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Original Research

Economic burden of public health care and hospitalisation associated with COVID-19 in China

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ABSTRACT

Objectives: This study aimed to evaluate the socio-economic burden imposed on the Chinese healthcare system during the coronavirus disease 2019 (COVID-19) pandemic.
Study design: A cross-sectional study was used to investigate how COVID-19 impacted health and medical costs in China. Data were derived from a subdivision of the Centers for Disease control and Prevention of China.
Methods: We prospectively collected information from the Centers for Disease Control and Prevention and the designated hospitals to determine the cost of public health care and hospitalisation due to COVID-19. We estimated the resource use and direct medical costs associated with public health.
Results: The average costs, per case, for specimen collection and nucleic acid testing (NAT [specifically, polymerase chain reaction {PCR}]) in low-risk populations were $29.49 and $53.44, respectively; however, the average cost of NAT in high-risk populations was $297.94 per capita. The average costs per 1000 population for epidemiological surveys, disinfectant, health education and centralised isolation were $49.54, $247.01, $90.22 and $543.72, respectively. A single hospitalisation for COVID-19 in China cost a median of $2158.06 ($1961.13-$2325.65) in direct medical costs incurred only during hospitalisation, whereas the total costs associated with hospitalisation of patients with COVID-19 were estimated to have reached nearly $373.20 million in China as of 20, May, 2020. The cost of public health care associated with COVID-19 as of 20, May, 2020 ($6.83 billion) was 18.31 times that of hospitalisation.
Conclusions: This study highlights the magnitude of resources needed to treat patients with COVID-19 and control the COVID-19 pandemic. Public health measures implemented by the Chinese government have been valuable in reducing the infection rate and may be cost-effective ways to control emerging infectious diseases.

Introduction

During the coronavirus disease 2019 (COVID-19) pandemic, there has been a substantial impact on global health care and medical systems. By 9, June, 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 20, May, 2020, there were 82,967 confirmed cases, 740,967 close contacts and 4634 deaths in China.[3] Faced with an enormous number of cases within a short period of time, the government, healthcare professionals and healthcare systems voiced concern that demand would exceed the existing capacity, and they requested the urgent provision of additional resources and financial support. An effective method of mitigating the impact of the pandemic on the healthcare 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, healthcare system and medical insurance system had

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to provide sufficient public health resources and hospital accommodation to quickly curb the spread of COVID-19.

The COVID-19 pandemic was brought under control in China within a relatively short period of time; therefore, it is useful to evaluate the costs of public health measures and hospitalisation 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.

In China, the healthcare system is composed of two sections: (i) medical institutions (e.g. hospitals, primary medical and health centres, such as township hospitals or community health centres); and (ii) public health organisations, such as the Centers of Disease Control and Prevention (CDC) and Centres of Health Supervision (these medical organisations are stratified into five levels: state, province, city, county/district and town).[6] After the outbreak of the COVID-19 pandemic, the Chinese government released pandemic control policies called a 'unanimous nationwide system' to form a joint defence and control programme with multiple departments.[7] All hospitals and primary medical centres were administrated by Health Commissions (HCs) and CDCs at each level.[7] The HCs and CDCs at each level planned the supplies and human resources for the hospitals and primary medical centres in their areas.[8]

However, limited studies have reported the costs of emerging infectious diseases. Bartsch et al.[9] 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. In addition, two studies[10,11] developed computational models to forecast the potential economic burden and the cost-effectiveness of measures addressing Zika in the US. Bartsch et al.[12] also 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.[13] A few studies have estimated healthcare utilisation and cost using structured interview methods, but a review of the literature reveals that, to date, there are no studies determining the costs of both public health and hospitalisation associated with COVID-19.

In this study, we investigate the actual expenses associated with public healthcare resources and hospitalisation from COVID-19. From these figures, we estimate the healthcare costs of COVID-19 control in China during the initial outbreak period of the pandemic. This study estimates the potential financial cost to control the outbreak of an infectious disease, without health insurance support, in an emergency situation. Results from this study will help governments worldwide in the management of infectious disease outbreaks.

Methods

Study design

A cross-sectional study was used to investigate how COVID-19 impacted health and medical costs in China. Data were derived from a subdivision of the CDC of China.

Data sources for the COVID-19 epidemic in China

This study used COVID-19 data from the official website of the National Health Commission of the People's Republic of China from 20, January, 2020, to 20, May, 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.

Definition of medical costs

Medical expenses associated with COVID-19 are composed of the costs of public health care and treatment during hospitalisation (see supplementary figure S2). Public healthcare costs included nucleic acid testing (NAT [specifically, polymerase chain reaction {PCR}]) (including NAT for both people and the environment), epidemiological surveys, centralised quarantine (see supplementary figure S2), disinfection and health education. The costs associated with public health care had two dimensions, namely, financing resources (e.g. protective equipment, medical materials, medical equipment and ambulances) and human resources (i.e. medical staff participating in the prevention of COVID-19). The hospitalisation costs include the direct cost of acute hospitalisation according to the discharge settlement amount.

Data collection

To accurately estimate the costs of pandemic control, including both public health care and hospitalisation, three criteria were taken into consideration when selecting the study district, as follows: first, there must be sufficient residents and COVID-19 cases in this district; second, the chosen district should contain both urban and rural areas so that urban-rural differences could be eliminated; and finally, the district must have hospitals with sufficient funds to cover total medication costs for patients with COVID-19 and isolation expenses for residents.

The Jiulongpo District was selected as the study area. In total, 1.2 million people permanently resided in Jiulongpo District and there were >20 reported cases of COVID-19. Jiulongpo District is located to the west of the Chongqing metropolitan region, with both semirural and semiurban areas, including nine urban streets and four rural towns. Furthermore, in this district, there are sufficient hospitals, including every grade of hospital in China, which formed a loop, so that the centralised isolation and treatment of patients with COVID-19 could be carried out locally to make the cost data transparent. Therefore, in Chongqing, the Jiulongpo District met all the three selection criteria and thus provides a suitable study area resulting in good representation for the costs associated with COVID-19 in China.

Data on medical costs related to the treatment of COVID-19 were collected using a micro-cost survey approach. The total public healthcare costs in Jiulongpo District were collected. The urban area in Jiulongpo District is very prosperous, and it could represent the typical costs of COVID-19 in the urban areas of Chongqing or other metropolitan cities. In addition, the four rural towns in Jiulongpo District can represent rural areas of Chongqing. The survey was administered to one CDC, seven secondary or tertiary medical institutions, 15 community health centres and 10 township hospitals or temporary medical institutions in Jiulongpo District, which includes all subdistricts and 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. The questionnaire survey of local survey data was collected from the CDC and hospitals and health insurance system. All relevant medical centres at all levels in Jiulongpo District were investigated, and the CDC of Jiulongpo District provided support for all the surveys. The detailed method of quantitative cost collection is provided in Supplementary Method 1.

Method of cost calculation

The average exchange rate of RMB to US$ equivalent during the period of the survey was 1 RMB = 0.1402 US$. The detailed method of cost calculation is provided in Supplementary Method 2.

Statistical analyses

The Wilcoxon test was used to compare the differences in various hospitalisation expenses, payment methods (e.g. 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 hospitalisation in different subgroups. The 95% confidence interval (CI) of the median or mean cost was calculated by the bootstrap method with 1000 iterations. In addition, a generalised linear regression model (GLM) was used to estimate the factors impacting the hospitalisation costs, which were log-transformed to ensure a normal distribution.

Data analyses for this study were conducted using SAS, version 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.

Results

The cost of public health care

The per sample cost of obtaining samples for NAT at the CDC, secondary or tertiary hospitals, community healthcare centres and township hospitals or temporary institutions were \$8.81, \$42.10, \$23.94 and \$23.76, respectively, with corresponding labour costs of 0.13 days, 0.52 days, 0.33 days and 0.40 days, respectively (Table 1). Moreover, single-use personal protective equipment (PPE) cost approximately \$50.95 (see Supplementary Table S1). 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 (those who did not closely contact with confirmed cases) and high-risk (close contacts) populations (Supplementary Table S2). The costs of NAT and diagnostic examinations for the first time and the last time tests for people before diagnosed as suspected cases was \$154.41 per capita, including \$124.92 for test material cost and \$29.49 of NAT cost. And NATs of people after diagnosed as suspected cases for the first time and for the last time NATs was \$77.86. Moreover, the costs of NATs for predischarge and postdischarge of confirmed cases were \$119.64 and \$147.54, respectively (in Supplementary Table S3).

The CDC completed 156 epidemiological surveys (on-site investigations or telephone follow-ups), including 3629 individuals in high-risk populations, and the direct costs (labour costs, PPE and ambulance costs) were calculated (Table 2). The average epidemiological costs for people in centralised isolation, 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

Table 1
The cost of obtaining sample specimens for NAT in different medical institutes.

Items	Number of samples	Labour resource of medical staff, days	Price, \$	Cost per sample, \$	Human resource, days/per sample
In CDC					
Labour to obtain specimen	4267	214	42.06	2.11	0.05
Community policeman	4267	81	28.04	0.53	0.019
Labour to deliver specimen	4267	252	28.04	1.66	0.059
Ambulance	4267	252	16.82	0.99	–
PPE	4267	295	50.95	3.52	–
Total average cost*	–	–	–	**8.81**	**0.128**
In secondary or tertiary hospitals					
Labour to obtain specimen	9547	3760	42.06	16.56	0.394
Community policeman	9547	1164	28.04	3.42	0.122
Labour to deliver specimen	9547	1164	16.82	2.05	–
Ambulance	9547	3760	50.95	20.07	–
Total average cost*	–	–	–	**42.1**	**0.516**
Community healthcare centre					
Labour to obtain specimen	4850	939	42.06	8.14	0.194
Labour to deliver specimen	4850	642	28.04	3.71	0.132
Ambulance	4850	642	16.82	2.23	–
PPE	4850	939	50.95	9.86	–
Total average cost*	–	–	–	**23.94**	**0.326**
Township hospitals or temporary participating institutions					
Labour to obtain specimen	192	23	42.06	5.04	0.12
Labour to deliver specimen	192	54	28.04	7.89	0.281
Ambulance	192	54	16.82	4.73	–
PPE	192	23	50.95	6.1	–
Total average cost*	–	–	–	**23.76**	**0.401**
Total average cost in all medical institutes					
Labour to obtain specimen	18,856	4936	42.06	11.01	0.262
Community policeman	18,856	81	28.04	0.12	0.004
Labour to deliver specimen	18,856	2112	28.04	3.14	0.112
Ambulance	18,856	2112	16.82	1.88	–
PPE	18,856	4936	50.95	13.34	–
Total average cost*	–	–	–	**29.49**	**0.378**

CDC: Centers for Disease Control and Prevention; PPE: personal protective equipment; NAT: nucleic acid testing.
*The cost per sample in bold, was calculated by adding the cost of subgroups, such as 8.81=2.11+0.53+1.66+0.99+3.52. The human resource (days per sample) in bold, was calculated by adding the human resource of subgroups, such as 0.128=0.05+0.019+0.059.
Note: The typical exchange rate of RMB to US\$ equivalent in the period of this survey is 1 RMB = 0.1402 US\$.

Table 2
The cost of epidemiological surveys for COVID-19.

Type of cases	Survey administrations	Cases	Survey cost of CDC				Total labour, days	Total labour cost, $	Total cost, $[a]	Cost per case or per administration, $
			Survey labour, days	Data analysis labour, days	PPE cost, $	Survey cost, $				
Centralised quarantine locations[b]	15	697	19	0	1885.1	2663.2	27	1016.5	3187.6	4.57
Home quarantine	2	66	4	0	407.56	575.8	6	224.32	699.18	10.59
Jail[c]	14	1816	28	0	2445.5	3581.1	40	1472.1	4287.7	2.36
Antibody-positive individuals	1	18	3	2	–	189.27	5	189.27	189.27	10.52
Close contacts of cases	81	872	280	1	764.23	12,583	287	11,959	12,892	14.78
Patients with confirmed cases	10	19	62	100	458.59	7272.3	165	6897.8	7406.9	389.84
Fever clinics[d]	5	15	6	3	560.38	917.89	12	427.61	1072.1	214.42[e]
Patients who retested as positive after recovery	2	2	3	4	–	273.39	7	273.39	273.39	136.7
Individuals with suspected cases	26	124	323	391	152.82	30,163	714	30,024	30,193	243.5

CDC: Centers for Disease Control and Prevention; PPE: personal protective equipment.
Note: The typical exchange rate of RMB to US$ equivalent in the period of this survey is 1 RMB = 0.1402 US$.
[a] Including the PPE, total labor and ambulance costs.
[b] Three missing data points represented by the median (33).
[c] Prison staff and criminals in custody.
[d] The CDC supervised and inspected the fever clinics of hospitals four times. The number of cases was not recorded, and average cost per time was used.
[e] Cost per time.

epidemiological costs were $60,201.18, and the average epidemiological cost per 1000 population was $49.54.

The financial costs of disinfection, PPE, health education and centralised isolation were calculated (Table 3). The total cost of disinfectant was $300,141.84 in Jiulongpo District, and the average cost of disinfectant per 1000 population was $247.01, including disinfectant materials at $238.71 and a disinfectant labour cost of $8.30. The cost of PPE was $1,568,651.95 from 20, January, 2020 to 30, April, 2020, and the average cost of PPE per 1000 population was $1290.97. The total human resource costs and publicity material costs associated with COVID-19 health education were $59,865.40 and $49,758.31, respectively; the average health education costs for human resources and publicity materials were $49.27 and $40.95 per 1000 population, respectively. The average cost of health education per 1000 population was $90.22. The costs of centralised 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 centralised isolation per 1000 population was $543.72 in Jiulongpo District.

The cost of hospitalisation

The median hospitalisation costs associated with COVID-19 were analysed based on the hospitalisation costs of 220 inpatients with COVID-19 (Table 4 and Supplementary Table S4). A single SARS-CoV-2 infection cost a median of $2158.06 (95% CI = $1991.93–$2321.28) in direct medical costs, that is, only including the costs that were accrued during the course of hospitalisation. The median cost of hospitalisation in the negative-pressure isolation ward (NPIW) was higher than that in the general isolation ward ($3439.00 [95% CI = $2942.59-$4573.96] vs $1902.26 [95% CI = $1745.77-$2146.22]; $P < 0.001$). Hospitalisation with non-invasive ventilation cost a median of $9278.05 (95% CI = $6990.72-$11,151.19), which was higher than the cost of hospitalisation without ventilation ($2017.16 [95% CI = $1837.62-$2224.99]; $P < 0.001$). The median cost of hospitalisation in the intensive care unit (ICU) was significantly higher than that in general isolation wards ($11,114.88 [95% CI = $9278.05-$31,283.93] vs $2114.65 [95% CI = $1880.72-$2254.52]; $P < 0.001$). In addition, the median cost of hospitalisation for severe and critical COVID-19 was markedly higher than that for mild and moderate COVID-19 ($3439.00 [95% CI = $3055.95-$4573.96] vs $1898.59 [95% CI = $1731.59-$2130.93]; $P < 0.001$). Patients with two or more hospitalisations for COVID-19 had a higher hospitalisation cost than those with a single hospitalisation ($3437.72 [95% CI = $2432.65-$5828.88] vs $2120.00 [95% CI = $1898.59-$2257.09]; $P = 0.002$). Also, the median cost of hospitalisation for patients from abroad was $4567.89 (95% CI = $2992.07-$5072.00), which was higher than for local patients ($2132.99 [95% CI = $1938.52-$2298.65]; $P = 0.01$).

The total direct hospitalisation 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 hospitalisation fees ($27.60 [95% CI = $25.41-$31.51]), median of basic medical fees ($0.14 [95% CI = $0.08-$0.22]), median of Chinese patent medicine fees ($28.49 [95% CI = $12.25-$49.36]), median of surgery fees ($2.61 [95% CI = $0-$8.15]) and median of Chinese herbal medicine fees ($6.77 [95% CI = $3.56-$10.07]) (Table 4).

The median and mean hospitalisation costs are compared in Table 4. Treatments in the NPIW with non-invasive ventilation or

Table 3
Costs of disinfection, PPE, health education and centralised quarantine.

Items	Price/suit, $	Number	Total price, $
Cost of disinfectant			
Effervescent tablets for disinfection	5.61	4,760	26,694.08
Medical 84 disinfectant	15.84	16,624	263,367.38
Total cost of disinfectant materials*	-	-	***290,061.46***
Human resource for disinfecting	-	215	6,028.6
Ambulance	16.83	-	757.36
Ultra-low-volume sprayer	140.2	6	757.08
Fuel atomizer	490.7	5	841.2
Total cost of disinfectant*	-	-	***300,141.8***
Average cost of disinfectant materials, per 1000	-	-	238.71
Average cost of disinfectant labor, per 1000	-	-	8.3
Average cost of disinfecting, per 1000*	-	-	***247.01***
Cost of PPE			
Surgical mask	1.26	64,574	81,479.47
N95 mask	6.73	7,770	52,288.99
3M mask	4.21	5,162	21,711.37
Protective suit	67.3	6,988	470,264.45
Medical gown	15.14	44,257	670,121.79
Gloves	0.7	233,707	163,828.61
Shoe cover	0.07	28,190	1,976.12
Medical hat	0.07	42,402	2,972.38
Face shield	28.04	3,424	96,008.96
Medical goggles	6.31	1,268	7,999.81
Total cost of PPE, $*	-	-	***1,568,652***
Cost of PPE, per 1000, $*	-	-	***1,290.97***
Health education			
Human resources, person time (days)	28.04	2,135	59,865.4
Average human resources, per 1000	-	-	49.27
Publicity materials			
Making informational film	42.06	480	20,188.8
Printing publicity materials	0.13	222,010	29,569.51
Materials, per 1000	-	-	40.95
Average cost of health education, per 1000*	-	-	***90.22***
Centralized isolation			
People from abroad	647.72	550	356,248.2
Close contacts	647.72	430	278,521.32
Discharge patients	1295.45	20	25,908.96
Average cost of centralized isolation, per 1000*	-	-	***543.72***

PPE: personal protective equipment.
Note: The typical exchange rate of RMB to US$ equivalent in the period of this survey is 1 RMB =0.1402 US$
* Total cost in italic bold represented the sum of each items of cost in the corresponding category.
# The average cost per 1000 in italic bold represented the total price of all items in the corresponding category for every 1000 samples.

in the ICU were associated with relatively higher hospitalisation costs (all $P < 0.05$). Severe and critical COVID-19 was associated with higher hospitalisation costs than mild and moderate COVID-19 ($P < 0.001$). Moreover, patients with two or more hospitalisations and patients from abroad had higher hospitalisation fees than their counterparts (all $P < 0.05$).

In addition, multivariable GLM analyses revealed that the factors impacting hospitalisation cost were age (45–59 years vs < 18 years; $P = 0.027$), duration of hospitalisation ($P < 0.001$), hospitalisation in the NPIW ($P < 0.001$), the use of non-invasive ventilation ($P < 0.001$), admission to the ICU ($P < 0.001$), the classification of COVID-19 as severe and critical ($P < 0.001$) and the number of hospitalisations ($P = 0.001$) (Table 5).

Compensation methods for hospitalisation cost

The methods of paying for hospitalisation include basic medical insurance, medical insurance claims for large expenses, other assistance and out-of-pocket payments. The results (Table 4 and Supplementary Table S4) revealed that the mean hospitalisation costs for COVID-19 were mainly paid by medical insurance ($2531.85 [95% CI = $1953.46-$3310.91]) and by the patients ($1134.45 [95% CI = $610.75-$2084.81]). Compared with their counterparts, the compensation paid by medical insurance was higher for patients who were hospitalised in the NPIW ($5046.69 [95% CI = $3033.67-$7605.15] vs $1610.27 [95% CI = $1480.19-$1750.64]; $P = 0.003$), received non-invasive ventilation ($10,789.11 [95% CI = $6362.94-$16,478.35] vs $1751.32 [95% CI = $1480.90-$2218.23]; $P < 0.001$) and were hospitalised in the ICU ($16,940.65 [95% CI = $8334.59-$26,511.06] vs $1773.50 [95% CI = $1578.50-$1988.21]; $P < 0.001$). In addition, patients with severe and critical COVID-19 and those with two or more hospitalisations 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 patients with COVID-19 in China.

Furthermore, the results show 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 (Supplementary Table S5). The government paid approximately $94.12 million for the hospitalisation of patients with confirmed COVID-19 in China until 20, May, 2020. Medical insurance covered 60.08–84.49% of the hospitalisation costs for COVID-19.

Table 4
The cost of hospitalisation for COVID-19, median (95% CI).[a]

Variables	Total	Negative-pressure isolation ward			Noninvasive ventilation		
		No	Yes	*P*	No	Yes	*P*
Sample size, n	220	161	59		201	19	
Duration of hospitalization, days	18 (17.00-20.00)	17 (16.00-19.00)	20 (17.00-25.00)	0.053	18 (16.00-19.00)	27 (20.00-35.00)	0.001
Drug fee, $	364.16 (330.21-390.17)	353.63 (329.04-381.36)	416.63 (294.02-496.55)	0.446	338.3 (315.43-372.78)	1522.11 (1145.39-2466.65)	<0.001
Medical examination fee, $	200.21 (200.21-266.94)	200.21 (200.21-215.35)	241.85 (200.21-333.68)	0.205	200.21 (200.21-209.74)	467.15 (400.41-492.94)	<0.001
Clinical laboratory fee, $	513.24 (481.57-543.49)	472.05 (442.72-493.19)	890.59 (639.94-1140.39)	<0.001	492.31 (469.25-531.43)	2430.44 (1496.00-3235.54)	<0.001
Consultation fee, $	52.58 (47.67-57.48)	50.47 (46.27-54.68)	58.88 (49.07-71.50)	0.044	51.87 (46.27-54.68)	79.91 (60.29-100.94)	<0.001
Treatment fee, $	182.45 (152.64-232.66)	152.27 (119.55-185.62)	292.2 (213.97-500.54)	<0.001	158.65 (134.98-188.61)	1757.9 (1383.51-2119.68)	<0.001
Nursing fee, $	62.25 (57.20-68.98)	60.57 (55.52-65.61)	67.97 (57.20-85.80)	0.088	61.24 (55.52-65.61)	92.53 (72.34-122.82)	<0.001
Bed fee, $	205.04 (177.70-226.16)	159.83 (150.36-181.56)	514.53 (385.55-685.23)	<0.001	186.82 (168.24-216.96)	817.02 (577.27-1280.38)	<0.001
Medical supply fee, $	409.52 (357.55-460.71)	375.15 (331.69-443.16)	531.91 (388.99-775.53)	0.018	372.13 (333.94-426.39)	1404.57 (1008.86-1529.84)	<0.001
Basic medical fee, $	0.14 (0.08-0.22)	0.12 (0.08-0.14)	0.13 (0.10-0.23)	0.042	0.14 (0.08-0.20)	0.21 (0.14-0.32)	0.007
Chinese patent medicine fee, $	28.49 (12.25-49.36)	12.76 (9.77-17.48)	60.72 (40.28-166.78)	<0.001	19.14 (11.29-40.32)	82.46 (48.39-557.21)	<0.001
Surgery fee, $	2.61 (0.00-8.15)	2.61 (0.00-2.61)	2.61 (0.00-18.20)	0.115	2.61 (0.00-2.61)	5.75 (0.00-18.20)	<0.001
Chinese herbal medicine fee, $	6.77 (3.56-10.07)	4.13 (3.31-8.58)	9.79 (4.20-14.07)	<0.001	6.77 (3.44-10.07)	7.36 (4.04-11.70)	0.175
Other hospitalization fees, $	27.60 (25.41-31.51)	25.94 (23.83-29.30)	38.56 (27.44-46.76)	<0.001	26.95 (24.54-29.30)	44.3 (38.56-55.73)	<0.001
Total medical expenses, $	2158.06 (1961.13-2325.65)	1902.26 (1745.77-2146.22)	3439 (2942.59-4573.96)	<0.001	2017.16 (1837.62-2224.99)	9278.05 (6990.72-11151.19)	<0.001
Compensation methods							
Paid by medical insurance, $	1467.21 (1367.85-1700.27)	1415.33 (1294.50-1529.39)	2176.95 (1471.08-2864.34)	0.003	1415.33 (1301.30-1525.23)	5717.11 (4795.72-6058.62)	<0.001
Paid by medical insurance claims for large expenses, $	0 (0.00-0.00)	0 (0.00-0.00)	0 (0.00-0.00)	<0.001	0 (0.00-0.00)	2023.71 (0.00-3706.92)	<0.001
Total general medical insurance, $	1467.21 (1369.82-1700.27)	1415.33 (1294.50-1529.39)	2176.95 (1471.08-2924.36)	0.003	1415.33 (1301.30-1525.23)	8053.25 (5320.54-10804.81)	<0.001
Paid by the patient, $[b]	406.35 (317.92-491.63)	381.81 (292.35-476.83)	554.89 (318.88-902.85)	0.061	404.88 (298.80-490.05)	902.85 (318.50-1688.98)	0.017
Other assistance, $	0 (0.00-0.00)	0 (0.00-0.00)	0 (0.00-0.10)	0.012	0 (0.00-0.00)	0.21 (0.00-65.05)	<0.001

CI, confidence interval.
Note: The typical exchange rate of RMB to US$ equivalent in the period of this survey is 1 RMB= 0.1402 US$.
[a] The 95% confidence interval of the median was based on 1000 bootstrap iterations (seed: 30459584).
[b] The fee that would ordinarily have been paid by the patients was covered by the government subsidies.

Table 5
The factors influencing total medical expenses ($n = 218$).

Variables	Univariate GLM			Multivariate GLM[a]		
	β	SE	*P*-Value	β	SE	*P*-Value
Sex, female vs male	0.016	0.083	0.848	0.003	0.03	0.926
Age, ref. <18 years						
18–44	0.345	0.189	0.068	0.081	0.069	0.243
45–59	0.517	0.19	0.007	0.154	0.07	0.027
≥60	0.639	0.198	0.001	0.132	0.073	0.072
Duration of hospitalisation, days	0.054	0.003	<0.001	0.045	0.002	<0.001
Negative-pressure isolation ward, yes vs no	0.614	0.084	<0.001	0.226	0.039	<0.001
Non-invasive ventilation, yes vs no	1.434	0.114	<0.001	0.756	0.078	<0.001
ICU, yes vs no	1.635	0.176	<0.001	0.459	0.102	<0.001
Severe and critical COVID-19, yes vs no	0.631	0.083	<0.001	–	–	
Frequency of hospitalisation, ≥2 vs. 1	0.43	0.206	0.037	0.243	0.076	0.001
Imported from abroad, yes vs no	0.555	0.25	0.026	0.013	0.098	0.894

Note: The typical exchange rate of RMB to US$ equivalent in the period of this survey is 1 RMB = 0.1402 US$.
GLM: generalized linear regression model (dependent variable was logarithm of total medical expenses); ICU: intensive care unit; SE: standard error.
[a] The variable of severe and critical COVID-19 was excluded because it had collinearity with hospitalization in the negative-pressure isolation ward.

The estimated cost of COVID-19 in China

The cost of public health care associated with COVID-19 included the cost of centralised quarantine, NAT, epidemiological surveys, disinfectant and PPE (see Supplementary Table S6). The costs of centralised quarantine for high-risk individuals from abroad, close contacts and postdischarge patients were $1.11 million, $479.93 million and $101.37 million, respectively, totalling $582.41 million. The cost of centralised isolation was $761.24 million, based on the cost of centralised quarantine per 1000 population 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 costs 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 costs 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 $1833.99 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, $1807.42 million and $126.31 million, respectively. Finally, the total cost of public health care as a result of COVID-19 was $6.83 billion.

As of 20, May, 2020, the total number of COVID-19 cases in China was 82,967, which included 1709 cases from abroad and 81,258 local cases; the estimated number of severe cases was 17,147, and there were 4634 deaths and 78,249 recoveries. According to the average hospitalisation cost of $3792.69 of all cases, the total direct cost of hospitalisation in China was $314.668 million. According to the source of cases, the hospitalisation cost was $314.43 million, and individuals from abroad and local individuals were $7.20 million and $307.23 million, respectively (see Supplementary Table S6). Moreover, 17,147 patients with severe COVID-19 cost $140.10 million, which was almost equal to the cost for 65,820 patients with mild and moderate COVID-19 ($144.04 million). In addition, the hospitalisation cost for 98,430 patients with suspected cases was $58.53 million, and the total hospitalisation cost for patients with confirmed and suspected cases was $373.20 million. The estimated total direct costs of public health care and hospitalisation were approximately $7.2 billion, and the components related to COVID-19 are shown in Supplementary Figure S3.

Discussion

This study found that the total direct medical costs for public health care as a result of COVID-19 were $6.83 billion, which is substantially higher than the hospitalisation cost of $0.37 billion (these sums only consider 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). Our study estimates the public healthcare costs from six aspects, namely, the costs due to centralised 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 healthcare system. In addition, we also estimated the hospitalisation costs, and the results showed that the average cost of hospitalisation for severe COVID-19 was four times that of hospitalisation for non-severe COVID-19 ($9278.05 vs $2017.16).

Estimating the cost of public health interventions for COVID-19 will provide a reference for determining the financial budget of government policy-making departments. Public health measures play critical roles in preventing the spread of emerging novel infectious diseases, such as COVID-19.[14–16] Such diseases require the government and the healthcare system to provide financial support and effective public health care. In addition to outpatient and inpatient treatment expenses, public health services should be paid for by the government. However, there are limited studies estimating the cost of public health care,[17] and to date, no study has calculated the public healthcare cost due to COVID-19. This is the first study to document the public healthcare 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 burden.[17–19] Our study found that the costs of obtaining samples in secondary or tertiary hospitals were five times and two times, respectively, more than the costs of obtaining samples at the CDC, community healthcare centres and township hospitals owing to the higher costs of labour and PPE; this agrees with the findings of a previous study.[17] The average cost of NAT (such as PCR) and diagnostic testing in the high-risk population reached $297.94 per capita, which was six times that in the low-risk population owing to the fact that the number of tests per capita was far larger in the

high-risk population.[20,21] The huge cost of NAT should be considered when deciding which population groups need 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-19[22] because they can reduce the spread of the pandemic. The main cost incurred by epidemiological investigation is that associated with labour.[17] This study found that the average epidemiological survey costs were approximately $389.84 for confirmed cases and $243.50 for suspected cases, which is 20–30 times higher than costs for other 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 labour involved in the control of COVID-19 and did not include the general salaries of medical employees.

Another critical measure for preventing the spread of SARS-CoV-2 in China is to require the use of disinfectant[23] and PPE.[24] Based on the current estimation, the cost of the additional disinfectant accounted for more than 5% ($0.35 billion) of the public healthcare costs associated with COVID-19, primarily driven by the cost of the disinfectant solutions and the materials themselves. The cost of disinfection reported in our study is lower than the actual cost because the labour cost associated with the disinfection of hospital waste was not calculated. Wang et al.[23] 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 healthcare 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;[13,25,26] one study suggested wearing PPE in certain circumstances,[25] and one study from Wuhan found that the use of PPE can protect healthcare professionals from COVID-19.[27]

Moreover, the centralised quarantine of high-risk populations is another effective way to reduce transmission,[28] minimising the spread of COVID-19 among family members and the community.[29] In this study, we found that the cost of centralised quarantine accounted for 19.68% of the increased public healthcare costs associated with COVID-19, including the Chinese government's reimbursements for medical expenses and the costs of the accommodation and meals provided during centralised quarantine (it is important to note that the provision of these items significantly improved compliance with centralised 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-19.[30] Our study found that the making of videos and publicity materials by authorities and the healthcare system to increase public awareness of COVID-19 accounted for 1.85% of the public healthcare costs associated with COVID-19 and had a significant effect.[30]

Isolation within hospitals is necessary for patients with confirmed and suspected cases of COVID-19,[12,21] and the choice of treatment for patients was impacted by the method of compensation for hospitalisation expenses. To provide hospitalisation 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 hospitalisation-associated costs for patients with confirmed cases (Supplementary Table S5). In contrast, out-of-pocket healthcare costs have placed an enormous burden on many patients with COVID-19 in some countries, preventing patients from receiving medical treatment[31] 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)[32] and 3.68 times that of the average medical expenses for bacterial pneumonia ($1039.71 in medical costs in 2020 values), which was similar to the results of Bartsch et al.[12] 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.[32–34] Moreover, we found that the hospitalisation-associated costs for severe patients with COVID-19 (those treated in the NPIW, treated with non-invasive ventilation, treated in the ICU, and with two or more hospitalisations), patients from abroad and older patients were greater than those for their counterparts, which was in agreement with the findings of another published study.[17] The hospitalisation-associated costs in our study included only the expenses incurred during hospitalisation 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 diabetes.[34] Furthermore, the costs of subsidies for emergency medical personnel (40,000 medical staff members supported the efforts to control COVID-19 in Wuhan), follow-up care and potential rehospitalisation are likely to be considerable because of the long-term effects of COVID-19,[35] making patients more susceptible to other health problems. These costs will further increase the cost of hospitalisation. The compensation policy for out-of-pocket hospitalisation costs for COVID-19 in China and the average hospitalisation cost in our study will provide references for other countries coping with the pandemic.

The current study has several limitations. 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 reduced economic activity and lost productivity owing to absenteeism and premature mortality, as we cannot contact the patients during the pandemic. In addition, we can only get the hospitalisation cost from the medical insurance information systems. 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. Fourth, costs for environmental NAT sampling were not included in this study, which may underestimate the cost of public health care of COVID-19. Fifth, 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 labour costs. Finally, we did not test the external validity of this study because we did not obtain the cost data from other areas of China.

However, the data regarding COVID-19 were from the National Health Commission of People's Republic of China (http://www.nhc.gov.cn/), which collected information from patients in all of China. In addition, the Jiulongpo District, from which we collected the COVID-19 public healthcare and hospitalisation cost data, is a middle-income area in China, which may partially, represent an average cost of hospitalisation and treatment in the whole of China. Furthermore, and different to other countries, the health policies (especially the policies on COVID-19 medication and public health) were exactly the same throughout mainland China. The facilities, equipment, drugs and health services were uniformly priced by the

Chinese government, so that even the cost data from a small part of China, such as Jiulongpo district, can represent the data for the whole of mainland China, which results in our conclusions having good external validity.

In conclusion, this study found that the COVID-19 pandemic has resulted in the expenditure of $6.83 billion in public health care and $0.37 billion in direct medical costs associated with hospitalisation. As large numbers of people must be tested and treated to prevent hospitalisation and potential death, the public healthcare costs were far greater than the hospitalisation costs. This suggests that governments should plan to increase the financial investment both in emergency public health care and hospitalisation during infectious disease outbreaks to effectively contain the spread of disease. 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. Therefore, tremendous health resources are needed to control the outbreak of infectious disease pandemics. However, at the beginning of pandemics, the medication and public healthcare costs of infectious diseases (such as SARS or COVID-19), are often not covered by health insurance, which will be an obstacle for the quick control of the pandemic. The quick control of the COVID-19 pandemic in China has been described in our previous study.[8] The estimated cost of pandemic control, especially the financial resources required from government to cover the medication and public health demand, will be of great help in achieving the goal to prevent the 'burst-out' situation of an infectious disease public health emergency.

Author statements

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Ethical approval

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 patients.

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Competing interests

The authors declare that they have no competing interests.

Author contributions

An X and Xiao L conceived and designed the study; Yang X and Tang X participated in the acquisition and management of the data; An X analysed the data; Liang XH wrote the manuscript and all authors revised the manuscript. All authors took responsibility for the integrity of the data and the accuracy of the data analysis. All authors made critical revisions to the manuscript for important intellectual content and gave the final approval of the manuscript.

Data statement

Data are available on request owing to privacy/ethical restrictions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.12.001.

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