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Impact of prolonged cardiopulmonary bypass on gastrointestinal complications in cardiac surgery: a retrospective cohort study

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Abstract

Background Gastrointestinal complications (GICs) following cardiac surgery with cardiopulmonary bypass (CPB) significantly impact postoperative recovery and clinical outcomes.

Methods This single-center, retrospective cohort study evaluated the incidence, risk factors, and outcomes of GICs in patients undergoing cardiac surgery with CPB between January 2018 and December 2023. Patients were stratified by CPB duration (≥ 120 min vs. < 120 min). Propensity Score Matching (PSM) in a 1:2 ratio was used to control for baseline confounders. The primary outcome was the occurrence of GICs within 30 days post-surgery.

Results Among 1444 patients, 686 had prolonged CPB duration, with an overall GICs incidence of 8.59% (124/1444). After PSM, the prolonged CPB group exhibited a significantly higher incidence of GICs compared to the normal CPB group (8.09% vs. 4.31%, $p = 0.041$). Multivariate logistic regression identified prolonged CPB duration (≥ 120 min; OR, 1.86; 95% CI, 1.06–3.26, $p = 0.029$), hypertension (OR 1.86; 95% CI, 1.01–3.44; $p = 0.049$), left ventricular ejection fraction (LVEF; OR, 0.92; 95% CI, 0.88–0.96; $p < 0.001$), and aortic surgery (OR, 2.72; 95% CI, 1.20–6.19; $p = 0.017$) as independent risk factors for GICs. Additionally, prolonged ventilator time and higher in-hospital costs were more prevalent in the prolonged CPB group.

Conclusions Prolonged CPB (≥ 120 min), hypertension, LVEF, and aortic surgery are significant risk factors for GICs following cardiac surgery with CPB. Early identification of high-risk patients may facilitate timely intervention, reduce complications, and improve postoperative recovery outcomes.

Trial registration ClinicalTrials.gov: NCT06697405.

Keywords Cardiopulmonary bypass, Cardiovascular surgery, Gastrointestinal complications, Propensity score matching

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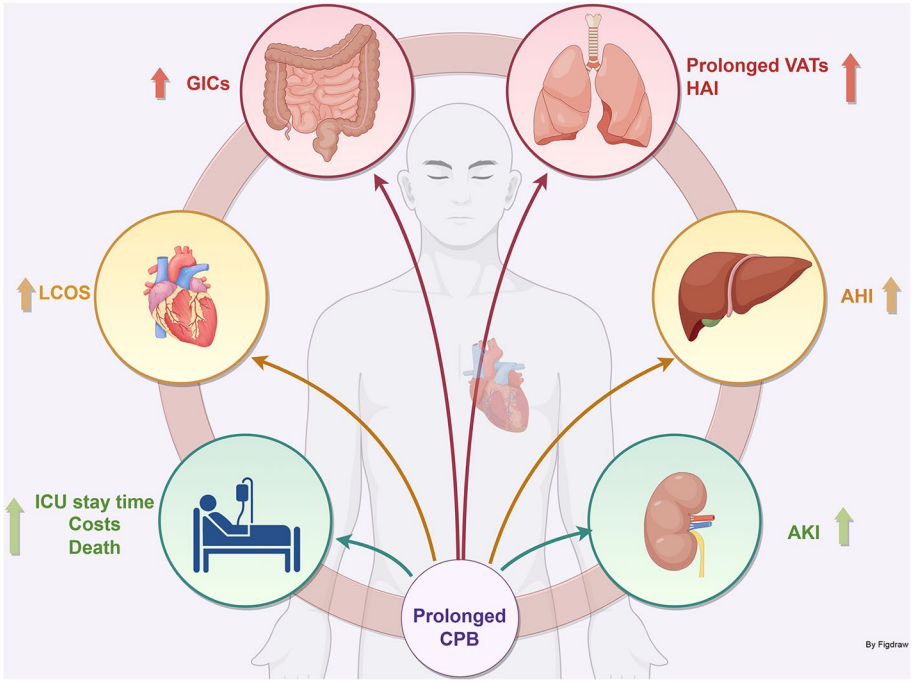
Graphical Abstract



Background

Gastrointestinal complications (GICs) following cardiac surgery, though relatively uncommon (occurring in 2.4–10% of cases), are associated with significant morbidity, prolonged recovery, and increased mortality (Hess et al. 2021; Elgharably et al. 2021; Lu and Yang 2023; Williams et al. 2019). Despite their clinical importance, GICs are often under-recognized, particularly in patients undergoing cardiopulmonary bypass (CPB), where delayed diagnosis can exacerbate the condition and lead to worse outcomes (Lu and Yang 2023). This under-recognition is partly due to the lack of standardized diagnostic criteria and evidence-based management strategies, which hampers timely and effective intervention.

GICs typically present with nonspecific symptoms, such as abdominal distension, nausea, and fatigue, which overlap with common postoperative signs, making them difficult to distinguish from other postoperative conditions (Chaudhry et al. 2017; Haywood et al. 2020). In the intensive care setting, where multiple organ dysfunction syndrome (MODS) is prevalent, gastrointestinal symptoms are often subtle, and reliable biomarkers for early detection are lacking (Chaudhry et al. 2017; Haywood et al. 2020). Furthermore, existing research on GICs is predominantly retrospective, with few large-scale prospective studies, limiting the ability to identify high-risk patients and establish robust predictive models (Hess et al. 2021; Elgharably et al. 2021; Lu and Yang 2023; Chaudhry et al. 2017).

The pathophysiology of GICs in cardiac surgery is multifactorial, with CPB playing a central role. During CPB, visceral hypoperfusion and systemic inflammatory responses can lead to gastrointestinal ischemia, disruption of the intestinal barrier, and bacterial translocation (Paparella et al. 2002; Jormalainen et al. 2009). Beyond these factors, ischemia–reperfusion injury (IRI) is a key driver of gastrointestinal dysfunction. During aortic cross-clamping, splanchnic hypoperfusion induces intestinal mucosal ischemia, while subsequent reperfusion exacerbates oxidative stress, mitochondrial dysfunction, and inflammatory cascades (Xia et al. 2005; Wang et al. 2023). This process disrupts the gut barrier, increases the risk of bacterial translocation, and contributes to multi-organ dysfunction, including acute kidney injury and systemic inflammatory response syndrome (SIRS) (Wang et al. 2023; Adamik et al. 2017; Madhavan et al. 2018; Gorjipour et al. 2019). Recent studies suggest that prolonged CPB further amplifies the effects of IRI; however, its precise impact on GICs remains poorly understood.

Given the clinical significance of GICs and the gaps in current knowledge, this study aims to investigate the incidence, risk factors, and outcomes of GICs in patients undergoing cardiac surgery with CPB. Using propensity score matching (PSM) to minimize confounding factors, we seek to identify high-risk patients and provide insights into strategies for early detection and management of GICs. By addressing these critical issues, this study aims to improve perioperative care and enhance recovery outcomes for cardiac surgery patients.

Methods

This study is a single-center, retrospective cohort study designed to investigate the incidence potential risk factors, and outcomes of GICs after cardiac surgery with CPB. This retrospective study was conducted in the cardiovascular surgery department of The First Hospital of Lanzhou University in China. All patients signed informed consent before surgery; the study was following the Declaration of Helsinki and was registered with ClinicalTrial.gov (NCT06697405). The study was approved by the Ethics Committee of The First Hospital of Lanzhou University (LDYYLL-2024–751). The study adheres to STROBE guidelines.

Population

Based on previous studies, we defined patients with CPB duration ≥ 120 min as the prolonged CPB group and those < 120 min as the normal CPB group (Bartoszko et al. 2022; Jabayeva et al. 2024).

Between January 2018 and December 2023, adult patients (age ≥ 18 years) with cardiovascular diseases who underwent CPB procedures were enrolled. The adult cardiac surgeries in this study followed the Society of Thoracic Surgeons (STS) guidelines, incorporating a range of procedures and techniques recognized by the STS standards. These surgeries included valve surgeries, aortic surgeries (including ascending aortic surgery, aortic arch surgery, and partial aortic arch surgery), coronary artery bypass grafting (CABG), etc. All surgical procedures adhered to the preoperative, intraoperative, and postoperative management protocols established by the STS to ensure data accuracy and comparability. To ensure uniformity in surgical techniques and perfusion strategies, all patients underwent nasopharyngeal temperature monitoring during surgery. CPB was conducted using non-pulsatile continuous flow perfusion under mild-to-moderate hypothermia (28–32 °C).

The exclusion criteria were as follows: (1) patients who had major gastrointestinal disorders; (2) patients who had previously undergone major gastrointestinal surgery within 5 years; (3) patients who died intraoperatively or within 24 h postoperatively; and (4) patients with missing data.

Data collection

Clinical data were extracted from electronic medical records. Patients' basic characteristics included age, sex, body mass index (BMI), history of smoking, New York Heart Association Classification (NYHA), preoperative use of the vasoactive agent, preoperative use of antibiotics, and history of diabetes, hypertension, stroke, arrhythmia, cardiovascular surgery, and virus hepatitis. Preoperative imaging examination included left ventricular ejection fraction (LVEF), and laboratory tests included white blood cells, uric acid, serum creatinine levels, total cholesterol, low-density lipoprotein, and serum blood glucose levels. Intraoperative information included the status of the operation, aortic surgery, modified maze procedure (MAZE), transfusion of blood, cross-clamp time, moderate hypothermic circulatory arrest (MHCA), and duration of CPB. Postoperative complications including low cardiac output syndrome (LCOS), hospital-acquired infection (HAI), acute liver injury (AHI), acute kidney injury (AKI), and ventilator-assisted time (VAT) were also recorded. After the research doctors recorded the basic information of all subjects, the follow-up researchers will verify and confirm that there were no defaults before filling out the subject registration form.

Outcomes

The primary outcome of this study was the occurrence of GICs following cardiac surgery with CPB, assessed within 30 days post-surgery. GICs were defined based on the STS Adult Cardiac Surgery Database and included any gastrointestinal event that developed after surgery. These events encompassed but were not limited to gastrointestinal (GI) bleeding requiring transfusion, pancreatitis with elevated amylase/lipase levels necessitating nasogastric suction, cholecystitis requiring surgical intervention (cholecystectomy or drainage), mesenteric ischemia requiring surgical exploration, prolonged ileus, and GI infections. Such complications may require medical treatment, monitoring, or surgical procedures for resolution (Hess et al. 2021; Williams et al. 2019). Secondary outcomes included 30-day mortality, length of stay in the intensive care unit (ICU), and total in-hospital costs.

Statistical analysis

Data were analyzed by SPSS v.27.0 (IBM, Armonk, New York, USA) and R software (version 4.3.1, R Foundation

for Statistical Computing). The measured data of skew distribution indicate the median ± interquartile range (M ± [IQR]) and compared using the Mann–Whitney *U* test. The frequency data indicate absolute numbers and percentages, and the χ^2 test or Fisher's exact probability method compares between groups. Univariate and multivariate logistic regression were taken to assess associated risk factors for GICs. All *P*-values < 0.05 were confirmed as statistically significant. Adjusted outcome ratios (OR) and corresponding 95% confidence intervals (95% CI) were calculated, too. A balanced cohort of prolonged CPB group and normal CPB group was constructed based on demographic and perioperative information using propensity score matching (PSM) (PSM ratio, 1:2; caliper, 0.2 SD of propensity scores) to reduce heterogeneity of baseline information between the two groups. The incidence of GICs after CPB was investigated in different subgroups.

Results

Baseline characteristics

Between January 2018 and December 2023, 1665 patients who matched the inclusion criteria were assessed for eligibility. After rigorous screening procedures, 221 patients were excluded from the study (Fig. 1). The remaining patients comprised 1444 and were classified into two groups based on the extent of CPB duration: prolonged CPB group ($N=686$) and normal group ($N=758$). The follow-up time was within 30 postoperative days. Table 1 displays the baseline and preoperative characteristics of the patients enrolled. Statistical differences significantly differed between the groups concerning sex, smoking, hypertension, stroke, arrhythmia, virus hepatitis, preoperative use of antibiotics, NYHA grade, LVEF, white blood cells, uric acid, creatinine, blood glucose, the status of the operation, aortic surgery, transfusion of blood, aortic cross-clamp time, MHCA, and type of surgery were significantly different between two groups. There were no statistical differences in other characteristics that were found between the two groups (Table 1).

Outcomes

A total of 124 patients (8.59%) developed postoperative gastrointestinal complications (GICs). Among them, prolonged CPB group was associated with a significantly higher incidence of GICs compared to normal CPB group (14.58% vs. 3.17%, $p<0.001$). Specifically, GI bleeding, hepatopancreatobiliary (HPB) dysfunction, ileus, and GI infections were more frequent in the prolonged CPB group ($p<0.001$ for all), while mesenteric ischemia was rare and approached statistical significance ($p=0.051$). There was no significant difference in mixed complications ($p=0.248$). These findings highlight the increased risk of GICs in patients undergoing prolonged CPB (Table 2).

Higher incidence of 30-day mortality, prolonged ICU stay time, and more in-hospital costs were significantly greater in the prolonged CPB group than the normal CPB group ($p<0.001$) (Table 3).

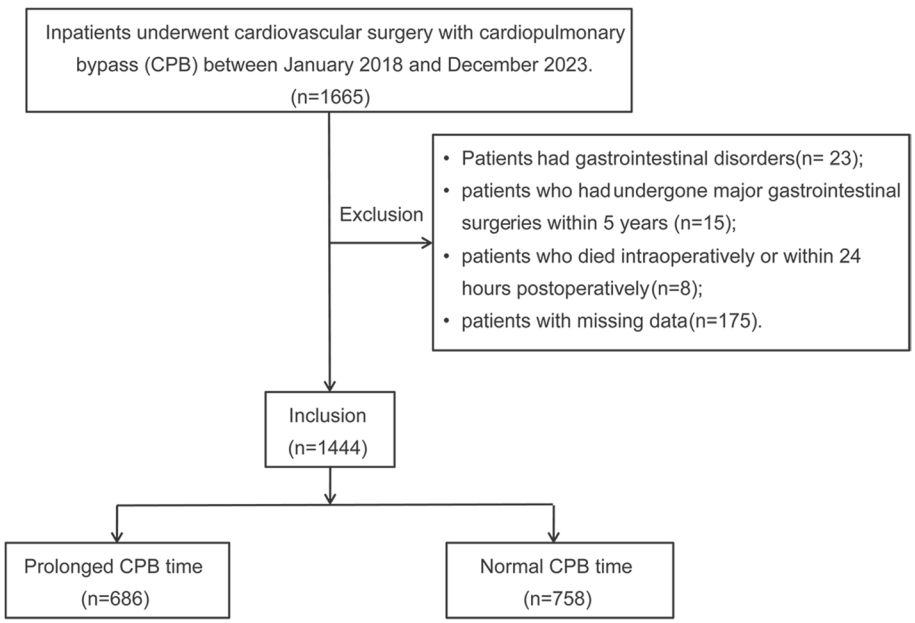


Fig. 1 Study flow chart

Table 1 Baseline and perioperative information before propensity score matching

Variable	Group			
	Total (*N* = 1444)	**Normal CPB (*N* = 758)**	**Prolonged CPB (*N* = 686)**	***p*-value**
Age (year, *N* (%))				0.966
< 65	1313 (90.93)	689 (90.90)	624 (90.96)	
≥65	131 (9.07)	69 (9.10)	62 (9.04)	
Sex, *N* (%)				<0.001
Female	666 (46.12)	385 (50.79)	281 (40.96)	
Male	778 (53.88)	373 (49.21)	405 (59.04)	
BMI (kg/m^2, *N* (%))				0.097
<23	649 (44.94)	325 (42.88)	324 (47.23)	
≥23	795 (55.06)	433 (57.12)	362 (52.77)	
Smoking, *N* (%)	162 (11.22)	62 (8.18)	100 (14.58)	<0.001
Diabetes, *N* (%)	32 (2.22)	18 (2.37)	14 (2.04)	0.667
Hypertension, *N* (%)	285 (19.74)	169 (22.30)	116 (16.91)	0.010
Stroke, *N* (%)	39 (2.7)	32 (4.22)	7 (1.02)	<0.001
Arrhythmia, *N* (%)	226 (15.65)	94 (12.40)	132 (19.24)	<0.001
History of cardiovascular surgery, *N* (%)	38 (2.63)	14 (1.85)	24 (3.50)	0.050
History of VH, *N* (%)	68 (4.71)	25 (3.30)	43 (6.27)	0.008
Preop use of VA, *N* (%)	169 (11.7)	77 (10.16)	92 (13.41)	0.055
Preop use of ABX, *N* (%)	133 (9.21)	54 (7.12)	79 (11.52)	0.004
NYHA, *N* (%)				<0.001
I	132 (9.14)	82 (10.82)	50 (7.29)	
II	708 (49.03)	430 (56.73)	278 (40.52)	
III	538 (37.26)	235 (31.00)	303 (44.17)	
IV	66 (4.57)	11 (1.45)	55 (8.02)	
LVEF (%, M (IQR))	57.00 (53.00, 59.00)	57.00 (55.00, 59.00)	56.50 (52.00, 58.00)	<0.001
WBC ($\times 10^9$/L, M (IQR))	5.68 (4.78, 6.88)	5.55 (4.73, 6.60)	5.84 (4.83, 7.19)	<0.001
UA (μmol/L, M (IQR))	354.00 (293.00, 416.00)	342.00 (280.00, 404.75)	362.00 (304.00, 428.00)	<0.001
Creatinine (μmol/L, M (IQR))	74.00 (65.00, 86.00)	73.00 (64.00, 85.00)	75.00 (66.00, 87.00)	0.032
TC (mmol/L, M (IQR))	3.90 (3.27, 4.59)	3.94 (3.31, 4.60)	3.89 (3.23, 4.57)	0.258
LDL (mmol/L, M (IQR))	2.50 (2.03, 3.00)	2.52 (2.07, 3.01)	2.49 (2.01, 2.99)	0.250
GLU (mmol/L, M (IQR))	4.80 (4.45, 5.32)	4.79 (4.42, 5.24)	4.82 (4.47, 5.45)	0.022
Status of the operation, N (%)				<0.001
Elective	1391 (96.33)	756 (99.74)	635 (92.57)	
Urgent	45 (3.12)	1 (0.13)	44 (6.41)	
Emergency	8 (0.55)	1 (0.13)	7 (1.02)	
Aortic surgery, *N* (%)	104 (7.2)	25 (3.30)	79 (11.52)	<0.001
MAZE procedure, *N* (%)	44 (3.05)	22 (2.90)	22 (3.21)	0.737
Transfusion of blood, *N* (%)	624 (43.21)	236 (31.13)	388 (56.56)	<0.001
Cross-clamp time, (min, M (IQR))	82 (62, 111)	64 (54, 75)	113 (97, 132)	<0.001
MHCA, *N* (%)	50 (3.46)	3 (0.40)	47 (6.85)	<0.001
Type of surgery, *N* (%)				<0.001
Aortic valve	722 (50)	403 (53.17)	319 (46.50)	
Mitral valve	188 (13.02)	106 (13.98)	82 (11.95)	
Tricuspid valve	32 (2.22)	20 (2.64)	12 (1.75)	
Aortic+mitral valve	145 (10.04)	23 (3.03)	122 (17.78)	
Aortic+tricuspid valve	13 (0.9)	3 (0.40)	10 (1.46)	
Aortic+mitral+tricuspid valve	250 (17.31)	182 (24.01)	68 (9.91)	
Valve surgery+CABG	94 (6.51)	21 (2.77)	73 (10.64)	

CPB Cardiopulmonary bypass, *BMI* Body mass index, *VH* Virus hepatitis, *VA* Vasoactive agent, *ABX* Antibiotics, *NYHA* New York Heart Association, *LVEF* Left ventricular ejection fraction, *WBC* White blood cells, *UA* Uric acid, *TC* Total cholesterol, *LDL* Low density lipoprotein, *GLU* Blood glucose, *MAZE* Modified maze procedure, *MHCA* Moderate hypothermic circulatory arrest, *CABG* Coronary artery bypass grafting

Table 2 Classification of gastrointestinal complications

Type of GICs, *N* (%)	Total*N* = 124	Normal CPB*N* = 24	Prolonged CPB*N* = 100	*p*-value
GI bleeding	50 (3.46)	14 (1.85)	36 (5.25)	<0.001
Mesenteric ischemia	4 (0.28)	0 (0)	4 (0.58)	0.051
HPB dysfunction	24 (1.66)	2 (0.26)	22 (3.21)	<0.001
Ileus	21 (1.45)	3 (0.40)	18 (2.62)	<0.001
GI infections	13 (0.90)	1 (0.13)	12 (1.75)	0.001
Mixed complications	12 (0.83)	4 (0.53)	8 (1.17)	0.248

CPB Cardiopulmonary bypass, *GICs* Gastrointestinal complications, *GI* Gastrointestinal, *HPB* Hepatopancreatobiliary

Table 3 Outcomes and postoperative complications before propensity score matching

Variable	Group			
	Total (*N* = 1444)	Normal CPB (*N* = 758)	Prolonged CPB (*N* = 686)	*p*-value
GICs, *N* (%)	124 (8.59)	24 (3.17)	100 (14.58)	<0.001
LCOS, *N* (%)	238 (16.48)	83 (10.95)	155 (22.59)	<0.001
HAI, *N* (%)	267 (18.49)	76 (10.03)	191 (27.84)	<0.001
AHI, *N* (%)	119 (8.24)	45 (5.94)	74 (10.79)	<0.001
AKI, *N* (%)	132 (9.14)	38 (5.01)	94 (13.70)	<0.001
Prolonged VATs, *N* (%)	178 (12.33)	55 (7.26)	123 (17.93)	<0.001
Death, *N* (%)	31 (2.15)	7 (0.92)	24 (3.50)	<0.001
ICU stay time, (hour, M (IQR))	76.00 (48.00, 118.00)	71.00 (46.62, 113.00)	91.00 (50.00, 133.38)	<0.001
Cost, (yuan, M (IQR))	115,389.21 (97,741.00, 141,814.50)	112,699.77 (95,206.75, 135,658.80)	118,340.88 (100,606.27, 149,085.00)	<0.001

GICs Gastrointestinal complications, *LCOS* Low cardiac output syndrome, *HAI* Hospital acquired infection, *AHI* Acute liver injury, *AKI* Acute kidney injury, *VAT* Ventilator assisted time, *ICU* Intensive care unit

Comorbidities

The prevalence of LCOS, HAI, AHI, and AKI was significantly greater in the prolonged CPB group than in the normal CPB group ($p < 0.05$). The incidence of prolonged VATs was higher in the prolonged CPB group ($p < 0.05$) (Table 3).

Risk factor analysis

Univariate logistic analyses showed that sex (OR, 1.82; 95% CI 1.23–2.69; $p = 0.003$), preoperative use of VA (OR, 3.00; 95% CI, 1.94–4.66; $p < 0.001$), prolonged CPB time (OR, 5.22; 95% CI, 3.30–8.26; $p < 0.001$), aortic surgery (OR, 2.25; 95% CI, 1.29–3.93; $p = 0.004$), cross-clamp time (OR, 1.02; 95% CI, 1.01–1.02; $p < 0.001$), and MHCA (OR, 3.20; 95% CI, 1.59–6.41; $p < 0.001$) were all strongly associated with an increased risk of post-CPB GICs. Additionally, higher NYHA classes showed a clear gradient of risk, with Class III (OR, 6.12; 95% CI, 1.89–19.77; $p = 0.002$) and Class IV (OR, 16.12; 95% CI, 4.54–57.21, $p < 0.001$) associated with significantly higher odds of GICs. Transfusion of blood (OR, 1.93; 95% CI, 1.33–2.80, $p < 0.001$) and combined heart valve surgeries, such as aortic + mitral valve surgery (OR 2.59, 95% CI 1.52–4.41, $p < 0.001$) and aortic + tricuspid valve surgery (OR 4.12, 95% CI 1.10–15.46, $p = 0.036$), also increased the odds of GICs. In contrast, age, BMI, smoking, diabetes, hypertension, and other lab parameters (e.g., white blood cells, blood glucose, creatinine, low-density lipoprotein) showed no significant association in the univariate analysis (Table 4).

In the multivariate logistic analysis, the association of sex (OR, 1.73; 95% CI, 1.13–2.66; $p = 0.012$), preoperative use of VA (OR, 2.75; 95% CI, 1.70–4.45; $p = 0.001$), prolonged CPB (OR, 3.19; 95% CI, 1.94–5.25; $p < 0.001$), aortic surgery (OR, 2.18; 95% CI, 1.18–4.02; $p = 0.013$), and MHCA (OR, 4.54; 95% CI, 2.02–10.24) remained significant. Additionally, NYHA Class III (OR, 5.84; 95% CI, 1.70–20.04; $p = 0.005$) and Class IV (OR, 10.65; 95% CI, 2.79–40.60; $p < 0.001$) remained strong predictors of GICs. These findings underscore the importance of careful preoperative risk stratification, particularly for patients with advanced NYHA classes, prolonged CPB, and those undergoing complex aortic or combined valve surgeries (Table 4).

Table 4 Logistic analysis of GICs after CPB before propensity score matched

Variables	Univariate		Multivariate	
	OR (95% CI)	*P* value	OR (95% CI)	*p*-value
Age (≥65 years vs. <65 years)	1.55 (0.89–2.71)	0.123		
Sex (female vs. male)	1.82 (1.23–2.69)	0.003	1.73 (1.13–2.66)	0.012
BMI (≥23 kg/m^2 vs. <23 kg/m^2)	0.99 (0.68–1.43)	0.960		
Smoking (yes vs. no)	0.67 (0.35–1.31)	0.247		
Diabetes (yes vs. no)	1.54 (0.53–4.46)	0.428		
Hypertension (yes vs. no)	1.40 (0.91–2.15)	0.125		
Stroke (yes vs. no)	0.27 (0.04–2.01)	0.204		
Arrhythmia (yes vs. no)	1.49 (0.94–2.35)	0.090		
History of cardiovascular surgery (yes vs. no)	1.26 (0.44–3.61)	0.666		
NYHA				
I	1.00 (Ref)			
II	2.30 (0.70–7.59)	0.170		
III	6.12 (1.89–19.77)	0.002	5.84 (1.70–20.04)	0.005
IV	16.12 (4.54–57.21)	<0.001	10.65 (2.79–40.60)	<0.001
History of VH (yes vs. no)	0.84 (0.33–2.12)	0.710		
Preop use of VA (yes vs. no)	3.00 (1.94–4.66)	<0.001	2.75 (1.70–4.45)	<0.001
Preop use of ABX (yes vs. no)	1.06 (0.57–1.98)	0.851		
WBC (×10^9/L)	1.05 (0.98–1.13)	0.191		
UA (μmol/L)	1.01 (1.01–1.01)	<0.001		
Creatinine (μmol/L)	1.00 (1.00–1.01)	0.153		
TC (mmol/L)	0.98 (0.82–1.18)	0.865		
LDL (mmol/L)	0.91 (0.71–1.16)	0.433		
GLU (mmol/L)	1.06 (0.96–1.16)	0.242		
LVEF (%)	0.93 (0.90–0.96)	<0.001		
Status of the operation				
Elective	1.00 (Ref)			
Urgent	0.75 (0.23–2.45)	0.634		
Emergency	0.00 (0.00–Inf)	0.980		
Prolonged CPB (yes vs. no)	5.22 (3.30–8.26)	<0.001	3.19 (1.94–5.25)	<0.001
Aortic surgery (yes vs. no)	2.25 (1.29–3.93)	0.004	2.18 (1.18–4.02)	0.013
MAZE (yes vs. no)	0.77 (0.24–2.53)	0.671		
Transfusion of blood (yes vs. no)	1.93 (1.33–2.80)	<0.001		
Cross-clamp time (min)	1.02 (1.01–1.02)	<0.001		
MHCA (yes vs. no)	3.20 (1.59–6.41)	0.001	4.54 (2.02–10.24)	<0.001
Type of surgery				
Aortic valve	1.00 (Ref)			
Mitral valve	1.19 (0.65–2.17)	0.570		
Tricuspid valve	0.92 (0.21–3.94)	0.906		
Aortic+mitral valve	2.59 (1.52–4.41)	<0.001		
Aortic+tricuspid valve	4.12 (1.10–15.46)	0.036		
Aortic+mitral+tricuspid valve	0.94 (0.52–1.68)	0.833		
Valve surgery+CABG	2.82 (1.53–5.19)	<0.001		

GICs Gastrointestinal complications, *CPB* Cardiopulmonary bypass, *BMI* Body mass index, *NYHA* New York Heart Association, *VH* Virus hepatitis, *VA* Vasoactive agent, *ABX* Antibiotics, *LVEF* Left ventricular ejection fraction, *WBC* White blood cells, *UA* Uric acid, *TC* Total cholesterol, *LDL* Low-density lipoprotein, *GLU* Blood glucose, *CPB* Cardiopulmonary bypass, *MAZE* Modified maze procedure, *MHCA* Moderate hypothermic circulatory arrest, *CABG* Coronary artery bypass grafting

Table 5 Baseline and perioperative information after propensity score matching

Variable	Group			
	Total (*N* = 965)	**Normal CPB (*N* = 557)**	**Prolonged CPB (*N* = 408)**	***p*-value**
Age (year, *N* (%))				0.160
< 65	877 (90.88)	500 (89.77)	377 (92.40)	
≥65	88 (9.12)	57 (10.23)	31 (7.60)	
Sex, *N* (%)				0.300
Female	416 (43.11)	248 (44.52)	168 (41.18)	
Male	549 (56.89)	309 (55.48)	240 (58.82)	
BMI (kg/m^2, *N* (%))				0.967
<23	425 (44.04)	245 (43.99)	180 (44.12)	
≥23	540 (55.96)	312 (56.01)	228 (55.88)	
Smoking, *N* (%)	110 (11.4)	58 (10.41)	52 (12.75)	0.260
Diabetes, *N* (%)	24 (2.49)	16 (2.87)	8 (1.96)	0.369
Hypertension, *N* (%)	172 (17.82)	100 (17.95)	72 (17.65)	0.902
Stroke, *N* (%)	11 (1.14)	5 (0.90)	6 (1.47)	0.602
Arrhythmia, *N* (%)	144 (14.92)	79 (14.18)	65 (15.93)	0.451
History of cardiovascular surgery, *N* (%)	25 (2.59)	14 (2.51)	11 (2.70)	0.860
History of VH, *N* (%)	43 (4.46)	23 (4.13)	20 (4.90)	0.566
Preop use of VA, *N* (%)	120 (12.44)	66 (11.85)	54 (13.24)	0.519
Preop use of ABX, *N* (%)	82 (8.5)	46 (8.26)	36 (8.82)	0.756
NYHA, *N* (%)				0.224
I	93 (9.64)	54 (9.69)	39 (9.56)	
II	495 (51.3)	300 (53.86)	195 (47.79)	
III	354 (36.68)	192 (34.47)	162 (39.71)	
IV	23 (2.38)	11 (1.97)	12 (2.94)	
LVEF (%, M (IQR))	57.00 (55.00, 59.00)	57.00 (55.00, 59.00)	57.00 (53.00, 59.00)	0.208
WBC (×10^9/L, M (IQR))	5.72 (4.78, 6.90)	5.62 (4.75, 6.77)	5.79 (4.80, 7.10)	0.168
UA (μmol/L, M (IQR))	346.00 (290.00, 409.00)	343.00 (283.00, 405.00)	355.50 (296.00, 412.00)	0.150
Creatinine (μmol/L, M (IQR))	73.00 (64.00, 85.00)	73.00 (64.00, 84.00)	74.00 (64.22, 85.00)	0.509
TC (mmol/L, M (IQR))	3.90 (3.27, 4.63)	3.89 (3.31, 4.61)	3.94 (3.25, 4.67)	0.686
LDL (mmol/L, M (IQR))	2.52 (2.06, 3.01)	2.50 (2.10, 3.00)	2.55 (2.03, 3.04)	0.929
GLU (mmol/L, M (IQR))	4.79 (4.43, 5.29)	4.81 (4.43, 5.27)	4.76 (4.42, 5.30)	0.986
Status of the operation, *N* (%)				0.051
Elective	955 (98.96)	555 (99.64)	400 (98.04)	
Urgent	5 (0.52)	1 (0.18)	4 (0.98)	
Emergency	5 (0.52)	1 (0.18)	4 (0.98)	
Aortic surgery, *N* (%)	58 (6.01)	24 (4.31)	34 (8.33)	0.009
MAZE, *N* (%)	24 (2.49)	15 (2.69)	9 (2.21)	0.631
Transfusion of blood, *N* (%)	400 (41.45)	208 (37.34)	192 (47.06)	0.002
Cross-clamp time, (min, M (IQR))	79 (61, 100)	65 (54, 76)	108 (90, 126)	<0.001
MHCA, *N* (%)	18 (1.87)	3 (0.54)	15 (3.68)	<0.001
Type of surgery, *N* (%)				0.313
Aortic valve	538 (55.75)	311 (55.83)	227 (55.64)	
Mitral valve	143 (14.82)	82 (14.72)	61 (14.95)	
Tricuspid valve	26 (2.69)	16 (2.87)	10 (2.45)	
Aortic+mitral valve	51 (5.28)	23 (4.13)	28 (6.86)	
Aortic+tricuspid valve	5 (0.52)	3 (0.54)	2 (0.49)	
Aortic+mitral+tricuspid valve	159 (16.48)	101 (18.13)	58 (14.22)	
Valve surgery+CABG	43 (4.46)	21 (3.77)	22 (5.39)	

Table 6 Outcomes and postoperative complications after propensity score matching

Variable	Group			
	Total (*N* = 965)	Normal CPB (*N* = 557)	Prolonged CPB (*N* = 408)	*p*-value
GICs, *N* (%)	57 (5.91)	24 (4.31)	33 (8.09)	0.014
LCOS, *N* (%)	142 (14.72)	75 (13.46)	67 (16.42)	0.200
HAI, *N* (%)	143 (14.82)	72 (12.93)	71 (17.40)	0.053
AHI, *N* (%)	74 (7.67)	37 (6.64)	37 (9.07)	0.162
AKI, *N* (%)	75 (7.77)	36 (6.46)	39 (9.56)	0.076
Prolonged VATs, *N* (%)	102 (10.57)	48 (8.62)	54 (13.24)	0.021
Death, *N* (%)	13 (1.35)	6 (1.08)	7 (1.72)	0.395
ICU stay time, (hour, M (IQR))	72.00 (48.00, 115.00)	71.00 (47.00, 113.00)	74.00 (48.00, 118.00)	0.079
Cost, (yuan, M (IQR))	113,790.63 (95,802.28, 135,801.40)	111,713.00 (94,218.94, 134,787.41)	116,334.02 (98,643.16, 137,414.50)	0.024

Post-PSM analysis

A 1:2 PSM analysis was conducted between the two groups to minimize baseline demographic and perioperative bias. The matched cohort included 965 patients, in the normal CPB group containing 557 cases, and in the prolonged CPB group containing 408 cases (Table 4). *p*-values for all variables > 0.05, indicating transfusion of blood, cross-clamp time, and MHCA, were significantly different between two groups. There were no statistical differences in other characteristics that were found between the two groups (Table 5).

The incidence of GICs in the PSM cohort was 5.91%. Patients in the prolonged CPB group exhibited a significantly higher incidence of GICs than those in the standard CPB group (8.09% vs. 4.31%, $p < 0.001$) (Table 6). There were no statistically significant differences between the two groups in LCOS, AHI, HAI, AKI, ICU stay time, and death, and also no significant difference in overall postoperative complications was observed. There were significant differences between the two groups in prolonged VATs, and in-hospital costs ($p < 0.05$) (Table 6).

Logistic regression analysis of the PSM cohort further identified that prolonged CPB time (≥ 120 min; OR, 1.86; 95% CI, 1.06–3.26; $p = 0.029$), hypertension (OR 1.86; 95% CI, 1.01–3.44; $p = 0.049$), LVEF (OR 0.92; 95% CI, 0.88–0.96; $p < 0.001$), and aortic surgery (OR 2.72; 95% CI, 1.20–6.19; $p = 0.017$) were independent risk factors for GICs in cardiac surgery patients with CPB (Table 7).

Subgroup analyses of the PSM cohort indicated an interaction between two groups and risk factors for postoperative GICs in cardiac surgery patients ($p = 0.015$). Compared with normal CPB duration, prolonged CPB duration significantly increased the risk of GICs (OR 1.95; 95% CI, 1.14–3.36; $p < 0.015$). The association between other variables, such as age, sex, BMI, NYHA, hypertension, preoperative use of VA, preoperative use of ABX, and the status of operation, was evaluated using PSM data, but no statistical significance was observed (Fig. 2).

Discussion

This study investigated the impact of prolonged CPB time on postoperative GICs in cardiac surgery patients with CPB. The results revealed significant associations between prolonged CPB time (≥ 120 min) and increased incidence of postoperative GICs, higher 30-day mortality, prolonged ICU stays, and greater in-hospital costs. These findings underscore the critical influence of CPB duration on postoperative GICs and highlight several important considerations for clinical practice and future research.

Prolonged CPB time emerged as a key determinant of poor outcomes, with a significantly higher incidence of GICs observed in the prolonged CPB group compared to the normal CPB group (14.58% vs. 3.17%, $p < 0.001$). This finding aligns with previous studies indicating that extended CPB duration exacerbates systemic inflammatory responses, coagulopathy, and multi-organ dysfunctions, particularly in the gastrointestinal system (Croome et al. 2009; Rossi et al. 2004; Ozyilmaz et al. 2024). IRI is a key mechanism in this process, as splanchnic hypoperfusion during CPB, followed by reperfusion, triggers oxidative stress, endothelial dysfunction, and inflammatory cascades (Adamik et al. 2017; Gorjipour et al. 2019; Zhang et al. 2023). These changes compromise intestinal barrier integrity and promote bacterial translocation, increasing the risk of complications such as gastrointestinal bleeding and ileus (Yang et al. 2023; Rimpiläinen et al. 2011). Moreover, logistic regression analysis of the PSM cohort confirmed that prolonged CPB time is an independent risk factor for GICs (OR, 1.86; 95% CI, 1.06–3.26; $p = 0.029$).

Table 7 Logistic analysis of GICs after CPB after propensity score matched

Variables	Univariate		Multivariate	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Age (≥65 years vs. <65 years)	0.54 (0.16–1.76)	0.305		
Sex (female vs. male)	1.84 (1.03–3.30)	0.039		
BMI (≥23 kg/m^2 vs. <23 kg/m^2)	0.93 (0.55–1.60)	0.805		
Smoking (yes vs. no)	0.42 (0.13–1.35)	0.145		
Diabetes (yes vs. no)	0.69 (0.09–5.18)	0.716		
Hypertension (yes vs. no)	2.26 (1.26–4.06)	0.006	1.86 (1.01–3.44)	0.049
Stroke (yes vs. no)	1.60 (0.20–12.75)	0.655		
Arrhythmia (yes vs. no)	1.07 (0.51–2.24)	0.850		
History of cardiovascular surgery (yes vs. no)	1.40 (0.32–6.09)	0.654		
NYHA				
I	1.00 (Ref)			
II	1.40 (0.41–4.76)	0.595		
III	2.88 (0.86–9.64)	0.086		
IV	1.36 (0.14–13.75)	0.792		
History of VH (yes vs. no)	0.77 (0.18–3.26)	0.722		
Preop use of VA (yes vs. no)	2.46 (1.30–4.65)	0.005		
Preop use of ABX (yes vs. no)	1.04 (0.40–2.67)	0.939		
WBC (×10^9/L)	1.01 (0.89–1.16)	0.848		
UA (μmol/L)	1.01 (1.01–1.01)	0.007		
Creatinine (μmol/L)	1.01 (1.00–1.02)	0.199		
TC (mmol/L)	1.02 (0.79–1.31)	0.909		
LDL (mmol/L)	0.91 (0.63–1.31)	0.612		
GLU (mmol/L)	1.08 (0.90–1.28)	0.413		
LVEF (%)	0.91 (0.87–0.95)	<0.001	0.92 (0.88–0.96)	<0.001
Status of the operation				
Elective	1.00 (Ref)			
Urgent	4.01 (0.44–36.51)	0.217		
Emergency	0.00 (0.00–Inf)	0.984		
Prolonged CPB (yes vs. no)	1.95 (1.14–3.36)	0.015	1.86 (1.06–3.26)	0.029
Aortic surgery (yes vs. no)	3.29 (1.53–7.08)	0.002	2.72 (1.20–6.19)	0.017
MAZE (yes vs. no)	0.69 (0.09–5.18)	0.716		
Transfusion of blood (yes vs. no)	0.95 (0.55–1.64)	0.862		
Cross-clamp time (min)	1.01 (1.00–1.01)	0.162		
MHCA (yes vs. no)	6.62 (2.27–19.27)	<0.001		
Type of surgery				
Aortic valve	1.00 (Ref)			
Mitral valve	0.94 (0.42–2.08)	0.873		
Tricuspid valve	0.63 (0.08–4.81)	0.658		
Aortic+mitral valve	0.65 (0.15–2.77)	0.556		
Aortic+tricuspid valve	3.95 (0.43–36.41)	0.225		
Aortic+mitral+tricuspid valve	1.06 (0.51–2.21)	0.874		
Valve surgery+CABG	1.19 (0.35–4.04)	0.785		

This study demonstrated that prolonged CPB was significantly associated with higher rates of GICs, including GI bleeding, HPB dysfunction, ileus, and GI infections, compared to normal CPB group. Although mesenteric ischemia was rare and only approached statistical significance ($p=0.051$), its clinical impact warrants caution in high-risk patients. The lack of difference in mixed complications ($p=0.248$) may reflect heterogeneous

Subgroups	Total	Normal CPB	Prolonged CPB	OR (95%CI)	P	P for interaction
		GICs/N	*GICs/N*			
All patients	965 (100.00)	24/557	33/408	1.95 (1.14 ~ 3.36)	0.015	
Age						0.538
<65	877 (90.88)	22/500	32/377	2.02 (1.15 ~ 3.53)	0.014	
≥65	88 (9.12)	2/57	1/31	0.92 (0.08 ~ 10.53)	0.944	
Sex						0.137
Female	416 (43.11)	10/248	7/168	1.03 (0.39 ~ 2.77)	0.946	
Male	549 (56.89)	14/309	26/240	2.56 (1.31 ~ 5.02)	0.006	
BMI						0.254
<23	425 (44.04)	13/245	13/180	1.39 (0.63 ~ 3.07)	0.417	
≥23	540 (55.96)	11/312	20/228	2.63 (1.23 ~ 5.61)	0.012	
Smoking						0.985
No	855 (88.60)	21/499	33/356	2.33 (1.32 ~ 4.09)	0.003	
Yes	110 (11.40)	3/58	0/52	0.00 (0.00 ~ Inf)	0.994	
NYHA						0.200
1	93 (9.64)	0/54	3/39	193572344.01 (0.00 ~ Inf)	0.996	
2	495 (51.30)	10/300	12/195	1.90 (0.81 ~ 4.49)	0.143	
3	354 (36.68)	14/192	17/162	1.49 (0.71 ~ 3.13)	0.291	
4	23 (2.38)	0/11	1/12	77685038.94 (0.00 ~ Inf)	0.997	
Hypertension						0.647
No	793 (82.18)	17/457	22/336	1.81 (0.95 ~ 3.47)	0.072	
Yes	172 (17.82)	7/100	11/72	2.40 (0.88 ~ 6.52)	0.087	
Preop use of VA						0.833
No	845 (87.56)	18/491	25/354	2.00 (1.07 ~ 3.72)	0.029	
Yes	120 (12.44)	6/66	8/54	1.74 (0.56 ~ 5.36)	0.335	
Preop use of ABX						0.349
No	883 (91.50)	21/511	31/372	2.12 (1.20 ~ 3.75)	0.010	
Yes	82 (8.50)	3/46	2/36	0.84 (0.13 ~ 5.33)	0.856	
Status Of The Operation						0.864
Elective	955 (98.96)	24/555	32/400	1.92 (1.11 ~ 3.32)	0.019	
Urgent	5 (0.52)	0/1	1/4	38549597.46 (0.00 ~ Inf)	0.998	
Emergency	5 (0.52)	0/1	0/4	1.00 (0.00 ~ Inf)	1.000	

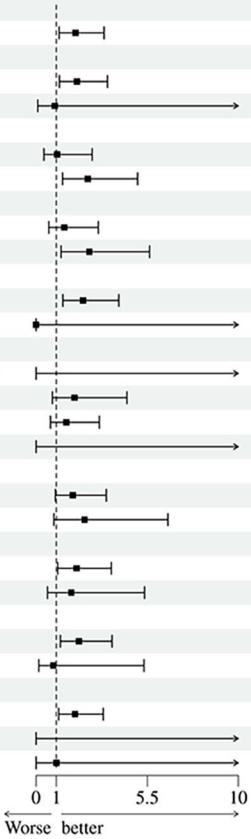


Fig. 2 Forest plot for subgroup analysis of gastrointestinal complications after cardiopulmonary bypass in the propensity score-matched cohort. NYHA, New York Heart Association; VA, vasoactive agent; ABX, antibiotics

definitions or competing risk factors. These findings align with existing evidence linking prolonged CPB to systemic inflammation, splanchnic hypoperfusion, and IRI (Xia et al. 2005; Gorjipour et al. 2019). Potential mechanisms include anticoagulation-related mucosal damage, gut barrier dysfunction, and bacterial translocation (Cha et al. 2024; Salomon et al. 2021). Clinically, strategies to minimize CPB duration, optimize perfusion pressure, and enhance perioperative GI monitoring should be considered in high-risk cases. Future prospective studies should further investigate causal relationships and explore targeted interventions to mitigate GICs in cardiac surgery patients.

The association of GICs with poor postoperative outcomes is well-established in the literature. Patients with GICs after cardiac surgery tend to experience longer ICU stays, longer mechanical ventilation, and increased mortality. These complications not only contribute to extended hospitalization but also lead to significant long-term morbidity. Our study reinforces this by showing that patients in the prolonged CPB group exhibited significantly higher incidences of LCOS, AKI, and HAI, corroborating prior evidence linking extended CPB with multisystem complications (Liu et al. 2023; Hashemzadeh and Hashemzadeh 2012). Notably, prolonged VATs and higher in-hospital costs were more prevalent in this group, reflecting the increased resource utilization and economic burden associated with prolonged CPB.

The multivariate analysis identified additional independent predictors of adverse outcomes, including complicated with hypertension, reduced LVEF and combined aortic surgery. These findings align with existing literature suggesting that lower LVEF predisposes patients to hemodynamic instability during CPB, thereby increasing the risk of postoperative complications (D'Ancona et al. 2003; Hao et al. 2024). Similarly, aortic surgery is inherently complex, often requiring longer CPB times and exposing patients to higher perioperative risk (Liu et al. 2023; Hao et al. 2024). The association of higher NYHA class with increased adverse events further emphasizes the vulnerability of patients with advanced heart failure

undergoing cardiac surgery (Lin et al. 2021; Lazar et al. 1995).

PSM analysis was conducted to minimize baseline demographic and perioperative biases, confirming the robustness of the observed associations (Wan 2025). Even after matching, prolonged CPB was associated with a significantly higher incidence of GICs (8.09% vs. 4.31%, $p < 0.001$), highlighting the intrinsic impact of CPB duration on postoperative GICs. Interestingly, the matched analysis revealed no significant differences between the groups in other complications such as LCOS, AKI, or HAI, suggesting that these may be more reflective of baseline differences rather than CPB duration alone.

These findings have important implications for clinical practice. First, strategies to minimize CPB duration, such as advanced perfusion techniques, meticulous surgical planning, and using off-pump approaches where feasible, should be prioritized. Second, high-risk patients, particularly those with prolonged CPB, low LVEF, or undergoing complex aortic surgeries, require enhanced perioperative monitoring and tailored interventions to mitigate complications. Early identification and management of GICs may also help improve outcomes in these vulnerable populations. Given the significant impact of GICs on patient recovery and outcomes, their early detection and intervention should be integral components of postoperative care in patients undergoing cardiac surgery with CPB.

This study benefits from a large sample size, detailed risk factor analysis, and the use of PSM to reduce confounding. However, several limitations should be acknowledged. The observational design precludes definitive causal inferences, and residual confounding may persist despite the use of PSM. Furthermore, the study was limited to 30-day outcomes, which may not capture the full spectrum of CPB-related complications. Future studies with longer follow-up periods and more rigorous control of confounding factors are needed to validate our findings.

Conclusions

In conclusion, after PSM prolonged CPB duration is strongly associated with increased postoperative complications, including GICs, higher mortality, and greater in-hospital costs. Multivariate analysis identified additional risk factors such as hypertension, LVEF and aortic surgery. These findings underscore the importance of minimizing CPB time and implementing targeted strategies to improve outcomes in high-risk cardiac surgery patients. Future research should focus on refining CPB techniques and exploring novel interventions to reduce the burden of CPB-related complications.

Abbreviations

ABX	Antibiotics
AHI	Acute hepatic injury
AKI	Acute kidney injury
BMI	Body mass index
CABG	Coronary artery bypass grafting
CI	Confidence interval
CPB	Cardiopulmonary bypass
GICs	Gastrointestinal complications
GI	Gastrointestinal
GVIF	Generalized variance inflation factors
HAI	Hospital acquired infection
HPB	Hepatopancreatobiliary
ICU	Intensive care unit
IRI	Ischemia-reperfusion injury
IQR	Interquartile range
LCOS	Low cardiac output syndrome
LVEF	Left ventricular ejection fraction
MAZE	Modified maze procedure
MHCA	Moderate hypothermic circulatory arrest
MODS	Multiple organ dysfunction syndrome
NYHA	New York Heart Association
OR	Odds ratio
POD	Postoperative day
PSM	Propensity score matching
SIRS	Systemic inflammatory response syndrome
STS	Society of Thoracic Surgeons
VA	Vasoactive agents
VAT	Ventilator assisted time

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Authors' contributions

Conceptualization, X Yang, N Lu and W Meng; methodology, X Yang, N Lu, and B Song; investigation, L Yang, Y Li and W Zhou; statistical analysis, B Li, X Yang; resources, X Yang; writing – original draft, X Yang, W Meng and L Yang; writing – review & editing, X Yang, B Li, J Yuan, and W Meng; funding acquisition, X Yang and B Li; supervision, X Yang, B Song, J Yuan, and W Meng had unrestricted access to all data. All authors read and approved the final version to be published.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of The First Hospital of Lanzhou University (LDYYLL-2024-751).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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