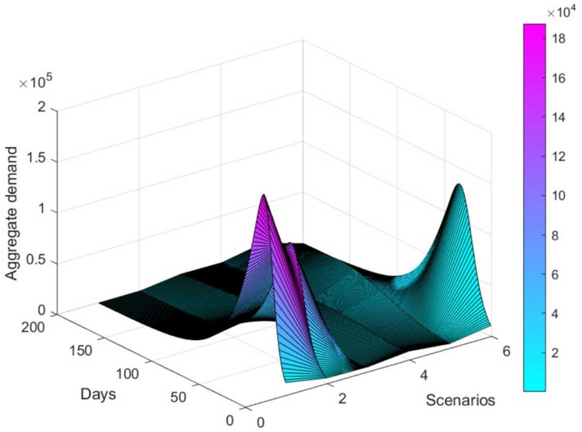

Fig. 5 Estimation of demand for nucleic acid testing under scenarios 1–6

Under scenario 6, where vaccination coverage increased and residents' willingness to test decreased on the basis of scenario 2, the number of infected people increased by 3685, the proportion of undetected cases rose by 11.24%, and the total demand for nucleic acid testing increased by 13,119. This analysis underscores the intricate dynamics between prevention and control measures, testing strategies, and their collective impact on epidemic outcomes.

DISCUSSION

Based on the transmission characteristics of COVID-19, the traditional SEIR model was improved in this study. Information and data published on official Israeli websites during the outbreak were collected to construct a dynamic model of the infectious disease considering detection measures. This model can provide some theoretical basis and support for the prevention and control of the epidemic. We also summarized the prevention and control experience and laboratory resource requirements of China and other countries during the COVID-19 epidemic, focusing on the impact of nucleic acid detection capacity on the prevention and control of the epidemic. This study used a transmission dynamics model to simulate the development trend of the epidemic in different scenarios, and comprehensively analyzed the demand for medical and health resources under different circumstances, so as to provide reference for emergency preparedness and prevention and control strategy adjustment of medical resources under the epidemic. Guidance on resource input and allocation of control materials is also provided.

As a result of infectious diseases being affected by many factors in real life, it is difficult to analyze the development of epidemics in different scenarios in the future. However, the scenario simulation method provides new ideas for the analysis of the development trend of COVID-19 and the decision-making of prevention and control [21, 22]. Scenario simulation is a setting method that mimics the real-life scene. Scenario simulation can set up a scene to carry out research by analyzing the determined conditions, limit the uncertainty of the development of things, predict the possible impact of various scenarios in the future, and provide guidance for the reality of the situation. Israel, which has one of the highest vaccination rates globally, is the country hardest hit by the current outbreak [23]. Using this data to validate our modified SEIR model, which takes into account the effect of vaccination, we found that the results fit well, with Israel having 1892 confirmed cases per million population on September 1, 2022, which was the highest in the world and well ahead of Mongolia, which had 1119 cases. The results showed that when the national testing strategy changed to voluntary testing, the willingness of residents to test decreased by 44%. The number of infected patients increased by 11,640, the proportion of undetected cases increased to 63.60%, and the total demand increased by 2.5 times, which was far beyond the set nucleic acid testing capacity. It is necessary to strengthen the intensity of interventions and increase testing in the early stage of the epidemic to help control the demand for testing and keep it within the capacity.

We estimated the demand for nucleic acid testing by quantifying the change in the number of infections during the COVID-19 epidemic, explored how to optimize the nucleic acid testing strategy with the nucleic acid testing capacity as the constraint, and determined the best nucleic acid testing implementation plan to provide guidance for the use and deployment of resources. China's previous epidemic prevention experience shows that once a regional epidemic occurs, it is necessary to organize a large-scale nucleic acid screening immediately to find the infected patients in time and immediately isolate the positive cases. Active detection can be an effective strategy to prevent the spread of SARS-CoV-2 [24]. Our findings suggest that increased frequency of nucleic acid testing with increased intensity of non-pharmaceutical interventions may delay the peak of the epidemic by 78 days under low nucleic acid testing capacity. Xiang et al. showed that the implementation of traffic control policies reduced the peak number of infected people in Changsha by 66.03%, and the peak period was delayed by 58 days [25]. Early large-scale testing and strict prevention and control measures can effectively reduce the scale of infection and the potential demand for nucleic acid testing. The results of a Brazilian study suggest that the relatively early adoption of quarantine in the state of Sao Paulo, compared to the lockdown in Spain, resulted in a prolonged duration of the first wave of the outbreak and a delay in its peak [26]. This is consistent with the results of our study.

We consider the initiation and false negative rate of nucleic acid testing, and the improvement of SEIR model is beneficial to distinguish the infected persons who have been detected from those who have not been detected, which is beneficial to estimate the level of future risk. Bhaduri et al. [27] simulated and estimated the number of undetected infections and deaths in India by modifying the SEIR model. In addition, nucleic acid screening requires significant time, resources, and personnel, and as the risk of infection changes in different regions, governments may simplify their testing models, so it is critical to estimate the need for nucleic acid testing in different scenarios. Studies have shown that costs lost as a result of lockdowns can be avoided through large-scale nucleic acid testing [28]. However, the key to the implementation of nucleic acid testing measures lies in the testing capacity. It is helpful to optimize the allocation of testing resources by estimating the testing needs in different situations. Sainz-Pardo et al. [29] introduced a heuristic to minimize the spread of COVID-19 by planning an effective distribution of tests in a population in an area over time. Some studies have pointed out that in the case of limited medical resources, the optimal allocation of resources in multiple regions depends on the state of the whole region, and a region may change from limited testing resources to having enough testing resources [30]. Therefore, it is necessary to accurately and rapidly assess the demand for nucleic acid testing in different situations.

This study still has some limitations. Firstly, most of the published literature was referred to in terms of parameter selection for the infectious disease model. As a result of the differences in model parameters between regions and periods, further validation with empirical data is lacking. Second, we ignored the heterogeneity of incidence in different regions and did not consider socioeconomic factors such as age and underlying diseases that are related to the risk of COVID-19 infection. Third, this study focused on the impact of nucleic acid screening measures on the development of the epidemic and only involved nucleic acid testing resources. Subsequent studies can comprehensively evaluate the resources needed after the outbreak, including beds, drugs, vaccines, etc. Future studies should collect more case data and epidemiological data, combined with socioeconomic factors, and improve the parameter settings and values to improve the accuracy of the model. In addition, this demand estimation method can also be used to solve the problem of resource allocation optimization in specific places such as communities, schools, and hospitals.

CONCLUSIONS

The implementation of strict nucleic acid testing strategy can reduce the infection peak and delay the peak time. However, when testing capacity is limited, more stringent prevention and control measures can reduce the number of infections and the need for resources. The improved SEIR model can better predict reported and unreported cases and make recommendations for future infection risk. Rapid assessment of testing needs in different situations can solve the problem of limited resources in some areas through resource allocation and provide reference for the prevention and control of infectious diseases in the future.

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Declarations

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