

Economic Burden of Public Health Care Was Higher Than That of Hospitalization and Treatment Associated With COVID-19 in China

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Abstract

Background: During the coronavirus disease 2019 (COVID-19) pandemic, it is essential to evaluate the socioeconomic burden imposed on the Chinese health care system.

Methods: We prospectively collected information from the Center for Disease Control and Prevention and the designated hospitals to determine the cost of public health care and hospitalization due to COVID-19. We estimated the resource use and direct medical costs per confirmed case and the costs associated with public health care per thousand people at the national level.

Results: The average costs per case for specimen collection and nucleic acid testing (NAT) were \$29.49 and \$53.44, respectively, while the average cost of NAT for high-risk populations was \$297.94 per capita. The average costs per thousand people for epidemiological surveys, disinfectant, health education and centralized isolation were \$49.54, \$247.01, \$90.22 and \$543.72, respectively. A single hospitalization for COVID-19 in China cost an average of \$3,792.69 (\$2,754.82-\$5,393.76) in direct medical costs incurred only during hospitalization, while the total costs associated with hospitalization were estimated to have reached nearly \$31,229.39 million in China as of 20 May 2020. The cost of public health care (\$6.81 billion) was 20 times that of hospitalization.

Conclusions: This study highlights the magnitude of resources needed to control the COVID-19 pandemic and treat COVID-19 cases. Public health measures implemented by the Chinese government have been valuable with regard to reducing the infection rate and may be cost-effective ways to control emerging infectious diseases.

Background

During the coronavirus disease 2019 (COVID-19) pandemic, there has been a substantial impact on the global healthcare and medical systems. By June 9, 2020, a total of 7,085,894 cases had been confirmed worldwide, and 405,168 deaths had been reported; the case fatality rate of COVID-19 (5.70%) is gradually approaching that of severe acute respiratory syndrome (SARS) (9.6%)^{1,2}. As of May 20, 2020, there were 82,967 confirmed cases, 740,967 close contacts and 4,634 deaths in China³. Faced with an enormous number of cases in a short time, the government, health care professionals, and health care systems have voiced concern that the demand will exceed the existing capacity, and they have requested the urgent provision of additional resources and financial support. An effective method of mitigating the impact of the pandemic on the health care system is to reduce the percentage of the population who become infected by implementing preventive measures mediated by public health officials^{4,5}. Therefore, the government, the health care system and the medical insurance system should consider providing sufficient public health resources and hospital accommodations to quickly curb the spread of COVID-19.

The COVID-19 pandemic was brought under control in China within a relatively short period; therefore, it is useful to evaluate the costs of public health measures and hospitalization due to COVID-19 in China. Such information is critical for efficiently developing strategies to mitigate the impacts of potential

outbreaks of new infectious diseases in the future. However, limited studies have reported the costs of emerging infectious diseases: Sarah M Bartsch et al.⁶ used a mathematical model to quantify the cost of Ebola virus disease (EVD) from the perspectives of providers and society in Guinea, Liberia, and Sierra Leone, and two studies^{7,8} developed computational models to forecast the potential economic burden and the cost-effectiveness of measures addressing Zika in the US. In addition, Sarah M. Bartsch et al.⁹ Developed a computational model to estimate the potential resource use and direct medical costs of COVID-19 in the US under various conditions. Previous cost studies primarily used a proxy disease to obtain estimates of the clinical costs of an emerging infectious disease and used a mathematical model to forecast the medical costs associated with the target infectious disease; these studies have lacked a clear scientific source of the estimated costs.¹⁰ A few studies have estimated health care utilization and costs using structured interview methods, but a review of the literature reveals no such studies determining the costs of both public health and hospitalization associated with COVID-19. In this study, we investigated the actual expenses associated with public health care resources and hospitalization and used those expenses to estimate the cost of addressing COVID-19 in China.

Methods

Data sources pertaining to the COVID-19 epidemic in China

Data regarding COVID-19 used in the current study were obtained from the official website of the National Health Commission of the People's Republic of China from January 20, 2020, to May 20, 2020. The epidemiological data included the daily numbers of total confirmed cases, suspected cases, close contacts, people under medical observation, inpatient cases, severe cases, deaths and discharged cases.

The Institutional Review Board at the Children's Hospital of Chongqing Medical University gave its approval for the study.

Definition of medical cost

The medical cost associated with COVID-19 is composed of the costs of public health care and treatment during hospitalization. The assessed items pertaining to public health care were NAT, epidemiological surveys, centralized quarantine, disinfection and health education. The cost associated with public health care had two dimensions, namely, financing resources (protective equipment, medical materials, medical equipment and ambulances) and human resources (medical staff participating in the prevention of COVID-19). The hospitalization costs include the direct cost of acute hospitalization according to the discharge settlement amount.

Data collection for medical costs

Data on medical costs related to the treatment of COVID-19 were collected using a micro-cost survey approach. The survey was administered to 1 Center for Disease Control and Prevention (CDC), 7 secondary or tertiary medical institutions, 15 community health centers and 10 township hospitals or

temporary medical institutions in Jiulongpo District, which includes 8 subdistricts and 11 towns (in the countryside) with 1.2 million permanent residents.

Medical cost data were collected by conducting a series of key information interviews at the CDC and designated medical institutions. Quantitative cost questionnaires were used to collect expense information about public health care, including medical materials and human resources. The questionnaire for the cost of NAT contained detailed information on the type of case (close contacts, suspected cases, confirmed cases, cases from abroad, etc.), frequency and date of sample collection, sample type (nasopharyngeal swab, throat swab, anal swab and serum specimen, etc.), medical institution to which the specimens were transported, ID numbers, time the NAT was performed, NAT results, the institution performing the NAT, the source of cases (Wuhan, abroad and other) and other related information. A flow chart for NAT (Supplementary Fig. 1) was created according to the guidelines for COVID-19 in the high-risk population, including items for different stages of the diagnosis and management of COVID-19. Moreover, the prices of medical materials (charge per item), human resources and protective equipment were collected from the CDC and designated hospitals. The cost of NAT was collected from January 21, 2020, to April 24, 2020, and the test number in person-times was 18,856, which included 13,645 people who participated in NAT.

The cost of epidemiological surveys included costs associated with the investigation of confirmed cases, close contacts of confirmed cases and suspected cases, centralized isolated cases and fever-clinic patients through follow-up in the homes of cases, going to the hospital or centralized isolation locations, or making telephone calls. The epidemiological survey questionnaire included the type of case, number of cases per day, survey points (household survey, centralized isolation locations or other special institutions), number of medical staff administering the survey and analyzing the data, duration of the survey and data analysis, and use of emergency vehicles and other human resources. The costs related to epidemiological surveys were collected from January 21, 2020, to May 10, 2020, during which time 3629 high-risk individuals (those with confirmed cases, close contacts of people with confirmed cases and people who stayed at isolated points) and people working in public places.

The public health care costs associated with disinfection during the epidemic were investigated by the CDC, which was responsible for distributing disinfection supplies throughout the region. The questionnaire regarding disinfection included the name, amount and price of disinfection items; the date of distribution; and the disinfection machines. Moreover, the cost of performing the disinfection (in the home and work environments of patients with diagnosed cases and preventive disinfection procedures) was collected. The costs of all disinfection materials used from January 21, 2020, to April 29, 2020 were collected.

The cost of health education about COVID-19 was investigated using a quantitative questionnaire. Cost information was collected, including the costs related to health education activities (making the publicity plan, printing the publicity materials, making informational popular science videos about COVID-19, disseminating popular science information about the COVID-19 epidemic via WeChat), the quantity and

price of printed publicity materials (promotional foldouts, promotional posters, health education guidelines, stickers reminding the public to practice social distancing), and the human resources with regard to the number of staff members participating in health education and the number of hours they spent engaged in such work (time logs).

The hospitalization costs were collected from a designated hospital that received cases from 9 counties in Chongqing. The costs of hospitalization included drug fees, medical examination fees, clinical laboratory fees, consultation fees, treatment fees, nursing fees, bed fees, medical supply fees, other hospitalization fees, basic medical fees, Chinese patented medicine fees, surgery fees, Chinese herbal medicine fees and total medical expenses. The medical expense payment methods were also collected. The government paid the fees that otherwise would have been paid by the patients. Hospitalization costs were collected from January 21, 2020, to May 20, 2020.

Method of cost calculation

Calculating the cost of public health care pertaining to COVID-19

The flow chart of the calculation of the cost of COVID-19 in China is displayed in Fig. 1. Based on the NAT workflow model (Supplementary Table 1), the cost of NAT was the sum of the cost of obtaining samples and the cost of performing NAT in different medical institutes. The cost of performing NAT on 18,856 samples was calculated, which included 4,267 samples collected by the CDC, 9,547 samples collected by the 7 secondary or tertiary medical institutions, 4,850 samples collected by the 15 community health care centers and 192 samples collected by the 10 township hospitals or temporary participating institutions. First, the total human resources and the medical material costs associated with obtaining the samples were calculated and analyzed based on the work logs. Human resources involved the medical staff (collecting and delivering samples), community police and ambulance drivers, and only the subsidy salary paid during the COVID-19 pandemic was included. The medical materials included the ambulances, reagents and personal protective equipment (PPE), and the total cost of the medical materials was calculated based on the actual amount of equipment used. Then, the average cost of testing a sample in different medical institutes was calculated. Second, the costs of NAT for different types of populations were calculated, and the people who underwent NAT belonged to either a low-risk population (people from medical institutes, the floating population and workers in public places) or a high-risk population (close contacts, patients with suspected cases, patients with confirmed cases and SARS-CoV-2 virus carriers). Detection times per capita in different medical institutes were also calculated based on the frequency of NAT and the number of people undergoing NAT. The price of NAT was \$40.18, and the average NAT cost per capita was calculated using detection times per capita multiplied by price. Third, the cost of the NAT of patients with suspected cases and confirmed cases was calculated based on the guidelines for COVID-19, which contain different requirements for testing during the observation period, the treatment period and the post-discharge period.

The cost of the epidemiological survey for COVID-19 mainly included costs associated with human resources, ambulance costs and PPE. First, the cost of the epidemiological survey was calculated by the type of case, and the human resources and PPE costs were added based on the work logs. Second, the total cost of the epidemiological survey and the average cost per thousand people were calculated and used to estimate the overall cost in China.

The costs of disinfection materials and PPE (Supplementary Table 1) in the surveyed county were calculated using the distribution records (amount and price) of the CDC, which distributed preventive materials uniformly throughout the county. The human resources needed to perform the disinfection were assessed as the number of participating staff. The health education costs included the costs associated with the human resources and materials. Finally, the average cost of the disinfection materials and equipment, PPE and health education per thousand people was calculated, which was used to estimate the total cost of coping with the COVID-19 pandemic in China.

Calculating the cost of hospitalization

The cost of hospitalization was calculated using the costs assessed at discharge, and the mean costs for 220 patients were analyzed for 6 situations. Moreover, all hospitalization costs were classified and compared according to the use of the negative-pressure isolation ward (NPIW), the use of noninvasive ventilation, the use of the intensive care unit (ICU), whether the patients had severe and critical COVID-19, the times of hospitalization and whether the cases involved local transmission or were imported from abroad.

Calculating the total cost of public health and hospitalization

The hospitalization costs associated with confirmed cases were calculated using the epidemiological data on confirmed cases through May 20, 2020, and the average hospitalization costs of 220 cases from 9 districts in Chongqing; the costs of subgroups stratified by resources used and disease severity were also analyzed. The number of permanent residents in China in 2018 (1.4 billion) and the average cost associated with public health care per thousand people were used to calculate the total public health care costs. Finally, the total cost was calculated by summing the hospitalization and public health care costs.

Statistical analysis

The Wilcoxon test was used to compare the differences in various hospitalization expenses, payment methods (paid by medical insurance, medical insurance subsidies for official staff, medical insurance claims for large expenses, social assistance, the hospital and the patient) and duration of hospitalization in different subgroups. The 95% confidence interval of the median or mean cost was calculated by the bootstrap method with 1000 iterations. In addition, a generalized linear regression model (GLM) was used to estimate the factors impacting the hospitalization costs, which were log-transformed to ensure a normal distribution.

Data analysis for this study was conducted using SAS 9.4 software (Copyright © 2016 SAS Institute Inc. Cary, NC, USA). A significant difference was defined by an α level of 0.05 with a two-sided test.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, writing of the report or making decision to submit the paper for publication. The corresponding authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

The cost of public health care

The per sample cost of obtaining samples for NAT at the Center for Disease Control and Prevention (CDC), secondary or tertiary hospitals, community health care centers, and township hospitals or temporary institutions were \$8.81, \$42.10, \$23.94, and \$23.76, respectively, with corresponding labor costs of 0.13 days, 0.52 days, 0.33 days and 0.40 days in those different levels of medical institutes (Table 1). Moreover, PPE used once cost approximately \$50.95 (in Supplementary Table 1). The average per sample cost of NAT among different medical institutes was \$29.49, and the human resources used were the equivalent of 0.38 days. There were significantly different detection times and costs for NAT between low-risk and high-risk populations (Supplementary Table 2). The cost of NAT and diagnostic examinations for the first and last tests for patients with suspected cases was \$154.41, the costs for the first and last tests for patients with suspected cases was \$77.86 per capita, and the costs of tests pre- and post-discharge in patients with confirmed cases were \$119.64 and \$147.54 (in Supplementary Table 3).

The CDC completed 156 epidemiological surveys (on-site investigations or telephone follow-ups), including 3629 high-risk people, and the direct costs (labor costs, PPE and ambulance cost) were calculated (Table 2). The average epidemiological costs for people in centralized isolation locations, home isolation and jail were \$4.57, \$10.59 and \$2.36 per case, respectively. Moreover, the average epidemiological costs of antibody-positive individuals, close contacts of people with confirmed cases, people with confirmed cases, people who retested positive after recovery and individuals with suspected cases were \$10.52, \$14.78, \$389.84, \$214.42, \$136.70 and \$243.50 per case, respectively. The average epidemiological cost associated with the inspection of hospital fever clinics by the CDC was \$214.42 per incident. The total epidemiological costs were \$60201.18, and the average epidemiological cost per thousand people was \$49.54.

The financial costs of disinfection, protective products, health education and centralized isolation were calculated (Table 3). The total cost of disinfectant was \$300,141.84 in Jiulongpo District, and the average cost of disinfectant per thousand people was \$247.01, including disinfectant materials at \$238.71 and a disinfectant labor cost of \$8.30. The cost of PPE was \$1,568,651.95 from January 20 to

April 30, and the average cost of PPE per thousand people was \$1290.97. The total human resource costs and publicity material costs associated with health education about COVID-19 were \$59,865.40 and \$49758.31, respectively, and the average health education costs for human resources and publicity materials were \$49.27 and \$40.95, respectively. The average cost of health education per thousand people was \$90.22. The costs of centralized isolation for people from abroad, close contacts, and discharged patients were \$647.72, \$647.72 and \$1295.45 per case, respectively, and the average cost of centralized isolation per thousand people was \$543.72 in Jiulongpo District.

The cost of hospitalization

The median and mean hospitalization costs associated with COVID-19 were analyzed based on the hospitalization costs- of 220 inpatients with COVID-19 (Table 4 and Supplementary Table 4). A single SARS-CoV2 infection cost a median of \$2,158.06 (95% CI: \$1,991.93–\$2,321.28) in direct medical costs, that is, only including costs that accrued during the course of hospitalization. The median cost of hospitalization in the NPIW was higher than that in the general isolation ward (\$3,439.00 [95% CI: \$2,942.59-\$4,573.96] vs. \$1902.26 [95% CI: \$1745.77-\$2146.22], $P < 0.001$). Hospitalization with noninvasive ventilation cost a median of \$9,278.05 (95% CI: \$6,990.72-\$11,151.19), which was higher than the cost of hospitalization without ventilation (\$2,017.16 [95% CI: \$1,837.62-\$2,224.99], $P < 0.001$). The median cost of hospitalization in the ICU was significantly higher than that in general isolation wards (\$11,114.88 [95% CI: \$9,278.05-\$31,283.93] vs. \$2,114.65 [95% CI: \$1,880.72-\$2,254.52], $P < 0.001$). In addition, the median cost of hospitalization for severe and critical COVID-19 was markedly higher than that for mild and moderate COVID-19 (\$3,439.00 [95% CI: \$3,055.95-\$4,573.96] vs. \$1,898.59 [95% CI: \$1,731.59-\$2,130.93], $P < 0.001$). Patients with ≥ 2 hospitalizations for COVID-19 had a higher hospitalization cost than those with a single hospitalization (\$3,437.72 [95% CI: \$2,432.65-\$5,828.88] vs. \$2,120.00 [95% CI: \$1,898.59-\$2,257.09], $P = 0.002$). In addition, the median cost of hospitalization for patients from abroad was \$4,567.89 (95% CI: \$2,992.07-\$5,072.00), which was higher than for local patients (\$2,132.99 [95% CI: \$1,938.52-\$2,298.65]) ($P = 0.01$).

The total direct hospitalization medical expenses consist of drug fees (\$364.16 [95% CI: \$330.21-\$390.17]), medical examination fees (\$200.21 [95% CI: \$200.21-\$266.94]), clinical laboratory fees (\$513.24 [95% CI: \$481.57-\$543.49]), consultation fees (\$52.58 [95% CI: \$47.67-\$57.48]), treatment fees (\$182.45 [95% CI: \$152.64-\$232.66]), nursing fees (\$62.25 [95% CI: \$57.20-\$68.98]), bed fees (\$205.04 [95% CI: \$177.70-\$226.16]), medical supply fees (\$409.52 [95% CI: \$357.55-\$460.71]), other hospitalization fees (\$27.60 [95% CI: \$25.41-\$31.51]), mean basic medical fees (\$0.14 [95% CI: \$0.08-\$0.22]), mean Chinese patent medicine fees (\$28.49 [95% CI: \$12.25-\$49.36]), mean surgery fees (\$2.61 [95% CI: \$0-\$8.15]) and mean Chinese herbal medicine fees (\$6.77 [95% CI: \$3.56-\$10.07]) (Table 4).

The median and mean hospitalization costs are compared in Table 4. Treatment in the NPIW, with noninvasive ventilation or in the ICU were associated with relatively higher hospitalization costs (all $P < 0.05$). Severe and critical COVID-19 was associated with higher hospitalization costs than mild and

moderate COVID-19 ($P < 0.001$). Moreover, patients with ≥ 2 hospitalizations and patients from abroad had higher hospitalization fees than their counterparts (all $P < 0.05$).

In addition, multivariable GLM analyses revealed that the factors impacting hospitalization cost were age, duration of hospitalization, hospitalization in the NPIW, the use of noninvasive ventilation, ICU, the classification of COVID-19 as severe and critical and the number of hospitalizations (Supplementary Table 5).

Compensation methods for hospitalization cost

The methods of paying for hospitalization included basic medical insurance, medical insurance claims for large expenses, other assistance and out of pocket. The results (Table 4 and Supplementary Table 4) revealed that the mean hospitalization costs for COVID-19 were mainly paid by medical insurance (\$2,531.85 [95% CI: \$1,953.46-\$3,310.91]) and by the patients (\$1,134.45 [95% CI: \$610.75-\$2,084.81]). Compared with their counterparts, the compensation paid by medical insurance was higher for patients who were hospitalized in the NPIW (\$5,046.69 [95% CI: \$3,033.67-\$7,605.15] vs. \$1,610.27 [95% CI: \$1,480.19-\$1,750.64], $P = 0.003$), received noninvasive ventilation (\$10,789.11 [95% CI: \$6,362.94-\$16,478.35] vs. \$1,751.32 [95% CI: \$1,480.90-\$2,218.23], $P < 0.001$) and were hospitalized in the ICU (\$16,940.65 [95% CI: \$8,334.59-\$26,511.06] vs. \$1,773.50 [95% CI: \$1,578.50-\$1,988.21], $P < 0.001$). In addition, patients with severe and critical COVID-19 and ≥ 2 hospitalizations received more compensation from medical insurance than their counterparts (all $P < 0.001$). The government paid the medical expenses that should have been paid by COVID-19 patients in China.

Furthermore, the results showed that the expense percentages paid by basic medical insurance and medical insurance claims for large expenses were 51.92% and 16.48%, respectively and that the expense percentages paid by medical insurance, the government and other forms of compensation were 68.40%, 30.65% and 0.95%, respectively (in Supplementary Table 6). The government paid approximately \$94.12 million for the hospitalization of confirmed COVID-19 patients in China through May 20. Medical insurance covered 60.08 ~ 84.49% of the hospitalization costs for COVID-19.

The estimated cost of COVID-19 in China

The cost of public health care associated with COVID-19 included the cost of centralized quarantine, NAT, epidemiological surveys, disinfectant and PPE (in Table 5). The cost of centralized quarantine for high-risk individuals from abroad, close contacts and post-discharge patients were \$1.11 million, \$479.93 million and \$101.37 million, respectively, for a total of \$582.41 million, and the cost of centralized isolation was \$761.24 million based on the cost of centralized quarantine per thousand people in Chongqing. This may reflect the true cost because some regions did not report the number of people in the high-risk population at the beginning of the pandemic. The cost of NAT was assessed for the high-risk population and for other populations. The cost of NAT for the high-risk population including individuals from abroad, close contacts, individuals with suspected cases and individuals with confirmed cases were \$0.13 million, \$89.09 million, \$21.18 million and \$53.40 million, respectively. In addition, the cost of NAT for the low-risk population of people from Wuhan, from abroad, from Hubei outside of

Wuhan, from Guangdong and from other regions were \$599.22 million, \$18.12 million, \$159.24 million, \$362.89 million and \$1,833.99 million, respectively. Based on the total population of 1.4005 billion in mainland China at the end of 2019, the costs of epidemiological surveys, disinfectant, PPE and health education were \$69.36 million, \$345.83 million, \$1,807.42 million and \$126.31 million, respectively. Finally, the total cost of public health care was \$6.83 billion.

As of May 20, 2020, the total number of COVID-19 cases in China was 82,967, which included 1,709 cases from abroad and 81,258 local cases, and the estimated number of severe cases was 17,147, with 4,634 deaths and 78,249 recoveries. According to the average hospitalization cost of \$3,792.69, the total direct cost of hospitalization was \$314.668 million in China, and the hospitalization costs for individuals from abroad and local individuals were \$7.20 million and \$307.23 million, respectively (in Table 5). Moreover, 17,147 patients with severe cases cost \$140.10 million, which was nearly equal to the cost for 65,820 patients with mild and moderate cases, which was \$144.04 million. In addition, the hospitalization cost for 98,430 patients with suspected cases was \$58.53 million, and the total hospitalization cost for patients with confirmed and suspected cases was \$373.20 million. The estimated total direct costs of public health care and hospitalization were approximately \$7.2 billion, and the components related to COVID-19 are shown in Fig. 2.

Discussion

This study found that the total direct medical costs for public health care were \$6.83 billion, which were substantially higher than the hospitalization cost of \$0.37 billion, even when only the increased direct costs during the pandemic period and not the costs due to lost productivity or the indirect costs of the efforts to control COVID-19 were considered. Our study estimates the public health costs from 6 aspects, namely, the costs due to centralized quarantine, NAT, epidemiological surveys, disinfectants, PPE and health education. The estimation in our analysis revealed that the cost of NAT was enormous and that NAT has imposed a tremendous economic burden on the health care system. In addition, we also estimated the hospitalization costs, and the results showed that the average cost of hospitalization for severe COVID-19 was four times that of hospitalization for non-severe COVID-19 (\$9,278.05 vs. \$2,017.16).

Estimating the cost of public health interventions for COVID-19 will provide a reference for those determining the financial budget of the government policy-making departments. Public health measures play critical roles in preventing the spread of emerging novel infectious diseases such as COVID-19¹¹⁻¹³. Such diseases require the government and the health care system to provide effective public health care and financial support. As measures distinct from outpatient and inpatient treatment, public health services should be paid for by the government. However, there are limited studies estimating the cost of public health care¹⁴, and no study has calculated the public health care cost due to COVID-19. This is the first study to document the public health care cost associated with COVID-19 (i.e., not including the cost of the traditional monitoring of the incidence of communicable diseases and performance of routine investigations). The public health costs in our study were associated with efforts to control the COVID-19

outbreak and epidemiological investigations. Of the public health measures taken, NAT, when both sampling and testing costs were considered, imposed the largest burden¹⁴⁻¹⁶. Our study found that the costs of obtaining samples in secondary or tertiary hospitals were 5 times and 2 times, respectively, the cost of obtaining samples at the CDC, community health care centers and township hospitals due to the higher costs of labor and PPE; this agrees with the findings of a previous study¹⁴. The average cost of NAT (PCR) and diagnostic testing in the high-risk population reached \$297.94 per capita, which was 6 times that in the low-risk population due to the fact that the numbers of tests per capita was far larger in the high-risk population^{17,18}. The enormous cost of NAT should be considered when deciding which population needs to be tested and which medical institutes should perform priority NAT.

In addition to pathogen detection, epidemiological field investigations in high-risk populations are important to control COVID-19¹⁹ because they can reduce the spread of the pandemic. The main cost incurred by epidemiological investigation is that associated with labor¹⁴. The study found that the average epidemiological survey costs were approximately \$389.84 for confirmed cases and \$243.50 for suspected cases, which were 20 ~ 30 times higher than those for populations. Moreover, our study revealed that epidemiological survey costs accounted for approximately 1.02% of the total increased medical costs associated with COVID-19; this may be significantly lower than the actual cost, as our study only included the subsidy for labor involved in the control of COVID-19 and did not include the general salaries of medical staff.

Another critical measure for preventing the spread of SARS-CoV-2 in China is to require the use of disinfectant²⁰ and PPE²¹. Based on the current estimation, the cost of the additional disinfectant accounted for more than 5% (\$0.35 billion) of the public health care costs associated with COVID-19, primarily driven by the cost of the disinfectant solutions and materials themselves. The cost of disinfection reported in our study is lower than the actual cost, because the labor cost associated with the disinfection of hospital waste was not calculated. Jiao Wang et al²⁰ found that the disinfection of hospital waste and wastewater is very important for controlling the COVID-19 pandemic. In addition to NAT, the cost of PPE accounted for 26.46% of the public health care costs in our study, in part due to the shortages in medical masks, gowns and protective suits at the beginning of the pandemic. There are debates about whether wearing masks is effective and who needs to wear masks^{10,22,23}; one study suggested wearing PPE in certain circumstances²², and one study from Wuhan found that the use of PPE can protect healthcare professionals from COVID-19²⁴. Moreover, the centralized quarantine of high-risk populations is another effective way to reduce transmission²⁵, minimizing the spread of COVID-19 among family members and the community²⁶. In this study, we found that the cost of centralized quarantine accounted for 19.68% of the increased public health care costs associated with COVID-19, including the Chinese government's reimbursements for medical expenses and the costs of the accommodations and meals provided during centralized quarantine; the provision of those items significantly improved compliance with centralized isolation and reduced the psychological stress of those in quarantine. Health education is an essential measure that can increase people's knowledge,

attitudes, and practices (KAP) towards COVID-19²⁷. Our study found that the making of videos and publicity materials by authorities and the health care system to increase public awareness of COVID-19 accounted for 1.85% of the public health care costs associated with COVID-19 and had a significant effect²⁷.

Isolation within hospitals is necessary for patients with confirmed and suspected cases of COVID-19^{9,18}, and the choice of treatment for patients was impacted by the method of compensation for hospitalization expenses. To provide hospitalization and treatment for every patient with a confirmed and suspected case, the Chinese government paid all medical expenses that would ordinarily have been paid by individuals, and our study found that the government provided 30.65% (nearly \$0.11 billion) of the hospitalization-associated costs for patients with confirmed cases (Supplementary Table 3). In contrast, out-of-pocket health care costs have placed an enormous burden on many COVID-19 patients in some countries, preventing patients from receiving medical treatment²⁸ and exacerbating the spread of COVID-19. The average cost is 2.58 times that of the average medical expenses for inpatient treatment in general (\$1468.78 in medical costs in 2020 values) and 3.68 times that of the average medical expenses for bacterial pneumonia (\$1039.71 in medical costs in 2020 values)²⁹, which was similar to the results of the study by Sarah M. Bartsch *et al*⁹. The direct medical costs are higher for COVID-19 than for other common infectious diseases because inpatients with COVID-19 have a longer average hospital stay (18 days vs. 8.5 days) and higher mortality than patients with seasonal influenza and other infectious diseases^{30–32}. Moreover, we found that the hospitalization-associated costs for severe COVID-19 patients (those treated in the NPIW, treated with noninvasive ventilation, treated in the ICU, and with two or more hospitalizations), patients from abroad and older patients were greater than those for their counterparts, which was in agreement with the finding of another published study¹⁴. The hospitalization-associated costs in our study included only the expenses incurred during hospitalization and did not consider the potential continued medical costs after the acute infection had run its course, including the cost of caring for those who had survived with major complications, such as cardiovascular disease and diabetes³¹. Furthermore, the costs of subsidies for emergency medical personnel (40 thousand medical staff have supported Wuhan), follow-up care, and potential rehospitalization are likely to be considerable because long-lasting damage has been done³³, making patients susceptible to other health problems. These costs will further increase the cost of hospitalization. The compensation policy for out-of-pocket hospitalization costs for COVID-19 in China and the average hospitalization cost in our study will provide references for other countries coping with the pandemic.

Our study has several limitations to address. First, we focused on the increased direct medical costs associated with COVID-19. Therefore, we did not consider the potentially substantial indirect medical costs that may be associated with COVID-19, such as those related to reduce economic activity and lost productivity due to absenteeism and premature mortality. Second, the results in this study may underestimate the direct medical costs because we only used the situation in Chongqing to calculate the costs for China as a whole. For example, we did not include the additional costs of building the mobile cabin hospitals in Wuhan or the tent hospitals in other places. Third, we did not include the financing of

emergency medical equipment used for the control of COVID-19. Finally, our analysis included only the subsidies paid to medical staff during the COVID-19 pandemic and did not include their regular salaries, which may have resulted in a significantly underestimation of the labor costs. Thus, the estimated costs in the study may still be underestimates of the increased medical costs due to COVID-19 in China.

Conclusions

In conclusion, this study found that the COVID-19 pandemic has resulted in the expenditure of \$6.83 billion for public health care and \$0.37 billion for direct medical costs associated with hospitalization. The public health care costs were far greater than the hospitalization costs, suggesting that the government should plan to increase the financial investment in emergency public health care during infectious disease outbreaks to effectively contain their spread. Our study also highlights the magnitude of the resources needed to prevent the spread of the COVID-19 pandemic and to treat patients with COVID-19. Even when considering only the costs during the most severe pandemic period and not those associated with routine surveillance and treatment following an acute outbreak, the increased medical costs related to the COVID-19 pandemic are likely to be substantially higher than those reported in this study. The public health measures implemented by the Chinese government have shown the value of strategies that mitigate viral spread as much as possible, which may be a cost-effective way to address emerging infectious diseases.

Abbreviations

COVID-19

Coronavirus disease 2019; NAT:Nucleic acid testing; SARS:Severe acute respiratory syndrome; EVD:Ebola virus disease; GLM:Generalized linear regression model; PPE:Personal protective equipment; NPIW:Negative-pressure isolation ward; ICU:Intensive care unit; CDC:Center for Disease Control and Prevention; KAP:Knowledge, attitudes, and practices

Declarations

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Authors' contributions

Liang XH, Gu DF and Bi Y conceived and designed the study; Xiao L, Yang XL, Zhong XF, Zhang P, Tang X and Luo YT participated in the acquisition and management of the data; Liang XH and Luo YT analyzed the data; Liang XH wrote the paper and all authors revised the manuscript; and all authors critically reviewed and approved the final paper.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. Data are available from Xiao-Hua Liang (Clinical Epidemiology and Biostatistics Department, Children's Hospital of Chongqing Medical University, No.136 2nd Zhongshan Road, Yuzhong District, Chongqing, China, 400016; Email: xiaohualiang@hospital.cqmu.edu.cn or liangxiaohua666@sina.com).

Ethics approval and consent to participate

The Institutional Review Board at the Children's Hospital of Chongqing Medical University approved this study ((2020) No.59). Informed consent was provided by all subjects.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

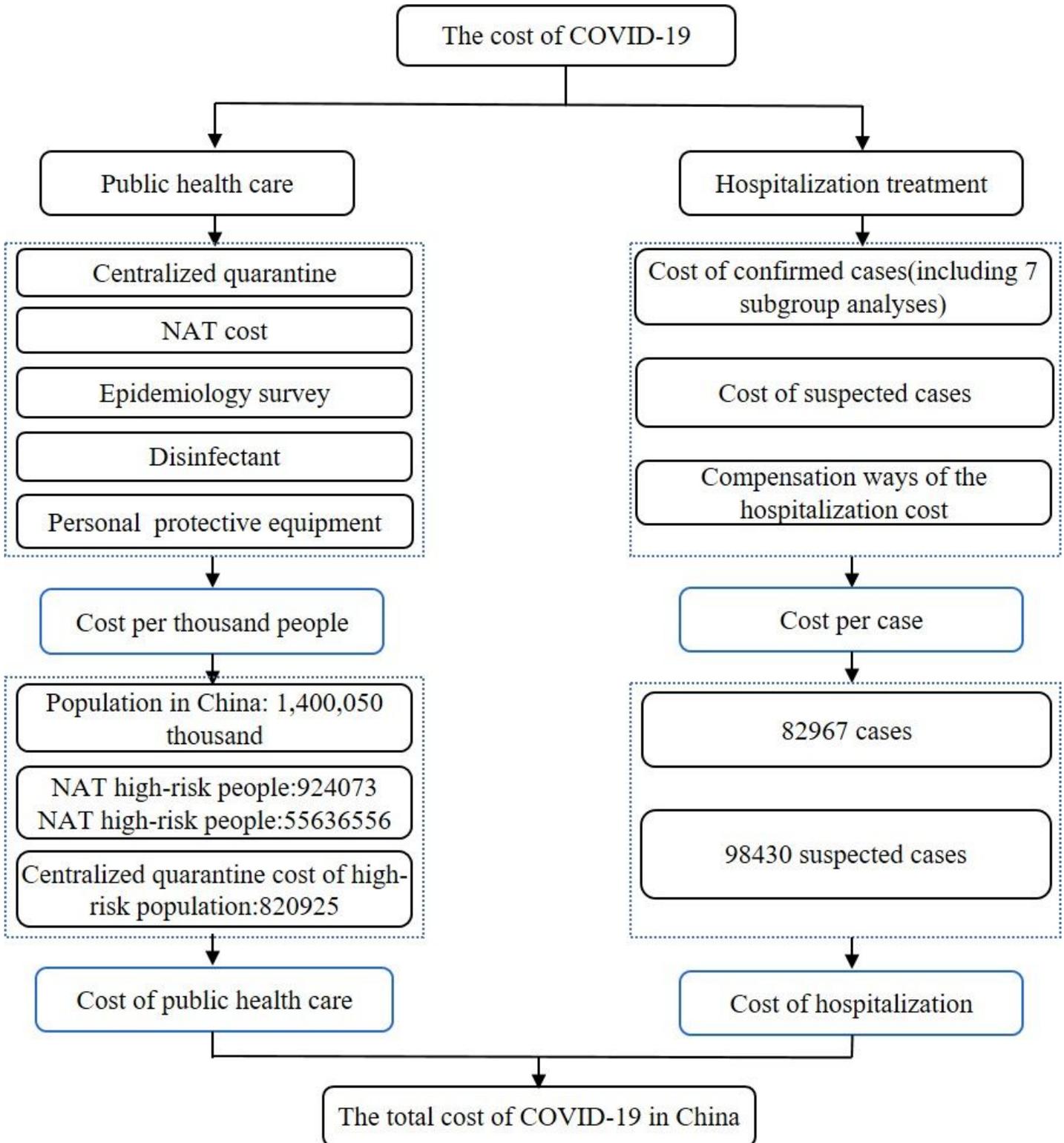


Figure 1

The flow chart showing the calculation of the cost of COVID-19 in China

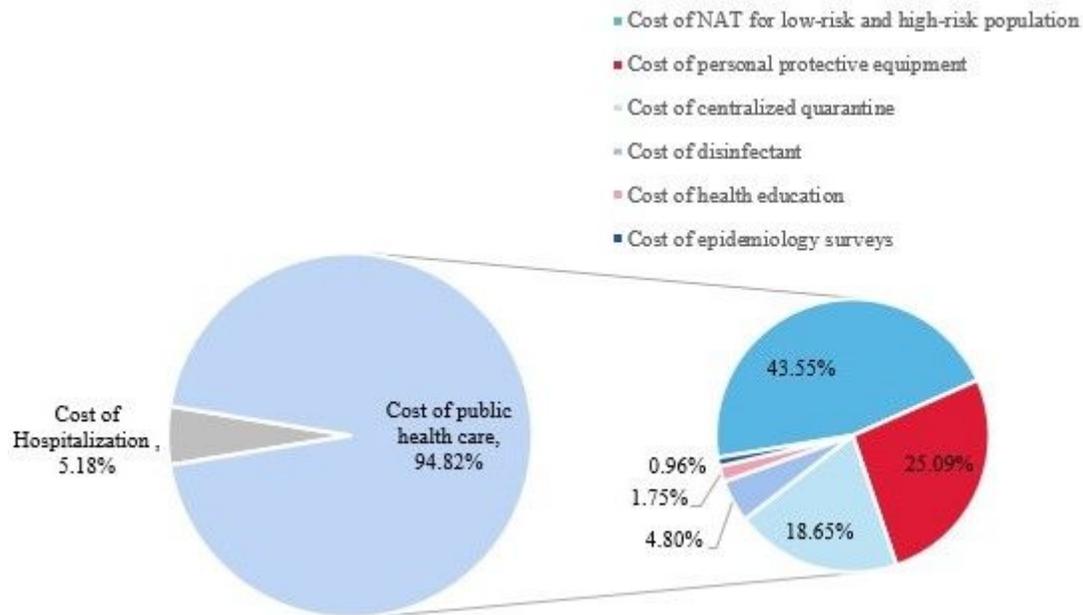


Figure 2

The components of the costs due to COVID-19 in China

Supplementary Files

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