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Preoperative and Intraoperative Predictors of Prolonged Intensive Care Unit Stay After Cardiac Surgery: A Retrospective Nested Case-Control Study

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Abstract:

Objective: Prolonged intensive care unit (ICU) stay following cardiac surgery is associated with increased morbidity, mortality, and healthcare resource utilization. This study aimed to identify preoperative and intraoperative factors associated with prolonged ICU stay after open heart surgery.

Methods: This retrospective nested case-control study included 147 adult patients who underwent open heart surgery with cardiopulmonary bypass between January 2024 and December 2025. Patients were classified as prolonged ICU stay (≥5 days, n=50) or non-prolonged ICU stay (<5 days, n=97). Demographic, clinical, laboratory, and perioperative variables were analyzed. Univariable and multivariable logistic regression analyses were performed to identify independent factors associated with prolonged ICU stay. Receiver operating characteristic (ROC) curve analysis was conducted to evaluate the discriminative performance of key variables.

Results: Patients with prolonged ICU stay had higher EuroSCORE II values, lower left ventricular ejection fraction (LVEF), higher preoperative creatinine levels, lower albumin levels, longer cardiopulmonary bypass (CPB) duration, and more complex surgical procedures. Multivariable analysis identified higher EuroSCORE II (OR=2.14; 95% CI: 1.42–3.22; P=0.002), lower LVEF (OR=1.42 per 5% decrease; 95% CI: 1.15–1.76; P=0.012), elevated creatinine (OR=6.84; 95% CI: 2.15–21.78; P=0.005), lower albumin (OR=4.12; 95% CI: 1.08–15.65; P=0.038), longer CPB duration (OR=1.28 per 10 minutes; 95% CI: 1.04–1.57; P=0.041), and complex surgical procedures as independent factors. EuroSCORE II demonstrated high discriminative performance (AUC=0.981), while CPB duration showed intermediate performance (AUC=0.750).

Conclusion: Both preoperative physiological reserve and intraoperative variables contribute to prolonged ICU stay after cardiac surgery in a multifactorial manner. These findings may support perioperative risk stratification and ICU resource planning, though prospective validation in larger cohorts is warranted.

Keywords: Open Heart Surgery, Prolonged ICU Stay, EuroSCORE II, Cardiopulmonary Bypass, Postoperative Outcomes

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Cardiovascular surgery remains a cornerstone in the treatment of severe cardiac diseases. Nonetheless, the recovery of patients and clinical results depend heavily on their stay in the intensive care unit (ICU) following surgery. Specifically, early prognosis and successful surgical care are indicated by the duration of ICU stay [1, 2].

Increased morbidity, mortality, and unfavorable clinical outcomes are linked to prolonged ICU stays, which have been observed in 4–11% of cardiac surgery patients, with some studies finding rates as high as 36% [1]. This is a crucial factor in the planning and administration of ICU resources and has a negative impact on the clinical course. To maximize clinical decision-making and enhance patient outcomes, early detection of patients at risk of extended ICU stays is essential [1, 2].

In the literature, various preoperative and intraoperative factors influencing ICU length of stay after cardiac surgery have been identified. These factors included patient-related clinical characteristics, surgical complexity, and perioperative variables. However, the definition of prolonged ICU stays, evaluated variables, and analytical approaches vary considerably across studies. This heterogeneity limits the comparability of findings and reduces the applicability of existing prediction models to different clinical settings. Therefore, evaluating these perioperative factors within a well-defined surgical population may improve the understanding of clinical characteristics associated with prolonged ICU stay and support perioperative risk stratification [1, 3, 4].

Previous studies have used different cutoff values, commonly ranging from 3 to 7 days, to define prolonged ICU stay after cardiac surgery, reflecting differences in institutional protocols, patient populations, and methodological approaches. This variability may limit direct comparison between studies and affect the generalizability of prediction models across different clinical settings.

In cardiac surgery patients, advanced age, comorbidity burden, and surgical complexity may increase the risk of prolonged intensive care unit stay and adversely affect postoperative recovery and resource utilization [2, 3, 5]. However, clinically applicable and population-specific data for perioperative risk stratification remain limited.

Previous retrospective studies have identified several factors associated with prolonged intensive care unit stay after cardiac surgery; however, differences in study populations, definitions, and evaluated perioperative variables have limited the comparability and generalizability of existing findings. In addition, data from tertiary cardiac referral centers managing patients with substantial surgical complexity and perioperative risk burden remain relatively limited.

Therefore, the present study aimed to evaluate preoperative and intraoperative factors associated with prolonged intensive care unit stay after open heart surgery using a retrospective nested case-control design and to contribute to clinically applicable perioperative risk stratification and postoperative resource planning. To minimize temporal variations in perioperative management and ICU practice patterns, controls were selected sequentially from patients admitted immediately after each index case.

METHODS

Design of the Study and Patient Selection

This retrospective nested case-control study was conducted at a tertiary care center between January 2024 and December 2025. Included were adult patients who needed postoperative intensive care unit (ICU) monitoring following open heart surgery. The Institutional Ethics Committee (Approval No: 2024-TBEK 2025/11-01) authorized the study protocol, which was carried out in compliance with the Declaration of Helsinki.

Patients undergoing open heart surgery were admitted to the cardiovascular surgery ICU during the early postoperative period. Patients with prolonged or complicated clinical courses requiring advanced ICU support were subsequently transferred to the anesthesiology and reanimation ICU for continued management. Patients who met the inclusion criteria were consecutively enrolled.

The present study was designed as a retrospective nested case-control study conducted within a cohort of adult patients who underwent open heart surgery with cardiopulmonary bypass during the study period. Patients with prolonged ICU stay (≥5 days) were identified as cases [6]. For each case, the next two consecutive patients admitted to the cardiovascular surgery ICU after the index patient and having ICU stay <5 days were selected as controls. An approximate 1:2 case-to-control ratio was applied [7, 8]. This sequential sampling strategy was used to minimize temporal variations in perioperative management and ICU practice patterns.

Accordingly, for each patient with prolonged ICU stay, two consecutive control patients who underwent surgery during the same calendar month, did not meet any exclusion criteria, and had an ICU stay of <5 days were included in the non-prolonged ICU stay group. Patients were classified as prolonged ICU stay (≥5 days) or non-prolonged ICU stay (<5 days) according to ICU length of stay. The ≥5-day threshold for prolonged ICU stay was selected based on previous cardiac surgery literature and institutional clinical practice [6]. In our institution, ICU stays exceeding 5 days are generally considered to represent a clinically meaningful prolongation of postoperative critical care.

Inclusion and Exclusion Criteria

The study included adult patients aged ≥18 years who underwent open heart surgery with cardiopulmonary bypass (CPB) and required postoperative ICU follow-up.

Patients with insufficient data for analysis, those undergoing emergency or repeat surgery, those requiring preoperative, intraoperative, or postoperative intra-aortic balloon pump (IABP) support at any stage of perioperative management, and patients undergoing surgery for congenital heart disease or cardiac tumor excision were excluded.

In total, 147 patients were included in the final analysis. Of these, 50 patients were identified as the prolonged ICU stay group (≥5 days), whereas 97 patients comprised the non-prolonged ICU stay group (<5 days).

Data Collection

Hospital information management systems, operating room records, ICU electronic databases, and patient medical records were used as sources for retrospective data collection. Demographic variables included age, sex, and body mass index (BMI). Preoperative variables included hemoglobin, creatinine, albumin, left ventricular ejection fraction (LVEF), and EuroSCORE II. Preoperative laboratory parameters were obtained from the most recent blood tests performed within 24 hours before surgery.

Intraoperative variables included the type of surgical procedure, cardiopulmonary bypass (CPB) duration, aortic cross-clamp time, need for inotropic support, and volume of red blood cell transfusions.

Postoperative variables included the Acute Physiology and Chronic Health Evaluation II (APACHE II) score within the first 24 hours of ICU admission, mechanical ventilation status at 24 hours, ICU and hospital length of stay, ICU mortality, 30-day mortality, and ICU readmission within 30 days.

Open Heart Surgery and ICU Protocol

All patients underwent CPB according to the institution's standard open heart surgery protocol. During the early postoperative period, all patients were admitted to the cardiovascular surgery ICU. Hemodynamic stabilization, mechanical ventilation management, fluid therapy, inotropic support, and routine postoperative monitoring were conducted according to standardized institutional protocols. Patients requiring prolonged ICU follow-up, advanced organ support, or extended critical care were subsequently transferred to the anesthesiology and reanimation ICU for further management.

Primary and Secondary Outcomes

Prolonged ICU stay (≥5 days) was the study's primary outcome. ICU mortality, 30-day mortality, ICU readmission within 30 days, hospital length of stay, and perioperative variables linked to extended ICU stay were secondary outcomes.

Statistical Analysis

IBM SPSS Statistics software (IBM Corp., Armonk, NY, USA) was used for all statistical analyses. The Kolmogorov-Smirnov test was used to evaluate the distribution of continuous variables. For normally distributed data, continuous variables were displayed as mean±standard deviation (SD); for non-normally distributed data, they were displayed as median with interquartile range (IQR). Counts (n) and percentages (%) were used to express categorical variables. For regularly distributed continuous variables, the Student's t-test was utilized for group comparisons; for non-normally distributed variables, the Mann-Whitney U test was utilized. Fisher's exact test or Pearson's chi-square test were used to compare categorical variables, depending on the situation.

The factors linked to extended ICU stays and ICU death were found using univariate logistic regression analysis. In the multivariable logistic regression model, variables with $p < 0.20$ in the univariable analysis, together with clinically relevant perioperative variables and baseline characteristics differing between groups, were considered for inclusion in the multivariable logistic regression model. To reduce the risk of overfitting, only clinically meaningful variables were retained in the final model using a backward elimination approach. Prior to multivariable modeling, multicollinearity among candidate variables was assessed using correlation analysis and variance inflation factors. Variables demonstrating substantial collinearity were not included in the same multivariable model.

Continuous variables included in the regression analyses were modeled using clinically meaningful units to improve interpretability. EuroSCORE II was analyzed per 1-point increase, LVEF per 5% decrease, preoperative creatinine per 1 mg/dL increase, preoperative albumin per 1 g/dL decrease, and CPB duration per 10-minute increase. The surgical procedure category was included as a categorical variable using isolated CABG as the reference group. ROC curve analysis was performed to evaluate the discriminative performance of EuroSCORE II and CPB duration for prolonged ICU stay. The area under the curve (AUC), sensitivity, specificity, and optimal cutoff values were calculated.

Given the retrospective nested case-control

TABLE 1. Baseline and Preoperative Characteristics of the Study Population

Variable	Prolonged ICU stay group (≥5 days) n=50	Non-prolonged ICU stay group (<5 days) n=97	P-value
Age (years)	67 (57–72)	61 (55–67)	**0.021***
Gender, n (%)			
Female	21 (42.0)	31 (32.0)	0.228†
Male	29 (58.0)	66 (68.0)	
BMI (kg/m²)	27.76±4.40	27.55±2.97	0.761‡
LVEF (%)	45 (35–55)	55 (50–60)	**<0.001***
EuroSCORE	12 (8–22)	3 (2–4)	**<0.001***
Diabetes mellitus, n (%)	27 (54.0)	54 (55.7)	0.847†
Hypertension, n (%)	32 (64.0)	74 (76.3)	0.116†
COPD, n (%)	7 (14.0)	2 (2.1)	**0.008§**
CKD, n (%)	8 (16.0)	2 (2.1)	**0.003§**
Preoperative hemoglobin (g/dL)	11.58±2.49	13.91±2.07	**<0.001‡**
Preoperative creatinine (mg/dL)	1.14 (0.80–1.59)	0.83 (0.76–0.94)	**<0.001***
Preoperative albumin (g/dL)	3.2 (3.1–3.5)	3.7 (3.5–4.1)	**<0.001***
Isolated CABG, n (%)	19 (38.0)	92 (94.8)	**<0.001§**
Valve/Structural surgery, n (%)	15 (30.0)	4 (4.1)	
Combined/Complex surgery, n (%)	16 (32.0)	1 (1.0)	

Data are shown as mean±standard deviation or median (IQR= interquartile range) or n (%) where appropriate. BMI, body mass index; CABG, coronary artery bypass graft; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction.

*Mann-Whitney U. †Pearson Chi-square. ‡ Independent samples t test. §Fisher's Exact test.

Statistically significant P-values are shown in bold.

design, no a priori sample size calculation was performed. A post-hoc power analysis was conducted based on the observed between-group differences and the final sample of 50 cases and 97 controls, using a two-sided alpha level of 0.05. For the primary continuous variables of interest, including EuroSCORE II (Cohen's d=1.46), LVEF (Cohen's d=0.95), CPB duration (Cohen's d=0.93), preoperative creatinine (Cohen's d=0.87), and albumin (Cohen's d=1.25), the estimated statistical power exceeded 99% for each comparison, indicating that the available sample size was adequate to detect the observed between-group differences. Nevertheless, given the limited total sample size, the findings should be interpreted as exploratory associations rather than definitive conclusions, and prospective validation in larger cohorts is warranted.

RESULTS

During the study period, patients who underwent open heart surgery and required postoperative ICU follow-up were retrospectively screened. Patients meeting the predefined exclusion criteria, including insufficient clinical data, repeat or emergency surgery, intra-aortic balloon pump support, and surgeries for congenital heart disease or cardiac tumors, were excluded from the analysis.

The study period covered a 24-month interval between January 2024 and December 2025. During this period, 50 patients with prolonged ICU stay were identified. Accordingly, for each patient with prolonged ICU stay, two consecutive control patients who underwent surgery during the same calendar month, did not meet any exclusion criteria, and had an ICU stay of <5 days were selected for the control group. If one of the consecutively screened control patients met any exclusion criterion, the next consecutive eligible patient was included instead. Due to the temporal distribution of prolonged ICU stay cases throughout the study period, the intended 1:2 case-to-control ratio could not be achieved for all index cases, resulting in a final control group of 97 patients.

In total, 147 patients were included in the final analysis. Patients were classified according to ICU length of stay as prolonged ICU stay (≥5 days) and non-prolonged ICU stay (<5 days). Table 1 provides a summary of the research groups' clinical and demographic traits. Patients in the group with longer ICU stays were older (P=0.021). Regarding cardiac function, the prolonged ICU stay group had higher EuroSCORE II values (P<0.001) and lower LVEF (P<0.001). The prolonged ICU stay group had higher rates of chronic renal disease and chronic obstructive pulmonary disease (COPD) (P=0.003 and P=0.008, respectively). The prolonged ICU stay group had lower preoperative hemoglobin and albumin levels (both P<0.001) and higher creatinine levels (P<0.001) among the laboratory measures. Additionally, there

TABLE 2. Intraoperative Characteristics of the Study Groups

Variable	Prolonged ICU stay group (≥5 days) n=50	Non-prolonged ICU stay group (<5 days) n=97	P-value
CPB duration (min)	133 (107–172)	105 (97–115)	**<0.001***
ACC time (min)	79 (58–101)	80 (75–86)	0.954*
Single inotrope n (%)	11 (22.0)	72 (74.2)	**<0.001†**
Double inotrope n (%)	13 (26.0)	21 (21.6)	
Triple inotrope n (%)	16 (32.0)	4 (4.1)	
Quadruple inotrope n (%)	4 (8.0)	0 (0.0)	
RBC transfusion (units)	1 (0–1)	0 (0–2)	0.933*

Data are shown as median (IQR= interquartile range) or n (%) where appropriate. ACC, aortic cross-clamp; CPB, cardiopulmonary bypass; RBC, red blood cells.

*Mann–Whitney U test, †Fisher's Exact test. Statistically significant P-values are shown in bold.

TABLE 3. Univariate Predictors of Prolonged ICU Stay (ICU LOS >5 Days)

Variable	Unadjusted OR	95% CI	P-value
Age (per 1-year increase)	1.035	0.996–1.077	0.082
Sex (female)	1.542	0.762–3.121	0.229
Body mass index (per 1 kg/m² increase)	1.017	0.923–1.122	0.729
Preoperative hemoglobin (per 1 g/dL decrease)	1.592	1.321–1.918	**<0.001**
Preoperative creatinine (per 1 mg/dL increase)	47.827	8.323–274.835	**<0.001**
Preoperative albumin (per 1 g/dL decrease)	27.126	7.972–92.297	**<0.001**
LVEF (per 5% decrease)	1.682	1.359–2.082	**<0.001**
EuroSCORE (per 1-point increase)	3.055	1.923–4.852	**<0.001**
Valve/structural	18.158	5.423–60.799	**<0.001**
Combined/complex	77.474	9.681–619.99	**<0.001**
CPB duration (per 10-minute increase)	1.50	1.27–1.78	**<0.001**
ACC time (per 10-minute increase)	1.088	0.941–1.259	0.255
RBC transfusion (per 1-unit increase)	0.857	0.635–1.156	0.313

ACC, aortic cross-clamp; CABG, coronary artery bypass grafting; CI, confidence interval; CPB, cardiopulmonary bypass; ICU, intensive care unit; LOS, length of stay; LVEF, left ventricular ejection fraction; OR, odds ratio; RBC, red blood cells.
Male sex was used as the reference category. Isolated CABG was used as the reference for the procedure type.
Statistically significant P-values are shown in bold.

were substantial differences between groups in the type of surgical treatment (P<0.001).

Table 2 displays the groups' intraoperative characteristics. The prolonged ICU stay group had a significantly higher CPB duration (P<0.001). Inotropic support also showed a significant difference between the groups (P<0.001), with the prolonged ICU stay group using several inotropes at a higher rate. Table 3 displays the findings of the univariate logistic regression analysis carried out to determine the determinants of extended ICU stay.

Longer ICU stays were significantly correlated with every 1 g/dL drop in preoperative hemoglobin level (odds ratio [OR] = 1.592; 95% confidence interval [CI]: 1.321–1.918; P<0.001), every 1 mg/dL increase in creatinine level (OR = 47.827; 95% CI:

TABLE 4. Multivariable Logistic Regression Analysis of Factors Associated with Prolonged ICU Stay

Variables	Adjusted OR	95% CI	P-value
EuroSCORE (per 1-point increase)	2.14	1.42–3.22	**0.002**
LVEF (per 5% decrease)	1.42	1.15–1.76	**0.012**
Preoperative creatinine (per 1 mg/dL increase)	6.84	2.15–21.78	**0.005**
Preoperative albumin (per 1 g/dL decrease)	4.12	1.08–15.65	**0.038**
CPB duration (per 10-minute increase)	1.28	1.04–1.57	**0.041**
Valvular/structural surgery	4.55	1.22–16.92	**0.024**
Combined/complex surgery	11.24	2.45–51.62	**0.003**

CABG, coronary artery bypass grafting; CI, confidence interval; CPB, cardiopulmonary bypass; LVEF, left ventricular ejection fraction; OR, odds ratio.
Variables with P<0.20 in the univariable analysis and/or those considered clinically relevant were included in the multivariable logistic regression model. Isolated CABG was used as the reference for the procedure type.
Statistically significant P-values are shown in bold.

8.323–274.835; P<0.001), and every 1 g/dL drop in albumin level (OR = 27.126; 95% CI: 7.972–92.297; P<0.001). Significantly higher risk was also linked to a 5% drop in LVEF (OR = 1.682; 95% CI: 1.359–2.082; P<0.001) and a 1-point increase in EuroSCORE II (OR = 3.055; 95% CI: 1.923–4.852; P<0.001).

When the surgical procedure type was evaluated using isolated coronary artery bypass grafting (CABG) as the reference category, valvular/structural surgery (OR = 18.158; 95% CI: 5.423–60.799; P<0.001) and combined/complex procedures (OR = 77.474; 95% CI: 9.681–619.99; P<0.001) were strongly associated with prolonged ICU stay. In addition, each 10-minute increase in CPB duration was associated with increased risk (OR = 1.50; 95% CI: 1.27–1.78; P<0.001).

To further evaluate characteristics associated with longer ICU stays, multivariable logistic regression analysis was employed (Table 4). Variables with P<0.20 in the univariable analysis were included in the multivariable model. Every 1-point rise in EuroSCORE II was substantially linked to a higher likelihood of an extended ICU stay, according to multivariable logistic regression analysis (OR = 2.14; 95% CI: 1.42–3.22; P=0.002). Similarly, a greater risk was linked to every 5% decline in LVEF (OR = 1.42; 95% CI: 1.15–1.76; p = 0.012).

Regarding laboratory parameters, an increase in preoperative creatinine level (OR = 6.84; 95% CI: 2.15–21.78; P=0.005) and a decrease in albumin level (OR = 4.12; 95% CI: 1.08–15.65; P=0.038) were identified as independent risk factors. Among intraoperative variables, each 10-minute increase in CPB duration was independently associated with an increased risk (OR = 1.28; 95% CI: 1.04–1.57; P=0.041). Surgical procedure type also emerged as a significant determinant; using isolated CABG as the reference category, valvular/structural procedures (P=0.024) and particularly combined/complex procedures (OR = 11.24; 95% CI: 2.45–51.62; P=0.003) were significantly associated with prolonged ICU stay.

ROC analysis was used to assess the discriminative performance of EuroSCORE II and CPB duration in predicting extended ICU stay. The AUC for the EuroSCORE II was 0.981 (95% CI, 0.964–0.997; P<0.001). Sensitivity and specificity were 100% and 85.6%, respectively, for a cutoff value of 5.5. The AUC for CPB duration was 0.750. The sensitivity and specificity were 82.6% and 45.4%, respectively, at a cutoff value of 104 minutes (Figure 1).

Table 5 displays the two groups' postoperative clinical results. The APACHE II scores of patients in the extended ICU stay group were significantly higher (P<0.001). This group had a considerably larger need for mechanical ventilation within the first 24 hours (P<0.001). Compared to the short ICU stay group, the prolonged ICU stay group had a considerably longer

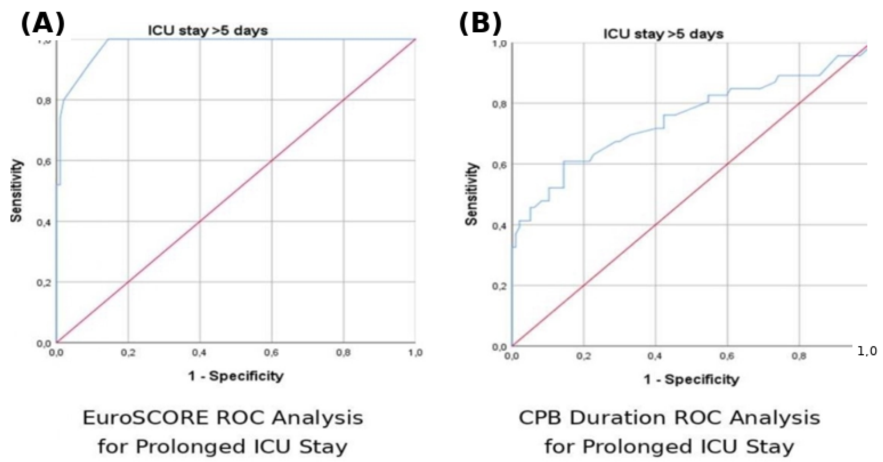

FIGURE 1. Receiver operating characteristic (ROC) curve analysis for predicting prolonged intensive care unit (ICU) stay (>5 days) after cardiac surgery. (A) EuroSCORE II demonstrated excellent discriminative performance, with an area under the curve (AUC) of 0.981. (B) Cardiopulmonary bypass (CPB) duration demonstrated moderate discriminative ability, with an AUC of 0.750. The diagonal reference line represents no discriminative ability (AUC = 0.5).

TABLE 5. Early Postoperative Severity and Clinical Outcomes

Variable	Prolonged ICU stay group (≥5 days) n=50	Non-prolonged ICU stay group (<5 days) n=97	P-value
APACHE II score (first 24 h)	38 (29–53)	26 (23–30)	**<0.001***
Mechanical ventilation at 24 h, n (%)	45 (90.0)	3 (3.1)	**<0.001†**
Length of hospital stay, days	53 (35–80)	7 (6–8)	**<0.001***
ICU mortality, n (%)	30 (60.0)	1 (1.03)	**<0.001†**
30-day mortality, n (%)	17 (34.0)	1 (1.03)	**<0.001†**
ICU readmission within 30 days, n (%)	7 (14.0)	0 (0.0)	**<0.001†**

Data are shown as median (IQR= interquartile range) or n (%) where appropriate. APACHE II, acute physiology and chronic health evaluation II; ICU, intensive care unit.

*Mann-Whitney. †Fisher's Exact test. Statistically significant P-values are shown in bold.

hospital stay (P<0.001). The prolonged ICU stay group had significantly higher ICU and 30-day mortality rates (both P<0.001). Furthermore, the lengthier ICU stay group had a significantly greater probability of ICU readmission after 30 days (P<0.001).

DISCUSSION

Prolonged ICU stay following cardiac surgery is a significant clinical issue with substantial implications for patient prognosis and overall clinical outcomes. The development of this condition is affected by a combination of patient-related factors, surgical characteristics, and early postoperative variables [1]. Previous studies have demonstrated that advanced age, increased comorbidity burden, greater surgical complexity, and an increased need for perioperative hemodynamic support are associated with prolonged ICU stay [2, 4]. Furthermore, prolonged ICU stay has been reported to adversely affect not only short-term outcomes, but also long-term functional status and quality of life [9]. Therefore, identifying factors that predict prolonged ICU stay is of considerable importance for optimizing clinical management. In this context, the findings of the present study should be interpreted cautiously, given the retrospective design, limited sample size, and potential baseline differences between groups.

The current study's results show that the factors linked to extended ICU stays are multivariate in nature when preoperative and intraoperative features are assessed jointly. Therefore, it is important to consider the study design when interpreting the variations in baseline characteristics across the groups. These variations were anticipated to represent the clinical variability of the research population because the study was observational and retrospective in nature. To reduce potential confounding effects, clinically relevant variables and baseline characteristics differing between groups were incorporated into the multivariable model in addition to variables meeting the univariate threshold (P<0.20). Therefore, the findings should be interpreted as associations rather than causal relationships. Although advanced age differed significantly between groups, it demonstrated only borderline significance in the univariate analysis, suggesting that age may act in conjunction with other clinical and perioperative factors rather than as an isolated determinant. Consistent with previous studies, advanced age has been associated with prolonged ICU stay after cardiac surgery; however, its clinical impact is generally considered within a broader multifactorial risk profile that includes comorbidity burden and procedural complexity [3, 10].

One of the most important indicators of a longer ICU stay in our study was the EuroSCORE. The preoperative risk assessment in this study was done using EuroSCORE II. It was found to be an independent risk factor in both the univariate and multivariable analyses, and it was also considerably greater in the longer ICU stay group. This finding suggests that the EuroSCORE may reflect not only perioperative mortality risk but also the likelihood of a prolonged postoperative ICU stay. The high discriminative performance observed in the ROC analysis further indicates that the EuroSCORE demonstrates predictive ability for prolonged ICU stay.

The extremely high AUC found in this study should be regarded cautiously, though, since it might be partially due to the significant differences in baseline risk profiles between groups rather than the effectiveness of a prediction model that can be applied universally. This highlights the potential value of preoperative risk assessment in both predicting patient prognosis and enabling more efficient ICU resource allocation and planning. In addition, the relatively small sample size and marked baseline differences between groups may have contributed to an overestimation of discriminative performance.

Consistent with the literature, the EuroSCORE has been reported as a reliable tool for identifying high-risk patients and is associated not only with mortality but also with postoperative morbidity and healthcare resource utilization [11]. Higher EuroSCORE values have been linked to longer ICU stays and a higher risk of postoperative complications, according to several studies [12, 13]. More recent studies have demonstrated that preoperative risk stratification models may help identify high-risk cardiac surgery patients with increased postoperative morbidity and resource utilization [13, 14]. In this regard, our findings are in line with the existing literature and further support the clinical relevance of EuroSCORE as a meaningful parameter for predicting not only mortality but also the postoperative ICU course.

LVEF also emerged as a key preoperative variable associated with prolonged ICU stay in this study. In addition to being significantly lower in the prolonged ICU stay group, it remained significant in both the univariate and multivariable analyses. This finding suggests that reduced ejection fraction is not merely an echocardiographic marker of impaired cardiac reserve but is also associated with a prolonged postoperative recovery process. This relationship may be explained by the limited hemodynamic reserve of patients with reduced left ventricular systolic function, leading to an increased need for perioperative supportive therapy.

Reduced LVEF has been linked to poor clinical outcomes after heart surgery [15], which is consistent with the literature. Recent research has also shown that a low ejection fraction is specifically linked to postoperative complications and extended ICU stay [1]. Preoperative ventricular dysfunction is generally acknowledged as a significant element of a high-risk patient profile, despite the fact that it has not been consistently found as an independent predictor [1]. In keeping with these conclusions, our data validate LVEF's clinical significance as a useful metric for forecasting extended hospital stays.

Recent studies have emphasized that prolonged ICU stay following cardiac surgery is not attributable to a single variable but is rather closely related to the patient's preoperative physiological reserve and overall organ function capacity. Hădăreanu *et al*. [1] described prolonged ICU stay as a reflection of preoperative comorbidity burden and organ dysfunction, while Kao *et al*. [15] reported that comorbid conditions and indicators of organ function are among the primary determinants of ICU length of stay. These findings suggest that prolonged ICU stay represents a composite clinical condition arising from limited physiological reserves and multisystem functional impairment. When the comorbidity profiles and laboratory findings in our study were considered together, patients with prolonged ICU stay appeared to have a more vulnerable preoperative profile. The higher prevalence of COPD and chronic kidney disease in the prolonged ICU stay group suggests a reduced organ reserve in these patients. Similarly, higher preoperative creatinine levels and lower hemoglobin and albumin levels indicated a more compromised baseline physiological status. Notably, the persistence of creatinine as a significant variable in the multivariable analysis suggests that renal function may play a more central role in determining prolonged ICU stay. The relatively large odds ratios and wide confidence intervals observed for certain variables, particularly creatinine level and complex surgical procedure categories, likely reflect the limited sample size, subgroup imbalance, and the distribution characteristics of the study population. Therefore, these estimates should be interpreted cautiously as indicators of association rather than precise effect-size measures. However, these differences are more likely to reflect relative variations in the physiological reserves between the groups rather than severe biochemical derangements. Therefore, these findings should not be interpreted as isolated abnormalities but rather as components of an integrated risk profile shaped by comorbidity burden and impaired organ function.

The type of surgical procedure also emerged as a key determinant of prolonged ICU stay. Although isolated CABG was more common in the control group, valvular and particularly combined/complex procedures were more frequently observed in the prolonged ICU stay group, supporting the role of surgical complexity in this process. Indeed, the strong association of these surgical categories with prolonged ICU stay in both the univariate and multivariable analyses suggests that the procedure type may represent an independent determinant beyond the overall surgical complexity and other clinical variables. Consistent with the literature, more complex cardiac surgical procedures have been associated with increased surgical trauma, longer operative duration, and higher perioperative risk burden, which may result in a greater need for postoperative organ support and prolonged ICU stay [4]. This effect is particularly pronounced in surgeries involving combined or multiple procedures. The relatively wide confidence intervals observed for certain surgical procedure categories likely reflect subgroup imbalance and the limited sample size of some procedural subgroups.

CPB duration was also a significant variable. Its persistence as a significant factor in both univariate and multivariable analyses suggests that CPB duration may serve as an independent predictor of prolonged ICU stay. Furthermore, the favorable discriminative performance observed in the ROC analysis indicates that this parameter demonstrates meaningful predictive capacity for prolonged ICU stay. In open heart surgery, ischemia–reperfusion injury represents a fundamental pathophysiological mechanism, and prolonged CPB duration may increase this burden, thereby contributing to an enhanced inflammatory response and subsequent organ dysfunction [16]. In addition, contemporary myocardial protection strategies during cardiopulmonary bypass have been shown to play a critical role in modulating ischemia–reperfusion injury and postoperative outcomes, further emphasizing the clinical relevance of intraoperative factors such as CPB duration [17]. Consistent with this finding, multicenter models have identified CPB duration as a key intraoperative variable associated with ICU length of stay following cardiac surgery [4]. In this context, the independent association between prolonged CPB duration and extended ICU stay observed in our study suggests that prolonged bypass time may reflect not only a technical aspect of the procedure, but also a clinically relevant burden influencing postoperative recovery.

The postoperative outcomes observed in our study showed that patients with prolonged ICU stay exhibited worse clinical outcomes. Indeed, the observed associations with a longer duration of mechanical ventilation, higher complication rates, increased mortality, and higher rates of readmission suggest that prolonged ICU stay should be interpreted not merely as a causal factor, but rather as a reflection of an adverse clinical trajectory. The markedly prolonged hospital stay observed in this cohort likely reflects the high burden of postoperative complications and disease severity in patients with extended ICU stay. This interpretation is consistent with existing literature. These postoperative variables were intentionally presented as descriptive outcome measures reflecting postoperative clinical trajectory and disease severity, rather than candidate predictors included in the multivariable risk model. In a study by Curran *et al*. [18], prolonged ICU stay was associated with increased mortality and poorer long-term outcomes. The relatively high ICU mortality observed in our cohort may reflect the tertiary referral nature of our institution and the inclusion of patients requiring prolonged postoperative critical care. In addition, patients transferred to the anesthesiology and reanimation ICU generally represented a subgroup with greater clinical complexity and higher perioperative risk burden. Similarly, the relatively high proportion of prolonged ICU stay observed in our cohort may also be related to the characteristics of our institution as a tertiary cardiac referral center managing patients with high clinical complexity and increased perioperative risk burden. The higher frequency of combined and complex surgical procedures, together with substantial comorbidity burden, may have contributed to prolonged postoperative recovery and increased ICU resource utilization. Furthermore, institutional postoperative monitoring and ICU transfer practices may also influence ICU length-of-stay patterns and limit direct comparison with other cohorts.

Therefore, these parameters should be interpreted as outcome variables reflecting disease severity rather than independent determinants. Accordingly, the findings should be interpreted at the level of clinical association rather than causality. The high mortality observed in the prolonged ICU stay group likely reflects increased clinical severity and postoperative complexity rather than a direct consequence of prolonged ICU stay itself.

Strengths and Limitations

There were a number of restrictions on this study. First, the results' generalizability and causal inference were constrained by their retrospective and single-center methodology. The exclusion of patients requiring preoperative, intraoperative, or postoperative IABP support may limit the generalizability of the findings to the highest-risk cardiac surgery population, as these patients are frequently associated with severe hemodynamic instability and prolonged postoperative critical care requirements. However, this approach was adopted to avoid a highly selected subgroup that could substantially confound the assessment of baseline perioperative risk factors associated with prolonged ICU stay. Second, some of the studies' statistical power might have been impacted by the very small sample size. In particular, the relatively high discriminative performance observed for certain variables and the magnitude of some effect estimates may partly reflect sample size limitations and the distribution characteristics of the study population. The relatively wide confidence intervals observed for certain variables, including CPB duration, preoperative creatinine and albumin levels, and surgical procedure category, may reflect the limited sample size and variability within the study population, rather than true model instability. Since this study was designed to identify clinical associations rather than develop a validated predictive model, the findings should be interpreted as exploratory associations requiring confirmation in larger prospective studies. In addition, defining prolonged ICU stay as ≥5 days may limit direct comparability with studies using different thresholds.

Additionally, rather than being causative factors, postoperative variables including the length of mechanical ventilation, complications, and ICU readmission should be viewed as outcome measures reflecting the severity of the condition.

This study has a number of advantages despite these drawbacks. A thorough evaluation of the risk profile linked to an extended ICU stay was made possible by the combined assessment of preoperative and intraoperative variables. Moreover, the consistency of the findings obtained from multivariable analysis and ROC evaluation supported the clinical validity of the results. In addition, the lack of a universally accepted definition for prolonged ICU stay and the use of different cutoff values across studies may limit direct comparability of findings and contribute to variability among reported predictors.

CONCLUSION

This retrospective study identified EuroSCORE II, LVEF, CPB duration, and preoperative creatinine level as clinically relevant variables linked to extended stays in the intensive care unit after heart surgery. These findings indicate that both preoperative risk profile and intraoperative variables contribute to a multifactorial clinical risk structure and may help determine which patients are most likely to require an extended stay in the intensive care unit. The results should be considered as associations rather than causal links because of the study's observational and retrospective nature. As a result, the results can be regarded as exploratory and hypothesis-generating, and they might serve as a foundation for further prospective research.

Ethics Approval and Consent to Participate

This study was approved by the University of Health Sciences, Bursa Yüksek Ihtisas Training and Research Hospital Medical Sciences Ethics Committee (Decision No: 2024-TBEK 2025/11-01; Date: 05.11.2025). All procedures were conducted in accordance with the ethical standards of the institutional and national research committees and with the 1964 Helsinki Declaration and its later amendments. Informed consent was waived because of the retrospective nature of the study and the analysis used anonymous clinical data.

Clinical Trial Registration

Not Available.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Authors' Contribution

Study Conception: DG, SE, GE; Study Design: DG, NM, SE, MI; Supervision: GE, BÖ, IC; Funding: N/A; Materials: GG, NM, AO, BÖ; Data Collection and/or Processing: GG, IC, NM, AO; Statistical Analysis and/or Data Interpretation: DG, SE, MI; Literature Review: DG, SE, MI, AO; Manuscript Preparation: DG, GG, BÖ; Critical Review: GE, IC.

Conflict of Interest Statement

All authors have completed the ICMJE uniform disclosure form and declare that no potential conflicts of interest, financial or otherwise, exist regarding the research, authorship, or publication of this manuscript.

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Generative Artificial Intelligence Statement

The authors declare that no artificial intelligence-based tools were used during the preparation of this manuscript, except for a limited capacity in language editing and clarity in improvement. All content of the study was produced by the authors in accordance with scientific research methods and academic ethical principles.

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