Original Article

Analysis of the hospitalization costs of surgical patients with congenital heart disease in the plateau region of western China, 2010–2019

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Background: Congenital heart disease (CHD) is one of the most common birth defects and consumes a substantial amount of health care resources. CHD leads to heavy economic burdens for families. However, there are limited data regarding the utilization of healthcare resources for CHD. The objectives of this study were to evaluate the composition, changing trends, and factors affecting hospitalization costs for patients with CHD in the western highlands area of China over a 10-year period.

Methods: We conducted a study using the International Quality Improvement Collaborative for Congenital Heart Surgery (IQIC) database and information management system of The First Hospital of Lanzhou University between January 2010 and December 2019.

Results: Among 3,087 patients hospitalized for CHD surgery, annual CHD hospitalization costs saw an increasing trend over the 10-year period, with an average growth rate of 4.6% per year. The major contributors to the hospitalization costs were surgery, surgical material, and drug costs. Length of stay (β=0.203; 0.379; 0.474, P<0.01), age at hospitalization (β=0.293, P<0.01), proportion of surgery (β=0.090; –0.102; –0.122; –0.110, P<0.01) and drug costs (β=–0.114; –0.147; –0.069, P<0.01), and use of traditional Chinese medicine (β=0.141, P<0.01) were independent factors affecting average hospitalization costs.

Conclusions: The financial burden of patients with CHD in the Chinese western highland region is high. Independent of inflation, CHD hospitalization costs are increasing. Measures taken by medical institutions to control the increase in drug costs, and to shorten the length of stay may be expected to have positive effects on reducing the financial burden of individuals with CHD and their families.

Keywords: Congenital heart disease (CHD); hospitalization costs; length of stay; influencing factors; random forest model

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Introduction

Globally, the prevalence of congenital heart disease (CHD) is on the rise. In China, surveillance data show that the incidence of CHD has increased since 1997, with a similar trend observed in the Chinese western highland areas (1). The Annual Report on Cardiovascular Health and Diseases in China reported that 90,000 to 150,000 neonates are born with CHD each year (1).

Although the overall child mortality caused by CHD has declined recently, the disease burden caused by CHD remains high in low- and middle-income countries where complex healthcare resources are relatively scarce (2). Newborns with CHD frequently need early surgical treatment after birth, and patients with CHD often require long-term expert medical care and higher health care-related costs throughout their lives, leading to financial impact (3,4). Hospitalization costs constitute the primary component of the direct financial burden.

Accumulating evidence suggests an increased incidence of CHD among newborns in highland areas where chronic exposure to a high altitude, hypoxic environment may be a risk factor for CHD (5). Moreover, the geographical distributions of economic and medical resources in China are manifestly uneven, and considerable subnational disparities exist in individuals' access to high-quality care (6). The disparity in the accessibility of high-quality medical resources has led to a more common phenomenon of missing the optimal age of treatment for patients with CHD in China, especially in western resource-scarce regions. Therefore, it is imperative to have reliable information on the current medical costs for CHD treatments so that allocation of healthcare resources can be improved to cope with the medical challenges brought about by CHD in order to provide timely interventions for optimal outcome.

For these reasons, we sought to (I) describe the evolution of hospitalization costs and, (II) characterize the factors influencing the change in hospitalization costs over a 10-year period in the Chinese western highland area. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1246/rc).

Highlight box

Key findings

- The economic burden of hospitalized patients with congenital heart disease (CHD) remains high in the western region of China.

What is known and what is new?

- Patients with CHD have heavy economic burden in low and middle-income countries.
- The age at surgery, length of stay, and cost of surgery were related to hospitalization costs.

What is the implication, and what should change now?

- Hospitalization costs for patients with CHD can be reduced by measures to control drug costs and reduce length of hospital stay.

Methods

Study design and data sources

This was a study using the International Quality Improvement Collaborative for Congenital Heart Surgery (IQIC) database (URL: https://childrensheartlink.org/) and the information management system of The First Hospital of Lanzhou University, Lanzhou, Gansu Province. The Department of Cardiovascular Surgery at the hospital is the largest cardiovascular surgery center in the Chinese western highland region, and is the treatment facility for patients with CHD in the western region of China. We identified CHD patients who were admitted to the hospital from January 1, 2010, to December 31, 2019, using the International Classification of Diseases, 10th revision (ICD-10).

Data collected included: demographic variables (age, sex, ethnic group), admission date, discharge date, discharge diagnosis, and surgical procedures. The cost of hospitalization was obtained from the hospital billing data system that contained detailed line-item charges comprised of the following categories: (I) medical service (including registration and outpatient consultation costs), (II) treatment (excluding drugs and diagnostic costs), (III) diagnostic (medical technology and clinical consultations), (IV) blood transfusions, (V) drug (use of medications), (VI) nursing care, (VII) surgery, and (VIII) surgical material costs. Annual hospitalization costs were expressed in U.S. dollars according to the 2010 average exchange rate (1 US $ for 6.7695 RMB) issued by the National Institute of Statistics.

Study subjects

All hospitalizations with a CHD code (ICD-10 Q20.0, Q21.0, Q21.1, Q21.2, Q21.3, and Q25.0) as the primary diagnosis were included. The CHD subtypes involved in this study were the following six subtypes: ventricular septal defect (VSD), atrial septal defect (ASD), patent ductus arteriosus (PDA), tetralogy of Fallot (TOF), endocardial cushion defect (ECD), and double outlet right ventricle (DORV) (Table S1). We broadly classified CHD as simple, complex, and compound defects in accordance with the U.S. Centers for Disease Control and Prevention criteria (7), the classification proposed by the New England Regional Infant Heart Protocol (8), the definition of critical CHD by the International Center for Birth Defects Detection and Research (9), the definition of critical CHD by the International Center for Birth Defects Detection and Research, and the actual difficulty of the operation.

Other inclusion criteria were surgical treatment during hospitalization and length of stay >1 day. The exclusion criteria included incomplete case records, discrepancy between the breakdown of hospitalization costs and total hospitalization costs, or erroneous values in the collected information. After sorting and checking the original data, a total of 3,201 pieces of CHD patient-related information were screened from the database, 114 invalid cases were excluded according to the exclusion criteria, and 3,087 valid cases were ultimately included.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of the First Hospital of Lanzhou University (No. LDYYLL2022-32) and individual consent for this retrospective analysis was waived.

Study methods

Comparable conversion of hospitalization costs

As the study spanned over a period of 10 years, the cost of hospitalization could be subjected to the influence of price and policy changes over the years. In order to mitigate these factors, the gross domestic product (GDP) deflator was used for the comparability transformation of hospitalization costs to enhance the comparability of hospitalization costs across years, and ensure the consistency and reliability of data (10). The GDP deflator reflects the trend and magnitude of changes in the price level of GDP in different epochs. The GDP deflator for each year was calculated using year 2010 as the reference period (Table S2).

$$GDP\ deflator = \frac{Nominal\ GDP}{Real\ GDP} \quad [1]$$

In Eq. [1], the nominal GDP represents the actual value during the reporting period, but the value includes price changes. The real GDP refers to the value calculated using the price level of a specific period as the constant price.

Calculated indicators

$$Adjusted\ hospitalization\ costs = \frac{Nominal\ hospitalization\ costs}{GDP\ deflator} \quad [2]$$

$$Chain\ growth\ rate = \left(\frac{a_n}{a_{n-1}}\right) - 1 \quad [3]$$

$$Average\ growth\ rate = \sqrt[n]{\frac{a_n}{a_0}} - 1 \quad (n = 1, 2, 3, \ldots, 9) \quad [4]$$

In Eqs. [3] and [4], the average growth rate is the average of the chain growth rate for each year, which represents the average change in hospitalization costs over a period of time. a_0 represents the average hospitalization costs in 2010, and a_n represents the n_{th} average hospitalization costs. a_{n-1} represents the value of the previous year.

The new grey relational analysis model

The grey correlation analysis model has the advantages of requiring fewer samples, simple arithmetic, easy testing, and there is no discrepancy between quantitative and qualitative results, which can make up for the problems caused by regression analysis, principal component analysis, and other mathematical and statistical methods for system analysis. Therefore, grey correlation analysis is a good means of judging social events and issues that are affected by various influences from a holistic viewpoint. The data on hospitalization costs present a certain degree of uncertainty, or grey characteristics because medical expenses are affected by a variety of complex factors. The grey relational analysis model was utilized to analyze the internal influencing factors of hospitalization costs. The grey relational analysis model assesses the relational degree between the factors based on the similarity or difference of the changing patterns and trends among factors. If the synchronous degrees of change of two variables are consistent, the related degree is greater; conversely, it is lower (11). The average hospitalization costs per year were used as the reference sequence, and the component costs (surgery costs, surgical material costs, drug costs, etc.) were used as the comparison sequence in this study. After determining the reference sequence and the comparison sequence, the difference sequence $\Delta_y(i)$ was calculated as follows:

$$\Delta_y(i) = |X_0(i) - X_y(i)| \quad (y = 1,2,\ldots,9, \quad i = 1,2,\ldots,10) \tag{5}$$

In Eq. [5], $\Delta_y(i)$ is the difference sequence between the comparison sequence $X_y(i)$ and reference sequence $X_0(i)$.

The correlation coefficient was calculated by the following formula:

$$\varepsilon_y(i) = \frac{\min \Delta_y(i) + \rho \max \Delta_y(i)}{\Delta_y(i) + \rho \max \Delta_y(i)} \quad (y = 1,2,\ldots,9, \quad i = 1,2,\ldots,10) \tag{6}$$

In Eq. [6], $\varepsilon_y(i)$ is the i-th element's correlation coefficient between the comparison sequence $X_y(i)$ and the reference sequence $X_0(i)$, $0 < \varepsilon_y(i) \leq 1$. ρ is the resolution coefficient ($0<\rho<1$). The resolution is best when $\rho \leq 0.5463$. The ρ value is 0.5, according to the related literature (12).

The value of the relational degree directly reflects the pros and cons of each comparison sequence and the reference sequence. The greater the relational degree, the greater the influence of the comparison sequence on the reference sequence.

The formula for calculating the degree of relationship is as follows:

$$\gamma_y = \frac{1}{N}\sum_{i=1}^{n} \varepsilon_y(i) \quad (i = 1,2,\ldots,10, \quad N = 10) \tag{7}$$

In Eq. [7], γ_y is the relational degree and $\varepsilon_y(i)$ is the correlation coefficient of the i-th element between the comparison sequence $X_y(i)$ and the reference sequence $X_0(i)$.

Statistical analysis

Data were summarized using median [interquartile range (IQR)] (for average hospitalization costs), and frequency and percentage (for categorical variables), as appropriate. The Shapiro-Wilk test was used to test the normality of continuous variables. The Mann-Whitney *U* test and Kruskal-Wallis *H* test were utilized to test comparison of medians. Since the distribution of the hospitalization costs was non-normal, we performed natural log-transformation of the costs to approximate a normal distribution. Multiple linear regression model was employed to analyze the factors influencing hospitalization costs. Age at hospitalization, sex, type of CHD, length of stay, proportion of drug costs, proportion of surgery costs, and use of traditional Chinese medicine were included in the linear regression model. Then, the random forest regression model was adopted to analyze the importance of the factors. The random forest regression model consists of multiple regression trees, decision trees in the forest are not connected to each other, and the final output of the model is jointly determined by each decision tree in the forest. The function of the model is to measure the importance of the covariables and to screen out variables with good correlation from multiple variables by performing repeated sampling of training samples with replacement, classifying the samples by building decision trees, and selecting highly related variables from different samples (13). In the random forest model, the number of random seeds was set to 1,000, the number of tree classifiers was set to 500, and the number of branches was selected as 3. First, the training set and the test set were identified. The training set was used to build the model, and the test set was used to evaluate the fitting effect and prediction performance of the model. Then, we randomly assigned the training set and test set sample cases at a ratio of 7:3. Finally, the value of the increase in the mean squared error (%lncMSE) was used to determine the importance of each influencing factor of the average hospitalization costs. The value of %lncMSE was higher, and the importance of the influencing factors was greater. All analyses were conducted using the Statistical Package for Social Sciences (SPSS version 22.0) and R (version 4.2.0). A P value <0.05 was interpreted as evidence of statistical significance.

Results

Patient population

We identified 3,201 CHD cases who were admitted to the hospital during our study period. After excluding 114 invalid cases, our study cohort consisted of 3,087 CHD cases (*Figure 1*). The most common subtypes of CHD were VSD (40.4%), ASD (35.6%), and PDA (10.8%) (*Table 1*). In this study, 8.1% of the patients had complex CHD, with TOF (4.2%) being the commonest complex CHD. Overall, 59.3% were female and a vast majority were Han Chinese (91.3%) (*Table 2*). There was a bimodal distribution of age at surgery: early childhood (1–4 years, 32.6%), and adulthood (>17 years old, 41.2%). For

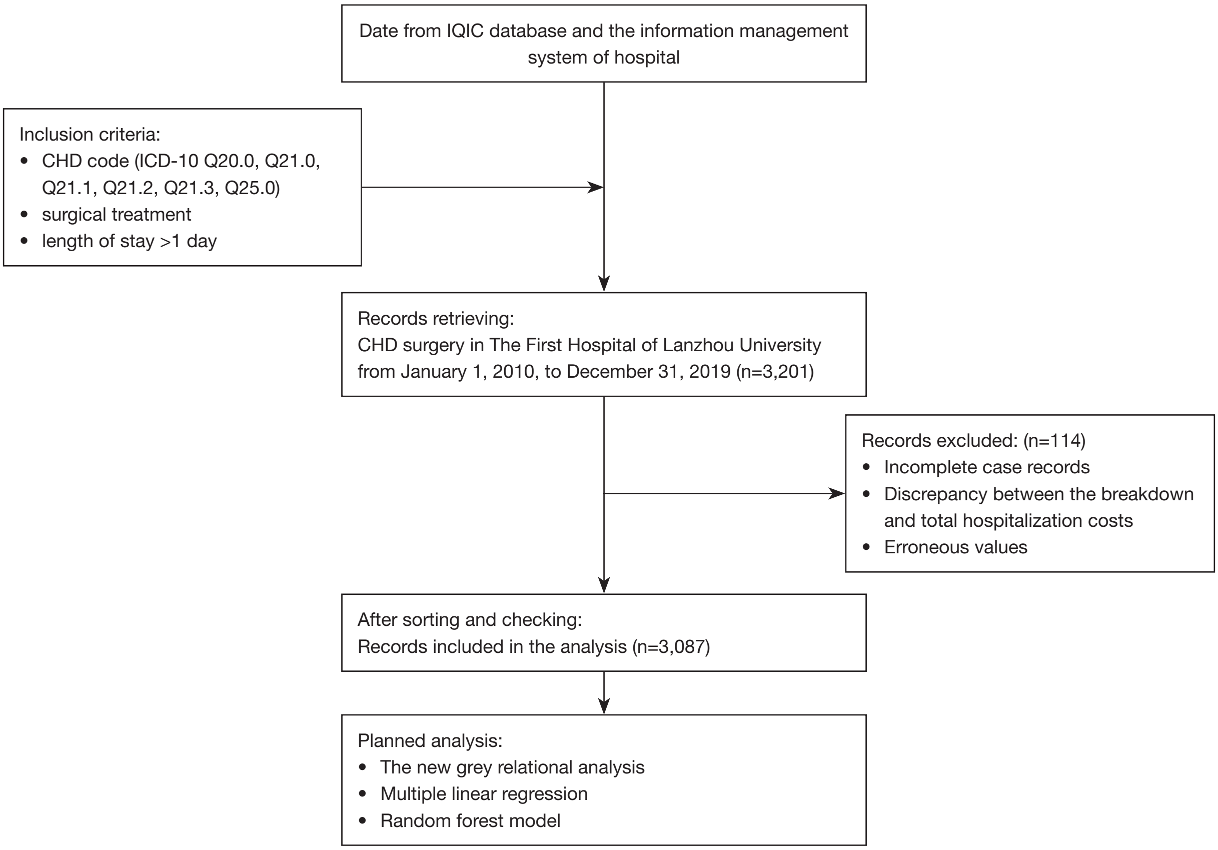

Figure 1 The flowchart of the analysis. IQIC, International Quality Improvement Collaborative for Congenital Heart Surgery; CHD, congenital heart disease; ICD-10, International Classification of Diseases, 10th revision.

Table 1 Disease composition of patients who underwent CHD surgery (n=3,087)

Subtypes of CHD	n	%
Simple CHD	2,679	86.8
VSD	1,247	40.4
ASD	1,099	35.6
PDA	333	10.8
Complex CHD	250	8.1
TOF	128	4.2
DORV	42	1.4
ECD	80	2.5
Compound defects	158	5.1
Total	3,087	100.0

CHD, congenital heart disease; VSD, ventricular septal defect; ASD, atrial septal defect; PDA, patent ductus arteriosus; TOF, tetralogy of Fallot; DORV, double outlet right ventricle; ECD, endocardial cushion defect.

patients with complex CHD and compound defects, most were treated surgically early in life (1–4 years old) (*Table 2*).

The composition and trend analysis of hospitalization costs for patients with CHD

The average hospitalization cost of surgery patients with CHD was $5,279.27 from 2010–2019. The average length of stay was 15 days (Table S3). During the study period, we observed an overall increase in the cost of hospitalization, with an average growth rate of 4.55% per year. Specifically, an upward trend in hospitalization costs for patients with CHD was observed from 2011–2013, 2014–2017 and 2018–2019, and with a substantial increase in year 2012 compared to 2011 (chain growth rate of 19.0%). However, there was reduction in the average hospitalization costs from 2010–2011, 2013–2014, and 2017–2018 (Figure S1). Compared to the year 2017, hospitalization costs decreased significantly in 2018, with a chain growth rate of –14.7%.

Table 2 Demographic characteristics of patients with CHD (n=3,087)

Variables	Total, n (%)	Simple CHD, n (%)	Complex CHD, n (%)	Compound defects, n (%)
Sex				
Male	1,257 (40.7)	1,076 (40.1)	110 (44.0)	71 (44.9)
Female	1,830 (59.3)	1,603 (59.9)	140 (56.0)	87 (55.1)
Ethnic group†				
Han	2,819 (91.3)	2,455 (91.6)	219 (87.6)	145 (91.8)
Hui	144 (4.7)	123 (4.6)	15 (6.0)	6 (3.8)
Tibetan	60 (1.9)	48 (1.8)	9 (3.6)	3 (1.9)
Others	64 (2.1)	53 (2.0)	7 (2.8)	4 (2.5)
Age at hospitalization, years				
<1	70 (2.3)	55 (2.0)	10 (4.0)	5 (3.2)
1–4	1,007 (32.6)	805 (30.1)	122 (48.8)	80 (50.6)
5–7	344 (11.1)	301 (11.2)	18 (7.2)	25 (15.8)
8–11	189 (6.1)	155 (5.8)	24 (9.6)	10 (6.3)
12–17	205 (6.6)	171 (6.4)	21 (8.4)	13 (8.3)
>17	1,272 (41.3)	1,192 (44.5)	55 (22.0)	25 (15.8)

†, according to statistics, the most populous ethnic groups in the area are Han, Hui, and Tibetan. Therefore, in this study, we divided ethnic groups into the following four categories: Han, Hui, Tibetan, and other ethnic groups. CHD, congenital heart disease.

From 2010–2012, the major contributor to the hospitalization costs was surgical material costs, followed by surgery and drug costs. However, from 2013 to 2019, surgery costs accounted for the largest proportion of hospitalization costs followed by surgical material and drug costs. The proportion of drug costs saw three stages of sharp declines from 2010 to 2019, with the most rapid decline in 2013–2014. Compared to 2010, the proportion of surgery costs increased, while the proportion of surgical material and drug costs decreased in 2019. Additionally, there was an upward trend in nursing care costs from 2015–2019, and notably, the proportion of nursing care costs in 2019 almost tripled that in 2010 (Table S4). In terms of the average annual cost of each component of hospitalization costs, blood transfusions costs continued to decrease from 2010 to 2013. An overall upward trend was shown in nursing care costs, and nursing care costs rose rapidly from 2015 to 2019. The average drug costs fluctuated between $700 and $1,200 from 2010 to 2019. The average treatment costs increased yearly from 2011–2016 (Figure S2). Irrespective of the CHD category (simple CHD, complex CHD, or compound defects), the largest contributor of hospitalization costs was surgery costs. The lowest contributor of hospitalization costs was blood transfusions costs for inpatients with simple CHD and compound defects. Interestingly, medical service costs accounted for the lowest percentage of hospitalization costs for patients with complex CHD (Figure S3).

The results of new grey relational analysis

Overall, the top three relational coefficients for hospitalization costs were surgery, surgical material, and drug costs (Table S5). However, in year 2016, the top three relational coefficients of the average hospitalization costs were surgery, surgical material, and treatment costs. From 2010 through 2012, the correlation coefficients between surgical material costs and average hospitalization costs were the greatest, at 0.921, 1.00, and 0.797, respectively. However, the correlation coefficients between surgery costs and average hospitalization costs were greatest from 2013 through 2019. The correlation degrees of each average component cost were obtained by bringing the data in Table S5 into Eq. [3] and sorting the correlation degrees. From 2010–2019, the correlation degrees of the component costs were ranked as follows: surgery costs (0.715), surgical material costs (0.703), drug costs (0.625), diagnostic costs

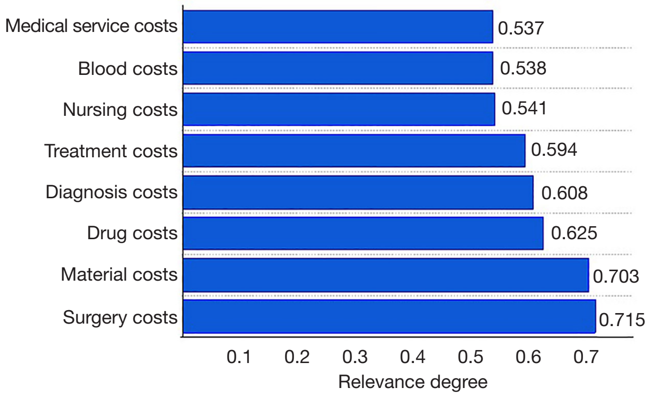

Figure 2 The relevance degree and relevance order of the average costs of each item for hospitalized patients with CHD from 2010 to 2019. CHD, congenital heart disease.

(0.608), treatment costs (0.594), nursing care costs (0.541), blood transfusions costs (0.538), and medical service costs (0.537). The relevance degree and relevance order were the largest for surgery costs, which indicated that surgery costs had the greatest influence on average hospitalization costs. The least related to the average hospitalization costs were medical service costs, suggesting that medical service costs were the internal component with the least impact on hospitalization costs (*Figure 2*).

Analysis of the factors influencing hospitalization costs for patients with CHD

There were significant differences in the average hospitalization costs for patients with CHD with respect to age at hospitalization, sex, type of CHD, length of stay, proportion of drug and surgery costs, and the use of traditional Chinese medicine (*Table 3*). The average hospitalization costs were significantly higher for females ($5,652.56 *vs.* males $5,396.30, P<0.01) and complex CHD ($7,015.98 *vs.* compound $5,853.39 *vs.* simple $5,368.88, P<0.01). The hospitalization costs increased with increased length of stay (P<0.01). Compared with other age groups, patients who underwent CHD surgery during infancy ($6,898.47) and as adults ($6,860.15) demonstrated higher hospitalization costs. Hospitalization costs increased significantly as the proportion of total costs for drug costs (P<0.01) and surgical costs (P<0.01) increased. The average hospitalization costs of patients with CHD who were treated with traditional Chinese medicine were significantly higher ($7,163.08 *vs.* $5,148.12, P<0.01). There was no significant difference in the average hospitalization costs across ethnic groups (P=0.08).

As the results of the linear regression model showed, age at hospitalization, type of CHD, length of stay, the proportion of drug costs, the proportion of surgery costs, and the use of traditional Chinese medicine were influential factors in average hospitalization costs (P<0.01) (*Table 4*). Finally, a random forest model revealed that length of stay and age at hospitalization were the strongest factors affecting hospitalization costs (*Figure 3*). The average length of stay for infants with CHD was 23 days, which was much longer than that for other pediatric age groups. On the other hand, the average length of stay for adults with CHD was 15 days (*Figure 4*).

Discussion

This study examined the cost of hospitalization for patients with CHD in the plateau region of western China over a 10-year period. Consistent with domestic and international reports, VSD was the most prevalent malformation among CHDs. A bimodal distribution was observed for age at CHD surgery with peaks during the toddler age group (1–4 years) and during adulthood. We found that there was an increase in CHD hospitalization costs over time, with major contributors being surgery, surgical material and drug costs. Length of stay and age at hospitalization were the two strongest factors influencing cost of hospitalization.

In our study, the average hospitalization cost for inpatients with CHD was $5,279.27, which was relatively higher than other regions of China (Table S6). Overall, our study demonstrated an increase in CHD surgery and hospitalization costs from 2010 through 2019, with an average growth rate of 4.6% per year. This is an indication of the increasing economic burden for patients with CHD, which remained high in these areas. However, the decrease in hospitalization costs during two of the studied years might be related to the implementation of local health care reform policies. (I) The provincial government issued an implementation plan for improving the reform of the medical and health system in 2013; (II) the area adjusted the prices of medical services in public hospitals in 2017 (14).

During the 10-year period, the top three contributors of hospitalization costs were, surgery, surgical material, and drug costs. The decline in the proportion of drug costs was inseparable from the implementation of the policy of gradually canceling drug mark-ups and implementing zero-mark-up on sales of drugs in the reformation of medical

Table 3 Comparison of the differences in hospitalization costs for CHD patients across different characteristics (n=3,087)

Variables	n	Average hospitalization cost ($), median (IQR)	*Z/H*	P
Age, years				
<1	70	6,898.47 (5,421.41–8,617.59)		
1–4	1,007	4,924.54 (4,442.81–6,164.15)		
5–7	344	4,640.72 (4,144.91–5,229.66)	709.27	<0.01
8–11	189	4,546.30 (3,978.34–5,191.83)		
12–17	205	5,002.63 (4,331.74–6,192.64)		
>17	1,272	6,860.15 (5,576.99–8,742.51)		
Sex				
Male	1,257	5,396.30 (4,636.85–7,359.60)	2.09	<0.01
Female	1,830	5,652.56 (4,637.02–7,358.01)		
Ethnic group				
Han	2,819	5,489.25 (4,546.47–7,308.27)		
Hui	144	5,900.09 (4,854.70–7,817.42)	6.59	0.08
Tibetan	60	5,921.45 (4,794.10–7,644.05)		
Other	64	5,666.64 (4,616.88–8,292.22)		
Type of CHD				
Simple CHD	2,679	5,368.88 (4,540.29–7,058.41)	107.56	<0.01
Complex CHD	250	7,015.98 (5,797.94–9,206.82)		
Compound defects	158	5,853.39 (4,834.50–7,647.89)		
Length of stay, days				
<10	436	4,549.22 (4,039.02–5,007.82)		
10–19	1,820	5,242.65 (4,524.03–6,494.46)	976.91	<0.01
20–29	607	7,449.53 (5,820.82–9,518.26)		
>29	224	11,102.14 (8,215.01–14,744.06)		
Proportion of drug costs, %				
<10	641	4,893.12 (4,501.53–6,158.31)		
10–19.99	1,544	5,667.76 (4,556.93–7,931.52)	68.74	<0.01
20–29.99	831	5,799.00 (4,783.60–7,129.89)		
>29.99	71	6,774.80 (5,770.58–8,677.47)		
Proportion of surgery costs, %				
<10	260	4,776.89 (4,543.27–5,122.79)		
10–19.99	471	5,122.79 (5,105.20–6,090.67)		
20–29.99	1,444	5,150.35 (4,294.70–6,546.26)	641.46	< 0.01
30–39.99	592	6,475.24 (5,342.35–7,926.26)		
>39.99	320	8,665.23 (7,354.3750–10,773.56)		
Use of traditional Chinese medicine				
No	2,355	5,148.12 (4,461.44–6,609.43)	9.16	< 0.01
Yes	732	7,163.08 (5,735.70–9,297.58)		

IQR, interquartile range; CHD, congenital heart disease.

Table 4 Multiple line regression analysis of hospitalization costs for patients with CHD

Variables	Unstandardized coefficients		Standard coefficient	*t*	P
	B	SE	β		
Constant	4.485	0.016		275.287	<0.01
Age at hospitalization, years	0.003	0.000	0.293	21.120	<0.01
Sex					
Male	–	–	–	–	–
Female	–0.010	0.004	–0.029	–2.357	0.018
Type of CHD					
Simple CHD	–	–	–	–	–
Complex CHD	0.085	0.008	0.135	10.465	<0.01
Compound defects	0.046	0.010	0.059	4.711	<0.01
Length of stay, days					
<10	–	–	–	–	–
10–19	0.071	0.007	0.203	10.631	<0.01
20–29	0.164	0.008	0.379	19.721	<0.01
>29	0.313	0.011	0.474	29.073	<0.01
The proportion of drug costs, %					
<10	–	–	–	–	–
10–19.99	–0.039	0.007	–0.114	–5.745	<0.01
20–29.99	–0.057	0.008	–0.147	–7.166	<0.01
>29.99	–0.079	0.016	–0.069	–4.971	<0.01
Proportion of surgery costs, %					
<10	–	–	–	–	–
10–19.99	0.034	0.013	0.090	2.726	<0.01
20–29.99	–0.037	0.013	–0.102	–2.860	<0.01
30–39.99	–0.061	0.014	–0.122	–4.506	<0.01
>39.99	–0.047	0.014	–0.110	–3.397	<0.01
Use of traditional Chinese medicine					
No	–	–	–	–	–
Yes	0.057	0.005	0.141	10.588	<0.01

CHD, congenital heart disease; B, unstandardized coefficients; SE, standard error; β, standardized regression coefficient.

institutions (13). However, drug costs still accounted for a large proportion, and the composition of costs needs to be further optimized. Through our new grey relational model, we discovered that surgery, surgical material and drug costs were also the major internal components affecting CHD hospitalization costs. Therefore, it is possible to mitigate the increase in hospitalization costs of patients with CHD by adjusting the costs of surgery, surgical materials, and drugs. Government and medical institutions should continue to strengthen the control of drug costs. On the one hand, the use of drugs should be regulated to prevent irrational drug use, and on the other hand, relevant medical insurance

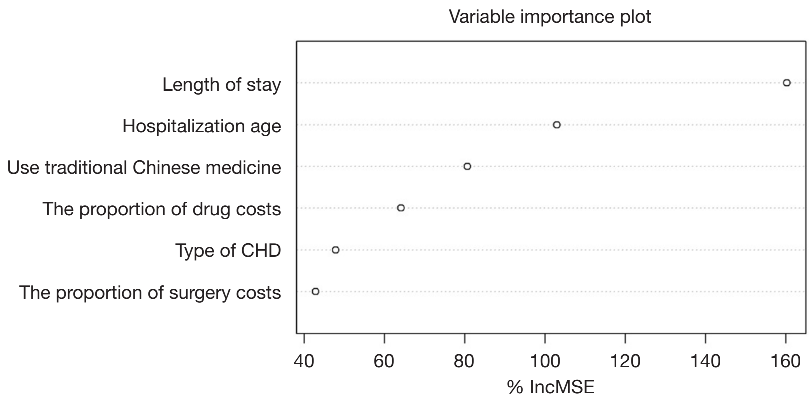

Figure 3 Analysis of the importance of factors that affected the average hospitalization costs of patients with CHD. CHD, congenital heart disease. %IncMSE, the value of the increase in the mean squared error.

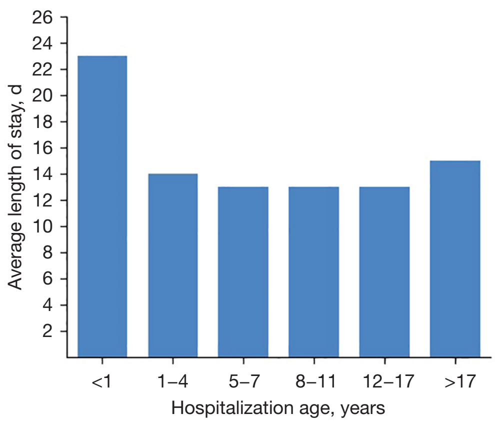

Figure 4 The average length of hospital stay for patients with CHD by age. CHD, congenital heart disease.

departments should strengthen the standardized supervision of drug use, regulate the use of common and special drugs for CHD treatment, and further achieve the control of cost growth. Whether or not to use traditional Chinese medicine is an influential factor in the hospitalization cost. The average hospitalization costs of patients with CHD who were treated with traditional Chinese medicine were significantly higher. Accordingly, appropriately controlling the use or adjusting the prices of traditional Chinese medicines may reduce the hospitalization costs of patients with CHD. In our study, length of stay was the primary influencing factor in hospitalization costs for inpatients with CHD. Length of stay is an important indicator of the quality and efficiency of medical care. An increased length of stay directly leads to an increase in treatment costs, bed costs, and nursing care costs, which results in an increase in total hospitalization costs. Thus, reasonable control of the length of stay is one of the important approaches for reducing hospitalization costs. Numerous studies have demonstrated that the clinical pathway is an effective measure to shorten the average length of stay. Some unnecessary diagnostic and treatment behaviors can be eliminated by the adoption of the clinical pathway. In the Clinical Pathways for 5 Diseases in Cardiac and Great Vascular Surgery [2010] issued by the Ministry of Health, the clinical pathways for 3 types of CHD in children, including ASD, VSD, and PDA, were formulated (15). The standardized management of clinical pathways clearly defines the use and timing of diagnosis and treatment items in children. Shortening the length of stay of children could control medical costs to a certain extent and further achieve a reduction in hospitalization costs (16). Therefore, management of the clinical pathway for CHD and reasonably shortening the number of ineffective hospitalization procedures can not only improve the hospital's bed turnover rate and economic benefits but also reduce the economic burden of patients with CHD. The overall increase in the average hospitalization costs for patients with CHD in this study might be attributed to the late implementation of the clinical pathway in the area. In addition, western plateau regions have relatively scarce medical services and a suboptimal healthcare system.

Additionally, age at hospitalization was one of the important factors that affected hospitalization costs for patients with CHD. Our findings suggested higher hospitalization costs for CHD among infants, which was consistent with the findings of related studies that investigated CHD hospitalization costs. As evidenced by a recent analysis of national data from the Kids'

Inpatient Database, patients under 1 year had higher mean hospitalization costs than other pediatric patients (17). The average length of stay is higher for infants up to 1 year of age than for other age groups, and they bear higher hospitalization costs. A study has demonstrated that the fatal and nonfatal burden of CHD is highly concentrated among children, especially infants under the age of 1 year (2). Patients with complex CHD tend to be treated surgically early in life. Great strides have been made in prenatal detection and congenital heart surgery over the past few decades, resulting in improved survival rates of neonates with CHD (18). Lu *et al.* demonstrated that the total annual costs of CHD hospitalizations as a percentage of all patient costs decrease during the transition from childhood to adolescence, which was also consistent with our findings (19). The optimal age for CHD treatment is closely related to operative mortality, postoperative complications, long-term prognosis and family economic burden. In our study, adults with a CHD diagnosis represented the largest population of inpatients with CHD. This observation was consistent with the continuing trends of increasing CHD hospitalization among adults (20). The hospitalization costs for CHD in adulthood may overtake the costs incurred in childhood. Interventional cardiology and congenital heart surgery advances have dramatically improved survival rates for the entire spectrum of CHD (21). The majority of children with CHD survive into adulthood, which leads to an increasing disease burden in adult medicine.

The type of CHD was also one of the influencing factors in hospitalization costs. Higher hospitalization costs were observed among patients with complex CHD, consistent with a previous study demonstrating that hospitalization costs were influenced by the complexity of CHD (19). A large study that evaluated hospitalization costs among more than 10,000 patients undergoing congenital heart surgery demonstrated that higher complexity in CHD cases was associated with increased hospital charges (22). Furthermore, the surgical procedures for complex CHD are more complex and cumbersome (14). Therefore, complex CHD patients with more complex operations had a higher economic burden.

Our study has several strengths and some limitations. To the best of our knowledge, it is the first study to examine hospitalization costs among both children and adults with CHD in the plateau region of western China. A major strength of our study was the attempt at accounting for the impact of inflationary pressures, and the changes in healthcare policies externally. There are inherent limitations due to the use of administrative data and to the retrospective nature of our study. In addition, hospitalized patients with CHD were identified by diagnostic codes, and the results of the study need to be interpreted with caution because of concerns about the accuracy of coding. Despite the high coding accuracy, a formal validation study is needed. Although inpatient hospitalization costs account for a large majority of costs, the lack of outpatient costs data constitutes a limitation of the study.

Conclusions

This study showed that the economic burden of hospitalized patients with CHD is high in the underdeveloped western region of China. We found that cost of hospitalization associated with CHD surgery is increasing, independent of inflation. The age at surgery, length of stay, and cost of surgery were related to hospitalization costs. Our findings suggest the need for measures to mitigate the increase in hospitalization costs by controlling drug costs and shortening the length of stay. Appropriate resource allocation may have positive effects on reducing the financial burden of individuals with CHD and their families.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1246/rc

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com/article/view/10.21037/jtd-23-1246/coif). A.M.Q. is a proctor and consultant for W.L. Gore and Associates and Medtronic Inc., outside the submitted work. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of the First Hospital of Lanzhou University (No. LDYYLL2022-32) and individual consent for this retrospective analysis was waived.

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Supplementary

Table S1 Subtypes of CHD diagnostic codes

CHD subtypes	ICD-10
VSD	Q21.0
ASD	Q21.1
PDA	Q25.0
TOF	Q21.3
DORV	Q20.0
ECD	Q21.2

CHD, congenital heart disease; VSD, ventricular septal defect; ASD, atrial septal defect; PDA, patent ductus arteriosus; TOF, tetralogy of Fallot; DORV, double outlet right ventricle; ECD, endocardial cushion defect.

Table S2 2010–2019 GDP deflator

Years	GDP index[a]	GDP deflator[b]
2010	2073.1	100
2011	2271.1	107.5
2012	2449.6	110.8
2013	2639.9	112.5
2014	2835.9	114.7
2015	3035.6	114.1
2016	3243.5	115.7
2017	3468.8	121.0
2018	3703	124.9
2019	3923.3	126.7

[a], The GDP index is a relative value reflecting the trend and degree of changes in GDP over a certain period of time. The data comes from the annual statistical yearbook of the National Bureau of Statistics, with the index of 100 in 1978 as the reference value; [b], the GDP deflator for each year is calculated by taking 2010 as the base period. GDP, Gross domestic product.

Table S3 The average length of stay and average hospitalization costs for hospitalized patients with CHD from 2010 to 2019

Years	N	Average length of stay (days), median (IQR)	Average hospitalization costs ($), median (IQR)	Chain growth rate (%)
2010	266	15 (11–22)	28,814.27 (24,415.50–34,686.71)	–
2011	299	13 (13–18)	26,308.61 (21,292.76–32,176.84)	–8.70
2012	356	14 (11–20)	30,589.87 (26,036.22–37,322.10)	16.27
2013	366	15 (10–20)	31,705.88 (26,260.70–39,634.99)	3.65
2014	388	14 (11–20)	29,182.31 (24,950.34–36,323.73)	–7.96
2015	296	15 (12–21)	34,819.61 (35,501.70–58,622.81)	19.32
2016	269	14 (11–19)	35,090.85 (27,249.13–45,987.66)	0.80
2017	207	17 (14–23)	38,584.93 (28,715.39–51,542.43)	9.96
2018	412	15 (11–21)	31,915.73 (25,841.37–43,957.82)	–17.28
2019	228	14 (10–20)	35,504.37 (27,366.73–50,192.03)	11.24
Total	3087	15 (11–20)	28,393.16 (26,762.98–43,044.71)	3.03

IQR, interquartile range.

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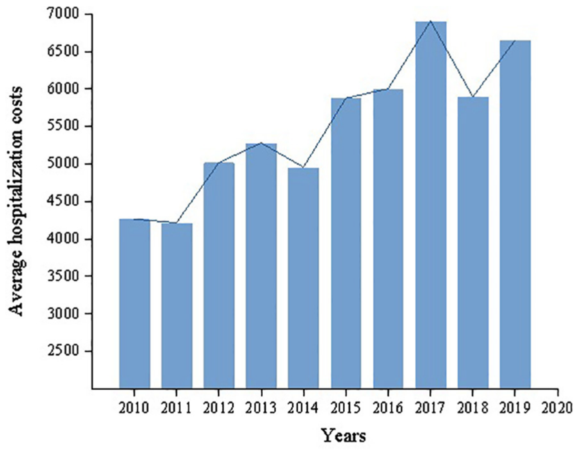

Figure S1 Trends in average hospitalization costs for patients with CHD in 2010–2019.

Table S4 Composition of average hospitalization costs for inpatients with CHD in 2010–2019

Years	Average hospitalization costs ($), median (IQR)	Service costs ($) (%)	Nursing costs ($) (%)	Diagnosis costs ($) (%)	Treatment costs ($) (%)	Surgery costs ($) (%)	Drug costs ($) (%)	Blood costs ($) (%)	Material costs ($) (%)
2010	28,814.27 (24,415.50–34,686.71)	480 (1.67)	369.50 (1.28)	3,541.7 (12.29)	2,526.00 (8.77)	6,059.25 (21.03)	5,455.39 (18.93)	1,114.00 (3.87)	8,445.74 (29.31)
2011	26,489.61 (21,292.76–32,176.84)	390.59 (1.47)	358.04 (1.35)	3,344.37 (12.63)	2,243.00 (8.47)	6,408.25 (24.19)	4,780.23 (18.05)	818.37 (3.09)	76,17.44 (28.76)
2012	30,589.87 (26,036.22–37,322.10)	433.13 (1.42)	416.17 (1.36)	4,034.38 (13.19)	3,637.34 (11.89)	7,325.78 (23.95)	5,268.26 (17.22)	569.61 (1.86)	7,694.64 (25.15)
2013	31,705.88 (26,260.70–39,634.99)	373.16 (1.21)	396.67 (1.25)	4,073.07 (12.85)	3,607.24 (11.38)	7,972.43 (25.16)	5,838.66 (18.41)	257.09 (0.53)	7,580.46 (23.91)
2014	29,182.31 (24,950.34–36,323.73)	400.73 (1.37)	372.16 (1.28)	3,880.06 (13.30)	3,674.10 (12.59)	6,876.51 (23.56)	4,342.88 (14.88)	210.32 (0.73)	6,826.24 (23.39)
2015	34,819.61 (35,501.70–58,622.81)	420.68 (1.21)	384.27 (1.10)	4,119.97 (11.83)	4,263.61 (12.25)	9,099.21 (26.13)	5,929.91 (17.03)	230.04 (0.49)	6,894.64 (19.80)
2016	35,090.85 (27,249.13–45,987.66)	414.94 (1.18)	465.85 (1.38)	4,138.27 (11.79)	4,424.71 (12.61)	9,480.94 (27.02)	4,342.88 (14.88)	209.9 (0.39)	7,752.04 (22.09)
2017	38,584.93 (28,715.39–51,542.43)	710.62 (1.84)	561.89 (1.46)	4,273.26 (11.07)	3,034.29 (7.86)	10,636.81 (27.57)	6,861.80 (17.78)	219.63 (0.57)	8,833.07 (22.89)
2018	31,915.73 (25,841.37–43,957.82)	734.76 (2.30)	722.75 (2.26)	4,065.83 (12.74)	2,954.95 (9.26)	8,743.69 (27.40)	5,393.63 (16.90)	272.28 (0.85)	8,294.25 (25.99)
2019	35,504.37 (2,7366.73–80,593.83)	700.58 (1.97)	1,314.34 (3.70)	4,224.82 (11.90)	3,153.46 (8.88)	10,209.58 (28.76)	5,893.93 (16.60)	252.61 (0.71)	9,365.39 (26.38)

IQR, interquartile range; CHD, congenital heart disease.

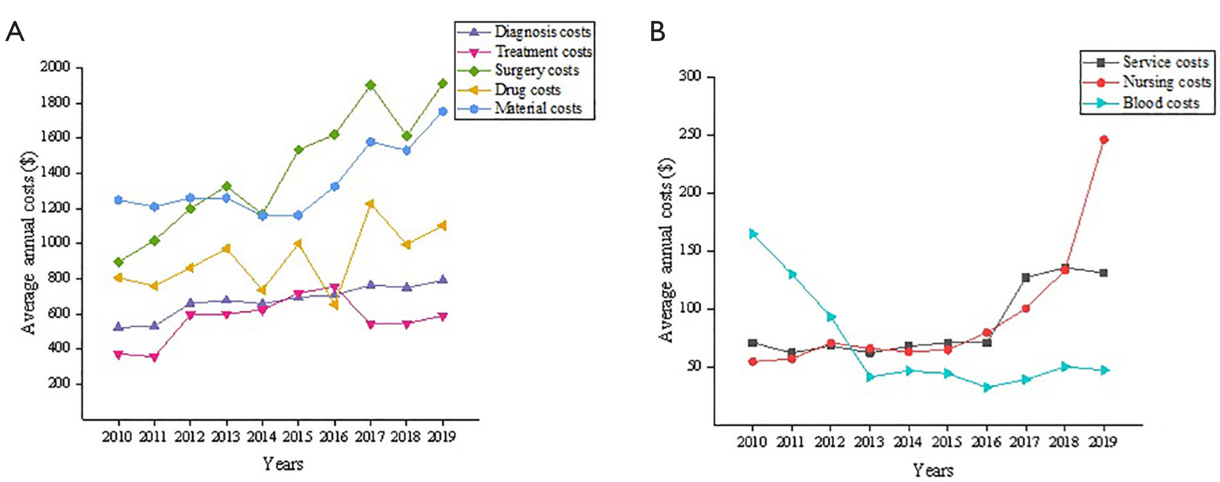

Figure S2 Trends in average annual costs (the components of hospitalization costs) for inpatients with CHD in 2010–2019.

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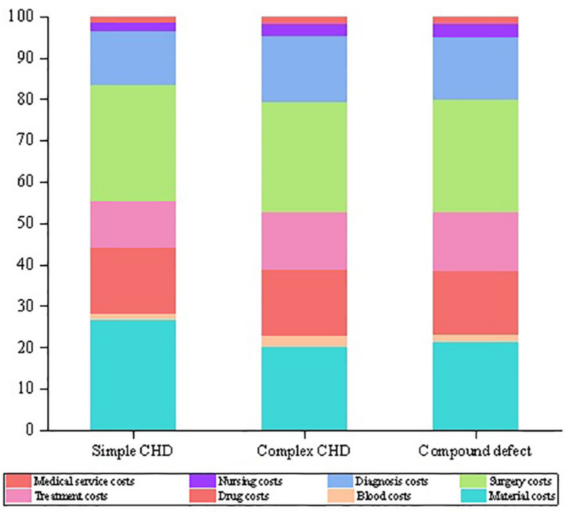

Figure S3 The composition and distribution of hospitalization costs for the three CHD types.

Table S5 The relational coefficient of the average costs of each item for hospitalized patients with CHD from 2010 to 2019

Years	Material costs	Drug costs	Treatment costs	Surgery costs	Diagnosis costs	Nursing costs	Medical service costs	Blood costs
2010	0.921	0.810	0.757	0.864	0.781	0.695	0.696	0.710
2011	1.00	0.851	0.786	0.912	0.821	0.733	0.732	0.744
2012	0.797	0.697	0.671	0.766	0.688	0.603	0.601	0.603
2013	0.73	0.651	0.629	0.741	0.633	0.567	0.551	0.559
2014	0.750	0.656	0.634	0.752	0.645	0.569	0.567	0.564
2015	0.659	0.595	0.565	0.724	0.579	0.514	0.513	0.509
2016	0.625	0.530	0.533	0.695	0.533	0.477	0.475	0.472
2017	0.495	0.476	0.437	0.566	0.445	0.398	0.399	0.396
2018	0.574	0.544	0.494	0.592	0.509	0.453	0.457	0.454
2019	0.519	0.485	0.436	0.526	0.444	0.408	0.399	0.395

CHD, congenital heart disease.

Table S6 The economic burden of CHD in the area compared to other regions

Years	Regions	Health care costs for CHD[a] (CN¥)	Disposable income per capita[b] (CN¥)	Ratios[c]
2019	Gansu, China	35,504.37	19,139.02	1.86
2017	Guangdong, China	37,555.00 (1)	33,003.29	1.14
2015	Qingdao, China	21,693.25 (2)	32,885.00	0.66
2011	Shanxi, China	25,000.00 (3)	21,810.00	1.15
2012	Beijing, China	25,408.00 (4)	36,000.00	0.71
2014	Shandong, China	30,713.99 (5)	20,864.00	1.47

[a], represents health care costs for patients with CHD (including average hospitalization costs, direct medical costs, etc.); [b], The data on disposable income per capita in each region is obtained from the National Bureau of Statistics; [c], represents the ratio of hospitalization costs to disposable income per capita. CHD, congenital heart disease.

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