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Fangcang shelter hospitals are a One Health approach for responding to the COVID-19 outbreak in Wuhan, China

In February 2020, the exponential growth of COVID-19 cases in Wuhan city posed a huge economic burden to local medical systems. Consequently, Wuhan established Fangcang Shelter hospitals as a One Health approach for responding to and containing the COVID-19 outbreak by isolating and caring for mild-to-moderate cases. However, it is unclear to what degree the hospitals contained COVID-19. This study performed an interrupted time series analysis to compare the number of new confirmed cases of COVID-19 before and after the operation of Fangcang Shelter hospitals. The initial number of confirmed cases in Wuhan increased significantly by 68.54 cases per day prior to February 4, 2020. Compared with the number of cases noted 20 days before the use of Fangcang Shelter hospitals, a sustained reduction in the number of confirmed cases (trend change, $-125.57$; $P < 0.0001$) was noted 41 days after the use of the hospitals. Immediate-level changes were observed for confirmed cases (level change, $725.97$; $P = 0.025$). These changes led to an estimated 5148 fewer confirmed cases ($P < 0.0001$). According to the mean confirmed cases of 395.71 per day before the intervention, we estimated that Wuhan had advanced the terminal phase of COVID-19 by 13 days. Furthermore, immediately after introduction of Fangcang Shelter Hospitals on February 5, the reproduction number dropped rapidly, from a pre-introduction rate of 4.0 to 2.0. The Fangcang Shelter hospitals most likely reversed the epidemic trend of COVID-19 while a containment strategy was implemented in Wuhan. In a One Health perspective, Fangcang Shelter hospitals, with their functions of isolation and treatment of confirmed COVID-19 patients, engaging professionals from many disciplines, such as medicine, engineering, architecture, psychology, environmental health, and social sciences. The results of this study provide a valuable reference for health policy makers in other countries.

1. Introduction

In December 2019, coronavirus disease 2019 (COVID-19), which was caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was reported in Wuhan, Hubei Province, China [1,2]. The emerging disease broke out in Wuhan and quickly spread to other provinces. As of September 4, 2020, China had 89,963 confirmed cases of COVID-19 in 31 provinces (autonomous regions and municipalities directly under the central government) [3].

SARS-CoV-2 belongs to the subfamily Coronavirinae, a taxon that includes other agents of disease such as the Severe Acute Respiratory Syndrome (SARS) in 2003 and the Middle East Respiratory Syndrome (MERS) in 2003 and the Middle East Respiratory Syndrome...
for COVID-19 in Wuhan was implemented from January 24, 2020 to
2.1. Materials and methods
series analysis.
trials, this study aimed to evaluate the effects of Fangcang Shelter hos-
containment strategy in China have not yet been well evaluated.
the control of the COVID-19 outbreak during the implementation of the
iciency 
[38x206]sions and convention and exhibition centres located in Wuchang,
symptoms, while designated hospitals were used to treat COVID-19
cases with mild-to-moderate symptoms. With this perspective, Fangcang Shelter hos-
Fangcang Shelter hospitals with a total of 12,365 beds. As of March 10,
Jiangnan, Hongshan and Dongxihu districts were transformed into
facilities have complete medical functions and can carry out basic
medicines, training centres, industrial park factories, vocational high
schools and other venues into special quarantine facilities for patients
with clinically mild-to-moderate symptoms of COVID-19 infection.
Named Fangcang Shelter hospitals, these temporary quarantine hospital
facilities have complete medical functions and can carry out basic
medical treatment, disease monitoring, diagnosis and other clinical
tasks. They also have a team of psychologists to provide counselling
services to patients. Fangcang Shelter hospitals were established to
reduce patient density in traditional hospitals, expand treatment ca-
pacity and control the community spread of the virus.

In February 2020, to stop the spread of COVID-19, Wuhan con-
verted several gymnasiums, convention and exhibition centres, sports
centres, training centres, industrial park factories, vocational high
schools and other venues into special quarantine facilities for patients
with clinically mild-to-moderate symptoms of COVID-19 infection.
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In the early stages of the epidemic, a serious shortage of medical
resources and hospital beds for admitted confirmed patients led to
a large number of confirmed patients unable to receive timely isolation
and treatment in time, which aggravated cross-infection in the com-
community and the spread of SARS-CoV-2 [14]. Understandably, the early
isolation and treatment of confirmed COVID-19 patients were of utmost
importance. To minimise the impact of this rapidly spreading virus, on
February 3, 2020, Wuhan decided to separate and treat patients on the
basis of their condition. With this perspective, Fangcang Shelter hos-
pitals were used to treat COVID-19 cases with mild-to-moderate
symptoms, while designated hospitals were used to treat COVID-19
cases with severe and critical conditions [15,16]. In total, 14 gymna-
siums and convention and exhibition centres located in Wuchang,
Jiangnan, Hongshan and Dongxihu districts were transformed into
Fangcang Shelter hospitals with a total of 12,365 beds. As of March 10,
2020, approximately 12,000 patients with mild COVID-19 have been
admitted to Fangcang Shelter hospitals in Wuhan, China. In a One
Health perspective, the isolation and treatment of confirmed COVID-19
patients implemented in Fangcang Shelter hospitals engaged profes-
sionals from many disciplines, such as medicine, engineering, archi-
tecture, psychology, environmental health, and social sciences.

Theoretically, COVID-19 cases should be admitted to Fangcang
Shelter hospitals over a short period of time, which should sufficient to
control infection sources and treat patients at low cost but high effi-
ciency [17,18]. However, the effects of Fangcang Shelter hospitals on
the control of the COVID-19 outbreak during the implementation of the
containment strategy in China have not yet been well evaluated.
Therefore, to provide a reference for COVID-19 control in other coun-
tries, this study aimed to evaluate the effects of Fangcang Shelter hos-
pitals on the epidemic trend of COVID-19 by using an interrupted time
series analysis.

2. Methods

2.1. Materials and methods

Wuhan, the capital city of Hubei Province and the traffic hub of
central China, has a population of 9,083,500. The containment strategy
for COVID-19 in Wuhan was implemented from January 24, 2020 to
March 16, 2020 and did not change except for the use of Fangcang
Shelter hospitals on February 5, 2020.

3. Fangcang shelter hospitals

The Fangcang Shelter hospitals operated in Wuhan were designed
according to the cabins used to carry out emergency medical care after
the Wenchuan earthquake in 2008 and the Yushu earthquake in 2010
[19]. These hospitals serve as temporary quarantine hospital facilities.

Fangcang Shelter hospitals are temporary quarantine houses with
healthcare facilities that take the Fangcang cabin as the carrier and
integrate medical treatment and clinical technology functions [15,20].
Composed of medical treatment units, ward units and technical support
units, Fangcang Shelter hospitals are mainly used in major disaster
rescue, emergency support, interim medical services and other tasks
[15,19]. With features such as good mobility, fast deployment and
strong environmental adaptability, these improvised facilities are cap-
able of undertaking emergency medical rescue tasks and are therefore
valued by many countries [20].

In February 2020, to stop the spread of COVID-19, Wuhan con-
verted several gymnasiums, convention and exhibition centres, sports
centres, training centres, industrial park factories, vocational high
schools and other venues into special quarantine facilities for patients
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reduce patient density in traditional hospitals, expand treatment ca-
pacity and control the community spread of the virus.

4. Datasets

The time series of observations of confirmed COVID-19 cases from
January 16, 2020 to March 16, 2020 was obtained from the websites of
the Bureau of Health (http://www.nhc.gov.cn/) and the Chinese Center
for Disease Control and Prevention (http://2019ncov.chinacdc.cn/
2019-nCoV/). The information collected included the number of con-
firmed cases in Wuhan, China.

Suspected cases were defined as people who had any of the epide-
miological history criteria plus any two clinical manifestations or had
all three clinical manifestations if there is no clear epidemiological
history [21].

History of epidemiology:

1. History of travel to or residence in Wuhan and its surrounding areas,
   travel to other communities in China where cases have been re-
   ported or travel to other countries/regions with severe outbreaks
   outside China within 14 days prior to the onset of the disease.
2. Contact with an individual infected with SARS-CoV-2 (who tested
   positive with a nucleic acid test) within 14 days prior to the onset of
   the disease.
3. Contact with patients with fever or respiratory symptoms from
   Wuhan, its surrounding areas, communities where confirmed
   COVID-19 cases have been reported or other countries/regions with
   severe outbreaks outside China within 14 days before the onset of
   the disease.
4. Clustered cases (two or more cases with fever and/or respiratory
   symptoms in a small area, such as in families, offices, schools,
   workplaces and other gatherings within 14 days).

Clinical manifestations:

1. Fever and/or respiratory symptoms.
2. Radiographic imaging consistent with COVID-19 pneumonia.
3. Normal or decreased White Blood Cell (WBC) count, or normal or decreased lymphocyte count in the early stages of illness.

A confirmed case was defined as a suspected case with one of the following etiological or serological pieces of evidence [21]:

1. Real-time fluorescent reverse transcription polymerase chain reaction positive result for SARS-CoV-2 nucleic acid.
2. Viral genetic sequence that is highly homologous to SARS-CoV-2.
3. 2019-nCoV virus-specific IgM and IgG detectable in serum, detectable SARS-CoV-2 virus-specific IgG or a fourfold increase in IgG between paired acute and convalescent sera.

Asymptomatic individuals were defined as those with etiological detection of SARS-CoV-2 in respiratory specimens or specific IgM detected in serum.

4.1. Statistical analysis

In our study, intervention was defined as the use of Fangcang Shelter hospitals. The effect of the intervention on new confirmed cases was analysed using interrupted time series analysis of the data collected between January 16, 2020 and February 4, 2020 as the pre-intervention and between February 5, 2020 and March 16, 2020 as the post-intervention. The intervention led to a level or slope change that could be explained by the interrupted time series analysis. In this study, the model of interrupted time series analysis was calculated using the following formula [22,23]:

\[ Y_t = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \]

where \( Y_t \) represents the outcome variable over time point \( t \), \( x_1 \) represents the elapsed time since the start of the study, \( x_2 \) is a dummy variable representing the intervention period (pre-intervention period = 0, post-intervention period = 1) and \( x_3 \) indicates an interaction term. \( \beta_0 \) is the baseline level of the outcome variable, \( \beta_1 \) indicates the slope of the outcome variable before the intervention, \( \beta_2 \) represents the immediate-level change following the intervention and \( \beta_3 \) indicates the slope change following the intervention.

The interrupted time series analysis was carried out using Stata 16 (StataCorp, College Station, TX, USA). Interrupted time series analysis was achieved by linear regression with Newey–West standard errors with a maximum lag of 1, which was then considered in the autocorrelation structure or the linear regressions with Prais using the generalised least-squares method to estimate the parameters. Errors were assumed to follow a first-order autoregressive process. All tests were two-sided, and a \( P \) value less than 0.05 was considered statistically significant.

The real-time reproduction number \( R(t) \) was the expected number of secondary cases that each infected individual would infect if the conditions remained as they were at time \( t \). A Bayesian statistical framework was used to calculate \( R(t) \) based on the number of COVID-19 cases, the number of secondary cases, the serial interval and the five-day moving average [7,10,24]. \( R(t) \) and its 95% credible interval (CI) for the whole period were calculated using R version 3.6.2.

5. Results

The number of new confirmed cases in Wuhan gradually increased to 3910 cases on February 13 and then slowly decreased (Fig. 1). In the first nine days after the implementation of Fangcang Shelter hospitals, the temporal number of confirmed cases significantly increased in Wuhan. On March 16, approximately 54 days from the start of the implementation of containment strategies, the terminal phase of COVID-19 was declared in Wuhan.

As shown in Fig. 2 and Table 1, the initial number of confirmed cases in Wuhan increased significantly by 68.54 cases per day between January 16, 2020 and February 4, 2020 as the pre-intervention period. After the intervention at February 5, 2020, the number of new confirmed cases per day decreased annually in confirmed cases by 57.02 cases per day decreased annually in confirmed cases by 57.02 cases per day decreased annually in confirmed cases by 57.02 cases per day decreased annually in confirmed cases by 57.02 cases per day decreased annually in confirmed cases by 57.02 cases per day.

The mean real-time effective production number \( R(t) \) had the highest value at 7.45 (95%CI, 6.71–8.22) on January 19, 2020 and then decreased to 2.23 (95%CI, 2.18–2.28) on February 5, 2020. After the implementation of Fangcang Shelter hospitals, the terminal phase of COVID-19 was advanced in Wuhan by 13 days.

\[ \text{Numbers of new confirmed cases over time in Wuhan, China.} \]

| Time (day) | Number of cases |
|------------|-----------------|
| Jan 16     | 2894            |
| Jan 17     | 2982            |
| Jan 18     | 3070            |
| Jan 19     | 3158            |
| Jan 20     | 3246            |
| Jan 21     | 3334            |
| Jan 22     | 3422            |
| Jan 23     | 3510            |
| Jan 24     | 3608            |
| Jan 25     | 3706            |
| Jan 26     | 3804            |
| Jan 27     | 3902            |
| Jan 28     | 4000            |
| Jan 29     | 4108            |
| Jan 30     | 4206            |
| Jan 31     | 4304            |
| Feb 1      | 4402            |
| Feb 2      | 4500            |
| Feb 3      | 4608            |
| Feb 4      | 4706            |
| Feb 5      | 4804            |
| Feb 6      | 4902            |
| Feb 7      | 5000            |
| Feb 8      | 5108            |
| Feb 9      | 5206            |
| Feb 10     | 5304            |
| Feb 11     | 5402            |
| Feb 12     | 5500            |
| Feb 13     | 5608            |
| Feb 14     | 5706            |
| Feb 15     | 5804            |
| Feb 16     | 5902            |
| Feb 17     | 6000            |
| Feb 18     | 6108            |
| Feb 19     | 6206            |
| Feb 20     | 6304            |
| Feb 21     | 6402            |
| Feb 22     | 6500            |
| Feb 23     | 6608            |
| Feb 24     | 6706            |
| Feb 25     | 6804            |
| Feb 26     | 6902            |
| Feb 27     | 7000            |
| Feb 28     | 7108            |
| Feb 29     | 7206            |
| Feb 30     | 7304            |
| Mar 1      | 7402            |
| Mar 2      | 7500            |
| Mar 3      | 7608            |
| Mar 4      | 7706            |
| Mar 5      | 7804            |
| Mar 6      | 7902            |
| Mar 7      | 8000            |
| Mar 8      | 8108            |
| Mar 9      | 8206            |
| Mar 10     | 8304            |
| Mar 11     | 8402            |
| Mar 12     | 8500            |
| Mar 13     | 8608            |
| Mar 14     | 8706            |
| Mar 15     | 8804            |
| Mar 16     | 8902            |

\[ \text{Number of confirmed cases from January 16, 2020 to March 16, 2020 in Wuhan. The vertical dashed line indicates the time of the operation of Fangcang Shelter hospitals.} \]

| Table 1 | Interrupted time-series analysis of confirmed cases in Wuhan, China. a |
|---------|-----------------------------------------------------------------------|
| Pre-interventional trend | 68.54 | 4.28 | < 0.0001 | 36.42 | 100.67 |
| Level change | 725.97 | 2.30 | 0.025 | 93.34 | 1358.59 |
| Post-interventional trend | –125.57 | –7.21 | < 0.0001 | –160.44 | –90.69 |
| Treated | –289.73 | –2.11 | 0.039 | –564.09 | –15.36 |

a Regression with Newey-West standard errors.

b Postintervention Linear Trend.
February 6, 2020, R(t) was less than 2 and gradually decreased to less than 1 on February 15, 2020 (Fig. 3).

6. Discussion

Given the range of basic reproduction number of SARS-CoV-2, which lies between 1.50 and 6.68, person-to-person transmission of the disease can occur through respiratory droplets and close contact [6,24]. To reduce the risk of transmission and infection and the social impact of the epidemic, a containment strategy was implemented in Hubei Province, China. A containment strategy involves the use of medical and non-medical (lockdown, closures, suspensions, closures, etc.) intervention strategies and measures within a limited geographical area in the early stages of an emerging infectious disease epidemic [13]. Fangcang Shelter hospitals were a One Health approach for responding to the COVID-19 outbreak in Wuhan, China, and provided isolation, triage, basic medical care, frequent monitoring, rapid referral and essential living and social engagement for mild-to-moderate COVID-19 patients [15]. Although R(t) fluctuated from 2.00 to 7.45 in the pre-operation periods of Fangcang Shelter hospitals, it decreased gradually to less than 1 along with the implementation of the hospitals. This shift might be due to the use of Fangcang Shelter hospitals to control the infection sources of COVID-19.

In this study, we estimated the immediate and sustained change in the number of confirmed cases of COVID-19 over the pre- and post-operation periods of Fangcang Shelter hospitals in Wuhan. A sustained reduction and immediate increase in the number of cases were observed in Wuhan city after the Fangcang Shelter hospitals were established. These changes resulted in an estimated 5148 fewer confirmed cases in Wuhan. In this study, an initial evaluation of the effects of Fangcang Shelter hospitals on the control of COVID-19 was conducted using an interrupted time series analysis. According to the mean confirmed cases of 395.71 per day before the intervention, we estimated that Wuhan had advanced the terminal phase of COVID-19 by 13 days.

Among COVID-19 cases, 80% are mild, 20% may develop severe cases and a small percentage (5%) may become critically ill [25,26]. The exponential growth of COVID-19 cases in Wuhan posed a huge economic burden to local medical systems. If all COVID-19 cases were cared for in designated hospitals, then the shortage of medical resources would have collapsed the medical system in China. From a One Health perspective, China needed a novel approach to control the COVID-19 outbreak in Wuhan. The Fangcang Shelter hospitals rapidly established by converting low-cost stadiums and exhibition centres to isolate and care for COVID-19 cases with mild-to-moderate symptoms avoided the costly construction of new traditional hospitals for the admission and treatment of COVID-19 cases. Once the epidemic has been curbed, these public buildings can be restored to their original use, and the long-term and inefficient use of space is avoided. Compared to traditional hospitals, the Fangcang Shelter hospitals, with their centralised treatment of COVID-19 cases with mild-to-moderate symptoms, also required fewer doctors and nurses [27]. A key role of disease monitoring provided by Fangcang Shelter hospitals was to ensure that patients were timely transferred to designated hospitals if their conditions worsen. The hospitals also helped ensure that scarce medical resources, such as in-patient units providing respiratory support and intensive care centralised and supplied only in designated hospitals, could meet the demands of caring for severely ill patients and thus avoid wastage of medical resources.

Isolating COVID-19 cases is one of the most important measures of prevention and control strategies for COVID-19. It is almost impossible for COVID-19 cases to stay at home without having any close contact with their family members and other people in the community. Compared to isolation in Fangcang Shelter hospitals, home isolation is likely to lead to a rapid increase in the number of second- and third-generation cases and some community and family clustering of COVID-19 [28]. The sharply increasing number of COVID-19 may arouse much fear in the community and even be a direct challenge to the prevention and control strategies for COVID-19. In a One Health perspective, the Fangcang Shelter hospitals are more a community of patients than they are medical institutions; besides basic medical care, they provide shelter, accommodation, food, sanitation, hygiene and social engagement for individuals with COVID-19 [15]. In Fangcang Shelter hospitals, patients’ recovery could be promoted and the anxiety from a COVID-19 diagnosis and isolation could be alleviated by the patients supporting one another and engaging in social activities. Of note, community activities such as eating together, reading, dancing, watching television and celebrating birthdays, all of which were supplied in Fangcang Shelter hospitals, may alleviate the anxiety from a COVID-19 diagnosis and isolation to some degree [29,30]. In addition, the involvement of psychiatrists makes it convenient for COVID-19 cases to obtain emotional support.

In the early period of the COVID-19 outbreak in Wuhan, many hospitals were not prepared for the tremendous treatment needs of patients. On February 5, 2020, the number of confirmed patients gradually decreased in Wuhan after the operation of Fangcang Shelter hospitals [15]. These findings suggest that the increased number of beds used in Fangcang Shelter hospitals may be beneficial for undiagnosed patients in the early stage of the disease. The linear fitting model also demonstrated that the downward trend of new confirmed cases in Wuhan after the operation of Fangcang Shelter hospitals is statistically significant. This change in trend reveals that the use of Fangcang Shelter hospitals played a crucial role in the control of COVID-19.

At present, the COVID-19 outbreak is sweeping through Italy (272,912 confirmed cases with 35,507 deaths), Spain (488,513 confirmed cases with 29,234 deaths), the USA (6,148,875 confirmed cases with 186,754 deaths) and Brazil (4,041,638 confirmed cases with 124,614 deaths) [3]. These countries are facing an exponential increase in the number of COVID-19 cases because of community outbreaks and the massive shortage of medical resources, both of which appeared in the early stage of the COVID-19 epidemic in Wuhan. However, approximately 41 days from the first use of Fangcang Shelter hospitals to March 16, the terminal phase of COVID-19 was declared in Wuhan. In China, most provinces outside of Hubei reported confirmed cases that were mostly imported cases from Wuhan, which spent about 30 days ending the COVID-19 epidemic. Therefore, besides a containment strategy, Fangcang Shelter hospitals are an available option to control
the disease spread for countries with local epidemics.

This study presents several limitations. First, considering the lack of a randomised control in other areas that did not implement Fangcang Shelter hospitals, we could not estimate the parallel reduction in the number of patients and days in these areas before the end of the epidemic. However, from the macroscopic view, we estimate that the number of patients will decrease after the use of Fangcang Shelter hospitals during the implementation of the containment strategy in Wuhan. Second, in the early stage of the epidemic, the difference between the reported and real data could have influenced the parameter estimations in the models. The effects of Fangcang Shelter hospitals on preventing the spread of COVID-19 was only observed in Wuhan, although the containment strategy alone also resulted in dramatic reductions in COVID-19 cases in other provinces. Finally, considering the lack of data on suspected cases in Wuhan, estimating the effects of the Fangcang Shelter hospitals on limiting the number of suspected cases was not possible.

Fangcang Shelter hospitals are a One Health approach for responding to the COVID-19 outbreak in Wuhan, China, and have basic functions such as isolation, triage, medical care, disease monitoring and referral. In a One Health perspective, the Fangcang Shelter hospitals are more a community of patients than they are medical institutions, providing shelter, accommodation, food, sanitation, hygiene and social engagement for individuals with COVID-19. Interrupted time series analysis revealed that Fangcang Shelter hospitals were likely to reverse the epidemic trend of COVID-19 while the containment strategy was implemented in Wuhan. Therefore, these hospitals could be a key component of national responses to future epidemics and public health emergencies. The results of this study provide a valuable reference for health policy makers in countries where the COVID-19 outbreak has also spread.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

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Author statement

YC had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. KW, JG, FC, YC conceived the study. KW, XS, HW, XZ, DH, QY, XX, and JH, FC designed the model, and JL made the figures. XL, and YC wrote the first draft of the manuscript. All authors interpreted the results, and approved the final version for submission.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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