Evaluation of COVID-19 outbreak prevention and control in Beijing using the emergency management theory

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Abstract

On April 29, 2020, China entered a normalization stage of prevention and control. By December 2021, more than 40 outbreaks had occurred in China, which reflected the shortcomings of the pandemic prevention and control measures in China at that time. As the capital city of China, Beijing faces more pressure in epidemic prevention and control. We used the COVID-19 cluster containment evaluation indicators to determine the effects of prevention and control measures on four COVID-19 outbreaks in Beijing. After considering the specificity and operability of evaluation indicators and the availability of evaluation data, the evaluation system in our study consisted of six dimensions: epidemic prevention and control effect, discovery and detection ability, precision prevention and control capability, public protection effect, medical treatment and nosocomial infection prevention and control ability, and information release and public opinion response ability. The composite scores of the prevention and control effects of the Xinfadi, Shunyi, Daxing, and Ejina Banner-associated COVID-19 outbreaks in Beijing were 62, 82, 87, and 76, respectively. In the six dimensions, the epidemic prevention and control effect, discovery and detection ability, precision prevention and control capability, and public protection effect scores for the Xinfadi outbreak were lower than those for the Shunyi, Daxing and Ejina Banner-associated outbreaks. The medical treatment and nosocomial infection prevention and control ability scores for the outbreak associated with Ejina Banner were lower than those for the Xinfadi, Shunyi, and Daxing outbreaks. In managing cluster outbreaks, Beijing was able to detect index cases early enough to reduce the scale and duration of the outbreak and consistently release official information to reduce public panic, standardize the management of centralized quarantine sites to prevent cross-infection, adhere to the “dynamic COVID-zero” strategy to accurately prevent and control outbreaks, reduce the societal influence of the pandemic, and coordinate the epidemic prevention and control and socio-economic development.

1. Introduction

Since its first outbreak in late 2019, coronavirus disease 2019 (COVID-19), which is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has spread globally and been declared a pandemic by the World Health Organization (WHO) [1]. SARS-CoV-2 is highly infectious and has multiple transmission routes. In addition, people are generally highly susceptible to SARS-CoV-2, and no specific drug has been developed to treat it. An improper response to an outbreak of COVID-19 can easily lead to the spread of the disease, particularly when the outbreak involves a familial cluster [2,3]. On June 11, 2020, locally transmitted cases were identified in Beijing. Infections related to this cluster continued to be identified for 25 days and were believed to be directly or indirectly connected with the Beijing Xinfadi Market, which sells various agricultural, meat and seafood products and involves complex operations and multiple personnel [4,5]. In response to the cluster outbreak, the Beijing COVID-19 Prevention and Control Working Group raised the public health emergency response level from 3 to 2 [6]. Between June 11 and July 6, 2020, 333 new confirmed cases were reported in Beijing [5]. The outbreak drew global attention.

On April 29, 2020, China entered a normalization stage of prevention and control. During this stage, China controlled the outbreak and spread of the pandemic by adopting a strategy of “import of external prevention and rebound of internal prevention” and reduced the number of pandemic-related deaths [7]. Within China, COVID-19 cases were generally sporadic, with occasional small-scale cluster outbreaks within limited regions, which were quickly and effectively controlled. The society and economy recovered quickly, and the downward trend in the number of new cases continued [7]. By December 2021, more than 40 outbreaks had occurred in China, with most outbreaks controlled within...
two maximum incubation periods (28 days). However, the cumulative number of infections and the transmission scale of some of the outbreaks exceeded the local epidemic scale of early 2020, which reflected the shortcomings of the epidemic prevention and control measures in China at that time.

Beijing is both the capital and the political and cultural epicenter of China. Therefore, the city hosts numerous major activities. Beijing also faces more pressure, more complex challenges, and higher requirements with respect to epidemic prevention and control. To summarize the prevention and control experiences of COVID-19 outbreaks in Beijing and enable a more effective response to future outbreaks, we used the COVID-19 cluster containment evaluation indicators to determine the effects of prevention and control measures on four COVID-19 outbreaks in Beijing.

2. Data and methods

2.1. Data source

We selected four outbreaks in Beijing for evaluation, the Xinfadi outbreak from June 11 to July 5, 2020, the Shunyi outbreak from December 25, 2020, to January 26, 2021, the Daxing outbreak from January 17 to 29, 2021, and an outbreak associated with Ejina Banner from October 26 to November 15, 2021. The data were collected from the epidemic data released by the National Health Commission and the Beijing Municipal Health Commission, as well as data released by the press.

2.2. Evaluation system

With reference to the COVID-19 Cluster Containment Evaluation System by Liu et al. [8], we considered the specificity and operability of the evaluation indicators and the availability of the evaluation data for examining the evaluation system in this study. The system comprised six dimensions: epidemic prevention and control effect, discovery and detection ability, precision prevention and control capability, public protection effect, medical treatment and nosocomial infection prevention and control ability, and information release and public opinion response ability. Epidemic prevention and control effect comprised of four secondary indicators: crude attack rate, epidemic spread scope, epidemic duration and number of medium and high-risk areas. Discovery and detection ability comprised of two secondary indicators: mode of index case detection and days required for all residents to complete nucleic acid tests. Precision prevention and control capability comprised of four secondary indicators: whether the origin of the outbreak was clear, the scope of the restricted activities of key populations, the scope of nucleic acid testing, and the proportion of infected people identified at centralized isolation points. Public protection effect comprised of one secondary indicator: positive rate among close contacts. Medical treatment and nosocomial infection prevention and control ability comprised of three secondary indicators: proportion of severe cases to confirmed cases, proportion of death cases to confirmed cases and number of infected staff in medical and health institutions or centralized isolation points. Information release and public opinion response ability comprised of two secondary indicators: timeliness of first information release and whether information continued to be released. The definition and weights of evaluation indicators are shown in Table 1. The score for the COVID-19 cluster containment effect was calculated by aggregating the scores of the secondary indicators and using a percentage system, ranging from 0 to 100 points, with higher scores, indicating a more favorable prevention and control effect. The evaluation system was used to evaluate the prevention and control effects of different cluster outbreaks through normalized methods.

3. Results

3.1. Basic information on four outbreaks in Beijing

The Xinfadi outbreak continued for 25 days, and 366 cases of infection were reported, comprising 335 confirmed cases and 31 asymptomatic infections. The confirmed cases were mostly moderate (273 cases, 74.6%). Four severe cases, two critical cases, and no deaths were reported. Six provinces reported cases associated with the Xinfadi outbreak, including Hebei (21 confirmed cases and 6 asymptomatic infections), Liaoning (3 confirmed cases), Sichuan (1 confirmed case), Tianjin (1 confirmed case), Zhejiang (1 confirmed case) and Henan (1 asymptomatic infection) [9].

The first case of the Xinfadi outbreak was reported on June 11, 2020. The patient had been admitted to Beijing Xuanwu Hospital on June 10, 2020, due to intermittent fever that had continued for 5 days. The patient was given a COVID-19 diagnosis and was confirmed as a case on June 11. Retrospective epidemiological investigation revealed that the case was related to Xinfadi market. Analyses of the viral genome sequence obtained from cases and environmental samples in the Xinfadi outbreak revealed that the strain sequence had clear mutation characteristics that differed from those of viruses in previous local and imported cases in China. The epidemiological investigations and big data analysis indicated that the most likely source of the Xinfadi outbreak was the cold-chain food imported from overseas areas with high COVID-19 incidence rates. Cold-chain transportation may be a route for the spread of COVID-19 [10].

The Shunyi outbreak continued for 23 days, and 42 cases of infection were reported, comprising 36 confirmed cases and 6 asymptomatic infections [11]. The confirmed cases were mostly moderate (19 cases, 52.8%). No severe cases or death cases were reported. On December 31, 2020, Huairou District reported a confirmed case to be associated with the Shunyi outbreak [12].

An asymptomatic infection was reported in Shunyi District on December 23, 2020. The person with the infection underwent a COVID-19 nucleic acid test in Shunyi District on December 22, 2020, before participating in a postgraduate entrance examination. On the same day, this person was on the CA8347 flight from Ningbo to Beijing Capital Airport. The person was given a diagnosis of asymptomatic COVID-19 on December 23, 2020 [13]. According to whole-genome sequencing analysis, the strain that caused this outbreak belonged to the L-Lineage European Branch 2.3 (B.1.160.3) and has high homology with the COVID-19 strains that were common in Southeast Asia during that period. The Shunyi Center for Disease Control (CDC) identified an asymptomatic imported case reported on December 28, 2020, as the source of the outbreak. The asymptomatic imported case entered China from Indonesia on November 26, 2020. After 14 days of isolation in Fujian, the person arrived in Beijing on December 10 and began living in Shunyi District after a negative nucleic acid test. However, on December 28, the person was tested again, and the nucleic acid test results were positive. The patient was given a diagnosis of asymptomatic infection [11].

The outbreak in Daxing continued for 13 days, and 33 cases of infection were reported, comprising 31 confirmed cases and 2 asymptomatic infections [14]. The confirmed cases were mainly moderate (22 cases, 66.7%). No severe cases or death cases were reported. Shunyi District reported a confirmed case on January 19, 2021, associated with the Daxing outbreak [15].

On January 17, 2021, a cluster community COVID-19 outbreak occurred in Daxing District, Beijing. The index case underwent a nucleic acid test on January 16, 2021, as was required for individuals intending to leave Beijing. The results were positive on January 17, and the patient was confirmed as having COVID-19 on the same day [16]. Whole-genome sequencing and lineage typing revealed that this outbreak was caused by SARS-CoV-2 B.1.1.7. This was the first local transmission of B.1.1.7 in China. This strain sequence was different from those of viruses in local and imported cases previously identified in China and had high
Table 1 Comprehensive epidemic prevention and control effects of four outbreaks in Beijing.

| Secondary indicators | Xinfadi outbreak | Shunyi outbreak | Daxing outbreak | Associated outbreak with Ejina Banner |
|----------------------|------------------|-----------------|-----------------|--------------------------------------|
| 1.1 Crude attack rate | 15.3 per million | 1.6 per million | 1.4 per million | 2.1 per million                      |
| 1.2 Epidemic spread scope | Trans-province | Only in Beijing | Only in Beijing | Trans-province                        |
| 1.3 Epidemic duration | 25 | 23 | 13 | 28 |
| 1.4 Number of medium and high-risk areas | 44 | 8 | 1 | 5 |
| 2.1 Mode of the index case detection | Seeking medical advice actively | Nucleic acid detection of key population | Nucleic acid detection of key population | Voluntary reporting |
| 2.2 Days required for all residents to complete nucleic acid tests | 9 | 2 | 3 | 2 |
| 3.1 Whether the origin of the outbreak was clear | Yes | Yes | Yes |
| 3.2 Scope of restricted activities of key populations | Community (Village) | Streets (Town) | Community (Village) | Building (Village group) |
| 3.3 Scope of nucleic acid testing | County (District) | County (District) | County (District) | Township (Street) level |
| 3.4 Proportion of infected people identified at centralized isolation points | 2.5% | 39.02% | 42.42% | 24.49% |
| 4.1 Positive rate among close contacts | 21.32% | 1.82% | 1.23% | 0.49% |
| 5.1 Proportion of severe cases to confirmed cases | 1.79% | 0% | 0% | 6.38% |
| 5.2 Proportion of death cases to confirmed cases | 0% | 0% | 0% |
| 5.3 Number of infected staff in medical and health institutions or centralized isolation points | 0% | 0% | 0% |
| 6.1 Timeliness of first information release | Timely | Timely | Timely |
| 6.2 Whether information continued to be released | More than 80% of the days have information release | More than 80% of the days have information release | More than 80% of the days have information release |

\*Epidemic duration was defined as the interval between the reporting time of the index case and the reporting time of the last case in a clustered outbreak. 
\*High-risk areas were defined as communities with two or more local cluster outbreaks or more than five new local confirmed cases within 14 days; medium-risk areas were defined as communities with one new local cluster outbreak or two to five new local confirmed cases within 14 days.
\*Index case was defined as the first documented case of COVID-19 in a population, region, or family.
\*Close contacts were defined as those who had close contact with a suspected or confirmed case 2 days before the onset of symptoms, or with an asymptomatic infected person 2 days before sample sampling, but had not taken effective protective measures.
\*Timeliness of first information release was defined as whether authoritative information was released within 5 h and a press conference was held within 24 h after a clustered outbreak occurs.

homology with COVID-19 strains identified in the United States. The source of infection was preliminarily determined to be imported from abroad [14].

The outbreak associated with Ejina Banner continued for 28 days, and 49 cases of infection were reported, comprising 47 confirmed cases and 2 asymptomatic infections. The confirmed cases were mostly moderate (37 cases, 75.5%). Three severe and critical cases (6.1%) were also reported. Jilin reported a confirmed case associated with this outbreak on November 10, 2021 [17].

The outbreak associated with Ejina Banner involved three independent transmission chains, namely the Fengtai (involving 3 infected people), Changping (involving 25 infected people) and Fengtai, Haidian and Changping transmission chain (involving 21 infected people) [18]. The index case in the Fengtai transmission chain involved an individual who lived in Wuwei, Gansu Province, and had traveled to Beijing on the K42 train on October 15, 2021. In transit to Beijing, the individual shared a carriage with another person from Yinchuan, Ningxia Hui Autonomous Region, who was confirmed as having COVID-19 and had traveled with a Shanghai tour group in Ejina Banner, Inner Mongolia. On October 18, 2021, the individual as the index case of the Fengtai Chain reported to the CDC after having seen the news of the confirmed case. As a close contact of the confirmed case, the individual underwent nucleic acid test, from which he was identified as a confirmed case [19]. The individual as the index case of the Changping transmission chain and four other people drove to Inner Mongolia, Ningxia, Shanxi and other locations on October 12; passed Ejina Banner, Inner Mongolia, and returned to Beijing on October 16. The nucleic acid test results of the index case were determined to be positive on October 22, and the case was confirmed [20]. Because some of the aforementioned individuals returned to Beijing with only a fever, they still went out to dinner and played cards with friends, which spread the virus in Changping District. The index case in the Fengtai, Haidian and Changping transmission chains involved an individual who had traveled to Inner Mongolia, Gansu, and Shanxi with three others from October 10 to October 20, 2021. The individual returned to Beijing on October 21 and voluntarily reported the trip. The results of the nucleic acid test for the index case were determined to be positive on October 24, and the case was confirmed [21]. The basic information of the four outbreaks is shown in Fig. 1.

3.2. Composite score of prevention and control effect of COVID-19 outbreaks in Beijing

The composite scores of the prevention and control effects of the Xinfadi, Shunyi, Daxing, and Ejina Banner–associated COVID-19 outbreaks in Beijing were 62, 82,87 and 76, respectively (Table 1). After the Xinfadi outbreak, Beijing's prevention and control of clustered outbreaks significantly improved. With respect to the reduction in manpower and material resource expenditure, the scale of the epidemic and its influence on people's lives was considerably reduced.
Fig. 1. Basic information on four outbreaks in Beijing.
3.3. Different dimensions of prevention and control effect scores of COVID-19 outbreaks in Beijing

The epidemic prevention and control effect, discovery and detection ability, precision prevention and control capability, and public protection effect scores for the Xinfadi outbreak were lower than those for the Shunyi, Daxing and Ejina Banner–associated outbreaks. The medical treatment and nosocomial infection prevention and control ability scores for the outbreak associated with Ejina Banner were lower than those for the Xinfadi, Shunyi, and Daxing outbreaks, as displayed in Fig. 2.

In the Xinfadi outbreak, only 2.5% of the infected individuals were identified at centralized isolation points. In the Shunyi, Daxing and Ejina Banner–associated outbreaks, 39.02%, 42.42% and 24.49% of the infected individuals were identified at centralized isolation points respectively. The positive rates for close contacts in the Xinfadi, Shunyi, Daxing, and Ejina Banner–associated outbreaks were 21.32%, 1.82%, 1.23% and 0.49% respectively. Only the Xinfadi and Ejina Banner–associated outbreaks had severe cases, which accounted for 1.79% and 6.38% of the cases, respectively, as shown in Fig. 3.

4. Discussion

During the normalization stage of epidemic prevention and control, China effectively controlled the outbreak and spread of the virus by adopting a strategy of “import of external prevention and rebound of internal prevention”, and effectively reduced the number of COVID-19–related death cases. Both society and the economy recovered quickly, and the trend in new cases continued to consolidate [7]. However, the Omicron COVID-19 variant has since become a dominant strain worldwide. This strain has led to considerable challenges for China’s pandemic prevention and control. As China’s capital, Beijing faces even tougher challenges. Therefore, reviewing and evaluating Beijing’s COVID-19 prevention and control measures can provide insights for future pandemic response measures.

According to our evaluations of four cluster outbreaks in Beijing during the normalization prevention and control stage, the composite prevention and control effect scores of the Xinfadi, Shunyi, Daxing, and Ejina Banner–associated COVID-19 outbreaks were 62, 82, 87 and 76, respectively. The epidemic prevention and control effect, discovery and detection ability, precision prevention and control capability, and public protection effect scores for the Xinfadi outbreak were lower than those of the Shunyi, Daxing and Ejina Banner–associated outbreaks. The medical treatment and nosocomial infection prevention and control ability scores for the Ejina Banner–associated outbreak were lower than those for the Xinfadi, Shunyi, and Daxing outbreaks. After the Xinfadi outbreak, the prevention and control effects of the clustered outbreaks in Beijing significantly improved. Most outbreaks were controlled within two maximum incubation periods (28 days).

After April 2020, COVID-19 pandemic prevention in China entered a phase of normalized prevention and control. After this phase, China entered a “dynamic COVID-zero” phase in terms of pandemic prevention and control, which involved whole-chain prevention and control. The dynamic COVID-zero strategy involved “external prevention of import and internal prevention of rebound”; that is, when local COVID-19 cases emerge, comprehensive prevention and control measures should be adopted, and the “find one, extinguish one” approach should be implemented to quickly cut off the chain of viral transmission to ensure that each chain of transmission is quickly terminated, which can achieve maximum effectiveness and minimal costs [22]. Among the four outbreaks in Beijing, only the Xinfadi had large-scale epidemic overflow. This was because the source of the outbreak was unclear at the beginning, which led to widespread community transmission prior to the index case being reported. Because of these factors, the outbreak lasted for a long time and affected six provinces. The Shunyi and Daxing outbreaks did not spread across provinces, and only one cross-provincial case was identified in Jilin Province in the Ejina Banner–associated outbreak [17]. The four outbreaks were suppressed within 28 days, indicating the prevention and control of the cluster outbreaks in Beijing were relatively effective.

In the normalization prevention and control stage, “early detection, early treatment and early disposal” were completed as early as possible [7]. Timely detection and reporting of new cases are crucial for follow-up investigation of transmission chains, management of close contacts, treatment of severe cases, and early control of the outbreak and spread of the epidemic [8]. The index case of the Xinfadi outbreak was con-
confirmed as a COVID-19 case when the patient was admitted to the hospital. However, the patient had COVID-19-related symptoms before being admitted to the hospital, indicating that the outbreak had already spread in the community. Because of this, the Xinfadi outbreak had the most infections, the widest spread and the highest social effect among the four outbreaks. The index cases in the Shunyi and Daxing outbreaks were discovered during nucleic acid tests of key populations, whereas the index case in the Ejina Banner-associated outbreak proactively reported to the CDC as having come into contact with a confirmed case. Because of this, these outbreaks did not lead to a large-scale spread of the pandemic. In future outbreaks, nucleic acid testing and voluntary reporting by key populations could enable the detection of infected individuals in a timely manner. These measures may enable the early detection and isolation of infected individuals when the local spread of the virus has been controlled, but the risk of imported cases persists. In the normalization stage of pandemic prevention and control, prevention and control measures at the social level gradually improved, the public's subjective initiative and awareness of epidemic prevention and control gradually increased, and the positive rate for close contacts gradually decreased. The positive rate for close contacts in the Ejina Banner-associated outbreak was only 0.49%.

Hospitals and quarantine sites are high-risk areas for cross-infection, so medical staff members and workers at quarantine sites are key groups with high exposure risks. In December 2021, at least five quarantine-site infections occurred in China, including in Jiangsu, Sichuan, Fujian, and Shaanxi provinces. Strict implementation of nosocomial infection prevention and control measures and quarantine-sites management is an essential and effective means of preventing nosocomial and cross-infection. Management of quarantine sites in Beijing is relatively standardized; various prevention and control measures are implemented, and the health monitoring of staff at quarantine-sites is relatively strict. Therefore, no infection was reported among the medical staff or other staff in the centralized quarantine sites during the four outbreaks in Beijing.

In addition, the release of information regarding the state of the pandemic in Beijing was timely. In the initial stages of an outbreak, people can easily become nervous or frightened due to the consistent reports of confirmed and nucleic acid test positive cases. Only by fully protecting the public's right to know and meeting the public's information needs can the government win the trust of the people, gather consensus and enhance confidence. Therefore, timely release of authoritative and accurate information and response to social concerns is an important force to stabilize people's hearts and smooth social operation. It can eliminate people's panic and reduce the spread of rumors.

The four outbreaks in Beijing released authoritative information within 5 hours of the discovery of the index cases, held a press conference within 24 hours, and released official information every day during the epidemic period.

At the time of the Xinfadi outbreak, the permanent population of Fengtai District was approximately 2.01 million, and the maximum daily nucleic acid testing capacity of Beijing was more than 230,000 samples. Therefore, all nucleic acid testing in Fengtai District could be completed within nine days. At the time of Shunyi and the Daxing outbreaks, the maximum daily nucleic acid testing capacity of Beijing had increased to 746,000 samples. In Shunyi District, with a permanent population of 1.32 million, nucleic acid testing was estimated to have been completable within two days. In Daxing District, with a permanent population of 1.84 million, testing was estimated to have been completable within three days. The Ejina Banner-associated outbreak, which occurred on October 19, 2021, mainly affected Changping District, which has a permanent population of approximately 2.17 million. At that time, the maximum nucleic acid testing capacity of Beijing had increased to 1.563 million samples per day. Therefore, all nucleic acid testing for the district was estimated to be completable within 2 days. The decline in the number of days required to complete all nucleic acid tests in the districts of Beijing reflects its improved nucleic acid testing capacity.

The main characteristics of the cluster outbreaks that occurred in Beijing during the normalization prevention and control stage are as follows: (1) the main modes of index case detection were active monitoring, detection and screening of key populations and fever outpatient reports; (2) some containers and imported cold-chain products were contaminated with SARS-Cov-2, which led to transmission through high-risk individuals, such as cold-chain workers, becoming infected; (3) the outbreaks were effectively controlled within 1-2 incubation periods; and
(4) multiple transmission chains caused by multiple sources appeared in various places, and multiple factors increased the difficulty of controlling the outbreaks and tracing their sources [7].

5. Strengths and limitations

Using a COVID-19 cluster containment evaluation system, we evaluated the prevention and control effects of four outbreaks in Beijing, which may enable the identification of inadequacies in epidemic prevention and control measures and the implementation of more effective epidemic prevention and control measures in the future. Using data released by the National Health Commission, the Beijing Municipal Health Commission and the press, we evaluated the prevention and control effects of the four outbreaks in Beijing. However, our study has some limitations. The dimensions, parameters, and results of evaluations of prevention and control effects may become more comprehensive with the future optimization of evaluation systems, improvement of data collection, and investigation of emerging mutations.

6. Conclusion

Leading up to its epidemic prevention and control entering the “dynamic COVID-zero” phase of whole-chain precise prevention and control, Beijing effectively controlled the outbreak and spread of the epidemic. The trend in new cases began to consolidate. In managing cluster outbreaks, Beijing was able to detect index cases early enough to reduce the scale and duration of the outbreak and consistently release official information to reduce panic, standardize the management of centralized quarantine sites to prevent cross-infection, adhere to the “dynamic COVID-zero” strategy to accurately prevent and control outbreak, reduce the societal influence of the pandemic, and coordinate the epidemic prevention and control and socio-economic development.

Author contributions

Yu Wu searched the literature, designed the study, collected the data, analyzed the data, interpreted the results, and drafted the article. Jue Liu supervised the study and revised the article. Min Liu conceived the study, designed the study, supervised the study, interpreted the results, and revised the article.

Declaration of competing interest

The authors declare that they have no conflicts of interest in this work.

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Supplementary materials

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