Hospitalization costs due to healthcare-associated infections: An analysis of propensity score matching

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ARTICLE INFO

ABSTRACT

Background: In 2018, diagnosis-related group-based prospective payment system (DRG-PPS) was implemented nationwide by China that did not fully consider the additional costs caused by healthcare-associated infections (HAIs). HAIs can increase hospitalization costs, but only a few studies have been conducted in China. We aimed to assess the additional costs caused by HAIs.
Methods: A retrospective matched case-control (1:1) study was performed in one of the largest tertiary hospitals in Sichuan Province, China. A multiple linear regression was used to identify confounding factors, and the propensity score matching (PSM) method was used to balance confounding factors between cases and controls. On this basis, we estimated the additional costs caused by HAIs.
Results: Of the 109,294 inpatients observed, 1912 had HAI. After the PSM method was implemented, 1686 cases were successfully matched. Median hospitalization costs were €5613.03 for patients with HAIs and €3414.83 for patients without HAIs ($P < 0.001$), resulting in an absolute difference of €2198.19. With the exception of pathological diagnosis costs, surgical treatment costs and disposable medical material costs for surgery, all other types of costs for the cases with HAIs were larger.
Conclusions: Patients with HAIs incurred greater hospitalization costs than non-HAI patients, which warrants closer attention if we are to reform the payment method of medical insurance in China.

Introduction

In January 2018, the Chinese government issued a plan to reform the medical insurance payment method that required the full implementation of the medical insurance payment method based on the diagnosis-related groups-based prospective payment system (DRG-PPS) [1]. Under the guidance of this document, most provinces refined catalogues of payment standards by DRG-PPS [2]. China's medical insurance payment methods are gradually changing from fee-for-service (FFS) to DRG-PPS-based hybrid payment systems. Different from the more mature DRGs in other developed countries, the DGR-PPS currently being tried by China can be regarded as a transitional version of genuine DRGs [3]. There are numerous problems in the implementation of DRG-PPS, one of which is a lack of consideration for the added economic burden caused by complications such as healthcare-associated infections (HAIs). This situation may result in quota reimbursement if hospitals cannot cover the cost of consumption, which can compel hospitals to reduce the quality of medical care [4,5]. Research

on the extra economic burden caused by HAIs is particularly urgent.

HAIs increase hospitalization costs for patients, reduce health-related quality of life, have a substantial effect on morbidity and mortality, prolong the length of stay, reduce bed turnover rates, and seriously affect the quality of medical care [6–8]. An analysis of the direct economic burden of HAIs can help us explore the value of the prevention and control of HAIs. Many scholars have already reported on the direct economic burden of HAIs [9–12], and their results have revealed wide variation in cost estimates, and in the methods used to estimate costs. One reason for this phenomenon may be differences in regional economic levels, hospital levels, and health insurance policies. It is also possible that various confounding factors have affected study results. Therefore, we used a propensity score matching analysis (PSM) to analyze the direct economic burden of HAIs with the goal of minimizing the influence of confounding factors. PSM is a method of control bias in non-randomization studies. The goal is to achieve randomization through PSM. Currently, PSM is commonly used in two-group data research.

Material and methods

Design

A retrospective case control study was performed in one of the largest tertiary A-level hospitals in Sichuan Province, China. From January 1, 2017 to December 31, 2017, all admitted patients who had been hospitalized for more than 48 h were included.

Setting

The hospital chosen for our study has 3740 beds and admits approximately 130,000 inpatients per year. From 2015 to 2017, the annual incidence of HAIs at the hospital ranged from 1% to 3%. The hospital has an electronic health records system that includes data for clinical and laboratory results and HAIs.

Diagnostic criteria and review of HAIs

The diagnostic criteria were the "HAIs Diagnostic Criteria" issued by the Ministry of Health of the People's Republic of China in 2001 [13]. HAIs were defined as infections acquired by inpatients in hospitals, which included infections that occurred during hospitalization and those acquired in hospitals but occurred after discharge. The criteria excluded infections that occurred prior to or at the time of admission.

All reported cases of HAIs were examined by three infectious disease specialists to ensure accurate identification of the infected cases.

Selection of cases and controls

All inpatients who met the HAI diagnostic criteria were selected as cases, and non-HAI patients who were successfully matched through the PSM method were selected as controls.

Calculation of costs

For each patient, the total hospitalization costs for the entire hospital stay were obtained through medical records. Costs were calculated as the sum of the cost of general medical service and general treatment operations, nursing costs, pathological diagnosis costs, laboratory diagnostic costs, imaging diagnostic costs, clinical diagnostic item costs, non-surgical clinical physiotherapy costs, surgery treatment costs, rehabilitation costs, medicine costs,

antibacterial drugs costs, Chinese herbal medicine costs, and the costs of disposable medical materials for examination, treatment, or surgery.

Chinese herbal medicines were defined as products derived from raw or refined plants or parts of plants (e.g., leaves, buds, flowers, stems, roots, or tubers), minerals (e.g., borneol), and/or animals (e.g., the prepared centipede or earthworm), and were used for the treatment of disease [14]. In China, Chinese herbs are generally considered to be effective and are commonly prescribed by physicians for patients with HAIs. Some Chinese herbs are considered to have antibacterial and anti-inflammatory properties. Although these properties have been observed in previous studies [15,16], it is unclear how they work.

Confounders

When considering the factors that had an impact on hospitalization and HAI costs, our study referred to previous literature [17–20], which factored in patient age, gender, principal diagnosis, underlying chronic diseases, blood transfusion or the use of blood products, the use of hemodialysis, prior invasive operations, prior surgeries, ICU admission now or in the past, and pre-infection time.

Definitions of confounding factors

Underlying chronic diseases were defined as diabetes, hypertension (systolic blood pressure $\geq$140 mmHg and/or diastolic blood pressure $\geq$90 mmHg [21]), and chronic obstructive pulmonary disease in the patient diagnosis list.

Principal diagnosis was classified according to ICU-10 [22].

Pre-infection time was considered to be the period in which inpatients had not yet acquired an infection but could still acquire an infection later on during their stay. It was necessary to eliminate the confounding bias of pre-infection time. Therefore, the pre-infection time in the case group referred to the length from the date of arrival to the date of HAI, while the control group referred to the length from the date of arrival to the date of discharge.

Invasive operations were defined as venous catheterization, mechanical ventilation, urinary catheterization, and tracheotomy.

Surgery was defined as all procedures recorded by the surgical anesthesia system, which included neurosurgery, gastrointestinal surgery, hepatobiliary surgery, vascular surgery, breast surgery, orthopedic surgery, urology surgery, thoracic surgery, cardiac surgery, burn surgery, obstetrics and gynecology surgery, ophthalmic surgery, otolaryngology surgery, stomatology surgery, emergency surgery, dermatology surgery, transplant surgery, oncology surgery, and traditional Chinese medicine surgery.

Information collection

We collected information from inpatient records and the HAI management information system. Information collected from the inpatient records included age, gender, principal diagnosis, prevalence of underlying chronic diseases, blood transfusion or the use of blood products, the use of hemodialysis, prior invasive operations, prior surgeries, ICU admission now or in the past, hospitalization costs, admission date, discharge date, and HAI date. Details on HAIs were collected from the HAI management information system.

Statistical methods

Statistical analysis of the data was performed using SPSS 23.0 software and STATA 12.0. Skewness and Kurtosis were used to assess the normality distribution. Binary outcomes were tested using the χ^2 test, and continuous data were compared using

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┌─────────────────────────────────────────────┐
│ Total no. of patients(Jan 01,2017-Dec 31,2017)│
│              (126659 patients)                │
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17363 patients were hospitalized within 48 hours

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┌──────────────────────┐   ┌──────────────────────┐
│ Total no. of Non-HAIs │   │   Total no. of HAIs   │
│   (107382 patients)   │   │    (1914 patients)    │
└──────────────────────┘   └──────────────────────┘
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2 cases do not meet the diagnostic criteria

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┌──────────────────────────────────────┐
│       Propensity score matching       │
│   (1912 HAIs and 107382 Non-HAIs)     │
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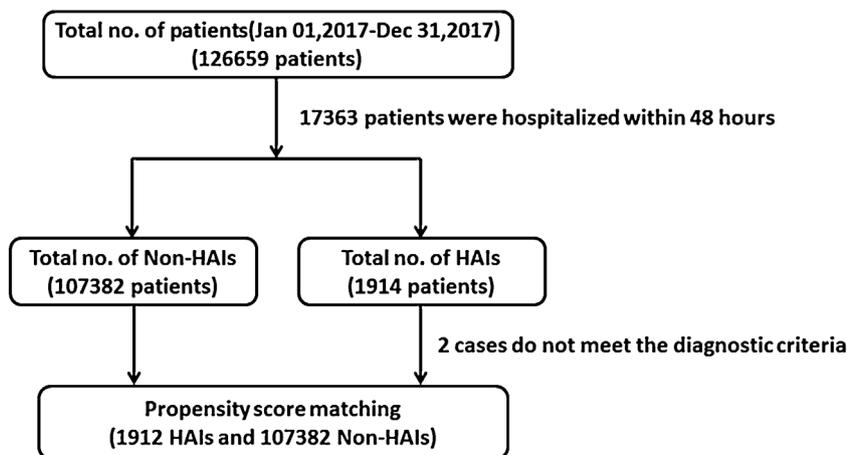
Fig. 1. Flow chart of patient inclusion.
A total of 126,659 inpatients were admitted to the hospital, including 1914 cases of HAIs. After data collation and screening, finally 1912 inpatients with HAI and 107,382 inpatients without HAI were included.

Mann–Whitney test, the Kruskal–Wallis test or the T-test. The chi-square trend test was used for trend analysis.

Confounding factors affecting hospitalization costs were tested using multiple linear regression analysis. The nearest distance matching method was used to make a 1:1 match between the same or similar patients during the PSM process, and the caliper values were continuously adjusted so that all confounding factors matched successfully. The significance level was set to 0.05.

Data availability statement

All data generated and analyzed during this study are included in this article.

Results

Patient inclusion

From January 1, 2017 to December 31, 2017, a total of 126,659 inpatients were admitted to the hospital, including 1914 patients with HAIs. Because 17,363 patients were hospitalized within 48 h and 2 reported HAI cases did not meet the diagnostic criteria, 1912 inpatients with HAI and 107,382 inpatients without HAI were included in the final data set, as Fig. 1 shows.

Hospitalization costs of HAIs

The median hospitalization costs of HAI patients were €6381.89, which was 3.6 times that of non-HAI patients, who incurred €1771.29 ($Z = 50.329$, $P < 0.001$). This resulted in an absolute cost difference of €4016.60. Most hospitalized patients had only one HAI, but as the number of infections increased, hospitalization costs increased significantly. Trend test results showed that the difference was statistically significant (chi-square = 2543.549, $P < 0.001$). Organ-space infections were ranked first regardless of the hospitalization costs, followed by intracranial infections and ascites. The details are shown in Table 1.

Confounding factors affecting hospitalization costs

We performed logarithmic conversion of the cost data because it involved skewed data. After conversion, the Skewness was 0.295, the standard error of skewness was 0.007, Kurtosis was 0.538, and the standard error of kurtosis was 0.015, which satisfied the normal distribution.

Multiple linear regression analysis showed that factors affecting hospitalization costs included HAIs, age, gender, principal diagnosis, pre-infection time, underlying chronic diseases, blood transfusion or the use of blood products, community infections, hemodialysis, invasive operations, surgery, and ICU admission now or in the past. Table 2 shows these details.

Propensity score matching

All possible confounding factors affecting hospitalization costs were considered during PSM, among all available variables. After continuous adjustment of a caliper, we chose a caliper 0.00003 to ensure that all confounding factors matched successfully, as Table 3 shows.

After PSM was performed, all confounding factors were balanced between the cases and controls, as Table 4 shows. The kernel density graph before and after PSM shows that the PSM score became more balanced after matching, as Fig. 2 shows.

Comparison of hospitalization costs after PSM

After PSM, the median hospitalization cost of patients with HAIs was €5613.03, which was only 1.6 times that of non-HAI patients, who incurred a median cost of €3414.83 ($Z = -15.575$, $P < 0.001$). This resulted in an absolute difference of €2198.19, which was 52.32% lower than the €4616.60 that was incurred before matching. As estimated from the 1912 cases examined during the study period, the additional hospitalization costs due to HAIs were €4,202,945.12.

Comparison of hospitalization costs between the cases and controls showed that there were no statistically significant differences in pathological diagnosis costs, surgical treatment costs, or disposable medical material costs for surgery. However the cases and controls had significantly different western medicine costs (€15,195.67 vs. €838.56; $P < 0.001$), laboratory diagnostic costs (€740.77 vs. €378.17; $P < 0.001$), imaging diagnostic costs (€272.44 vs. €197.41; $P < 0.001$), general medical service costs (€200.84 vs. €105.16; $P < 0.001$), general treatment operating costs (€308.33 vs. €135.55; $P < 0.001$), nursing costs (€100.20 vs. €56.96; $P < 0.001$), clinical diagnosis project costs (€151.32 Vs. €79.98; $P < 0.001$), non-surgical clinical physiotherapy costs (€11.31 vs. €0.00; $P < 0.001$), inspection disposable medical materials costs (€7.62 vs. €5.93; $P < 0.001$), and treatment disposable material costs (€267.10 vs. €133.88; $P < 0.001$). In the costs of western medicine, the difference in antibacterial drugs costs was very obvious (€416.10 vs. €102.84; $P < 0.001$), as Table 5 shows.

Table 1
Hospitalization costs of HAIs.

	Number of cases	Hospitalization costs (€)		Statistics	P
		Median	Interquartile range		
Number of infections					
No infection	107,382	1771.68	2085.61		
Single	1838	6195.15	9341.70		
Double	65	13,201.12	21,466.04	2517.235	<0.001
Triple	9	27,556.33	61,517.59		
HAIs sites					
Organ-space	8	15,151.37	11,511.19		
Intracranial	17	13,353.55	5822.97		
Ascites	34	13,409.13	13,728.97		
Intra-abdominal tissue	31	11,448.73	12,327.27		
Soft-tissue	18	10,288.25	12,971.29		
Deep incision	26	8328.54	13,588.19		
Superficial incision	49	7843.04	7905.92		
Septicemia	142	7760.57	11,140.04		
Lower respiratory	983	7164.62	10,955.40	210.098	<0.001
Gastrointestinal	51	6866.19	7264.15		
Oral	11	6398.03	9720.16		
Vascular-related	18	6335.77	18,659.24		
Skin	20	5935.35	8650.30		
Other	78	5214.80	9762.84		
Urinary Tract	186	4837.90	5871.89		
Infectious diarrhea	16	4357.11	3788.57		
Upper respiratory	224	2840.41	3808.39		

Table 2
Equation parameters of confounding factors affecting hospitalization costs.

Covariate	Parameter	Standard error	Standardized coefficients	t	P
Constant	3.805	0.004		1032.147	<0.001
Gender	−0.033	0.002	−0.042	−19.927	<0.001
Invasive operation	0.219	0.002	0.245	100.678	<0.001
Underlying chronic diseases	0.041	0.002	0.048	19.766	<0.001
HAIs	0.236	0.006	0.080	38.289	<0.001
Age	0.003	0.000	0.158	62.503	<0.001
ICU admission now or in the past	0.208	0.004	0.136	59.111	<0.001
Blood transfusion or the use of blood products	0.215	0.003	0.158	69.650	<0.001
Hemodialysis	0.083	0.027	0.006	3.091	0.002
Pre-infection time	0.009	0.000	0.274	127.753	<0.001
Surgery	0.203	0.002	0.255	109.013	<0.001
Community infections	0.012	0.003	0.010	4.262	<0.001
Principal diagnosis (ICU-10 code)					
Certain infectious diseases and parasites(A00–B99)	−0.070	0.005	−0.033	−14.357	<0.001
Tumor (C00–D48)	/	/	0.000	0.000	1.000
Blood and hematopoietic diseases and certain diseases involving immune mechanisms (D50–D89)	−0.152	0.009	−0.037	−17.585	<0.001
Endocrine, nutritional, and metabolic diseases (E00–E90)	−0.070	0.005	−0.029	−12.793	<0.001
Mental and behavioral disorders (F00–F99)	−0.059	0.007	−0.020	−9.065	<0.001
Nervous system diseases (G00–G99)	−0.013	0.005	−0.006	−2.770	0.006
Eye and appendage diseases (H00–H59)	−0.301	0.006	−0.121	−53.839	<0.001
Ear and mastoid diseases (H60–H95)	−0.157	0.008	−0.040	−19.064	<0.001
Circulatory diseases (I00–I99)	0.054	0.003	0.047	16.684	<0.001
Respiratory diseases (J00–J99)	−0.055	0.004	−0.039	−13.883	<0.001
Digestive diseases (K00–K93)	−0.113	0.003	−0.097	−34.854	<0.001
Skin and subcutaneous tissue diseases (L00–L99)	−0.230	0.007	−0.071	−32.897	<0.001
Musculoskeletal system and connective tissue diseases (M00–M99)	0.001	0.004	0.001	0.344	0.731
Genitourinary diseases (N00–N99)	−0.199	0.004	−0.130	−53.477	<0.001
Pregnancy, childbirth, and puerperium (O00–O99)	−0.325	0.004	−0.187	−76.356	<0.001
Diseases that originated in the perinatal period (P00–P96)	0.124	0.012	0.022	10.050	<0.001
Congenital malformations, deformation, and chromosomal abnormalities (Q00–Q99)	−0.081	0.007	−0.027	−12.328	<0.001
Abnormal symptoms, signs, clinical and laboratory results, and cannot be classified in other categories (R00–R99)	−0.146	0.008	−0.040	−18.676	<0.001
Injury, poisoning and other external pathogenic factors (S00–T98)	−0.018	0.004	−0.010	−4.221	<0.001
External causes of illness and death (V01–V98)	−0.040	0.003	−0.030	−11.407	<0.001

Discussion

Closer attention must be given to the reform of China's medical payment system, especially the additional economic burden caused by HAIs. The results of our study showed that the hospitalization costs of HAI patients were 1.6 times higher than that of non-HAI patients. During the study period, the tertiary A-level hospital caused an additional burden of about €4.20 million.

The fully operated DGR-PPS used in Sichuan Province, like most provinces in China, could be defined as the highest-cost prospec-

Table 3
Matching results after continuous adjustment of caliper.

Caliper	% of cases matched	Confounding factors matched successfully
0.02	100.00	Hemodialysis
0.006169 (0.2 × SD of Pscore)	99.84	Hemodialysis, gender, ICU admission now or in the past, underlying chronic diseases, surgery, community infections, pre-infection time
0.002	99.48	Hemodialysis, gender, ICU admission now or in the past, underlying chronic diseases, surgery, community infections, pre-infection time, age, blood transfusion or the use of blood products, invasive operation
0.00003	88.18	Hemodialysis, gender, ICU admission now or in the past, underlying chronic diseases, surgery, community infections, pre-infection time, age, blood transfusion or the use of blood products, invasive operation, principal diagnosis

Table 4
Base line characteristics before and after matching.

Covariate	Before matching				After matching			
	Non-HAI	HAI	Statistics	P	Non-HAI	HAI	Statistics	P
Invasive operation			793.864	<0.001			0.343	0.558
Unexposed	80,689	896			868	885		
Exposed	26,693	1016			818	801		
Gender			80.458	<0.001			0538	0.463
Male	52,970	1141			995	974		
Female	54,412	771			691	712		
ICU admission now or in the past			1680.079	<0.001			0.467	0.494
Unexposed	100,406	1329			1269	1286		
Exposed	6976	583			417	400		
Hemodialysis			53.449	<0.001			0.668	0.414
Unexposed	107,298	1901			1684	1682		
Exposed	84	11			2	4		
Blood transfusion or the use of blood products			2859.983	<0.001			0.419	0.518
Unexposed	98,429	1079			1093	1075		
Exposed	8953	833			593	611		
Underlying chronic diseases			241.253	<0.001			2.109	0.146
Unexposed	74,359	1007			896	938		
Exposed	33,023	905			790	748		
Surgery			22.180	<0.001			0.290	0.590
Unexposed	42,662	658			597	612		
Exposed	64,720	1254			1089	1074		
Community infections			75.448	<0.001			2.590	0.108
Unexposed	95,333	1576			1384	1419		
Exposed	12,049	336			302	267		
Principal diagnosis (ICU-10 code)			505.138	<0.001			19.807	0.344
1	3246	110			111	87		
2	15,107	344			267	320		
3	984	22			27	22		
4	2830	58			54	56		
5	1816	29			35	29		
6	3859	74			67	61		
7	2726	0			/	/		
8	1107	1			3	1		
9	13,720	340			263	282		
10	8733	297			219	223		
11	13,777	119			117	116		
12	1592	16			15	16		
13	5798	110			102	101		
14	7512	92			113	89		
15	5759	27			27	26		
16	474	25			17	24		
17	1858	18			28	18		
18	1233	7			5	7		
19	4936	101			105	86		
20	10,315	122			111	122		
Age ($M \pm SD$)	51.24 ± 21.80	59.85 ± 23.60	-17.101	<0.001	58.26 ± 21.70	58.43 ± 24.05	-0.221	0.825
Pre-infection time ($M \pm SD$)	11.31 ± 11.70	15.19 ± 12.76	-14.358	<0.001	15.90 ± 10.81	15.09 ± 13.11	1.955	0.051

tive payment system based entirely on the criteria for the initial diagnosis. If a patient's actual medical costs were higher than the standard, the hospital charged him/her a standard fee. However, if the patient's costs were below the standard, he/she had to pay the real costs. As in many developing countries, this type of DRG-PPS only sets a fixed price based on the situations of previously hospitalized patients and ignores other patient information, such as age, gender, complications, and HAIs [3]. After the wider implementation of the DGR-PPS, most of the extra economic burden caused by HAIs will be shouldered by the hospital rather than the
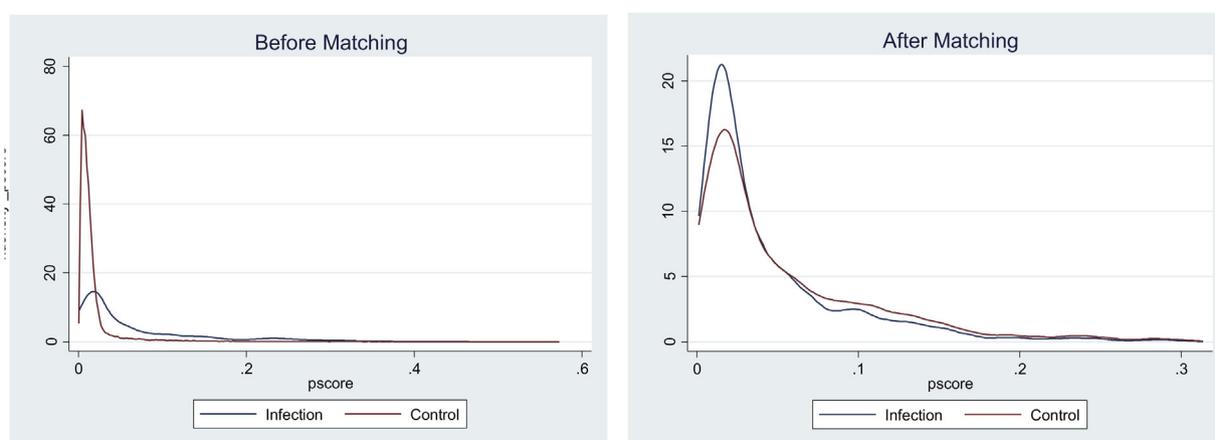
Fig. 2. Kernel density distribution of cases and controls before and after matching. Before matching, kernel density distribution of cases and controls differed greatly. However after matching it became more balanced.

Table 5
Hospitalization costs of patients with and without HAIs (€).

Charge details	Controls (n = 1686)		Cases (n = 1686)		Statistics Z	P
	Median	Interquartile range	Median	Interquartile range		
Total hospitalization costs	3414.83	5432.62	5613.03	8216.24	−15.575	<0.001
General medical service costs	105.16	105.05	200.84	185.55	−24.497	<0.001
General treatment operating costs	135.55	218.47	308.33	406.03	−21.967	<0.001
Nursing costs	56.96	77.54	100.20	171.61	−19.634	<0.001
Pathological diagnosis costs	0.00	8.90	0.00	8.90	−0.526	0.599
Laboratory diagnostic costs	378.17	474.68	740.77	858.39	−21.936	<0.001
Imaging diagnostic costs	197.41	261.82	272.27	375.54	−8.926	<0.001
Clinical diagnosis project costs	79.98	179.29	151.23	419.77	−10.072	<0.001
Non-surgical clinical physiotherapy costs	0.00	50.86	11.31	110.44	−9.279	<0.001
Surgical treatment costs	6.99	370.03	6.98	342.77	−0.676	0.499
Western medicine costs	838.56	1456.42	1931.12	3303.49	−21.117	<0.001
Antibacterial drug costs	102.84	333.69	415.85	1038.87	−24.327	<0.001
Inspection disposable medical materials costs	5.93	11.96	7.62	13.01	−3.905	<0.001
Treatment disposable material costs	133.88	289.93	302.50	578.10	−16.094	<0.001
Disposable medical material costs for surgery	0.00	390.71	0.00	505.34	−1.341	0.180
Other	4.57	9.65	8.06	14.72	−5.083	<0.001

patient. If hospitals do not receive reasonable compensation, they might take measures to compensate for the costs that are not covered by DGR-PPS, such as refusing patients with certain diseases to be admitted, reducing necessary treatments, or allowing patients to repeat hospital admissions. These measures would adversely impact the quality of medical services. Therefore, at the current stage of reform, the extra economic burden caused by HAIs should be given special attention.

Moreover, our study found that the difference in the extra economic burden caused by different characteristics of HAIs was relatively large, which suggested that the proportion and scope of medical payments should also be different. For instance, The Centers for Medicare & Medicaid Services (CMS) in the United States has formulated different reimbursement ranges according to different parts and different pathogens of HAIs [23]. At the beginning, the CMS paid all the extra costs caused by HAIs, and it eventually disallowed hospitals from receiving additional payments for CAUTI, vascular catheter-associated infections, selected SSIs, VAP, S. aureus bloodstream infections, C. difficile-associated disease, and MRSA HAIs. However, China's current DGR-PPS could gradually increase HAI-related payment items.

Our study found that HAIs increased the hospitalization costs. On average, each HAI increased hospitalization costs by €2198.19, an increase of 64.37%, which was basically consistent with the survey results in Beijing in 2014 [24]. In addition to pathological diagnosis costs, surgical treatment costs, and disposable medical material costs for surgery, other types of costs for patients with

HAI were higher than those for non-HAI patients. The difference was larger in laboratory diagnostic costs and western medicine costs, followed by general treatment operating costs and treatment disposable materials costs. In addition, the increase in antibacterial drugs costs in western medicine was significant. The direct economic burden caused by HAIs and its compositional characteristics indicated that the costs of laboratory diagnosis and western medicines such as antibacterial drugs were the main sources of the extra economic burden of HAIs.

At different sites of HAI, organ-space infections caused the heaviest cost burden, followed by intracranial infections; however, infectious diarrhea and upper respiratory infections were the least burdensome. A review from the United States shown that not all SSIs were alike although by definition all were costly, and the principal determinants of the cost of an SSI were geographic locale, the type of surgery performed, and, most importantly, the depth of the infection. The most severe infections were those involving an organ or space. Morbidity and the mortality risk both were higher than in patients with more superficial SSIs. The overall costs were high to extremely high [26].

The extra economic burden of HAIs caused by multidrug-resistant bacteria deserves more attention. Although our study did not match multidrug-resistant bacteria, a propensity-matched case control study in Singapore found that the median per-day costs of laboratory tests and antibiotics were 1.5–2 times higher than that of patients without gram-negative bacilli infections and were nearly 3 times higher than for susceptible gram-negative

infected patients [25]. Furthermore, a retrospective study in Spain found that the hospitalization costs for patients hospitalized with multidrug-resistant *Pseudomonas aeruginosa* were 1.7 times more than that for non-HAI patients [27].

The PSM analysis was a kind of "post-randomization" method, in that it used the covariates between treated and untreated patients to match in order to control the covariates and reduce the confounding bias. In previous studies, PSM was used repeatedly in the analysis of the direct economic burden of HAIs [25,28–30]. Our study used this method to successfully match patients with HAIs from more than 100,000 non-HAI patients and achieve good results. During the PSM process, we adjusted the caliper one by one according to previous literature prompts [31–33] and finally selected a caliper 0.00003 to ensure that all confounding factors matched successfully. We found that the principal diagnosis was more difficult to match successfully, and we lost nearly 11% of the sample size in order to complete it. This result was roughly the same as that of Vrijens's 2010 study. Vrijens investigated the influence of the choice of different matching factors on the additional length of stay caused by HAIs and showed that the most critical factor influencing the final estimate was the time preceding the infection. After matching principal diagnosis, the sample size would be lost nearly 20% [34].

Study limitations

The proportion of patient hospitalization costs that was reimbursed was not taken into account in this study. Moreover, there was no distinction between the individual economic burden and the hospital burden caused by HAIs. Our study only involved the analysis of a hospital; larger multi-center randomized studies should be conducted to validate our findings.

Conclusion

Our study found that the additional hospitalization costs caused by HAIs were substantial. At present, the DGR-PPS system widely implemented in China does not consider this part of the costs, which might cause hospitals to succumb to greater economic pressure. Hospital administrators in China should be aware of this situation and then work to strengthen HAI management.

Contributions

Yu J. Wu and Lan Chen conceived of this project. Yu Lv, Qian Xiang, Qiong S. Tang, and Feng D. Wang developed the study design. Hui Wang, Chen Wang, Jing Chen, Ting L. Li, Ying Fang, and Huan Wang assisted with information collection. Yu Lv and Qian Xiang co-wrote the manuscript text. Kun Zou, Qiong D Wei, and Hua Z. Zhou edited and revised the manuscript. All authors had final approval of the submitted manuscript.

Consent for publication

Not applicable.

Funding

Competing interests

None declared.

Ethical approval

Not applicable.

Acknowledgements

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