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Precise Control and Integrated Management of Public Health Emergencies

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Abstract: As public health emergencies become increasingly complex and frequent worldwide, the modernization of the public health emergency system is urgently required to improve the overall security level of a country, which is crucial for the modernization of the national governance system. In this study, we summarize China's response to public health emergencies from three aspects: epidemic surveillance and reporting systems, sentinel surveillance and multipoint trigger mechanisms, and mobile terminal applications for individuals. Moreover, we explore strategies for the precise control and integrated management of public health emergencies and propose corresponding suggestions. Specifically, precision control can be realized by combining the following aspects: temporal and spatial modeling and calculation of the epidemic, epidemic data collection and information statistics, grassroots community prevention and control, and emergency resource supply. Integrated management should focus on the collection and perception of social governance information, data analysis and calculation platforms, rapid response and command at the grassroots level, epidemic monitoring, early warning, and prediction, and continuous risk assessment. Furthermore, we suggest that China should strengthen its information technology to enable epidemic prevention and control, improve its epidemic monitoring and reporting system, and build an integrated system for public health governance.
Keywords: public health events; emergency management; epidemic prevention and control; accurate perception; information technology empowerment; integrated

1 Introduction

The COVID-19 outbreak has become the most widespread global pandemic affecting human beings over the past 100 years, with a huge impact on international order, economic development, and social stability. Epidemic prevention and control have become top priorities in every country and region of the world. Facing an exceptionally difficult situation with respect to epidemic prevention and control, China has gradually realized the resumption of work and production. Free vaccination for all and precise prevention and control strategies are implemented, and a public health emergency prevention and control system has been improved after strenuous effort.

Internationally, extensive research has focused on methods and strategies for the prevention and control of the COVID-19 epidemic. Research on non-pharmacological integrated intervention strategies has provided important references for the development of epidemic prevention and control strategies worldwide. For example, China's strategy of unified collaboration, timely adjustment of prevention and control measures, and resumption of work and production has effectively interrupted the spread of the virus [1]. By anonymized big data analysis, simultaneous large-scale travel restrictions and social distancing measures have positively impacted outbreak prevention and control in Europe [2,3]. Studies in the United Kingdom and the United States have pointed out that enhanced tracking

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of close contacts would improve epidemic prevention and control and curb the spread of the virus [4,5]. New Zealand used multiple testing systems, such as hospital-based severe acute respiratory illness surveillance, influenza-like illness-based sentinel integrated medical care surveillance, Southern Hemisphere Influenza and Vaccine Effectiveness Study Surveillance Program (SHIVERS-II & III), International Classification of Diseases (ICD)-coded admissions, laboratory surveillance, and data analyses to effectively control the spread of the virus [6]. Besides retrospective spatiotemporal dynamic analyses from multiple perspectives, including epidemiology, molecular pathogenesis, environmental ecology, and social sciences, studies have also focused on methods and technologies based on artificial intelligence and integrative big data analyses for monitoring, prevention, and control [7].

The novel coronavirus (SARS-CoV-2) continues to mutate and spread globally. China still faces critical challenges, such as imported cases from abroad, sporadic disseminated cases, and local outbreaks. Important measures and core requirements for achieving scientific governance and an efficient emergency response have been summarized, including the integration of technology and systems to support precise prevention and control and building an integrated management system.

2 Status of public health emergency prevention and control in China

After practical exploration, China initially established an emergency prevention and control system for public health emergencies, involving monitoring and reporting systems for the status of the epidemic, sentinel monitoring and multi-point triggering mechanisms, and personal "Health Code" mobile terminal applications, contributing substantially to the COVID-19 response.

2.1 Epidemic monitoring and reporting system

Since the outbreak of severe acute respiratory syndrome (SARS) in 2003, China has continued to strengthen its disease prevention and control system and built an Internet-based direct reporting system for infectious disease outbreaks and public health emergencies in 2015 [8]. The subsystem National Notifiable Disease Report System (NNDRS) enables the real-time, online, direct reporting of statutory infectious disease cases by medical and health institutions. Based on the NNDRS, a number of single disease surveillance systems have been built for tuberculosis, plague, AIDS, measles, and other infectious diseases to generate accurate case data [9]. With the increasingly in-depth integration of information technology and medical technology aimed at better reporting of suspected epidemic information, most hospitals in China have adopted a hospital disease monitoring information management subsystem (HDMIMS). Internal data for each hospital are transmitted to NNDRS by a data interface, forming a more efficient and accurate direct epidemic reporting mechanism. Since the establishment and operation of the epidemic monitoring and reporting system, the monitoring of pneumonia of unknown etiology (PUE) has improved; however, there are still loopholes in the monitoring of unknown initial infectious diseases that have not been recognized as "legal infectious diseases" [10].

For example, an influenza symptom monitoring network covering all of China was constructed [11], and hospitals and influenza laboratories were connected to the Centers for Disease Control (CDC) at all levels to continuously and systematically collect and analyze the occurrence of specific clinical syndromes and other data. In this way, early warning and rapid responses can be realized based on abnormalities in temporal, population, and spatial distributions, enabling the implementation of effective measures to address infections and reduce morbidity and mortality. The data sources for influenza symptom monitoring included pre-hospital data, in-hospital medical service data before diagnosis, and data for clinically diagnosed cases. There has been a recent increase in symptom monitoring in certain groups of people. At the same time, data acquisition and related medical treatment have improved. Data and information related to medical care and medical visits, such as absenteeism, pharmacy retail, and 120 emergency hotlines, are more complete, providing powerful data support for the prediction and early detection of infectious diseases.

2.2 Sentinel monitoring and multi-point triggering mechanism

2.2.1 Sentinel monitoring mechanism

The impacts of acute infectious disease outbreaks and epidemics are immeasurable, and "early" is the key to public health emergencies. "Early detection" was the premise of "early report, early isolation, and early treatment." Comprehensive monitoring of abnormalities, early warning, and timely responses were the key strategies to prevent and control infectious disease outbreaks. To a certain extent, pharmacies and community medical institutions functioned as "sentinels" in the grassroots epidemic prevention network. Since the outbreak of COVID-19,

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pharmacies, as offline retail terminals selling protective supplies and drugs, have been included in epidemic surveillance for strict control. In addition, temporary fever clinics were established in communities in Beijing, Shanghai, Hebei, and other regions; these were dedicated to the screening, registration, referral, and tracking of patients with fever. For the normalization of epidemic prevention and control and strengthening of the monitoring network, "sentinels" have been gradually established in many places, such as ports, airports, railway stations, bus stations, schools, communities, farmers' markets, cold chain warehouses, enterprises, and institutions. Nevertheless, in the epidemic prevention network in China, "sentinel" surveillance remained in a preliminary state. Looking forward, it was necessary to further improve the construction of "sentinel" systems for the monitoring of unknown diseases and abnormal health events and to form a mature and standardized mechanism to ensure the continuous improvement of the model system.

2.2.2 Multi-point triggering mechanism

To evaluate the infectious disease epidemic risk, monitoring by medical and health institutions was only a "single-point trigger," and broader monitoring was needed to integrate and analyze all data types. In the COVID-19 epidemic prevention and control process, Hubei, Shanxi, Shanghai, Hunan, Henan, Hebei, Chongqing, and other provinces and cities have gradually explored and constructed a multipoint early warning system. For example, the Shanghai public health system construction plan included a comprehensive public health monitoring and early warning system based on multi-source data and multi-point triggers [12]. Under the joint prevention and control framework, multiple departments, such as health, customs, transportation, market, agriculture, forestry, meteorology, environmental protection, and education departments, were included in the data collection channels. Based on a multiple data-sharing mechanism, a multi-subject, multi-level information source was established to improve the early monitoring and early warning capabilities for sudden and unexplained infectious diseases.

2.3 Personal mobile terminal applications

In response to the COVID-19 epidemic, a series of information-based epidemic prevention and control tools relying on mobile Internet, big data, and other technologies were formed, such as the "Stop Covid" Application in France, the epidemic self-quarantine service application in South Korea, and the "Trace Together" Application in Singapore. China's mobile terminal application products, such as Communication Big Data Travel Card and "Health Code," provide important management support tools and means for epidemic prevention and control and the comprehensive social resumption of work and production. By December 2020, the "Health Code" launched by the national integrated government service platform, was applied nearly 900 million times and used more than 40 billion times, becoming a necessary application in daily production and life [13].

Location and health data for users were obtained by applications such as "Health Code," mostly using of Bluetooth near-field communication, signaling data, positioning data, two-dimensional code, self-inspection and self-reporting on mobile devices. These data are used to identify individuals with potential and established infections, judge the exposure risk of relevant personnel through background big data comparison and analysis, prevent and track the spread of SARS-CoV-2, and finally avoid the risk of spread. With the continuous use of "Health Code" applications, the resolution of potential problems, such as data credibility, information security, and privacy rights, is urgently needed.

3 Precise prevention and control of public health emergencies

3.1 Spatio-temporal modelling and quantitative analyses of the epidemic status

Trends in the spread of infectious diseases were accurately predicted, and the effectiveness of infectious disease control measures was evaluated. Both analyses were based on studies of temporal and spatial transmission laws pertaining to infectious disease epidemics and the establishment of infectious disease transmission models. Relevant research fields have proposed an epidemic dynamic modelling method based on the SIR model, which divides the population into susceptible (S), infectious (I), recovered (R), exposed (E), quarantine (Q), and hospitalization (H). A variety of models based on SIR have been developed to describe the spread of infectious diseases, such as SIR, SIRS, SEIR, and SEQIHR [14–18]. In studies of the COVID-19 outbreak, some scholars had combined existing infectious disease transmission models [19–21] with data-driven models [22–31] and applied these to the prediction of outbreak trends with good results. Therefore, the combination of model calculation and data analysis techniques has been used in research on the spatio-temporal epidemic infection process, estimation of key parameters in epidemiology, deduction of epidemic conditions, and risk prediction, providing support for the accurate prevention and control of public health emergencies.

3.2 Epidemic data collection and information statistics

The recent epidemic is highly dynamic. A valuable practical experience in dealing with COVID-19 in China involved connecting various departments and levels of organization, taking concerted action, and utilizing real-time data. In the process of statistical analyses, unclear statistical indicators, inconsistent statistical standards, and insufficient sharing of statistical data could cause data biases, directly affecting the effectiveness of prevention and control measures. To meet the needs of epidemic prevention and control in the future, it is necessary to formulate relevant technical standards for data aggregation, and to establish a comprehensive and multidimensional standardization system for statistical data. For example, “T-G-P distribution” gathered standard data to dynamically and comprehensively analyze determinants and processes contributing to epidemics, which could be used to improve the efficiency of epidemic data collection and statistical analysis, as shown in Fig. 1.

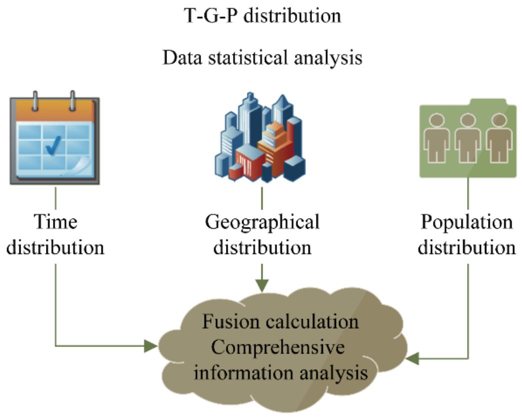

Fig. 1. Data acquisition standardization and fusion analysis of “T-G-P distribution”.

3.3 Community epidemic prevention and control

Community is key to COVID-19 epidemic prevention and control. Communities at the grassroots level should not only effectively implement epidemic prevention strategies but also broadly consider basic living security, market stability, special groups, and public opinion. Based on traditional grid management, the dynamic and complete implementation of diversified grids is an important strategy. Refined, personalized management and services are important grassroots tasks in public health emergency prevention and control. In the grassroots governance process, complete information covering epidemics, livelihoods, community appeals, and other aspects were integrated to form integrated epidemic and social data, which in turn supported the unified deployment of epidemic and social governance actions to realize precise, humanized, and science-based public health emergency control.

3.4 Emergency resource guarantee

In accordance with the principle of centralized management, unified allocation, integration of usual services and emergency response during disasters, combination of procurement and storage, and efficiency, a sound and unified emergency material guarantee system should be established to promote the security, efficiency, and control of the emergency material supply network. After the COVID-19 outbreak, the Ministry of Industry and Information Technology of the People’s Republic of China urgently developed a national key medical supply security dispatching platform, mainly to collect, count, analyze, monitor, dispatch, and filter the production capacity, output, and inventory of key medical material enterprises, and coordinate online and offline to timely learn the supply capacity of key medical materials, such as protective clothing, drugs, testing reagents, and special medical equipment. In the future, to meet the needs of the national emergency system, it is necessary to further improve the laws, regulations, and management of emergency material support. It is also necessary to improve the network, digitalization, intelligence level, basic storage and transportation conditions, accurate and scientific decision-making ability of emergency material support.

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4 Emergency prevention and control and integrated management of public health emergencies

Public health emergency prevention and control require broad social coordination. The integration of management is necessary for the reform of public health emergency prevention and control and involves five aspects: collection and perception of social governance information, accurate prevention and control enabled by data and calculation, rapid response and dispatch command of grassroots, epidemic monitoring warning and situation prediction, and continuous epidemic risk assessment.

4.1 Collection and perception of social governance information

4.1.1 Multi-source information collection and risk perception

In response to the pandemic, it is important to strengthen personal temperature monitoring and health information collection. China covers a wide region and has a large population. Under the epidemic, it was particularly important to improve all types of information collection and risk analyses. Therefore, it was necessary to establish multi-source collaboration and orderly cooperation among the government, community, enterprises, and residents, and to effectively integrate big data, Internet of Things (IoT), and other technologies. Multimodal information, such as tracks, text, and images, is fused and collected. The aggregated multi-source heterogeneous data cover human flow, logistics, and information flow. Effective multisource information collection and risk perception can provide accurate, effective, and comprehensive information for accurate epidemic prevention and control.

4.1.2 Digitalization and intellectualization of information management

In the early stages of the COVID-19 pandemic, many places in China still used traditional paper forms for information statistics. As a result, limited information-carrying capacity, low expansibility, complex processing technology, and loss and damage of content have gradually become prominent issues, revealing the insufficient information management capacity for public health emergency work. In response, the use of text recognition technology to realize the digitization of existing paper-based information and the use of various smart terminal devices, such as mobile phones, to achieve diversified and informalized data collection was considered a necessary path for the modernization of public health emergency information management capabilities. Through electronic information collection, timely preservation and accurate classification of information can be realized, making full use of big data, IoT, artificial intelligence, and other technologies to improve the efficiency of information sorting, thereby improving the efficiency and processing capacity of public health emergency responses.

4.1.3 Production and maintenance of high-value information

Information on high-risk populations, sites, transportation, and logistics played important roles in epidemic prevention and control in China and reflected the emphasis on accurate epidemic perception, prevention, and control. To adapt to the shift in information production from single to multiple subjects and the change in communication mode from linear to network in the mobile Internet era, further screening is necessary for information collected through multi-source channels to ensure the reliability of data. Accordingly, using big data and intelligent IoT technology as the foundation, accurate epidemic awareness and prevention and control as guidance, data analysis methods for support, and based on the service value of information, a closed-loop public health emergency information operation value chain with the process of "collection and editing–maintenance–release and application –demand feedback–analysis–collection and editing" was proposed. This process reduced the cost of information management, realized the professional and normal management of high-value information production and operation services, and was used for the centralized management of activities of high-risk individuals, such as confirmed cases, suspected patients, and close contacts. Fully and efficiently utilizing available information would improve the public health emergency response capacity, reduce the risk of epidemic spread, and better support the accurate perception and control of epidemics.

4.1.4 Enhancing information sharing and privacy protection

Public health emergency management requires coordination among multiple departments. It is important to strengthen information exchange and information fusion among governments at all levels, health institutions, enterprises, operators, and residents. Breaking the "information island" and establishing a reasonable information-sharing mechanism would help rapidly eliminate all types of public health risks. In addition, while strengthening the sharing of public health emergency information, it is necessary to focus on improving the level of privacy protection to avoid the sharing of raw personal data and to avoid the reduction of public cooperation due to privacy problems.

Then, technologies including desensitization and privacy removal design, processed information sharing, “minimization” rules for personal information collection, and information security laws can be adopted to comprehensively protect personal privacy and security.

4.2 Accurate prevention and control enabled by data and calculation

With the “New Infrastructure Construction” and smart city development in China, public health work, such as diagnosis and treatment at medical and health institutions, flow of cases through social networks, large-scale virus detection, and vaccination have gradually been digitized. The data resources required for the risk perception granularity of the epidemic were accurate for the risk analysis of individual data, integrated multimodal data, big-data-driven risk prediction, and multi-agent collaborative management under the “Internet +” mode. Given the constraints of data sharing, such as data segmentation, based on the improvement of data acquisition and standardized aggregation technology of multi-type and multi-level technical equipment, a data update and operation and maintenance mechanism was established to ensure the timeliness and accuracy of data. Credible data-sharing technology was developed to ensure the authenticity and reliability of data and to realize the traceability of the entire process of data management and sharing applications. To implement integrated big data fusion analyses and intelligent decision-making in public health emergencies, the development of multi-source heterogeneous big data fusion analysis methods and artificial intelligence technologies is an important goal.

Actions and intervention measures for epidemic prevention and control were also affected by social factors, such as political, economic, and cultural factors. Although social factors are not easily quantified, the increasing availability of data for individual behavior from mobile devices and other technologies and the mathematical modelling of social factors related to outbreak transmission, such as the SEIR model, has provided a scientific means to parameterize the decision-making process [32]. Various models, multi-source heterogeneous big data, artificial intelligence, and other technologies have been used for calculations and analyses, thereby supporting the realization of the accurate perception and management of public health emergencies. For example, based on hundreds of billions of computing platforms developed by the Virginia Bioinformatics Institute, a large-scale social contact network was simulated, the epidemic transmission process was analyzed, and the advantages and disadvantages of various prevention and control strategies were evaluated. While preventing and controlling the epidemic scientifically and efficiently, to prevent and resolve the risk of spillover as much as possible, it is necessary to establish a social computing science platform and supportive environment for public health emergency applications and to fully consider diversified social parameters by building a complex model and integrating the “New Infrastructure Construction” and various related technologies [33]. At present, popular multi-agent modelling tools for social computing include Swarm [34], Repast [35], and Netlogo [36], which provide a good reference for China to further apply social computing for the utilization of information and data empowerment in public health emergencies.

4.3 Rapid response and dispatch command at the grassroots level

4.3.1 Grassroots social responsibility subject

Many subjects were responsible for epidemic prevention and control in the grassroots community, and public health emergency management required a common response and action from multiple sectors. Therefore, the rapid response of the social grassroots needed efficient cooperation (or participation) among multiple subjects for command and dispatching at the decision-making level. It was necessary to clarify the specific responsibilities of each entity and to divide these specific responsibilities under abnormal conditions according to the strengths and capacity of each responsible entity, thereby ensuring that public health emergency work under abnormal conditions was carried out in an orderly and efficient manner. This also reduces responsibility gaps or overlap and promotes orderly progress in epidemic monitoring, information collection, emergency initiation, emergency response, and emergency recovery.

4.3.2 Rapid response and dispatch command

Rapid response and dispatch commands are important to ensure the effective development of public health emergency work. It is important to avoid the spread of infectious diseases with unknown risks due to an insufficient emergency response and to avoid the adverse effects of excessive responses on the economy and society. Therefore, it is necessary to establish an effective mechanism to identify and report abnormal public health events. Given China’s multi-level public health emergency command and dispatching chain structure, i.e., national–province–city–county–block–enterprise–community–neighborhood–individual, and according to the epidemic situation and degree

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of harm, rapid response mechanisms can be established at different emergency levels, the principles of hierarchical responsibility and territorial management can be implemented, and targeted measures can be taken to balance emergency control and the social-economic development order.

4.3.3 Emergency prevention and control plan at the grassroots level

Each subject should formulate effective and feasible emergency prevention and control plans according to the scope of responsibility and conditions to ensure that there is no omission in scientific prevention and control. At the same time, a series of complete mechanisms are needed to ensure the continuous improvement of emergency prevention and control plans and to improve the effectiveness of public health emergency actions, such as emergency preparedness, treatment, material support to residents, and the restoration of order.

4.3.4 Professional force building for emergency prevention and control

While ensuring the scientific and reasonable formulation of public health emergency plans, existing resources should be fully utilized to build a number of reliable professional teams able to be quickly transformed into emergency prevention and control forces, including groups for detection, isolation, treatment, logistics, public security, and other tasks, to ensure that the plan could be started quickly and implemented effectively during public health emergencies. This avoids the negative consequences of low organizational adaptability on the rapid response, command, and dispatching efficiency at the social grassroots level.

4.4 Epidemic monitoring, warning, and prediction

Under emerging infectious diseases, it is important to strengthen continuous tracking, monitoring, and prediction methods for the epidemic conditions. When high-risk factors or signs of aggravation and spread are observed, the timely and accurate release of early-warning information, mobilization, and organization of emergency preparedness as well as responses by relevant responsible subjects are the key to avoiding viral outbreaks, large-scale spread, and the deterioration of public health. Early warning with respect to social routines, sites and areas, and outpatients with fever are the three lines of defense for continuous monitoring and early responses during epidemics, as shown in Fig. 2.

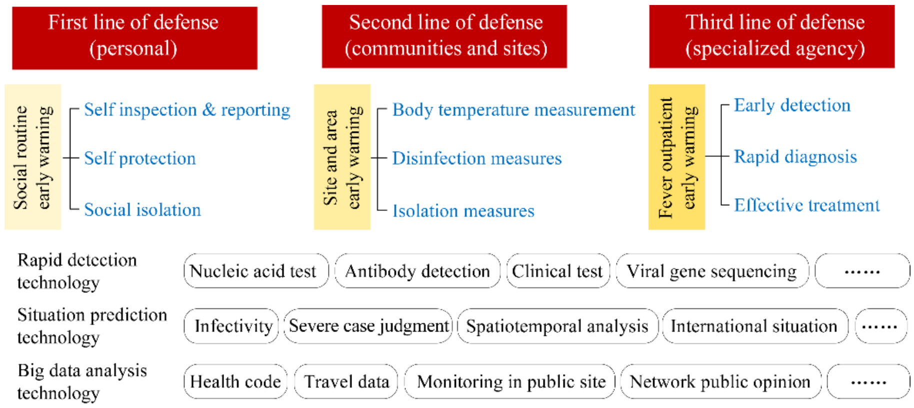

Fig. 2. Continuous monitoring, warning, and prediction of epidemics under abnormal conditions.

4.4.1 Routine monitoring and early warning

In the case of public health emergencies, to detect abnormal and typical pathogenic symptoms in a timely manner, extensive self-examination of physical health conditions, including body temperature monitoring, is necessary. Epidemic prevention and control by individuals were the core guarantees of this study. If public health security risks (suspected cases) or high-risk factors (confirmed cases) were found, immediate risk source investigations were needed, following by the reporting of relevant information to the public health emergency management department through special information sharing channels and properly issuing early warnings to remind the public to strengthen personal protection; this was the key to the first line of defense. In this process, adapting advanced Internet and information technology to the early warning mechanism for the epidemic was an important condition for the timely implementation of measures to avoid the expansion of the public health crisis, actively conduct accurate epidemic risk perception, and orderly implement hierarchical prevention and control actions.

4.4.2 Site and regional sentinel surveillance and early warning

After confirmed cases or other high-risk factors were detected, combined with epidemiological investigation, travel tracking, and other methods, activity areas of confirmed cases within a certain period of time and the timely location and isolation of close contacts and other high-risk personnel were used to block the epidemic transmission chain. In addition, this strategy was an important means to accurately perceive the epidemic risk and prevent and control the spread to low-risk areas, which delimited high-risk areas based on analyses of travel trajectory data for multiple confirmed cases. Then, the travel history of high-risk places and the populations inhabiting high-risk areas were quickly checked using combined samples and rapid detection technology, providing a basis for appropriate blockade control measures.

4.4.3 Surveillance and early warning for outpatients with fever

Outpatients with fever were a starting point for addressing epidemics of major infectious diseases. Rapid and professional medical diagnostic technology is usually used to identify infectious diseases. When people with abnormal health conditions, such as a high body temperature and other obvious typical symptoms, are found, they should be quickly transferred to the fever clinic for further screening and diagnosis. The improved triage screening ability of community grassroots hospitals for pathogen identification in patients with fever could further improve the diagnostic efficiency of the overall medical system. This would avoid the depletion of medical resources and the aggregation of related personnel under abnormal conditions, thereby reducing the risk of cross-infection in the hospital. Realizing the entire process of closed-loop management in physical and information spaces could significantly improve the accuracy and efficiency of large-scale epidemic responses.

4.4.4 Epidemic situation prediction

Public health emergencies require the distribution of various resource reserves in a timely manner according to predictions of epidemic dynamics. In the COVID-19 epidemic prevention and control practice, according to confirmed case data published by the national health committees at all levels daily combined with revised trends in confirmed cases of infectious diseases over time, various parameters were determined and an assimilation model was used for predictions, which achieved good results [37], as shown in Fig. 3. The effectiveness of current public health emergency management on epidemic prevention and control can be evaluated by comparing the predicted number of cases with the actual number of confirmed cases. When the predicted value deviates significantly from the actual value, the causes of the deviation are analyzed, and information is issued to areas with ineffective public health emergency work to supervise and take additional necessary measures to control the spread of the epidemic and generate new predictions for local epidemic trends.

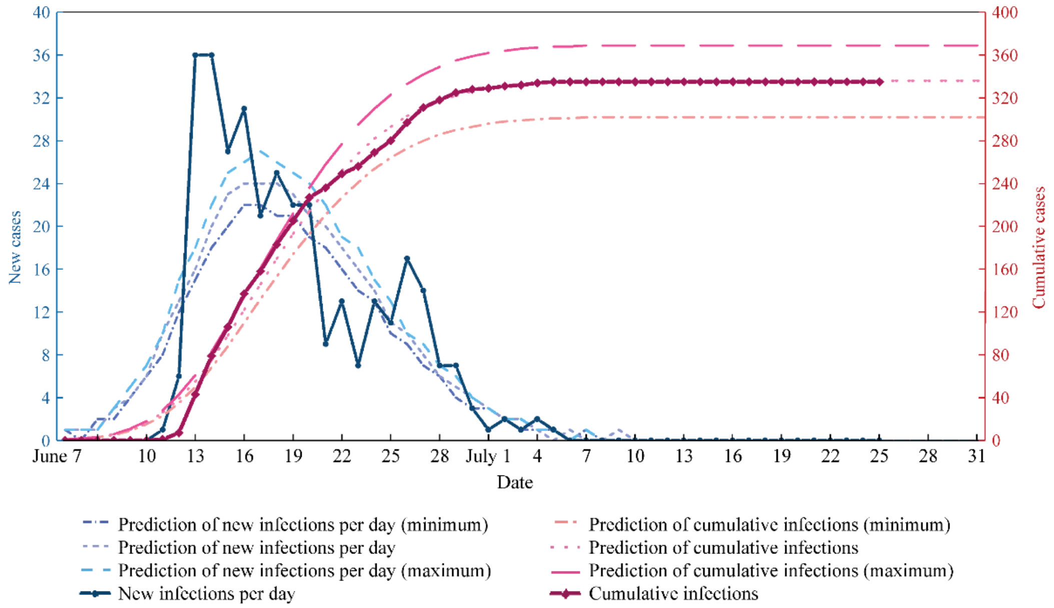

Fig. 3. Prediction efficacy of the epidemic situation: prediction of trends in Xinfadi aggregated epidemic for Beijing.
Note: The epidemic forecast was based on data from June 7, 2020, to 24:00 on June 25, 2020, and the validation data were from June 26, 2020, to 24:00 on July 25, 2020.

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4.5 Continuous epidemic risk assessment

To consolidate the results of epidemic prevention and control, various accurate risk assessments must be implemented to strengthen the management of high-risk areas and personnel. Under the abnormal conditions during an epidemic, the continuous assessment included four types: regional risk assessment, group risk assessment, source risk assessment, and environmental risk assessment.

4.5.1 Regional risk assessment

Carrying out an overall regional risk assessment under abnormal conditions could provide a reliable basis for public health emergency management in different regions and accurate awareness, with the aim of realizing accurate control in key areas. Through epidemiological investigations and itinerary tracking of all confirmed cases, areas where cases were concentrated were investigated and scientific and reasonable risk assessment rules were formulated. Based on these rules, regional epidemic prevention, controlled risks of epidemic spread, prevention and control measures, material resources, and biosecurity determined the risk level in each region. Early warning for high-risk areas and strengthening personnel mobility control in high-risk areas prevented the spread of the epidemic from high-risk to low-risk areas and improved accurate awareness regarding prevention and control in key areas.

4.5.2 Group risk assessment

Carrying out a group risk assessment under abnormal conditions could provide a reliable basis for public health emergency management and accurate detection, prevention, and control in different groups. By analyzing information on the average daily contact number and contact mode, we evaluated the risk levels of different groups and provided early warning to high-risk groups, taking corresponding protective measures. Strengthening the health management of high-risk groups and protective measures can prevent high-risk groups from becoming a source of spread and can prevent the emergence of “super spreaders.”

4.5.3 Source risk assessment

The outbreak and spread of the epidemic can be avoided to a certain extent by outsourced risk assessments under abnormal conditions. The contact history and other information for confirmed cases can be analyzed to infer the possible source of the epidemic, and then necessary measures should be taken to cut off the source. Continuous risk assessments of potential sources (such as wildlife) and logistics from different sources (such as the cold chain food) can provide a basis for virus traceability and the formulation of feasible scientific management measures.

4.5.4 Environmental risk assessment

Potential environmental sites with a high risk of epidemic spread are found, and early warning and required closure and killing measures are implemented by carrying out an environmental risk assessment under abnormal conditions. We should investigate similar environmental areas for the accurate detection, prevention, and control of epidemic situations in abnormal conditions, while discovering high-risk environmental sites. Potential sources of infection can be isolated quickly, and potential transmission channels can be cut off through an environmental risk assessment with the management of suspicious exposure.

5 Countermeasures and suggestions

5.1 Data and computing analysis technology together enable epidemic prevention and control to achieve the accurate management of perception

The application of information technology and computational analysis technology to epidemic prevention and control has significantly improved the operational efficiency of all links, improved the capacity for accurate prevention and control, and provided important support for rapid epidemic control in China and the resumption of work and production. At present, information technology tools are becoming more mature and systematic in practice. For example, a series of independent intellectual property applications in information technology, such as BDS Plus (BeiDou Navigation Satellite System Plus) and Internet Plus; the innovation of various equipment and tools, such as unmanned aerial vehicles, robots, and temperature detection; risk analysis of big data based on trajectories; and calculation and analysis technology based on the spread mechanism of infectious diseases and the integration of social data, are expected to become an important management means for epidemic prevention and control in the future.

Overall, China has made some achievements in epidemic prevention and control; however, there are still some deficiencies in the informatization of public health emergencies in China. To address this, it is suggested to actively explore the cross-application needs of public health and emergency management in the construction of a "New Infrastructure" and "Digital China," fully utilize the engine role of information technology and intelligent equipment in responding to the threat of sudden infectious diseases, mobilize special industrial support facilities, and promote the establishment of an integrated emergency prevention and control management system with human–machine coordination, multi-agent coordination, and technology and system adaptation.

5.2 Establishment and improvement of an infectious disease monitoring and reporting system

To meet the demand for accurate epidemic prevention and control, it is necessary to further establish a normalized joint prevention and control mechanism, implement credible data fusion and collaborative intelligent supervision, improve the overall informatization level of China's public health emergency system, and strengthen cooperation between various departments. Focus should be placed on upgrading the information integration and analysis system in key fields, such as disease prevention and control, biological inspection, and quarantine, optimizing the monitoring technology and procedures in important places and key populations, implementing a technical approach for information exchange and mutual reporting, and ensuring that all aspects of public health monitoring data can be collected, analyzed, fed back, and applied quickly and effectively.

The infectious disease monitoring and reporting system involves building a national network system of infectious disease monitoring and diagnostic laboratories and clarifying the responsibilities of clinical laboratories and public health laboratories in the laboratory network. For emerging infectious diseases, we should strengthen symptom monitoring through multiple channels, rapidly identify abnormal increases in diseases in time and space through the continuous and systematic collection and analysis of frequency data for clinical symptoms of specific diseases, and promote early detection, early warning, and rapid response monitoring for disease outbreaks or adverse health events; this is expected to improve the level of preparation for public health emergencies.

5.3 Building an integrated prevention and control system for public health governance

The community should be viewed as the frontline of data production, awareness, and decision-making, and a standardized method should be developed for the management of perception regarding public health emergency prevention and control at the grassroots level. It is important to break through the traditional unidirectional output mode of social governance at the grassroots level by taking informatization as the driving force, paying attention to participation and concerns regarding privacy protection, expanding the social aspect and communication of epidemic prevention and control, and exploring and developing a new mode of co-construction, co-governance, and sharing based on networking and multiagent cooperation. A multi-scenario, all-factor, cross-domain integration platform combining peacetime and wartime scenarios can be achieved through technology integration, business integration, and functional innovation. Furthermore, in-depth linkage is necessary between the interactive fusion and hybrid drive of "data–calculation–model–case–knowledge" for epidemic prevention and control at the front end of social governance with the biological risk of "active perception–intelligent prediction." Accordingly, an integrated prevention and control system for public health events can be built with cross-level communication and multi-sectoral institutional cooperation spanning individuals, households, communities, cities, and countries.

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