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Impact of hospital variation in hematologic malignancy patient proportions on outcomes of chronic lymphocytic leukemia patients undergoing cardiac surgery: insights from nationwide data analysis

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Abstract

Objective This study aimed to investigate the impact of the proportion of hematologic malignancy patients in hospitals on the prognosis of chronic lymphocytic leukemia (CLL) patients undergoing cardiac surgery. Perioperative management of CLL patients is complex, particularly regarding immunosuppression and infection risks.

Methods This retrospective study utilized data from the National Inpatient Sample (NIS) from 2010 to 2021. Adult CLL patients undergoing cardiac surgery were included, categorizing hospitals into five quintiles based on hematologic malignancy patient proportions. Outcomes included in-hospital mortality, acute kidney injury (AKI), postoperative bleeding, and infections.

Results AKI incidence was significantly lower in the Q5 group (OR: 0.68, 95% CI: 0.49–0.97), as was the rate of respiratory failure (OR: 0.53, 95% CI: 0.35–0.79). However, the rates of transfusion and acute heart failure were significantly higher in Q5 (acute heart failure OR: 1.70, 95% CI: 1.07–2.77). No significant differences were found in in-hospital mortality or other complications.

Conclusion The proportion of hematologic malignancy patients affects CLL patient outcomes, with higher proportions linked to lower AKI and respiratory failure rates but increased transfusion and heart failure risks. Further research is warranted.

Keywords Chronic lymphocytic leukemia, Hematologic malignancy, Cardiac surgery, NIS database, Clinical complications, Prognosis

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Introduction

Cardiovascular disease (CVD) remains a significant cause of morbidity and mortality worldwide [1]. CVD imposes a significant burden on global health [2]. In particular, patients with hematologic malignancies face unique challenges when confronted with concurrent cardiac conditions, necessitating surgical intervention. CLL is the most prevalent type of adult leukemia in Western countries, representing 25% of all cases of adult leukemia [3]. CLL is a typical leukemia of the elderly [4]. In recent years, the incidence of CLL has significantly increased in most countries worldwide, making it a major global public health concern [5]. Cardiac surgery (CS) in patients with CLL is associated with substantial perioperative risks, including bleeding complications and infections, which are exacerbated by the immunosuppressive effects of CLL and its treatments [6, 7].

The cardiotoxicity of chemotherapy drugs used in CLL treatment may exacerbate the severity of patients' cardiac conditions and negatively impact perioperative outcomes in CS [8, 9]. Additionally, CLL patients frequently present with comorbidities such as dyslipidemia, further complicating perioperative management [10].

The management of CLL patients requiring CS within the broader context of hematologic malignancy remains a relatively understudied domain. Hematologic malignancy patients undergoing CS represent a heterogeneous cohort, varying in disease severity, treatment history, and associated comorbidities. Importantly, the proportion of hematologic malignancy patients among CS recipients may differ across healthcare institutions, potentially influencing perioperative outcomes. For patients with hematologic malignancies, cardiac surgery strategies must be meticulously planned and carefully executed to minimize postoperative complications [11].

Addressing the paucity of literature regarding the impact of hospital case mix on the prognosis of CLL patients undergoing CS among hematologic malignancy cohorts is crucial for optimizing patient care and resource allocation. By elucidating the influence of hospital-level factors, such as caseload and institutional expertise in managing hematologic malignancies, on perioperative outcomes, this study aims at inform risk stratification strategies and enhance patient counseling. Furthermore, identifying disparities in outcomes across healthcare settings can guide quality improvement initiatives and facilitate the development of tailored interventions to optimize surgical care for this vulnerable patient population.

This study analyzed a nationwide dataset to investigate the impact of hospital case mix, particularly the proportion of hematologic malignancy patients, on the prognosis of CLL patients undergoing CS. This research aims at bridge existing knowledge gaps and contribute valuable insights into the perioperative management of CLL patients undergoing CS within the context of hematologic malignancies. Through a comprehensive analysis of hospital case mix and its impact on clinical outcomes, this study endeavors to advance our understanding of optimal care delivery for this complex patient cohort.

Methods

Data sources

This retrospective study utilized data from the Nationwide Inpatient Sample (NIS) database spanning the years 2010 to 2021. The NIS is part of the Healthcare Cost and Utilization Project (HCUP) database series and is sponsored by the Agency for Healthcare Research and Quality (AHRQ). It is the largest all-payer inpatient care database in the United States, containing information on patient discharges from 47 states and the District of Columbia, covering approximately 97% of the US population. The NIS employs a 20% random stratified sampling of all inpatient discharges, collecting information from over 7 million hospital stays annually. It provides a nationally representative sample of hospital inpatient stays, encompassing a diverse array of hospitals, regions, and patient populations across the country. It is the largest national database composed of all payers and is frequently used for national analyses of specific procedures [12, 13]. Institutional Review Board approval and informed consent were not required for this study, as the NIS database is publicly available.

Sample selection and study cohorts

We identified adult patients with CLL who underwent CS between January 1, 2010, and December 31, 2021, from the Nationwide Inpatient Sample (NIS) database Patients were initially selected based on their records of cardiac surgical procedures during this period. Subsequently, we calculated the proportion of hematologic malignancy patients relative to the total patient admissions for each hospital included in the dataset. Hospitals were stratified into quintiles based on this proportion. Within each quintile, patients diagnosed with CLL who underwent CS were further selected for analysis. Inclusion criteria encompassed patients with documented records of both CS and CLL during their hospital admissions, identified using International Classification of Diseases (ICD- 9 and ICD- 10) codes. Patients were required to be 18 years or older at the time of admission. Exclusion criteria involved cases where essential demographic data such as age, gender, or clinical information were incomplete or missing. A detailed methods flowsheet is presented in Fig. 1. The detailed ICD- 9 and ICD- 10 codes for disease identification are provided in Table S1. The detailed ICD- 9 and

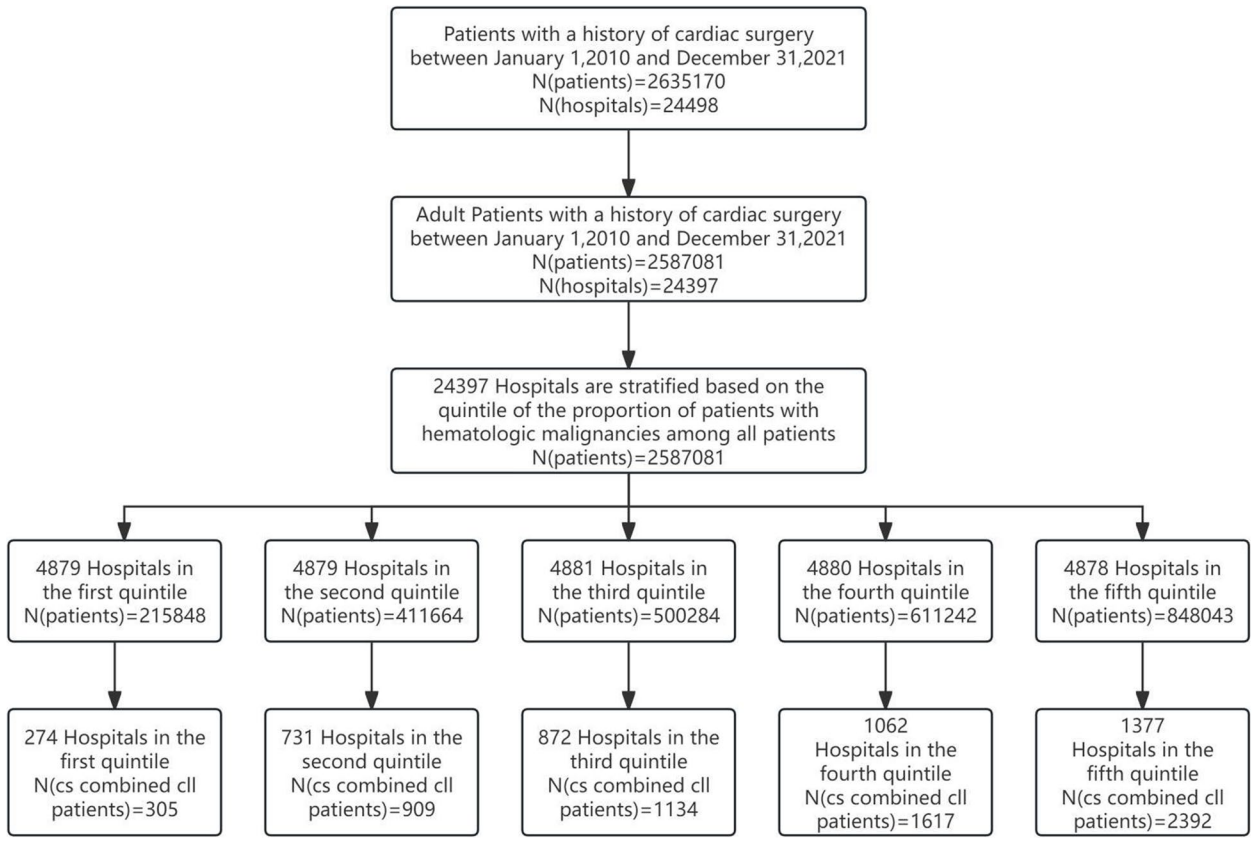

Fig. 1 Study flow diagram

ICD- 10 codes for baseline comorbidities are provided in Table S2.

Exposure

The exposure variable in this study is the proportion of hematologic malignancy patients, which serves as an indicator to ascertain the experience of hematologic malignancy treatment at each hospital. The proportion of hematologic malignancy patients is defined as the ratio of the number of hematologic malignancy patients (including CLL, CML, AML, ALL, MM, NHL, HL) hospitalized at the same hospital each year to the total number of patients. Subsequently, hospitals are divided into quintiles based on the proportion of hematologic malignancy patients. The lowest quintile represents hospitals with the lowest proportion of hematologic malignancy patients, while the highest quintile represents hospitals with the highest proportion of hematologic malignancy patients, indicating a propensity towards hematologic malignancy specialty hospitals. The detailed ICD- 9 and ICD- 10 codes for disease identification are provided in Table S1.

Study outcomes

The study investigated multiple clinical outcomes across different quintiles, focusing on various postoperative complications and mortality rates. Key outcomes included in-hospital mortality, acute kidney injury (AKI), permanent pacemaker implantation procedure, vascular complications, blood transfusion requirements, postoperative bleeding, gastrointestinal bleeding, hematuria, cardiogenic shock, cardiac arrest, respiratory failure, acute heart failure, urinary tract infection (UTI), skin infection, and thrombocytopenia. Each outcome was analyzed to assess its association with quintile stratification, providing insights into postoperative recovery and complication rates. The detailed ICD- 9 and ICD- 10 codes for clinical outcomes are provided in Table S3.

Covariate definitions

Baseline covariates encompassed both patient- and hospital-level attributes. Patient characteristics included demographic factors (age, gender, and race/ethnicity), socioeconomic status (ZIP code income quartile and payment method), and a range of comorbidities such as hypertension, chronic renal failure, coronary artery disease, chronic obstructive pulmonary disease (COPD),

dyslipidemia, chronic heart failure (CHF), atrial fibrillation (AF), smoking history, pneumonia, alcohol use, liver disease, obesity, cardiogenic shock, 3rd-degree heart block (HB), and carotid artery disease. Hospital characteristics comprised geographical region, bed size, teaching status, and ownership structure, providing a comprehensive framework for analyzing the impact of patient and hospital factors on study outcomes.

Statistical analysis

To evaluate the differences in patient and hospital characteristics between groups, we employed various statistical tests. Specifically, we used the Pearson chi-squared test for categorical variables and the independent samples t-test for continuous variables. Categorical variables were presented as frequencies and percentages, while continuous variables were reported as medians with interquartile ranges (IQRs) or means with standard deviations (SDs).

In the multivariable logistic regression analysis, we reported odds ratios (ORs) and their 95% confidence intervals (CIs) to assess the impact of variations in the proportion of hematologic malignancy patients within hospitals on the outcomes of CLL patients undergoing CS. This nationwide data analysis provided in-depth insights. Baseline covariates included a wide range of patient and hospital attributes. Patient characteristics comprised demographic factors (age, gender, race/ethnicity), socioeconomic status (ZIP code income quartile, payment method), and various comorbidities such as hypertension, chronic renal failure, coronary artery disease, chronic obstructive pulmonary disease (COPD), dyslipidemia, chronic heart failure (CHF), atrial fibrillation (AF), smoking history, pneumonia, alcohol use, liver disease, obesity, cardiogenic shock, third-degree heart block (HB), and carotid artery disease. Hospital characteristics included geographical region, bed size, teaching status, and ownership structure, providing a comprehensive framework for analyzing the impact of patient and hospital factors on study outcomes.

All statistical analyses were conducted using SAS version 9.2 and R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria). Two -sided statistical tests at an alpha level of <0.05 were considered statistically significant.

Results

Study population

This study included 6,357 patients diagnosed with CLL who underwent CS between January 1, 2010, and December 31, 2021, across 4,316 hospitals. The distribution of patients within the quintiles of the proportion of hematologic malignancy patients was significantly associated with the distribution over the years ($p< 0.001$) (Table 1).

Baseline characteristics by hematologic malignancy patient proportion quintiles

The baseline characteristics of patients, stratified by hospital quintiles of hematologic malignancy patient proportion, are presented in Table 1. The median age was 76 years (IQR 69–82), with a similar distribution across quintiles ($p= 0.179$). The majority of patients were male (72.2%), and this did not significantly vary between quintiles ($p= 0.229$). Racial composition showed significant differences ($p< 0.0001$), with a higher proportion of White patients in Q5 (90.0%) compared to Q1 (76.7%). Year of admission also varied significantly ($p< 0.0001$), with a higher concentration of recent admissions in Q1 and Q2. The Charlson Comorbidity Index (CCI) indicated greater comorbidity burden in Q1 (50.5% with CCI 9+) compared to Q5 (41.3%) ($p= 0.002$). Insurance type distribution did not show significant differences ($p= 0.635$), with most patients covered by Medicare. Hospital characteristics, including bed size and location, varied significantly, with smaller and rural hospitals more prevalent in Q1 ($p< 0.0001$). Ownership type also differed, with a higher proportion of government and private, non-profit hospitals in Q1 ($p< 0.0001$). Comorbidities such as congestive heart failure, coronary artery disease, endocarditis, pneumonia, coagulopathy, diabetes, hypertension, obesity, and smoking showed significant differences across quintiles, highlighting the varying health profiles of patients in different quintiles. These findings emphasize the importance of stratifying patients by quintiles when analyzing baseline characteristics and their potential impact on clinical outcomes in hematologic malignancies. Baseline Characteristics by Hematologic Malignancy Patient Proportion Quintiles are detailed in Table 1.

Clinical outcomes by hematologic malignancy patient proportion quintiles

In this study, we examined the clinical outcomes of patients stratified by the proportion of hematologic malignancy patients within hospitals. The analysis was conducted across quintiles, each representing a different range of hematologic malignancy patient proportions. Figure 2 presents the results of the logistic regression analysis on clinical outcome measures for patients with hematologic malignancies, categorized by quintiles.

The analysis of clinical outcomes across quintiles of hematologic malignancy patients reveals several notable findings. This study aims at examine the association

Table 1 Baseline characteristics of patients with cll stratified according to hospital blood malignancy proportion

Characteristics	No. (%)						*P*-value
		Proportion of Patients with Hematologic Malignancies by Quintile					
	Overall	Q 1	Q 2	Q 3	Q 4	Q5	
No. patients	6357	305	909	1134	1617	2392	
No. hospitals	4316	274	731	872	1062	1377	
Age (y),median (IQR)	76 (69,82)	75 (68,82)	76 (69,82)	77 (70,83)	77 (69,82)	76 (69,82)	.179
Age at admission							
18 ~ 54	151 (2.3)	10 (3.2)	21 (2.3)	27 (2.4)	28 (1.7)	65 (2.7)	.165
55 ~ 64	697 (11.0)	39 (12.8)	90 (9.9)	116 (10.2)	171 (10.6)	281 (11.8)	
65 ~ 74	1835 (28.9)	96 (31.5)	285 (31.4)	320 (28.2)	481 (29.8)	653 (27.3)	
75 +	3674 (57.8)	160 (52.5)	513 (56.4)	671 (59.2)	937 (57.9)	1393 (58.2)	
Gender							
Male	4590 (72.2)	220 (72.1)	670 (73.7)	824 (72.7)	1132 (70.0)	1744 (72.9)	.229
Female	1767 (27.8)	85 (27.9)	239 (26.3)	310 (27.3)	485 (30.0)	648 (27.1)	
Race							
White	5373 (89.3)	230 (76.7)	768 (87.7)	976 (90.2)	1375 (90.0)	2024 (90.0)	<.0001
Black	272 (4.5)	25 (8.3)	50 (5.7)	43 (4.0)	68 (4.5)	86 (3.8)	
Hispanic	181 (3.0)	26 (8.7)	33 (3.8)	37 (3.4)	34 (2.3)	51 (2.3)	
Asian/Pacific Islander	42 (0.7)	3 (1.0)	7 (0.8)	12 (1.1)	6 (0.4)	14 (0.6)	
Native American	14 (0.2)	5 (1.7)	1 (0.1)	0	3 (0.2)	5 (0.2)	
Other	138 (2.3)	11 (3.7)	17 (1.9)	14 (1.3)	26 (1.72)	70 (3.1)	
Missing data	337	5	33	52	105	142	
Year							
2010	511 (8.0)	6 (2.0)	24 (2.6)	76 (6.7)	173 (10.7)	232 (9.7)	<.0001
2011	551 (8.7)	4 (1.3)	22 (2.4)	45 (4.0)	167 (10.3)	313 (13.1)	
2012	448 (7.1)	6 (2.0)	17 (1.9)	38 (3.4)	144 (8.9)	243 (10.2)	
2013	563 (8.9)	7 (2.3)	21 (2.3)	50 (4.4)	164 (10.1)	321 (13.4)	
2014	524 (8.2)	2 (0.7)	23 (2.5)	38 (3.4)	126 (7.8)	335 (14.0)	
2015	576 (9.1)	3 (1.0)	39 (4.3)	59 (5.2)	196 (12.1)	279 (11.7)	
2016	483 (7.6)	52 (17.1)	118 (13.0)	117 (10.3)	101 (6.3)	95 (4.0)	
2017	497 (7.8)	51 (16.7)	134 (14.7)	139 (12.2)	81 (5.0)	92 (3.9)	
2018	498 (7.8)	51 (16.7)	117 (12.9)	137 (12.1)	90 (5.6)	103 (4.3)	
2019	558 (8.8)	35 (11.5)	136 (15.0)	140 (12.4)	120 (7.4)	127 (5.3)	
2020	570 (9.0)	30 (9.8)	131 (14.4)	156 (13.8)	132 (8.2)	121 (5.1)	
2021	578 (9.1)	58 (19.0)	127 (14.0)	139 (12.3)	123 (7.6)	131 (5.5)	
CCI							
0 ~ 4	80 (1.3)	4 (1.3)	7 (0.8)	15 (1.3)	15 (0.9)	39 (1.6)	.002
5 ~ 6	1060 (16.7)	35 (11.5)	132 (14.5)	168 (14.8)	278 (17.2)	447 (18.7)	
7 ~ 8	2412 (37.9)	112 (36.7)	343 (37.7)	429 (37.8)	609 (37.7)	919 (38.4)	
9 +	2805 (44.1)	154 (50.5)	427 (47.0)	522 (46.0)	715 (44.2)	987 (41.3)	
Insurance type							
Medicare	5175 (81.5)	244 (80.0)	749 (82.5)	934 (82.5)	1317 (81.5)	1931 (80.7)	.635
Medicaid	111 (1.8)	10 (3.3)	12 (1.3)	15 (1.3)	31 (1.9)	43 (1.8)	
Private including HMO	890 (14.0)	42 (13.8)	125 (13.8)	153 (13.5)	218 (13.5)	352 (14.7)	
Self-pay	38 (0.6)	0	2 (0.2)	7 (0.6)	11 (0.7)	18 (0.8)	
No charge	3 (0.1)	0	0	0	1 (0.1)	2 (0.1)	
Other	136 (2.1)	9 (3.0)	20 (2.2)	23 (2.0)	38 (2.4)	46 (1.9)	
Missing data	4	0	1	2	1	0	

Table 1 (continued)

Characteristics	No. (%)						*P*-value
		Proportion of Patients with Hematologic Malignancies by Quintile					
	Overall	Q 1	Q 2	Q 3	Q 4	Q5	
Hospital bed size							
Small	614 (10.7)	54 (22.0)	136 (17.5)	116 (11.7)	152 (10.2)	156 (6.9)	<.0001
Medium	1407 (24.4)	91 (37.1)	269 (34.5)	305 (30.7)	373 (25.0)	369 (16.4)	
Large	3744 (64.9)	100 (40.8)	374 (48.0)	572 (57.6)	969 (64.9)	1729 (76.7)	
Missing data	592	100	130	141	123	138	
Hospital location							
Rural	267 (4.6)	22 (9.0)	33 (4.2)	52 (5.2)	89 (6.0)	71 (3.2)	<.0001
Urban non-teaching	1377 (23.9)	63 (25.7)	200 (25.7)	245 (2.7)	406 (27.2)	463 (20.5)	
Urban teaching	4121 (71.5)	160 (65.3)	546 (70.1)	696 (70.1)	999 (66.9)	1720 (76.3)	
Missing data	592	60	130	141	123	138	
Ownership							
Government, nonfederal	440 (7.6)	21 (8.6)	62 (8.0)	54 (5.4)	110 (7.4)	193 (8.6)	<.0001
Private, non-profit	4636 (80.4)	137 (55.9)	536 (68.8)	831 (83.7)	1227 (82.1)	1905 (84.5)	
Private, invest-own	689 (12.0)	87 (35.5)	181 (23.2)	108 (10.9)	157 (10.5)	156 (6.9)	
Missing data	592	60	130	141	123	138	
Comorbidities							
CHF	2854 (44.9)	156 (51.2)	445 (49.0)	542 (47.8)	691 (42.7)	1020 (42.6)	<.0001
Coronary artery disease	2887 (45.4)	155 (50.8)	438 (48.2)	536 (47.3)	701 (43.4)	1057 (44.2)	.016
Atrial fibrillation	2585 (40.7)	120 (39.3)	365 (40.2)	441 (38.9)	638 (39.5)	1021 (42.67)	.146
Prior MI	852 (13.4)	37 (12.1)	113 (12.4)	167 (14.7)	223 (13.8)	312 (13.0)	.501
Cardiogenic shock	337 (5.3)	22 (7.2)	51 (5.6)	64 (5.6)	71 (4.4)	129 (5.4)	.252
Endocarditis	64 (1.0)	2 (0.7)	5 (0.6)	4 (0.4)	22 (1.4)	31 (1.3)	.025
Pneumonia	207 (3.3)	5 (1.6)	13 (1.4)	20 (1.8)	69 (4.3)	100 (4.2)	<.0001
Urinary Tract Infection	451 (7.1)	22 (7.2)	71 (7.8)	77 (6.8)	111 (6.9)	170 (7.1)	.909
Intracerebral Hemorrhage	10 (0.2)	1 (0.3)	0	3 (0.3)	2 (0.1)	4 (0.2)	.565
Chronic renal failure	1812 (28.5)	95 (31.2)	271 (29.8)	333 (29.4)	467 (28.9)	646 (27.0)	.291
COPD	1402 (22.1)	64 (21.0)	211 (23.2)	240 (21.2)	3373 (23.1)	514 (21.5)	.584
Obstructive sleep apnea	643 (10.1)	31 (10.2)	93 (10.2)	138 (12.2)	160 (9.9)	221 (9.2)	.117
Pulmonary Embolism	11 (0.2)	0	2 (0.2)	2 (0.2)	2 (0.1)	5 (0.2)	.902
Coagulopathy	1512 (23.8)	77 (25.3)	195 (21.5)	295 (26.1)	406 (25.1)	539 (22.5)	.044
Anemia	2426 (38.2)	119 (39.0)	332 (36.5)	429 (37.8)	658 (40.7)	888 (37.12)	.155
Diabetes	1608 (25.3)	86 (28.2)	236 (26.0)	282 (24.9)	452 (28.0)	552 (23.1)	.007
Hypertension	3301 (51.9)	161 (52.8)	490 (53.9)	636 (56.1)	820 (50.7)	1194 (49.9)	.007
Liver Disease	131 (2.1)	7 (2.3)	15 (1.7)	25 (2.2)	34 (2.1)	50 (2.1)	.912
Obesity	855 (13.5)	48 (15.7)	133 (14.6)	181 (16.0)	215 (13.3)	278 (11.6)	.004
Alcohol use	83 (1.3)	4 (1.3)	10 (1.1)	11 (1.0)	25 (1.6)	33 (1.4)	.714
Smoking	2271 (35.7)	116 (38.0)	359 (39.5)	449 (39.6)	530 (32.8)	817 (34.2)	.000
Syncope	157 (2.5)	6 (2.0)	18 (2.0)	34 (3.0)	39 (2.4)	60 (2.5)	.631
Dyslipidemia	3472 (54.6)	163 (53.4)	509 (56.0)	627 (55.3)	882 (54.6)	1291 (54.0)	.830

Abbreviations: *CHF* Congestive Heart Failure, *Prior MI* Prior Myocardial Infarction, *COPD* Chronic Obstructive Pulmonary Disease

among these quintiles and various clinical outcomes, focusing on statistically significant results. In-hospital mortality rates did not show statistically significant differences across quintiles. However, the incidence of AKI decreased significantly in quintile 5 (OR: 0.68, 95% CI: 0.49–0.97) compared to quintile 1. Blood transfusion rates increased with higher quintiles, with quintiles 3, 4, and 5 having significantly higher odds ratios (OR: 2.56, 95% CI: 1.37–5.34; OR: 3.47, 95% CI: 1.89–7.16; and OR: 3.70, 95% CI: 2.02–7.60, respectively). Postoperative

bleeding showed increased odds in higher quintiles, with quintile 3 (OR: 1.48, 95% CI: 0.99–2.29) and quintile 5 (OR: 1.36, 95% CI: 0.92–2.07) reaching near statistical significance. Gastrointestinal bleeding rates were higher in higher quintiles, though not statistically significant. Hematuria rates did not show significant differences across quintiles. Cardiogenic shock and cardiac arrest rates did not show significant differences across quintiles. Respiratory failure rates decreased significantly in quintile 5 (OR: 0.53, 95% CI: 0.35–0.79) compared to quintile 1. Acute heart failure showed a significantly higher odds ratio in quintile 5 (OR: 1.70, 95% CI: 1.07–2.77) compared to quintile 1. UTI and skin infection rates did not show statistically significant differences across quintiles. Thrombocytopenia rates were not significantly different across quintiles. Sepsis, Acute Bronchitis, Pneumonia, and Venous Thromboembolism rates did not show statistically significant differences across quintiles. In summary, statistically significant differences in clinical outcomes among hematologic malignancy patients were observed for AKI, blood transfusion, respiratory failure, and acute heart failure, indicating varied risks associated with different quintiles. Other outcomes, including in-hospital mortality, gastrointestinal bleeding, hematuria, cardiogenic shock, cardiac arrest, UTI, skin infection, and thrombocytopenia, sepsis, acute bronchitis, pneumonia, and venous thromboembolism, did not show significant differences across quintiles. Adjusted Clinical Outcomes Based on Quintiles of Hematologic Malignancy Patient Proportion are detailed in Table 2. The forest plot of adjusted clinical outcomes based on quintiles of hematologic malignancy patient proportion, following logistic regression, is presented in Fig. 2.

Discussion

This study, which analyzed the clinical outcomes of 6,357 patients with CLL who underwent CS across different hospital quintiles based on the proportion of hematologic malignancy patients, revealed several important findings. Firstly, the study established a significant association among the quintiles of hematologic malignancy patient proportion and various baseline characteristics and clinical outcomes. Notably, in hospitals with a higher proportion of hematologic malignancy patients, the rates of acute kidney injury and respiratory failure were significantly lower, suggesting better postoperative organ function preservation in these patients. This finding suggests that in hospitals with a lower proportion of hematologic malignancy patients, the higher rates of AKI and respiratory failure among patients should also be given due consideration. AKI is closely associated with the prognosis of patients undergoing CS, thus this condition warrants significant attention [14]. Physicians should

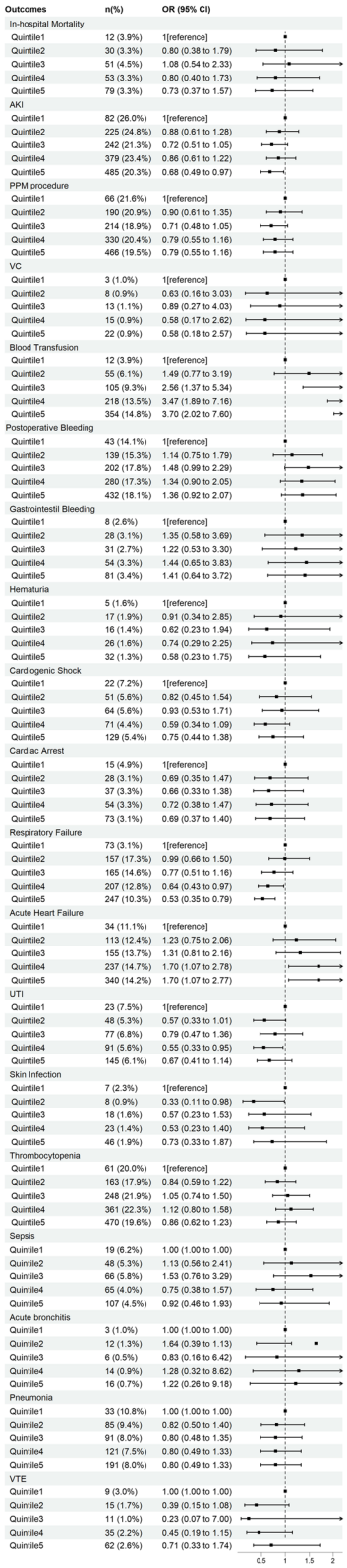

Fig. 2 Forest plot of clinical indicators after logistic regression analysis

Table 2 Clinical outcomes table for adjusted outcomes based on quintiles of proportion of patients with hematological malignancies

Outcomes	No. (%)						*P*-value
		Proportion of Patients with Hematologic Malignancies by Quintile					
	Overall	Q1	Q2	Q3	Q4	Q5	
No. patients	6357	305	909	1134	1617	2392	
No. hospitals	4316	274	731	872	1062	1377	
In-hospital mortality	225 (3.5)	12 (3.9)	30 (3.3)	51 (4.5)	53 (3.3)	79 (3.3)	0.399
AKI	1413 (22.2)	82 (26.0)	225 (24.8)	242 (21.3)	379 (23.4)	485 (20.3)	0.006
PPM procedure	1266 (19.9)	66 (21.6)	190 (20.9)	214 (18.9)	330 (20.4)	466 (19.5)	0.658
Vascular complications	61 (1.0)	3 (1.0)	8 (0.9)	13 (1.1)	15 (0.9)	22 (0.9)	0.97
Blood transfusion	744 (11.7)	12 (3.9)	55 (6.1)	105 (9.3)	218 (13.5)	354 (14.8)	<.0001
Postoperative bleeding	1096 (17.2)	43 (14.1)	139 (15.3)	202 (17.8)	280 (17.3)	432 (18.1)	0.205
Gastrointestinal bleeding	202 (3.2)	8 (2.6)	28 (3.1)	31 (2.7)	54 (3.3)	81 (3.4)	0.82
Hematuria	96 (1.5)	5 (1.6)	17 (1.9)	16 (1.4)	26 (1.6)	32 (1.3)	0.83
Cardiogenic shock	337 (5.3)	22 (7.2)	51 (5.6)	64 (5.6)	71 (4.4)	129 (5.4)	0.252
Cardiac arrest	207 (3.3)	15 (4.9)	28 (3.1)	37 (3.3)	54 (3.3)	73 (3.1)	0.539
Respiratory failure	833 (13.1)	57 (18.7)	157 (17.3)	165 (14.6)	207 (12.8)	247 (10.3\)	<.0001
Acute heart failure	879 (13.8)	34 (11.1)	113 (12.4)	155 (13.7)	237 (14.7)	340 (14.2)	0.333
UTI	384 (6.0)	23 (7.5)	48 (5.3)	77 (6.8)	91 (5.6)	145 (6.1)	0.442
Skin infection	102 (1.6)	7 (2.3)	8 (0.9)	18 (1.6)	23 (1.4)	46 (1.9)	0.213
Thrombocytopenia	1303 (20.5)	61 (20.0)	163 (17.9)	248 (21.9)	361 (22.3)	470 (19.6)	0.052
Sepsis	305 (4.8)	19 (6.2)	48 (5.3)	66 (5.8)	65 (4.0)	107 (4.5)	0.130
Acute bronchitis	51 (0.8)	3 (1.0)	12 (1.3)	6 (0.5)	14 (0.9)	16 (0.7)	0.301
Pneumonia	521 (8.2)	33 (10.8)	85 (9.4)	91 (8.0)	121 (7.5)	191 (8.0)	0.224
VTE	132 (2.1)	9 (3.0)	15 (1.7)	11 (1.0)	35 (2.2)	62 (2.6)	0.018

Abbreviations: AKI Acute Kidney Injury, *PPM procedure* Permanent Pacemaker Implantation Procedure, *UTI* Urinary Tract Infectione, *VTE* Venous Thromboembolism

carefully examine both preoperative and intraoperative care processes, with particular attention to the patient's serum creatinine (SCr) levels, as even subtle increases in SCr can serve as an early indicator of renal injury [15]. Simultaneously, close monitoring of early detection levels of novel AKI biomarkers, such as Cystatin C, Hepcidin, and Kidney Injury Molecule- 1 (KIM- 1), is also essential [16, 17]. Respiratory failure after cardiac surgery is a devastating complication that significantly impacts patient prognosis [18, 19]. Early identification of high-risk factors for respiratory failure is crucial. Physicians should also closely monitor the patient's serum levels of the soluble isoform of the receptor for advanced glycation end products (sRAGE) and Angiopoietin- 2, as these are important biomarkers for postoperative respiratory failure following CS [20, 21].

Moreover, the analysis showed that blood transfusion rates increased significantly with higher quintiles of hematologic malignancy patients. In hospitals within these higher quintiles, patients exhibited a greater need for transfusions, which may reflect an elevated perioperative bleeding risk or impaired coagulation function in these populations. This increased need for transfusions is likely influenced by a combination of factors, including baseline hematologic parameters such as platelet count and hemoglobin levels, as well as the stage of CLL and the treatment regimen prior to surgery. For example, patients with advanced-stage CLL or those who have undergone recent intensive chemotherapy may have impaired coagulation function, which could contribute to a higher incidence of bleeding and transfusion requirements. Therefore, a comprehensive evaluation of these factors is crucial when assessing transfusion needs in CLL patients undergoing surgery. This trend underscores the necessity for stricter perioperative management in such hospitals to minimize unnecessary transfusions and reduce the incidence of related complications. Previous studies have demonstrated that patients with CLL, as a high-risk population, indeed require more frequent blood transfusions [22, 23]. Since transfusion is not only closely associated with bleeding risk but also potentially increases the risk of mortality, postoperative infections, and other adverse outcomes, implementing preventive measures during the perioperative period is particularly critical [24]. Patient blood management for CS patients

is crucial and requires multidisciplinary collaboration for effective implementation [25].

In conclusion, the key findings of this study provide new evidence-based insights for clinical practice, highlighting the importance of considering the proportion of hematologic malignancy patients in hospitals when assessing and managing the surgical risk for CLL patients undergoing CS. This stratified analysis contributes to a deeper understanding of how variations in hospital practices might impact patient outcomes and supports the development of more individualized treatment strategies.

Based on the findings of this study, several avenues for future research are warranted to further elucidate the clinical implications and improve outcomes for CLL patients undergoing CS. First, future studies should focus on identifying the underlying mechanisms that contribute to the observed differences in acute kidney injury and respiratory failure rates across hospitals with varying proportions of hematologic malignancy patients. Understanding these mechanisms may help to tailor perioperative care strategies and optimize organ function preservation in these vulnerable populations. Additionally, further investigation into the role of novel biomarkers, such as sRAGE and Angiopoietin- 2, in predicting postoperative complications, including respiratory failure, is crucial. Large-scale prospective studies are needed to validate the utility of these biomarkers in clinical practice and to establish standardized thresholds for early detection and intervention.

Moreover, the significant increase in transfusion rates in hospitals with a higher proportion of hematologic malignancy patients underscores the need for future research on blood management strategies specifically tailored for this high-risk group. Future studies should examine the impact of baseline hematologic parameters, CLL stage, and preoperative treatment regimens on transfusion requirements and postoperative bleeding risks. Studies evaluating the efficacy of perioperative interventions, such as preoperative autologous blood donation, erythropoietin administration, and the use of platelet function testing, could provide valuable insights into reducing transfusion dependency and associated complications. Investigating the impact of these interventions on long-term survival and quality of life outcomes in CLL patients undergoing CS is also critical.

Lastly, given the variation in outcomes observed across hospital quintiles, future research should explore the potential influence of institutional factors, such as surgical expertise, perioperative protocols, and multidisciplinary team composition, on patient outcomes. Comparative studies across different healthcare systems may offer valuable insights into optimizing care delivery and ensuring equitable outcomes for CLL patients worldwide.

Limitations

This study has several limitations. First, the NIS database captures only single admission records per patient, preventing longitudinal tracking and thereby limiting the analysis of outcomes such as progression-free survival and overall survival. Additionally, outpatient data are not included, which further constrains the scope of our analysis. Another key limitation is the absence of indicators in the NIS database for conditions present at the time of admission. This gap hinders our ability to distinguish between pre-existing comorbidities and complications that arise during hospitalization, potentially affecting the accuracy of our assessment of certain clinical outcomes [26]. Moreover, while the NIS database relies on ICD- 9 and ICD- 10 codes to categorize comorbidities, diagnoses, procedures, and complications, these codes were not originally designed for research purposes. As a result, they may not fully capture all relevant clinical conditions. Additionally, because these codes are often generated from insurance claims or hospital records, they may be influenced by reimbursement policies or coding practices by non-medical staff, which could introduce bias into the data [27].

A specific limitation of this study is the reliance on ICD coding to quantify the proportion of hematologic malignancy patients in the hospital. While ICD codes are essential for administrative purposes, they may not accurately reflect the hospital's expertise in managing these conditions. Patients diagnosed or treated for hematologic malignancies may have received care at other institutions, and not all relevant clinical details may have been provided during cardiac surgery admission. As a result, ICD coding may not fully capture the true burden of hematologic malignancies in the hospital, potentially leading to a misinterpretation of the hospital's expertise in managing these patients. To address this limitation, future studies could explore alternative methods, such as incorporating hospital-specific tumor registry data, to better capture the hospital's role in treating hematologic malignancies. Additionally, complementary measures, such as physician certifications or assessments of multidisciplinary treatment involvement, could provide more insight into the institution's specialized capabilities.

Another significant limitation is the lack of detailed clinical data in the NIS database, such as baseline CBC values, CLL stage, and active treatment information for CLL patients. These factors are critical for assessing postoperative outcomes, including bleeding risk and transfusion needs. However, because the NIS database primarily collects billing-related data rather than detailed clinical

information, it does not include variables such as laboratory values or treatment regimens, which are key to understanding patient conditions. Future studies could address this gap by incorporating clinical databases that include more granular patient information, enabling a more accurate assessment of the factors influencing postoperative outcomes.

Additionally, hospitals in the higher quintiles of the NIS database may include tertiary centers, which are likely to manage more complex and critically ill patients. These institutions often have specialized resources and expertise in handling patients with severe comorbidities or advanced disease. As such, the outcomes observed in these hospitals may be partially influenced by their ability to manage more complicated cases, potentially leading to a selection bias. This could affect the generalizability of our findings, as outcomes at tertiary centers may not reflect those at community or lower-tier hospitals. Future studies could address this issue by examining the potential confounding effect of hospital specialization and by adjusting for hospital types in their analysis. Moreover, incorporating data on the level of hospital care, such as whether a hospital is a tertiary center, could help clarify the relationship between hospital characteristics and patient outcomes.

Conclusion

This study reveals significant differences in clinical outcomes among patients with CLL undergoing CS, stratified by the proportion of hematologic malignancy patients in hospitals. Specifically, a higher proportion of patients in hospitals with a greater concentration of hematologic malignancy patients experienced significantly lower rates of AKI and respiratory failure but higher rates of blood transfusion and acute heart failure. In-hospital mortality and other complications, such as GI bleeding, hematuria, and infections, did not vary significantly across quintiles. These findings underscore the impact of hospital-specific factors on clinical outcomes for CLL patients. Future research should focus on elucidating how hospital characteristics and patient demographics influence clinical outcomes to guide targeted interventions and improve patient prognosis.

Abbreviations

AHRQ	Agency for Healthcare Research and Quality
AKI	Acute Kidney Injury
Acute MI	Acute Myocardial Infarction
AML	Acute Myeloid Leukemia
ALL	Acute Lymphoblastic Leukemia
CCI	Charlson Comorbidity Index
CHF	Congestive Heart Failure
CLL	Chronic lymphocytic leukemia
CS	Cardiac Surgery
COPD	Chronic Obstructive Plumeria Disease
CML	Chronic Myeloid Leukemia
CVD	Cardiovascular disease
HL	Hodgkin Lymphoma
HCUP	Healthcare Cost and Utilization Project
ICD- 9-CM	International Classification of Diseases, Ninth Revision, Clinical Modification
ICD- 10-CM	International Classification of Diseases, Tenth Revision, Clinical Modification
KIM- 1	Kidney Injury Molecule- 1
MM	Multiple Myeloma
NHL	Non-Hodgkin Lymphoma
NIS	National (Nationwide) Inpatient Sample
Prior MI	Prior Myocardial Infarction
PPM procedure	Permanent Pacemaker Implantation Procedure
SCr	Serum creatinine
UTI	Urinary Tract Infection
VTE	Venous Thromboembolism

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Meizhen Yi: conception and design, acquisition of data, analysis, and interpretation of data, drafting the manuscript, and revising it critically for important intellectual content. Lanxin Hu: acquisition of data, analysis, and interpretation of data. Jifang Zhou: acquisition of data, analysis, and interpretation of data. Yali Ge: conception and design, revising the manuscript critically for important intellectual content. Cunhua Su: conception and design, revising the manuscript critically for important intellectual content. Fan Yang: conception and design, analysis and interpretation of data, revising the manuscript critically for important intellectual content, final approval of the version to be published.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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