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Impact of healthcare-associated infection on healthcare services and survival of patients with cancer: a propensity score-matched retrospective study

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Abstract

Background Healthcare-associated infections (HAI) lead to poor patient outcomes, including morbidity, mortality, length of hospital stay (LOS) and costs. However, limited data exists on the impact of HAI on LOS, cost at different quantiles and the survival of patients with cancer.

Objective To assess the impact of HAIs on LOS, costs, and survival of cancer patients.

Methods This retrospective cohort study used data from January 2017 to December 2018 from a tertiary cancer hospital in Henan. Patient demographic data were sourced from the hospital's electronic medical records. Inclusion criteria were primary cancer diagnoses (ICD codes C00–C97). We balanced the distribution of baseline characteristics between patients with HAI and without using propensity score matching. Quantile regression can estimate how independent variables affect dependent variables at different quantiles. We conducted a quantile regression that assessing the impact of HAI on LOS and costs for patients with cancer and using Kaplan–Meier survival curves to compare the survival.

Results Our study included 291,535 patients with cancer, among of whom 4,784(1.6%) were diagnosed with HAI and 286,748 were not. Patients with HAI exhibited significantly longer hospital stays, with a mean duration of 26.1 days (range: 17.0 to 40.6 days), compared to their counterparts without HAIs, who had an average stay of 7.2 days (range: 4.0 to 14.0 days) ($p < 0.01$). Economically, the average hospitalization cost for patients without HAI was $1575.8 (range: 865.6 to 3106.3), substantially lower than the $8710.8 (range: $4073.8 to 13434.0) observed for patients with HAI ($p < 0.01$). After adjusting for confounders in quantile regression models, HAI was associated with a median increase in LOS of 11.4 (95% confidence interval (CI): 10.9–12.0) days and with excess costs of USD 3449.3 (95% CI: 3281.9–3616.7). The hazard ratio (HR) of death for patients with an HAI was significantly higher than for patients without an HAI (HR: 1.62, 95% CI: 1.50–1.74).

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Conclusion HAI prolongs the LOS, increases hospital costs, and worsens the survival of patients with cancer compared with other diseases. Our quantile regression results indicate that the impact of HAI on hospitalization costs and LOS is more pronounced among patients with higher baseline costs and longer LOS (e.g., at the 95th percentile). This suggests that patients with more severe conditions or advanced disease stages are more vulnerable to the adverse effects of HAI.

Relevance to clinical practice : Targeted surveillance and preventive interventions, such as early infection screening and strict adherence to infection control protocols, should focus on high-risk patients with prolonged LOS and high costs. By preventing infections in these patients, we can more effectively reduce the additional burden of HAI on costs and LOS. This study informs clinical practice and decision-making for nurses and nursing educators who manage HAI.

Patient or public contribution Patients and healthcare professionals helped in data collection at the Hospital.

Keywords Healthcare-associated infection, Cancer, Length of stay, Cost, Survival

Introduction

Healthcare-associated infection (HAI) leads to adverse patient outcomes in terms of morbidity and mortality, longer length of hospital stay (LOS) and higher costs [1–4]. Reporting unbiased estimates of the burden of HAI is crucial to maintaining credibility with decision-makers and appropriately allocating limited resources [5].

HAI prolongs LOS and increases costs across all types of diseases in general hospitals [6, 7]. However, hospital LOS, costs, and survival are limited among patients with cancer. The immunosuppressive effects of malignancy and oncological treatment by surgery, chemotherapy, and radiotherapy cause patients with cancer to be more susceptible to HAI, worsening their prognoses [8]. HAI extends LOS by 5 days and increases costs by €EUR 431.34 (based on 2016 data) [9]. Karagiannidou et al. examined mortality, LOS, and healthcare costs of acquired bloodstream infections in pediatric and neonatal care, although only in-hospital mortality was considered [3]. They reported that the attributable mortality rate was 8% for patients with bloodstream infections. Antibiotic and endocrine therapies have been used to control infections, but these might delay the treatment of patients with cancer and lead to worse survival rates. Therefore, HAIs may have a greater overall impact on the survival of patients with cancer.

Furthermore, LOS and cost data fail to satisfy the assumption that residuals are normal, homoscedastic (with a constant variance), and uncorrelated. However, most studies examining the impact of HAIs on expenditure or LOS have been based on conventional linear regression methods [9]. Due to the skewed nature of inpatient healthcare expenditures, the analytical capability of standard linear regression models is constrained [10], and the influence of covariate distribution status on the dependent variable is similarly ignored [11]. Since quantile regression considers the distribution status of covariates on dependent variables and does not necessitate distributional assumptions for the outcome of interest, This method has been applied to studying costs in various fields [12]. Therefore, we used quantile regression to examine the associations between HAI and cost as well as LOS.

The main aim of this research was to comprehensively assess the impact of HAIs on patients with cancer using propensity score-matched analysis [13]. To comprehensively assess the impact of hospital-acquired infections in cancer patients, we chose to analyze all hospital admissions rather than specific admissions, which allows us to capture the variations in infection risk across different stages of treatment and during multiple admissions, and provides a broader understanding of how these infections influence hospital costs, lengths of stay, and prognostic outcomes.

Methods

Study design

A retrospective study was conducted in Henan Cancer Hospital, the only tertiary cancer center and teaching hospital, between January 2017 and December 2018. Most (about 98%) patients in this study were from the Henan Province, accounting for approximately 20% of all those with cancer in Henan. Of 670,335 patients who were newly diagnosed with cancer in Henan province in 2016, 121,947 were admitted to the hospital [14]. Data regarding patient demographics were obtained from the Hospital Information System (HIS). All patients with cancer who were diagnosed with HAI during hospitalization were included in the present study. Patients with incomplete medical records were excluded.

The criteria of HAI we followed are as follows [15]: (1) Infections without a clear incubation period: Any infection occurring after 48 h of hospitalization is considered nosocomial. (2) Infections with a clear incubation period: Infections that occur after the average incubation period of the pathogen, starting from admission, are classified as nosocomial. (3) Infections directly related to prior hospitalization. (4) New infections occurring in a different site during or after an existing infection (excluding septic metastases) or new pathogens isolated in a previously

known infection site (excluding contamination or mixed infections).

Data were collected from patients with bloodstream infections, urinary tract infections, lower respiratory tract infections, pneumonia, gastrointestinal infections, surgical site infections, and skin/soft tissue, bone and joint, cardiovascular, eye, ear, nose, throat, and systemic infections. Details of pathogen detection are provided in Table S1.

Ethical considerations

The study protocol was approved by the Ethics Committee of the Henan Cancer Hospital (2021-KY-0054-001). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000. Responses to our survey were anonymous, and protected by privacy laws. The need for informed consent was waived due to the retrospective nature of the study and the anonymized data.

Data collection

After reviewing the HIS, data were collected on hospitalization costs, LOS, age, treatment modality, year of admission, area of residence, marital status, medical insurance, and cancer type. We define LOS as the difference between the admission date and discharge date, as recorded in the patient's medical record. Professional case managers used the International Classification of Diseases (ICD-10) to code diagnoses of patients upon admission and discharge. The diagnoses were initially assigned by clinical doctors and subsequently encoded using ICD-10. The coded diagnoses were reviewed by additional coders and submitted to the provincial medical insurance bureau for verification, ensuring a robust process for accuracy control. Diseases were identified and included only if the primary diagnosis was cancer (codes C00–C97). All solid tumors were identified by histological or cytological pathology. Specific components of hospitalization expenses were listed as follow: (1) Diagnostic Costs: Pathology Diagnostic Fees, Laboratory Diagnostic Fees, Imaging Diagnostic Fees, Clinical Diagnostic Project Fees; (2) Treatment Costs: General Treatment Operation Fees, Non-Surgical Treatment Project Fees, Clinical Physical Therapy Fees, Surgical Treatment Fees, Anesthesia Fees, Surgery Fees, Rehabilitation Fees, Traditional Chinese Medicine Treatment Fees; (3) Nursing and Service Fees: General Medical Service Fees, Nursing Fees, Other Comprehensive Medical Service Fees; (4) Medication and Therapeutic Material Costs: Western Medication Fees, Antimicrobial Drug Fees, Traditional Chinese Patent Medicine Fees, Herbal Medicine Fees, Blood Fees, Albumin Products Fees, Globulin Products Fees, Coagulation Factor Products Fees, Cytokine Products Fees; (5) Medical Material Costs: Disposable Medical Materials for Examination, Disposable Medical Materials for Treatment, Disposable Medical Materials for Surgery; (6) Miscellaneous Fees: Other Fees. LOS was measured from the time of admission to discharge. We adjusted hospitalization costs using the Consumer Price Index (CPI) for Henan in 2017 (base year) in the analysis. Chinese CPI data were obtained from the official National Bureau of Statistics. Additionally, hospitalization costs were converted from Chinese Yuan (CNY) to United States Dollars (USD) using the average exchange rate for 2017. Inclusion and exclusion processes are detailed in the flowchart depicted in Fig. 1.

Follow-up

Follow-up assessments were repeated every three months after discharge for the first two years, every six months for the next three years, and then once annually. Vital statistics of the patients, including survival status, date of death, and most recent follow-up, were collected via telephone consultation during follow-up. All patients were followed until death or 6 January 2025.

Propensity score matching (PSM)

Patients with and without HAI were matched for age, sex, cancer type, treatment modality, remote metastasis, diabetes, and hypertension according to their baseline characteristics using propensity scores [16] to compare LOS, costs, and survival. The balance before and after matching was evaluated using standardized mean difference. Differences of <0.1 indicated that the groups were well-matched. The nearest neighboring matching approach and 1:1 matching with a caliper of 0.01 were used applied. The standardized bias across covariates for patients with and without HAI, both prior to and following the application of PSM, is visually summarized in Fig. 2.

Quantile regression analysis

The Kolmogorov-Smirnov findings revealed skewed distributions of hospital expenses and LOS ($p<0.05$). Accordingly, the sample population was summarized using medians with interquartile ranges (IQRs). Quartile regression was used to examine how hospitalization costs and LOS varied across groups at the lower and upper quartiles of the distribution. Expenses across many disciplines have been analyzed using quartile regression because distributional assumptions regarding the outcome of interest are not necessary [17]. Moreover, every conditional quantile of hospitalization costs can be modeled with quantile regression; thus, the relationships between the explanatory variables and costs can be investigated across the entire distribution [18]. As a result, quantile regression is more suitable than ordinary least squares regression for examining healthcare costs

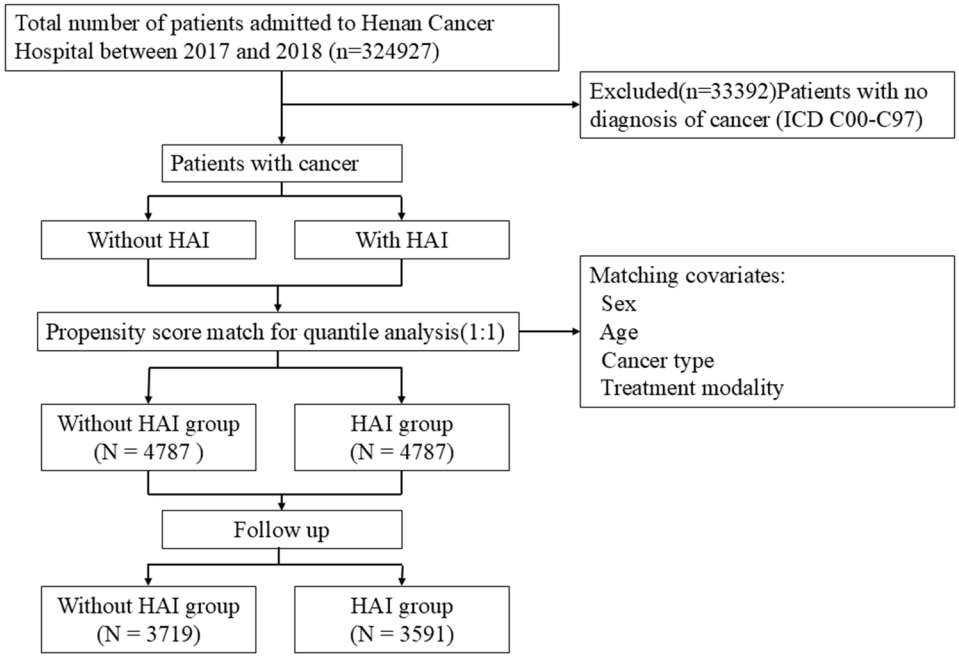

Fig. 1 Flowchart of patient enrolment from 2017 to 2018 in Henan Cancer Hospital. Without HAI: patients with no HAI. HAI: patients with healthcare-associated infections

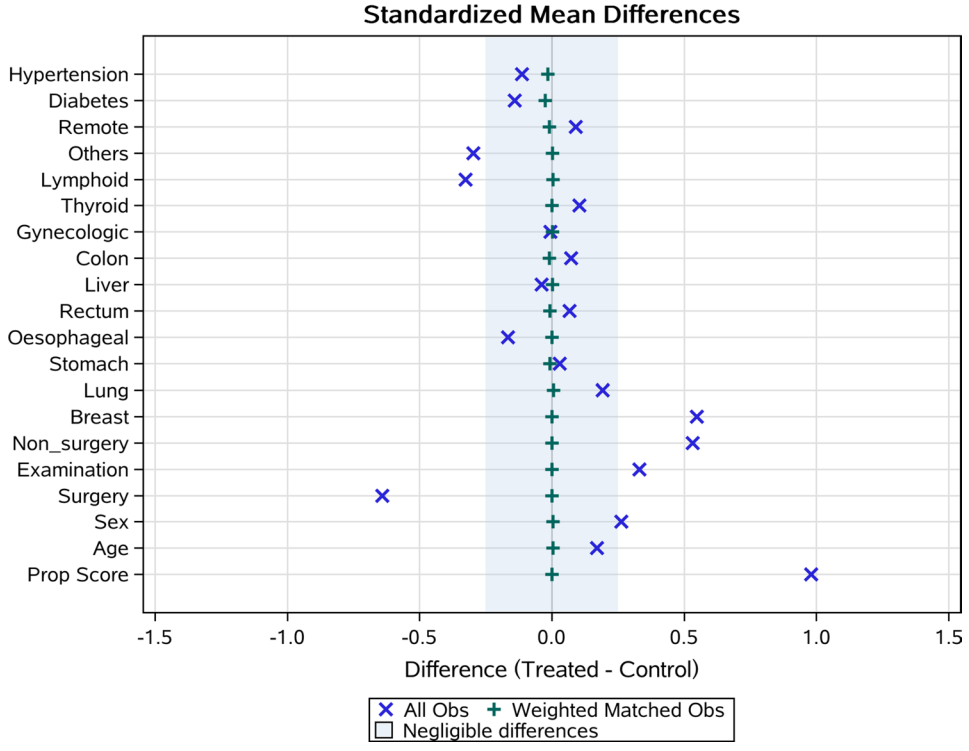

Fig. 2 Standardized bias across covariates between patients with and without HAI before and after PSM from 2017 to 2018 at Henan Cancer Hospital. Balance is satisfied in the model. Examination, patients only examined; HAI, healthcare-associated infection; Non surgery, treatments other than surgery, including chemotherapy, radiotherapy, and immunotherapy. PSM: propensity score matching

[19]. Age group (0–54, 55–69, and ≥ 70 years), treatment modality, year of admission, area of residence (in Zhengzhou or other cities), marital status, medical insurance, and cancer type were included in the quantile regression model to correct for potential influencing factors.

Statistical methods

We defined overall survival (OS) as the elapsed time between the date of the initial admission and death. We analyzed survival data using log-rank tests, cox regression, and Kaplan–Meier curves [20]. Categorical variables were presented as numbers (percentages) and continuous variables not conforming to normal distribution were expressed as medians (Q1, Q3) and were evaluated using the chi-square test or Mann–Whitney U test, as appropriate.

We applied a McNemar instead of standard chi-squared tests, and Wilcoxon matched pair rank, instead of Kruskal-Wallis Tests of paired-matched data structure after PSM. Given that LOS and costs were substantially greater for deceased patients, differences in LOS and costs could be caused by few patients; therefore, we restricted our sensitivity analyses to analyze LOS and costs only for survivors. This prompted the need for additional PSM using the same procedures as described above. To correct for bias introduced by PSM, we also conducted the sensitivity analyses that included all patients before PSM. All data were statistically analyzed using SAS 9.4 software (SAS Institute, Cary, North Carolina, USA). Two-tailed p values < 0.05 were considered statistically significant.

Results

Baseline characteristics

Our study included 291,535 patients with cancer, of whom 4,784 were diagnosed with HAI and 286,748 were not (Table 1). Patients with HAI exhibited significantly longer hospital stays, with a mean duration of 26.1 days (range: 17.0 to 40.6 days), compared to their counterparts without HAIs, who had an average stay of 7.2 days (range: 4.0 to 14.0 days) ($p < 0.01$). After adjusting for confounders using PSM, the length of stay for patients without HAI increased to an average of 14 days (range: 6.9 to 23.0 days). Economically, the average hospitalization cost for patients without HAI was $1575.8 (range: $865.6 to 3106.3), substantially lower than the $8710.8 (range: $4073.8 to 13434.0) observed for patients with HAI ($p < 0.01$). Following PSM, the hospitalization cost for the non-HAI group increased to $3474.2 (range: $1368.4 to 8481.2). Significant differences were also observed in the age and marital status distributions between the HAI and non-HAI groups ($p < 0.01$). The non-HAI group consisted of a lower percentage of male patients (45.7% vs. 58.7%) and was generally younger, with 48.6% of patients under the age of 55, compared to 37.8% in the HAI group. Additionally, the proportion of divorced or unmarried patients was lower in the non-HAI group (4.6% vs. 6.3%). Differences in disease distribution and treatment modalities between the non-HAI and HAI groups were also significant ($p < 0.01$). The prevalence of breast cancer was markedly higher in the non-HAI group (19.6% vs. 2.9%). In contrast, rates of esophageal cancer and lymphoma were lower in the non-HAI group (6.4% vs. 11.1% and 9.2% vs. 20.7%, respectively). Furthermore, the rate of surgical interventions was significantly lower in the non-HAI group (11.9% vs. 38.4%).

Quantile regression analysis

Table 2, Table S2 and Fig. 3 (A) show the impacts of HAI on overall treatment costs. After adjusting for potential confounders, a statistically significant correlation was found between HAI and increased healthcare costs across all quartiles. The impact of HAI on total treatment costs was greater in the upper tail of the cost distribution than in the lower tail ($1475.4, 95% CI: 1398.4–1552.4 for the 10th percentile; coefficient $7254.9, 95% CI: 6871.1–7638.6 for the 90th percentile). Table 3, Table S3 and Fig. 3 (B) demonstrate that from the 10th to the 90th percentile, the LOS rises along with the presence of a HAI. The effects of HAI on LOS were also significant and more pronounced in the upper tail of the outcome distribution (6.1 days, 95% CI: 5.9–6.4 for the 10th percentile; coefficient 21.7 days, 95% CI: 20.1–23.4 for the 90th percentile). The findings of covariates showed that sex, cancer type, and treatment modality were significantly and positively associated with costs and LOS. The results of the subgroup analyses on costs demonstrate that the impact of HAI on the various cost categories is similar to that on the total costs (Figure S2). After incorporating the length of hospital stay into the quantile regression model, our findings indicate that HAI led to an average increase in hospitalization costs of $967.4540 (95% CI: 852.5–1082.4) USD.

Survival analysis

In the cohort of patients with HAI, out of 3,719 total cases, 1,946 were censored, accounting for 52.33% of the cases. In the NHAI cohort, we observed that 2,263 out of 3,591 cases were censored, making up 63.02% of that group. Median OS values significantly differed between patients with and without HAI ($p < 0.001$). The median OS (months) was 45.9 (95% CI: 40.5–51.7) vs. 85.8 (95% CI: 86.8–85.6) for the groups with and without HAI, respectively. The overall median follow-up time was 32.2 months. The numbers of deaths that occurred within 1, 3, and 5 years from the date of admission among patients with HAI were 718 (36.90%) of 1,946, 1314 (67.52%) of 1,946, and 1509 (77.54%) of 1,946. The numbers of deaths that occurred within 1, 3, and 5 years from the

Table 1 Demographic and clinical characteristics of patients with cancer before and after PSM from 2017 to 2018 in Henan Cancer hospital

Characteristics	Before PSM			After PSM		
	Negative	Positive	P	Negative	Positive	P
	N = 286,751 (%)	*N* = 4784 (%)		*N* = 4784 (%)	*N* = 4784 (%)	
LOS	7.2 (4.0 to 14.0)	26.1 (17.0 to 40.6)	< 0.001	14.0 (6.9 to 23.0)	26.1 (17.0 to 40.6)	< 0.001
Costs	1575.8 (865.6 to 3106.3)	8710.8 (4073.8 to 13434.0)	< 0.001	3474.2 (1368.4 to 8481.2)	8710.8 (4073.8 to 13434.0)	< 0.001
Sex			< 0.001			0.09
Male	131,096(45.7)	2809(58.7)		2811(58.8)	2809(58.7)	
Female	155,655(54.3)	1975(41.3)		1973(41.2)	1975(41.3)	
Age group (years)			< 0.001			1.00
0–44	54,793(19.1)	755(15.8)		749(15.7)	755(15.8)	
45–54	84,714(29.5)	1051(22.0)		1052(22.0)	1051(22.0)	
55–64	81,945(28.6)	1392(29.1)		1403(29.3)	1392(29.1)	
65–74	53,780(18.8)	1253(26.2)		1257(26.3)	1253(26.2)	
> 75	11,519(4.0)	333(7.0)		323(6.8)	333(7)	
Marital status			< 0.001			0.71
Married	273,702(95.5)	4485(93.8)		4476(93.6)	4485(93.8)	
Other	13,049(4.6)	299(6.3)		308(6.4)	299(6.3)	
Medical insurance			< 0.001			0.47
Urban	52,490(18.3)	847(17.7)		827(17.3)	847(17.7)	
Rural	168,049(58.6)	2715(56.8)		2775(58.0)	2715(56.8)	
Own	39,401(13.7)	866(18.1)		816(17.1)	866(18.1)	
Other	26,811(9.4)	356(7.4)		366(7.7)	356(7.4)	
Cancer type			< 0.001			1.00
Breast	56,294(19.6)	140(2.9)		141(3.0)	140(2.9)	
Lung	48,449(16.9)	494(10.3)		507(10.6)	494(10.3)	
Stomach	28,404(9.9)	432(9.0)		425(8.9)	432(9.0)	
Esophageal	18,405(6.4)	531(11.1)		528(11.0)	531(11.1)	
Rectum	16,433(5.7)	204(4.3)		199(4.2)	204(4.3)	
Liver	13,164(4.6)	261(5.5)		260(5.4)	261(5.5)	
Colon	13,088(4.6)	152(3.2)		149(3.1)	152(3.2)	
Gynecologic	24,936(8.7)	425(8.9)		422(8.8)	425(8.9)	
Thyroid	7169(2.5)	53(1.1)		52(1.1)	53(1.1)	
Lymphoid	26,413(9.2)	992(20.7)		995(20.8)	992(20.7)	
Other	33,996(11.9)	1100(23.0)		1106(23.1)	1100(23.0)	
Treatment modalities			< 0.001			1.00
Surgery	34,074(11.9)	1836(38.4)		1836(38.4)	1836(38.4)	
Non-surgery	141,689(49.4)	1175(24.6)		1175(24.6)	1175(24.6)	
Examination	110,988(38.7)	1773(37.1)		1773(37.1)	1773(37.1)	
Metastasis	54,996(19.2)	551(11.5)	< 0.001	548(11.5)	551(11.5)	0.92
Diabetes	16,425(5.7)	380(7.9)	< 0.001	344(7.2)	380(7.9)	0.16
Hypertension	31,287(10.9)	567(11.9)	< 0.001	557(11.6)	567(11.9)	0.75

PSM: propensity score matching

date of admission among patients without HAI were 357 (15.78%) of 2,263, 855 (37.78%) of 2,263, and 1047 (46.27%) of 2,263 (Fig. 4). The hazard ratio (HR) was significantly higher for patients with than without an HAI (death HR: 1.62; 95% CI: 1.50–1.74). Subgroup analyses conducted across different cancer types revealed that (Fig. 5 and Figure S1), with the exception of thyroid cancer, which exhibited a HR of 10.10 (95% CI: 1.30–20.36), HR for all other cancers predominantly ranged from 1.43 to 2.21. Specifically, colorectal cancer demonstrated the lowest HR at 1.43 (95% CI: 1.17–1.80), while the highest HR was observed in tumors of the female reproductive system, at 2.21 (95% CI: 1.54–2.27).

Table 2 Quantile regression of the total treatment costs associated with HAI in patients with cancer after PSM from 2017 to 2018 in Henan Cancer hospital (USD)

Variable	Total treatment costs									
	10th percentile		25th percentile		50th percentile		75th percentile		90th percentile	
	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI
HAI	1475.4	1398.4 ~ 1552.4	2283.9	2146.8 ~ 2420.9	3449.3	3281.9 ~ 3616.7	5297.0	5065.1 ~ 5528.9	7254.9	6871.1 ~ 7638.6
Sex (Female)										
Male	-100.4	-189.2~-11.6	-46.2	-204.3 ~ 111.9	32.5	-160.6 ~ 225.5	124.5	-143 ~ 392	319.5	-123.1 ~ 762.1
Age group (years) (75-)										
0–44	137.1	-51.2 ~ 325.4	208.0	-127.3 ~ 543.3	223.1	-186.4 ~ 632.6	799.1	231.7 ~ 1366.4	1216.1	277.3 ~ 2155
45–54	224	51.2 ~ 396.9	396.2	88.4 ~ 704.0	265.7	-110.2 ~ 641.6	395.9	-125.0 ~ 916.8	559.0	-302.8 ~ 1420.8
55–64	273.8	108.7 ~ 438.9	303.6	9.6 ~ 597.6	114.3	-244.8 ~ 473.3	170.5	-326.9 ~ 668.0	-2.6	-825.7 ~ 820.5
65–74	291.6	125.5 ~ 457.8	604.4	308.6 ~ 900.3	471.2	109.8 ~ 832.5	558.6	57.9 ~ 1059.2	35.5	-792.9 ~ 863.9
Marital status (Other)										
Married	-16.3	-193.2 ~ 160.5	50.1	-264.9 ~ 365	341.9	-42.6 ~ 726.5	148.4	-384.5 ~ 681.3	-511.1	-1392.9 ~ 370.6
Insurance (Other)										
Urban	-135.8	-303.8 ~ 32.3	-77.5	-376.7 ~ 221.7	79.7	-285.7 ~ 445.0	-129.9	-636.1 ~ 376.4	192.2	-645.4 ~ 1029.9
Rural	-96.6	-246.5 ~ 53.3	-143.1	-410.0 ~ 123.9	-25.0	-351.1 ~ 301.0	-390.6	-842.3 ~ 61.2	-859.8	-1607.3~-112.3
Own	-186.7	-355.2~-18.2	-144.1	-444.0 ~ 155.9	-41.1	-407.5 ~ 325.2	108.2	-399.4 ~ 615.9	-238.3	-1078.3 ~ 601.6
Cancer type (Others)										
Breast	-283.2	-532.7~-33.7	-893.9	-1338.1~-449.7	-630.4	-1172.9~-87.9	-1275.5	-2027.1~-523.8	-1616.6	-2860.4~-372.8
Lung	662.1	512.9 ~ 811.3	600.7	335.1 ~ 866.3	166.4	-158.0 ~ 490.7	-61.8	-511.2 ~ 387.6	-77.9	-821.5 ~ 665.7
Stomach	936.4	783.4 ~ 1089.3	1561.7	1289.4 ~ 1834	2052.0	1719.5 ~ 2384.6	2607.7	2146.9 ~ 3068.4	2648.7	1886.3 ~ 3411.1
Esophageal	953.4	809.8 ~ 1097.0	2139.0	1883.2 ~ 2394.7	2197.9	1885.6 ~ 2510.2	1907.1	1474.4 ~ 2339.9	1779.7	1063.7 ~ 2495.8
Rectum	859.5	654.7 ~ 1064.2	972.9	608.3 ~ 1337.4	799.3	354.1 ~ 1244.5	359.9	-256.9 ~ 976.8	-590.6	-1611.3 ~ 430.1
Liver	261.2	75.5 ~ 447.0	-167.5	-498.3 ~ 163.3	-445.5	-849.4~-41.5	-1475.0	-2034.7~-915.3	-2526.2	-3452.3~-1600.1
Colon	1122.5	889.8 ~ 1355.1	1302.0	887.7 ~ 1716.3	1308.9	802.9 ~ 1814.8	1330.9	629.9 ~ 2031.9	1588.6	428.7 ~ 2748.5
Gynecologic	508.9	342.2 ~ 675.6	39.8	-257.1 ~ 336.7	-118.7	-481.2 ~ 243.9	145.2	-357.1 ~ 647.6	1708.3	877.1 ~ 2539.5
Thyroid	242.5	-137.4 ~ 622.4	-1314.8	-1991.3~-638.4	-2866.1	-3692.2~-2039.9	-4675.4	-5820.1~-3530.7	-6238.7	-8132.8~-4344.7
Lymphoid	755.7	622.9 ~ 888.4	1115	878.7 ~ 1351.3	2067.6	1779 ~ 2356.1	3029.1	2629.2 ~ 3428.9	6849.3	6187.6 ~ 7510.9
Treatment (Examination)										
Surgery	3399.4	3299.8 ~ 3498.9	5112.5	4935.3 ~ 5289.8	5916.7	5700.3 ~ 6133.2	5150.4	4850.5 ~ 5450.4	4730.6	4234.2 ~ 5226.9
Non-surgery	330.4	227.6 ~ 433.2	72.2	-110.8 ~ 255.3	-552.0	-775.5~-328.4	-2527.1	-2836.8~-2217.3	-4774.4	-5287~-4261.9

Table 2 (continued)

Variable	Total treatment costs									
	10th percentile		25th percentile		50th percentile		75th percentile		90th percentile	
	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI	Coefficients	95% CI
Metastasis	84.4	-43.1 ~ 211.9	126.8	-100.3 ~ 353.9	275.8	-1.5 ~ 553.1	679.9	295.7 ~ 1064.1	361.7	-274.1 ~ 997.5
Diabetes	-72.9	-222.8 ~ 77.1	15.7	-251.3 ~ 282.7	-96.6	-422.6 ~ 229.5	388.5	-63.3 ~ 840.3	479.5	-268 ~ 1227.1
Hypertension	35.7	-88.2 ~ 159.5	-149	-369.5 ~ 71.5	-380.7	-649.9~-111.4	-593.1	-966.2~-219.9	-1047.3	-1664.7~-429.9

The groups in parentheses represent the reference category. The values indicate the differences in costs relative to the reference group, with increases or decreases for other categories accordingly

Coefficients were estimated after adjusting for study variables including age, sex, marital status, insurance, cancer type, and treatment modalities

HAI: hospital-acquired infection

PSM: propensity score matching

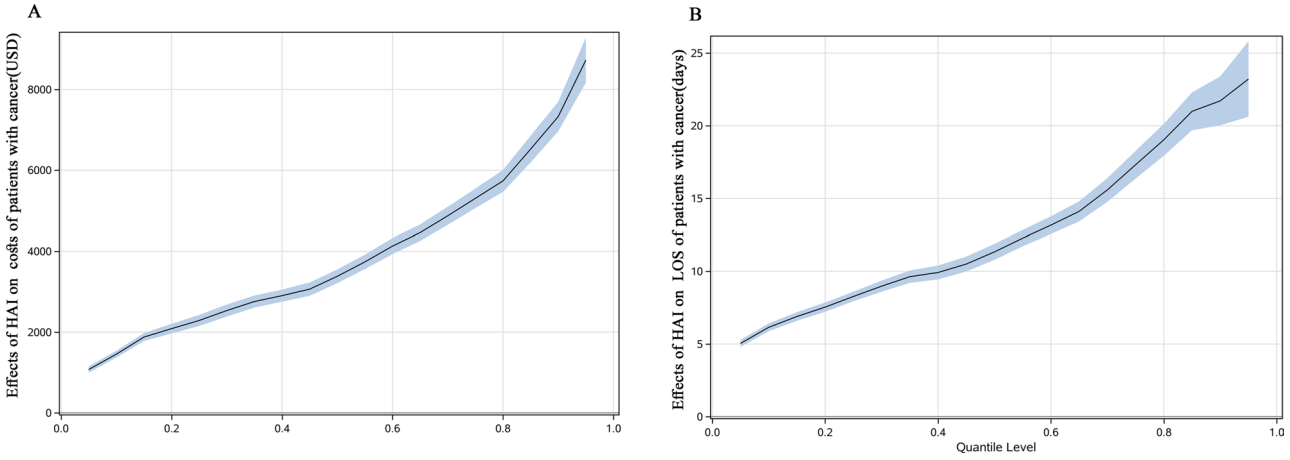

Fig. 3 Estimated coefficients and 95% confidence intervals of effects of healthcare-associated infection on hospitalization costs and LOS in regression model. Estimated coefficients and 95% confidence intervals of effects of HAI on (**A**) hospitalization costs and (**B**) LOS in the regression model. HAI: hospital-associated infections. LOS: length of hospital stays

Sensitivity analysis

An HAI was associated with a median increase in LOS of 13.4 (95% CI: 13.2–13.5) days and with excess costs $5,071.2 (5029.7–5,112.8). The impact of HAI on total treatment costs (USD) was greater in the upper than in the lower tail of the cost distribution (10th and 90th percentiles: $1,338.6; 95% CI: 1,320.1–1,357.2 vs. coefficient, $8,996.1, 95% CI: 8,851.8–9,140.3, respectively). The effect of HAI on LOS was also significant and more pronounced in the upper than in the lower tail of the outcome distribution (10th and 90th percentiles: 6.7 days; 95% CI: 6.6–6.8 vs. coefficient, 25.9 days; 95% CI: 25.1–26.8, respectively).

Discussion

Although HAI is prevalent among patients with cancer, comprehensive estimates of the LOS, cost, and survival associated with HAIs in such patients are scarce. Therefore, we aimed to assess the impact of HAI on these patients. In agreement with previous findings [15, 16], we showed that HAI indeed causes increased LOS and hospital costs [2, 21]. The increased LOS and costs induced by HAI were primarily due to the following reasons. First, additional treatments and medications, such as antibiotics are needed to contain the spread of HAI [22]. Second, extra tests and monitoring are needed to ensure that infection is stabilized. Furthermore, infections can occasionally complicate planned surgeries or treatments, requiring additional time and resources to complete these procedures [23]. Lastly, Patients may require extra time for rehabilitation and recovery care after infection treatment to regain normal function [24]. We also found a statistically significant difference in overall survival between patients with and without HAI. A comparison of the groups with and without an HAI in our consecutive cohort revealed substantial variations in baseline variables such as cancer type, sex, age, and treatment methods. However, direct comparisons of the results between the groups might have distorted conclusions. We avoided this by minimizing the effects of baseline characteristics

Table 3 Quantile regression of LOS associated with HAI in patients with cancer after PSM from 2017 to 2018 in Henan Cancer Hospital(days)

Variable	LOS									
	10th percentile		25th percentile		50th percentile		75th percentile		90th percentile	
	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI
HAI	6.1	5.9 ~ 6.4	8.3	8 ~ 8.6	11.4	10.9 ~ 12	17.6	16.7 ~ 18.5	21.7	20.1 ~ 23.4
Sex (Female)										
Male	-0.2	-0.5 ~ 0.1	-0.6	-1 ~ -0.3	-0.2	-0.8 ~ 0.4	0.3	-0.8 ~ 1.3	2.0	0.1 ~ 3.9
Age group (years) (75-)										
0–44	0.3	-0.4 ~ 0.9	0.5	-0.2 ~ 1.3	1.6	0.3 ~ 3	1.9	-0.4 ~ 4.2	6.7	2.7 ~ 10.7
45–54	0.6	0 ~ 1.2	0.5	-0.2 ~ 1.3	1.5	0.3 ~ 2.8	1.4	-0.7 ~ 3.5	4.2	0.5 ~ 7.8
55–64	0.3	-0.3 ~ 0.9	0.3	-0.4 ~ 1.0	0.6	-0.6 ~ 1.8	0.1	-1.9 ~ 2.1	0.9	-2.7 ~ 4.4
65–74	0.5	-0.1 ~ 1	0.8	0.1 ~ 1.5	0.9	-0.3 ~ 2.1	-0.5	-2.5 ~ 1.5	-0.6	-4.1 ~ 2.9
Marital status (Others)										
Married	-0.2	-0.9 ~ 0.4	-0.5	-1.2 ~ 0.2	-1	-2.3 ~ 0.2	-2.4	-4.6 ~ -0.3	-2.2	-6 ~ 1.6
Insurance (Other)										
Urban	-0.4	-1.0 ~ 0.2	0	-0.7 ~ 0.7	-0.4	-1.6 ~ 0.8	-1.0	-3.0 ~ 1.0	0.5	-3 ~ 4.1
Rural	-0.2	-0.7 ~ 0.4	0.5	-0.1 ~ 1.2	-0.1	-1.2 ~ 1	-1.8	-3.6 ~ 0	-2.0	-5.2 ~ 1.2
Own	-0.8	-1.4 ~ -0.2	0.1	-0.6 ~ 0.8	-0.1	-1.4 ~ 1.1	-0.7	-2.7 ~ 1.3	-0.6	-4.2 ~ 3
Cancer type (Others)										
Breast	-0.5	-1.4 ~ 0.4	-1.9	-2.9 ~ -0.8	-5.2	-7 ~ -3.4	-9.5	-12.5 ~ -6.5	-17.8	-23.2 ~ -12.5
Lung	0.2	-0.3 ~ 0.8	-0.2	-0.8 ~ 0.5	-2.0	-3.1 ~ -1.0	-4.5	-6.3 ~ -2.7	-10.7	-13.9 ~ -7.5
Stomach	0.1	-0.5 ~ 0.6	-0.3	-0.9 ~ 0.4	-2.0	-3.1 ~ -0.9	-4.3	-6.1 ~ -2.4	-10.7	-14 ~ -7.5
Esophageal	1.5	1.0 ~ 2.0	2.0	1.4 ~ 2.6	1.2	0.2 ~ 2.3	1.7	0 ~ 3.4	0.7	-2.3 ~ 3.8
Rectum	-0.3	-1.0 ~ 0.4	-0.3	-1.1 ~ 0.6	-2.7	-4.2 ~ -1.2	-5.4	-7.9 ~ -3	-9.6	-14 ~ -5.2
Liver	-0.5	-1.1 ~ 0.2	-0.9	-1.6 ~ -0.1	-3.5	-4.8 ~ -2.1	-7.3	-9.6 ~ -5.1	-14.4	-18.4 ~ -10.4
Colon	0.2	-0.6 ~ 1	-0.5	-1.4 ~ 0.5	-3.0	-4.7 ~ -1.4	-5.6	-8.4 ~ -2.8	-12.1	-17.1 ~ -7.1
Gynecologic	0.2	-0.4 ~ 0.8	-0.5	-1.2 ~ 0.2	-2.1	-3.3 ~ -0.9	-0.7	-2.7 ~ 1.4	7.1	3.6 ~ 10.7
Thyroid	0.8	-0.6 ~ 2.1	-2.3	-3.9 ~ -0.7	-7.4	-10.1 ~ -4.6	-13.8	-18.4 ~ -9.3	-21.4	-29.5 ~ -13.2
Lymphoid	0.5	0 ~ 0.9	1.7	1.2 ~ 2.3	3.7	2.7 ~ 4.6	2.6	0.9 ~ 4.2	-4.2	-7.1 ~ -1.4

Table 3 (continued)

Variable	LOS									
	10th percentile		25th percentile		50th percentile		75th percentile		90th percentile	
	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI	Coefficients	95%CI
Treatment (Examination)										
Surgery	8.8	8.4 ~ 9.1	10.0	9.6 ~ 10.4	8.4	7.7 ~ 9.2	0.2	-1.0 ~ 1.4	-8.9	-11~-6.7
Non-surgery	1.8	1.5 ~ 2.2	1.6	1.2 ~ 2	-1.7	-2.4~-0.9	-10.6	-11.8~-9.3	-17.2	-19.4~-15
Metastasis	0.7	0.2 ~ 1.1	1.0	0.5 ~ 1.6	1.3	0.4 ~ 2.3	2.7	1.2 ~ 4.2	4.9	2.2 ~ 7.6
Diabetes	-0.3	-0.8 ~ 0.2	0.2	-0.5 ~ 0.8	-0.2	-1.2 ~ 0.9	1.3	-0.5 ~ 3.1	3.0	-0.2 ~ 6.2
Hypertension	-0.5	-0.9 ~ 0	-0.4	-0.9 ~ 0.1	-0.2	-1.1 ~ 0.6	-0.5	-2 ~ 1	-1.9	-4.6 ~ 0.7

The groups in parentheses represent the reference category. The values indicate the differences in los relative to the reference group, with increases or decreases for other categories accordingly

Coefficients were estimated after adjusting for study variables including age, sex, marital status, insurance, cancer type, and treatment modality

HAI: hospital-acquired infection; LOS: length of stay

PSM: propensity score matching

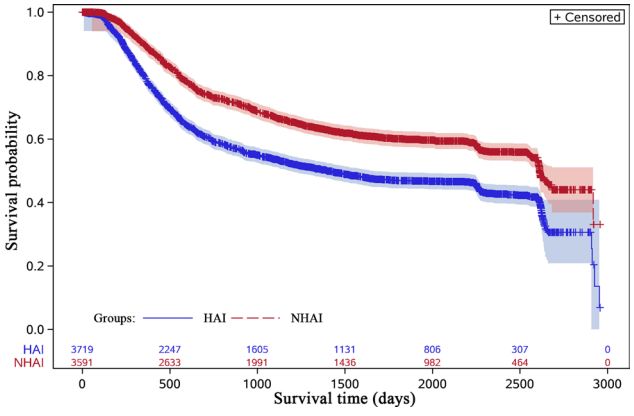

Fig. 4 Overall survival in the HAI and NHAI groups from 2017 to 2018 in Henan Cancer Hospital. HAI, patients with hospital-associated infections; NHAI, patients without hospital-associated infections

and treatment using PSM. We determined differences between the groups in hospitalization costs and LOS at the low and high quantiles of the distribution using quantile regression [19]. This method can be used to investigate correlations between explanatory factors and costs over the entire distribution because it can model every conditional quantile of hospitalization costs [25].

The LOS for patients in the general population was increased by 10.4 (from 8.2 to 12.6) days due to HAI in different regions [26]. A study conducted in west China reported that the attributable costs were €431.34 (based on 2016 data). Karagiannidou et al. reported an excess mortality of 8% in patients with bloodstream infections [9]. Therefore, our results of our analysis showed that HAI causes a longer LOS, higher hospital costs, and worse survival for patients with cancer compared with the general population in hospitals. Our findings further imply that the impact of HAI on costs and LOS did not remain consistent across the various quantiles of health costs and LOS. The effect of HAI on total treatment cost was greater among the upper than in the lower tail of cost distributions [17]. Therefore, preventing and effectively managing HAI is crucial, particularly for patients already facing elevated healthcare costs and extended hospitalization. Our quantile regression results indicate that the impact of HAI on hospitalization costs and LOS is more pronounced among patients with higher baseline costs and longer LOS (e.g., at the 95th percentile). This suggests that patients with more severe conditions or advanced disease stages are more vulnerable to the adverse effects of HAI. These findings have the potential for use as economically persuasive evidence that cancer screening and early detection are crucial. Promoting cancer screenings and early diagnosis among in high-risk groups can help clinicians to treat patients more cost-effectively and reduce LOS, which is important in light of the additional burden posed by HAI [27]. Early diagnosis and screening may help identify cancer patients at an earlier stage, when treatment is less intensive, hospitalization costs are lower, and LOS is shorter. Consequently, if HAI occurs in these early-stage patients, its impact on costs and LOS is likely to be smaller compared to patients with advanced disease. While further research is needed to confirm this hypothesis, our findings highlight the potential benefits of early detection in mitigating the burden of HAI. Promoting cancer screenings and early diagnosis among high-risk groups could

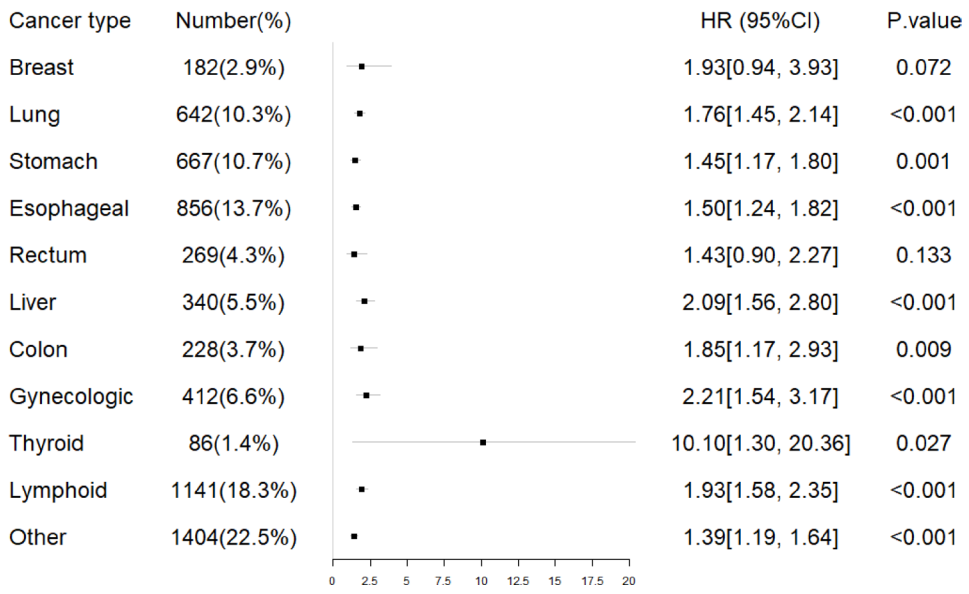

Fig. 5 Estimated Cox proportional hazard ratios with 95% confidence intervals of each cancer type

therefore help clinicians manage patients more effectively and reduce the additional burden posed by HAI. We also found that HAI had a separate and significant impact on survival rates. There are several explanations for poorer outcomes among patients with HAI. Infections might generate information that is not provided by conventional prognosticators as a measure of immunosuppression. Immunological markers have increased prognostic relevance for patients with cancer [28, 29]. In addition, the potential for infection-related hospitalizations to cause delays or cessations of cancer therapy might affect prognosis. Neutropenia and infections, particularly those of the respiratory tract, are substantial independent predictors of chemotherapy interruption [30], thus affecting disease control [31]. Our results support the notion that preventive strategies, maintaining sufficient monitoring, evaluating the motivation for targeted and individualized surveillance for certain high-risk patient groups are important. Identifying, managing, and preventing HAI in patients with cancer can be challenging. Infectious disease specialists, oncologists, microbiologists, and persons in charge of infection control all must collaborate. Raising awareness and implementing strong preventive, monitoring, and control techniques are needed to reduce the incidence and spread of HAI pathogens.

Although our findings demonstrate that HAIs significantly increase both LOS and hospitalization costs, it is essential to acknowledge that the economic burden of HAIs varies across different types of cancer, disease stage, and treatment regimen. Especially, patients with hematologic cancers, leukemia or lymphoma, often undergo aggressive and immunosuppressive treatments, which make them more susceptible to infections and may lead to a higher frequency of infections and, consequently, greater hospital costs [32, 33]. In contrast, patients with localized solid tumors (breast or prostate cancer) may experience less severe economic consequences from HAIs, as their treatment regimens are generally less intensive and less likely to lead to severe immunosuppression [34, 35]. Regarding the potential explanations for these differences, we hypothesize that the lower prevalence of breast cancer in the HAI group may be attributed to the generally younger age and better overall health status of breast cancer patients, which could result in a lower risk of infections [36, 37].

On the other hand, the higher prevalence of lung cancer, esophageal cancer, and lymphoma in the HAI group may be related to the nature of these cancers and their treatments. Lung and esophageal cancers often directly involve the respiratory or digestive tracts, which may increase the likelihood of pathogen invasion and subsequent infections [38]. Furthermore, patients with lymphoma typically have impaired immune function due to the disease itself, and they often receive immunosuppressive therapies, such as rituximab, which can further elevate the risk of infections [39].Moreover, cancer stage is another crucial factor influencing the financial impact of HAIs. Patients diagnosed at advanced stages may have more complicated disease management needs, and when an infection occurs, it could require additional interventions such as prolonged chemotherapy or complex surgeries, further escalating the costs [40]. In terms of treatment regimens, those undergoing more invasive procedures such as bone marrow transplants, major surgeries, or extended chemotherapy protocols are at higher

risk for infections and are likely to experience longer hospital stays and higher healthcare costs [35].

This study has several limitations. We did not have complete TNM classification information, which is critical for clinical treatment decisions. However, we did have data on distant metastasis (M), which plays a key role in both prognosis and treatment planning. In addition, we adjusted for treatment modalities to account for disease severity, as the choice of treatment is closely linked to the patient's condition. This adjustment was made to further control for potential biases. Although the matching process aimed to reduce bias, it could have introduced some unintended bias. We addressed this through sensitivity analyses, and the results were consistent with those obtained from PSM. Furthermore, as a retrospective study, our research may be subject to inherent biases. To mitigate these limitations, we plan to conduct a prospective study in the future.

Conclusions

The results of the analysis showed that HAI extends LOS, increase hospital costs, and worsens the survival of patients with cancer compared with other diseases. Moreover, patients with a longer LOS and higher costs are more susceptible to HAI. Our results support the notion that maintaining excellent monitoring and preventative efforts are important. In addition, the motivation for targeted and individualized surveillance should be evaluated in specific groups of patients.

Abbreviations

CPI	Consumer price index
ECDC	European Centre for Disease Prevention and Control
HAI	Healthcare-associated infection
IQR	Interquartile range
LOS	Length of hospital stay
OS	Overall survival

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12885-025-13975-7.

Supplementary Material 1

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Not applicable.

Author contributions

CL, DY, and HH conceptualized the study. YC managed the project.XL and XZ performed data collection, cleaning, and analysis. YQ performed the coding. CL and DY initiated the first draft manuscript. All authors reviewed and edited the manuscript and approved the final version.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Henan Cancer Hospital Research Ethics Committee and conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. Informed consent was waived by the Henan Cancer Hospital Research Ethics Committee, because this is a retrospective study and the data used in this study were anonymized. This study is based on publicly available data. The data were obtained and analyzed according to the requirements of this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Publisher's note