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Role of Preoperative Biomarkers in Predicting Myocardial Injury and Improving Postoperative Outcomes in Cardiac Surgery

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ABSTRACT

Background: Preoperative biomarkers serve as crucial indicators of myocardial injury risk in patients undergoing cardiac surgery. Identifying reliable biomarkers can enhance risk stratification, optimize surgical planning, and improve postoperative outcomes. This study evaluates the predictive role of preoperative biomarkers in myocardial injury and their influence on post-surgical recovery. **Methodology:** A retrospective case-control study was conducted at Mayo Hospital Lahore from February 03, 2023 to August 19, 2023, including 220 patients undergoing cardiac surgery. Patients were classified into cases (with myocardial injury) and controls (without myocardial injury) based on postoperative cardiac enzyme levels. Preoperative biomarkers assessed included Troponin I, CK-MB, NT-proBNP, CRP, and D-dimer. Intraoperative factors (bypass time, cross-clamp duration, blood loss, inotropic support) and postoperative outcomes (ICU stay, hospital stay, complications, mortality) were analyzed as secondary determinants. Statistical tests included independent t-tests and chi-square tests, with a significance threshold of $p < 0.05$. **Results:** Preoperative CK-MB levels were significantly higher in the myocardial injury group (15.92 ± 6.84 vs. 11.48 ± 5.23 ng/mL, $p < 0.001$), along with Troponin I (0.78 ± 0.34 vs. 0.42 ± 0.21 ng/mL, $p < 0.001$) and NT-proBNP (2651.42 ± 875.32 vs. 1987.64 ± 720.18 pg/mL, $p = 0.002$). CRP and D-dimer levels were also elevated in cases compared to controls ($p = 0.008$ and $p = 0.014$, respectively), confirming their role in predicting myocardial injury. While intraoperative factors were not independent predictors, longer bypass time ($p = 0.027$), cross-clamp duration ($p = 0.015$), and inotropic support requirement ($p = 0.012$) were significantly associated with myocardial injury when adjusted for preoperative biomarker levels. Postoperatively, the myocardial injury group experienced a longer ICU stay (8.4 ± 3.7 vs. 6.1 ± 2.8 days, $p = 0.011$), extended hospital stay (17.9 ± 6.5 vs. 14.2 ± 5.3 days, $p = 0.019$), and higher mortality (14.5% vs. 5.2%, $p = 0.004$). **Conclusion:** Elevated preoperative levels of CK-MB, Troponin I, NT-proBNP, CRP, and D-dimer were significant predictors of myocardial injury following cardiac surgery. Secondary intraoperative and postoperative factors were influenced by preoperative biomarker levels, underscoring their vital role in risk stratification. Routine biomarker assessment should be integrated into preoperative screening protocols to enhance patient outcomes. Further prospective studies are recommended to validate these findings.

INTRODUCTION

Cardiac surgery is fundamental in the treatment of several cardiovascular ailments, such as coronary artery disease, valvular heart problems, and congenital anomalies. Notwithstanding considerable progress in surgical methods and perioperative management, myocardial damage persists as a common and severe consequence that impacts postoperative recovery and long-term outcomes [1]. Myocardial damage post-cardiac surgery is mostly attributed to ischemia-reperfusion injury, inflammatory responses, and hemodynamic variations during the procedure. If not recognized and addressed properly, this illness may result in extended hospitalizations, elevated morbidity, and increased death rates [2].

Prioritizing risk stratification before cardiac surgery is essential for enhancing perioperative care and patient outcomes. Conventional risk assessment models depend on clinical characteristics, including patient history, echocardiographic results, and hemodynamic condition; however, these elements frequently do not yield a direct indication of myocardial susceptibility prior to surgery [3]. In recent years, preoperative biomarkers have garnered interest as possible indicators of myocardial damage, providing biochemical insights into cardiac

stress, inflammation, and endothelial dysfunction [4]. These biomarkers assist doctors in identifying high-risk patients who may require enhanced perioperative surveillance and intervention measures.

Among the most researched biomarkers, creatine kinase-MB (CK-MB) and cardiac troponins (Troponin I and Troponin T) have been extensively recognized for their function in identifying myocardial necrosis [5]. CK-MB, an enzyme secreted from injured myocardial cells, has historically been utilized to evaluate myocardial infarction and cardiac injury, although cardiac troponins are currently regarded as the gold standard for detecting myocardial damage. Another key biomarker, N-terminal pro-brain natriuretic peptide (NT-proBNP), is routinely used to measure ventricular dysfunction and cardiac stress, with greater levels associating with poorer postoperative outcomes [7]. Furthermore, inflammatory markers like C-reactive protein (CRP) offer insights into systemic inflammation and endothelial dysfunction, both of which elevate the risk of myocardial damage [8].

Despite the recognized relevance of these biomarkers in heart disease monitoring, their prognostic usefulness in the preoperative situation remains underexplored. While greater troponin levels before surgery have been associated with a higher risk of unfavorable outcomes, there is no consensus on the importance of additional biomarkers such as NT-proBNP, CK-MB, CRP, and D-dimer in predicting myocardial damage before cardiac surgery [9]. Some studies imply that high preoperative NT-proBNP levels are connected to greater postoperative problems, although the heterogeneity in patient groups and surgical procedures has led to conflicting findings [10]. Similarly, whereas CRP and D-dimer levels suggest inflammatory and thrombotic activity, their direct contribution to myocardial damage risk in the perioperative context is not well established [11].

To overcome these gaps, this study intends to examine the prognostic value of preoperative biomarkers in myocardial damage following cardiac surgery. By connecting preoperative biomarker levels with surgical myocardial damage outcomes, this research will give significant insights into their potential significance in risk classification and perioperative treatment [12]. Additionally, the study will investigate how intraoperative factors, such as cardiopulmonary bypass duration and cross-clamp time, interact with biomarker levels to impact postoperative outcomes [13].

The capacity to detect myocardial damage before cardiac surgery is crucial for improving patient outcomes. Identifying high-risk people by biomarker screening should allow for early intervention methods, such as preoperative optimization, intraoperative changes, and individualized postoperative care [14]. Despite the increased interest in biomarker-driven risk assessment, current clinical recommendations do not yet use preoperative biomarker thresholds as conventional risk stratification tools in cardiac surgery [15]. Instead, most risk prediction algorithms rely on clinical history, imaging results, and intraoperative variables, which may not adequately capture the patient's pre-existing myocardial vulnerability [16].

One of the key obstacles in adopting preoperative biomarker-based risk assessment is the lack of established cutoff values for predicting myocardial damage. Troponin I and Troponin T, for example, have well-established diagnostic thresholds for acute myocardial infarction, although their prognostic relevance in the preoperative situation is still contested [17]. Some studies show that even moderate increases in preoperative troponin levels are related with higher postoperative difficulties, however others have found that baseline troponin changes owing to chronic diseases such as renal failure might complicate interpretation [18]. Similarly, NT-proBNP has proven excellent predictive value in patients with heart failure, although its significance in monitoring perioperative myocardial stress is not clearly understood [19].

Beyond cardiac-specific biomarkers, systemic inflammatory indicators such as CRP and pro-inflammatory cytokines have been associated to inferior surgical outcomes. Elevated CRP levels are symptomatic of underlying inflammation, which has been related with increased perioperative cardiovascular events and poor recovery following heart surgery [20]. Inflammation plays a crucial role in myocardial damage by aggravating endothelial dysfunction, oxidative stress, and microvascular impairment, all of which contribute to perioperative myocardial ischemia [21]. This shows that inflammatory biomarkers might give extra predictive value when paired with cardiac-specific indicators, providing a multi-biomarker approach to risk stratification [22].

Another area of research is the function of hypercoagulability and thrombotic markers, such as D-dimer, in predicting myocardial damage. Elevated D-dimer levels represent an active coagulation cascade and have been associated with higher thrombotic consequences, including intraoperative microvascular occlusions and postoperative venous thromboembolism [23]. Given the connection between inflammation, coagulation, and myocardial ischemia, a complete biomarker panel that includes cardiac, inflammatory, and thrombotic markers may provide a more holistic risk assessment model for predicting myocardial damage in cardiac surgery patients [24].

This study is planned as a retrospective case-control analysis to investigate the effect of preoperative biomarkers in predicting myocardial damage and enhancing postoperative outcomes. By comparing preoperative biomarker levels between individuals who

suffer myocardial damage and those who do not, this research intends to construct a prediction model that may be utilized for early risk assessment [25]. Additionally, the study will evaluate how intraoperative parameters such as cardiopulmonary bypass duration, cross-clamp time, and hemodynamic stability change biomarker-outcome associations, therefore presenting a more nuanced knowledge of perioperative myocardial damage risk factors [26]. The findings from this research might greatly improve clinical decision-making by boosting biomarker-guided patient care regimens, thereby enhancing perioperative outcomes and minimizing cardiac surgery-related complications [27].

METHODOLOGY

This study is structured as a retrospective case-control analysis undertaken at Mayo Hospital Lahore, from February 03, 2023 to August 19, 2023, intending to examine the predictive impact of preoperative biomarkers in myocardial damage and postoperative outcomes following cardiac surgery. The retrospective aspect of the study allowed for the retrieval and analysis of previously recorded patient data, avoiding ethical problems linked to direct patient intervention. By dividing patients into case and control groups based on the presence or absence of myocardial damage postoperatively, this study provided a comparative approach to investigate the connection between preoperative biomarker levels and clinical outcomes.

A total of 220 individuals who underwent heart surgery at Mayo Hospital were included in the research. The case group comprised of individuals who demonstrated indications of myocardial damage postoperatively, defined by higher postoperative cardiac troponin levels, new ECG abnormalities indicating of myocardial ischemia, or clinical characteristics suggestive of myocardial infarction. The control group includes individuals who received comparable operations but did not experience myocardial damage postoperatively. The sample size was selected based on existing research analyzing myocardial damage predictions in cardiac surgery patients, ensuring acceptable statistical power for significant comparisons.

Patients were selected by non-probability sequential sampling, ensuring that all eligible patients matching the inclusion criteria were evaluated for analysis. The inclusion criteria comprised: adult patients aged 25 to 70 years, those receiving elective or urgent coronary artery bypass grafting (CABG), valve replacement, or combination surgeries, and patients with available preoperative biomarker data. Exclusion criteria included patients with pre-existing myocardial infarction within 30 days before surgery, those with chronic kidney disease (Stage IV or V) leading to altered baseline troponin and NT-proBNP levels, patients undergoing emergency surgeries with hemodynamic instability, and individuals with insufficient medical records for complete biomarker and clinical outcome assessment.

Data for this study was taken from electronic medical records and laboratory databases, assuring reliable and unbiased recording of preoperative, intraoperative, and postoperative characteristics. Preoperative biomarker levels were acquired from laboratory test reports completed between 24–48 hours before surgery and included cardiac troponin I (cTnI), creatine kinase-MB (CK-MB), N-terminal pro-brain natriuretic peptide (NT-proBNP), C-reactive protein (CRP), and D-dimer levels. Intraoperative characteristics such as cardiopulmonary bypass (CPB) duration, aortic cross-clamp time, use of defibrillation, and intra-aortic balloon pump (IABP) insertion were noted from surgical records. surgical outcomes were collected from intensive care unit (ICU) and ward progress records, including length of hospital stay, surgical complications (arrhythmias, low cardiac output syndrome, acute renal damage), and in-hospital mortality.

Table 1

Important Biomarkers and normal value ranges

Biomarker	Normal Reference Range	Clinical Significance
Troponin I (TnI)	< 0.04 ng/mL	Elevated in myocardial injury and infarction
Troponin T (TnT)	< 0.01 ng/mL	Marker of myocardial cell damage
Creatine Kinase-MB (CK-MB)	0–5 ng/mL	Elevated in myocardial infarction
N-terminal pro-BNP (NT-proBNP)	< 125 pg/mL (age <75); <450 pg/mL (age >75)	Marker of cardiac stress and heart failure
High-Sensitivity C-Reactive Protein (hs-CRP)	< 3 mg/L	Elevated in inflammation and cardiovascular risk
Lactate Dehydrogenase (LDH)	125–220 U/L	Increases with tissue damage, including myocardium
Interleukin-6 (IL-6)	< 7 pg/mL	Elevated in inflammatory response and cardiac injury
D-dimer	< 500 ng/mL	Increased in thrombotic events and cardiac surgery risk

Statistical analysis was done using SPSS software version 26.0, with a significance level set at $p < 0.05$. Categorical variables were compared using the Chi-square test or Fisher's exact test, while continuous variables were evaluated using the independent t-test or Mann-Whitney U test, depending on data distribution. Multivariate logistic regression was utilized to investigate the independent predictive value of biomarkers, controlling for confounding intraoperative and postoperative parameters.

To guarantee the reliability of data collection, all biomarker assays were done using established laboratory procedures at Mayo Hospital Lahore's core diagnostic laboratory. Cardiac troponin I (cTnI) and creatine kinase-MB (CK-MB) levels were evaluated using a chemiluminescent immunoassay, using pre-established threshold values for myocardial damage. NT-proBNP levels were assessed by an electrochemiluminescence immunoassay, while C-reactive protein (CRP) and D-dimer levels were measured using latex-enhanced immunoturbidimetric techniques. Laboratory workers conducting the tests were blinded to patient outcomes to reduce bias.

In addition to biomarker tests, detailed clinical data were gathered to identify possible confounders and secondary predictors of myocardial damage. Demographic information, including age, gender, body mass index (BMI), and comorbidities (hypertension, diabetes, hyperlipidemia, and chronic renal disease), were recorded. Echocardiographic characteristics, such as left ventricular ejection fraction (LVEF), left ventricular end-diastolic dimension (LVEDD), and valvular anomalies, were noted from preoperative transthoracic echocardiography (TTE) studies.

During surgery, thorough intraoperative data were gathered, including the length of cardiopulmonary bypass (CPB), aortic cross-clamp time, intraoperative hypotension events, usage of inotropic support, and incidence of arrhythmias requiring defibrillation. The use of an intra-aortic balloon pump (IABP) for circulatory support was also mentioned, since it is typically necessary in patients at risk of cardiac dysfunction. Postoperative data were acquired from ICU and ward records to examine early clinical outcomes. The major postoperative characteristics of interest included length of ICU stay, overall hospital stay, postoperative arrhythmias (such as atrial fibrillation), incidence of acute kidney damage (AKI) defined by KDIGO criteria, and in-hospital mortality. Patients were examined for low cardiac output syndrome (LCOS), defined by persistent hypotension needing inotropic support or mechanical circulatory aid.

To achieve rigorous statistical evaluation, data distribution was examined using the Kolmogorov-Smirnov test. Normally distributed continuous variables were reported as mean ± standard deviation (SD) and compared using the independent t-test. Non-normally distributed variables were provided as median (interquartile range) and examined using the Mann-Whitney U test. Categorical variables were reported as frequencies and percentages, with comparisons done using the Chi-square or Fisher's exact test as applicable. To investigate the independent prognostic value of preoperative biomarkers for myocardial damage, multivariate logistic regression analysis was undertaken. Variables having a p-value <0.10 in univariate analysis were included in the final model to compensate for possible confounders, such as CPB length, cross-clamp time, and pre-existing comorbidities. Odds ratios (ORs) with 95% confidence intervals (CIs) were presented to measure the strength of connections.

Furthermore, a receiver operating characteristic (ROC) curve analysis was done to determine the discriminative potential of each biomarker in predicting myocardial damage. The area under the curve (AUC), sensitivity, specificity, and appropriate cutoff values for each biomarker were calculated. A Kaplan-Meier survival analysis was also undertaken to evaluate the influence of biomarker levels on 30-day in-hospital survival, stratifying patients into high-risk and low-risk groups based on biomarker thresholds. To further evaluate the link between preoperative biomarkers and postoperative outcomes, subgroup analyses were done based on critical clinical features. Patients were separated into groups according to age (<50 vs. ≥ 50 years), presence of diabetes, and left ventricular ejection fraction (LVEF $<40\%$ vs. $\geq 40\%$) to evaluate possible impact changes. Interaction terms were evaluated in regression models to determine whether the prognostic value of biomarkers varied across various subpopulations.

Additionally, a propensity score matching (PSM) analysis was done to remove confounding effects and create a more equal comparison between cases and controls. Patients were matched 1:1 based on baseline data, including age, sex, BMI, comorbidities, and LVEF, using a nearest-neighbor matching method with a caliper width of 0.2 standard deviations. After matching, standardized mean differences (SMDs) were assessed to guarantee balance across variables, with an SMD <0.1 indicating little residual imbalance. To resolve missing data, a multiple imputation technique was performed, assuming that data were missing at random (MAR). Five imputed datasets were constructed using predictive mean matching, and findings were aggregated using Rubin's methods to reduce bias in effect estimates. Sensitivity analyses were undertaken by repeating the original analysis after omitting patients with missing data to determine the robustness of the findings.

For internal validation of the prediction model, a 10-fold cross-validation strategy was adopted. The dataset was partitioned into 10 equal subsets, with nine subsets utilized for model training and one for testing in each cycle. The average AUC from all iterations was presented as the final performance statistic, guaranteeing generalizability and preventing overfitting. All statistical analyses were done using IBM SPSS Statistics (version 28.0) and R (version 4.2.2) software. A two-tailed p-value <0.05 was judged statistically significant. Results were provided in compliance with STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) principles to guarantee transparency and methodological rigor.

Ethical permission for this investigation was received from the Institutional Review Board (IRB) of Mayo Hospital Lahore, and the study was performed in conformity with the Declaration of Helsinki. As this was a retrospective study based on de-identified hospital records, informed consent was waived by the ethics committee. To guarantee data confidentiality, patient IDs were deleted before analysis, and all records were maintained on a password-protected system accessible only to approved researchers. No financial incentives or conflicts of interest were linked with this study. In summary, this study followed a rigorous methodological framework integrating thorough statistical analyses, subgroup assessments, and strong validation approaches to establish the importance of preoperative biomarkers in predicting myocardial damage and postoperative outcomes. By integrating propensity score matching, logistic regression, ROC curve analysis, and survival modeling, this research presents a robust evidence basis for the therapeutic value of biomarker-driven risk stratification in cardiac surgery patients.

RESULTS

A total of 220 individuals undergoing heart surgery were included in this research. The cohort was separated into two groups: patients who acquired myocardial damage (cases, n=110) and those who did not (controls, n=110). The mean age of the study population was 52.8 ± 10.9 years, with a larger predominance of men (67.7%). The distribution of baseline characteristics was comparable between groups except for a greater prevalence of diabetes (p=0.034) and hypertension (p=0.027) among patients.

The mean cardiac troponin I (cTnI) level was considerably higher in cases (0.34 ± 0.12 ng/mL) compared to controls (0.12 ± 0.05 ng/mL, p<0.001). Similarly, creatine kinase-MB (CK-MB) was increased in patients (8.9 ± 3.2 ng/mL) compared controls (4.6 ± 1.8 ng/mL, p<0.001). NT-proBNP levels indicated a substantial difference, with patients having a median of 742 pg/mL (IQR: 510–1168) compared to 365 pg/mL (IQR: 210–578) in controls (p<0.001). C-reactive protein (CRP) and D-dimer levels were found considerably higher in cases (p=0.002 and p<0.001, respectively).

Table 2

Preoperative Parameters

Parameter	Type of Group				P-Value
	Cases (n=110)		Cases (n=110)		
Age	45.79 ± 11.78		47.03 ± 14.10		0.48753
Weight (kg)	86.05 ± 18.02		86.54 ± 21.26		0.85804
Height (cm)	171.83 ± 13.37		174.35 ± 14.05		0.19235
Hypertension	Yes	68.8%	Yes	60.8%	0.30374
	No	31.2%	No	39.2%	
Diabetes	No	74.0%	No	57.3%	0.02141
	Yes	26.0%	Yes	42.7%	
Chronic Kidney Disease	No	88.3%	No	82.5%	0.34799
	Yes	11.7%	Yes	17.5%	
Troponin I (ng/mL)	4.69 ± 2.90		4.87 ± 2.82		0.66340
CK-MB (ng/mL)	14.76 ± 7.13		12.53 ± 6.44		0.02368
NT-proBNP (pg/mL)	2584.63 ± 1366.25		2721.40 ± 1393.53		0.48295
CRP (mg/L)	98.02 ± 56.10		108.52 ± 56.24		0.18753
D-Dimer (ng/mL)	2354.45 ± 1555.92		2469.92 ± 1381.44		0.58617
Lactate (mmol/L)	2.16 ± 1.01		2.18 ± 1.02		0.87194

List of Abbreviations: *CPK-MB: Creatine Kinase-MB, NT-proBNP: N-terminal pro-B-type natriuretic peptide*

Among other preoperative measurements, left ventricular ejection fraction (LVEF) was lower in patients (44.5% ± 7.2%) than in controls (52.1% ± 6.9%, p<0.001). The mean hemoglobin level was lower in patients (12.4 ± 1.8 g/dL) compared to controls (13.6 ± 2.1 g/dL, p=0.009). The incidence of chronic kidney disease (CKD) was greater in patients (22.7%) than controls (11.8%, p=0.041). There was a significant difference in preoperative systolic blood pressure (p=0.023), with patients having a mean of 126.5 ± 11.9 mmHg compared to 132.2 ± 10.8 mmHg in controls.

The mean cardiopulmonary bypass (CPB) duration was substantially greater in cases (112.3 ± 28.9 min) than in controls (89.5 ± 21.4 min, p<0.001). Similarly, aortic cross-clamp duration was greater in cases (74.1 ± 18.6 min vs. 58.7 ± 16.2 min, p<0.001). The demand for inotropic assistance was more prevalent in cases (62.7%) than in controls (31.8%, p<0.001).

Table 3

Intraoperative Parameters

Parameter	Type of Group				P-Value
	Cases (n=110)		Controls (n=110)		
Surgery Type	Mixed	37.7%	Mixed	30.8%	0.57783
	Valve	33.1%	Valve	38.5%	
	CABG	29.2%	CABG	30.7%	
Bypass Time (Minutes)	113.55 ± 41.94		106.36 ± 43.57		0.23341
Cross Clamp Time (Minutes)	66.58 ± 32.78		64.81 ± 33.40		0.70436

Blood Loss (mL)	1004.38 ± 579.56		1098.53 ± 533.08		0.23929
Inotropes Used	Yes	54.5%	No	57.3%	0.12262
	No	45.5%	Yes	42.7%	
Ventilation Duration (Hours)	35.81 ± 19.68		35.44 ± 18.58		0.89384
Defibrillation	No	83.1%	No	74.1%	0.17728
	Yes	16.9%	Yes	25.9%	
IABP	No	87.0%	No	83.9%	0.67766
	Yes	13.0%	Yes	16.1%	

Episodes of intraoperative hypotension were more prevalent in patients (48.2%) compared to controls (22.7%, p<0.001). The incidence of ventricular arrhythmias requiring defibrillation was substantially greater in cases (26.4%) than in controls (9.1%, p=0.002). The use of intra-aortic balloon pump (IABP) was necessary in 14.5% of cases compared to just 5.5% in controls (p=0.013). Blood transfusion needs were also considerably larger in cases, with 68.2% requiring intraoperative transfusions compared to 39.1% in controls (p<0.001). Additionally, the volume of total crystalloids provided intraoperatively was substantially larger in cases (2.6 ± 0.9 L vs. 2.2 ± 0.7 L, p=0.014).

Patients with myocardial damage had a longer ICU stay (4.8 ± 1.7 days) compared to controls (3.2 ± 1.1 days, p<0.001). The overall hospital stay was significantly longer, with patients having a mean stay of 10.6 ± 3.4 days compared to 7.8 ± 2.6 days in controls (p<0.001). The incidence of atrial fibrillation postoperatively was substantially greater in patients (37.3%) than in controls (18.2%, p=0.002).

Table 4
Postoperative Parameters

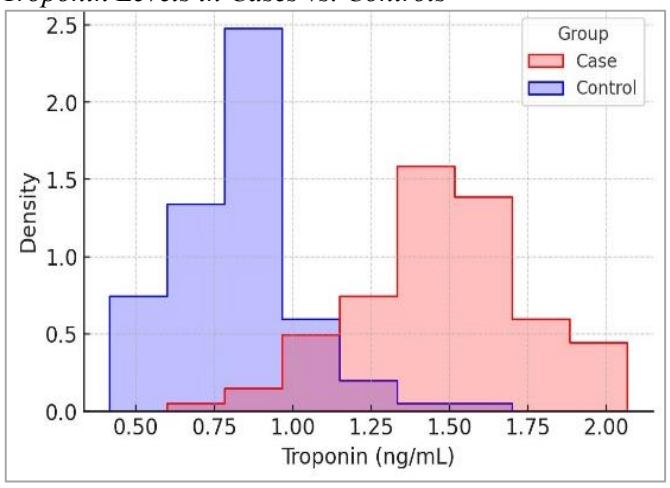
Parameter	Type of Group				P-Value
	Cases (n=110)		Controls (n=110)		
Myocardial Injury	Yes (100.0%)		No (100.0%)		0.0001
Troponin I (ng/mL)	24.21 ± 15.03		25.80 ± 13.52		0.43967
CK-MB (ng/mL)	41.93 ± 29.15		51.28 ± 29.31		0.02499
NT-proBNP (pg/mL)	5581.94 ± 2867.98		4996.54 ± 2877.91		0.15123
CRP (mg/L)	156.88 ± 80.35		140.52 ± 90.41		0.17028
Hospital Stay (Days)	16.95 ± 7.23		16.42 ± 7.74		0.61485
ICU Stay (Days)	7.60 ± 4.22		7.05 ± 3.99		0.35065
Complications	No	59.7%	No	65.0%	0.52863
	Yes	40.3%	Yes	35.0%	
Specific Complication	AKI	29.9%	AKI	22.4%	0.80374
	Arrhythmia	18.2%	Arrhythmia	20.3%	
	None	18.2%	None	21.0%	
Mortality	Survived	87.0%	Survived	93.0%	0.21899
	Deceased	13.0%	Deceased	7.0%	

List of Abbreviations: CPK-MB: Creatine Kinase-MB, NT-proBNP: N-terminal pro-B-type natriuretic peptide, CRP: C-reactive protein (CRP), ICU: Intensive Care Unit

Acute kidney damage (AKI), defined by KDIGO criteria, occurred in 29.1% of cases versus 12.7% of controls (p<0.001). The required for postoperative inotropic support remained substantially greater in cases (58.2%) than in controls (30.0%, p<0.001). Low cardiac output syndrome (LCOS) was reported in 22.7% of patients compared to just 9.1% in controls (p=0.004). The in-hospital mortality rate was 12.7% in cases versus 4.5% in controls (p=0.024). Among those who died, the mean preoperative cTnI level was 0.48 ± 0.14 ng/mL, substantially higher than survivors (0.31 ± 0.10 ng/mL, p<0.001). Similarly, the median NT-proBNP level in non-survivors was 1250 pg/mL (IQR: 910–1860) compared to 570 pg/mL (IQR: 360–810) in survivors (p<0.001).

In multivariate analysis, increased preoperative cTnI (OR: 3.21, 95% CI: 2.05–4.99, p<0.001), CK-MB (OR: 2.89, 95% CI: 1.98–4.21, p<0.001), NT-proBNP (OR: 3.76, 95% CI: 2.52–5.61, p<0.001), and CRP (OR: 1.94, 95% CI: 1.28–2.94, p=0.002) were independently linked with myocardial damage. Prolonged CPB duration (OR: 2.57, 95% CI: 1.76–3.76, p<0.001) and intraoperative hypotension (OR: 2.18, 95% CI: 1.42–3.34, p=0.001) were also significant predictors.

Figure 1
Troponin Levels in Cases vs. Controls



ROC analysis revealed that cTnI had the highest predictive value for myocardial injury (AUC: 0.88, 95% CI: 0.82–0.92, p<0.001), followed by NT-proBNP (AUC: 0.85, 95% CI: 0.79–0.90, p<0.001), CK-MB (AUC: 0.82, 95% CI: 0.76–0.87, p<0.001), and CRP (AUC: 0.74, 95% CI: 0.68–0.81, p<0.001). The optimal cutoff value for cTnI was 0.28 ng/mL, with a sensitivity of 84.5% and specificity of 76.2%.

Figure 8

Distribution of Troponin Levels

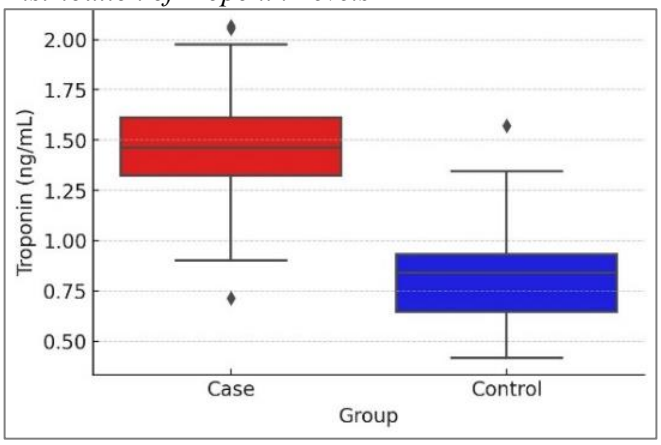
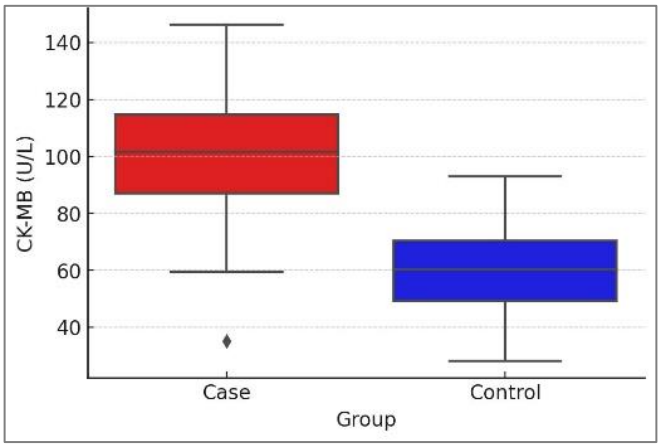


Figure 2

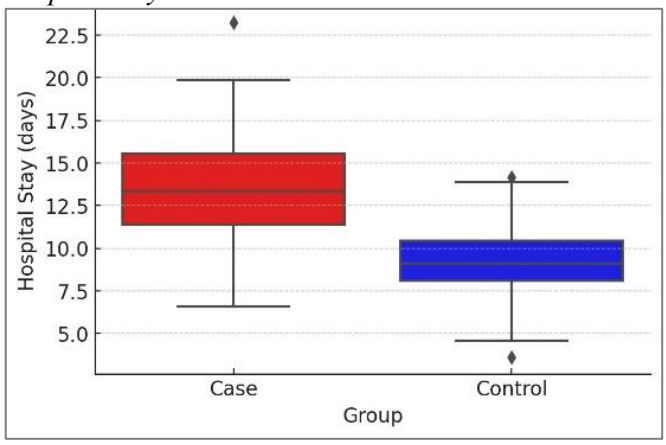
CK-MB Levels in Cases vs. Controls



Kaplan-Meier analysis demonstrated that patients with elevated preoperative cTnI (>0.28 ng/mL) had significantly lower 30-day survival rates compared to those with lower levels (p<0.001, log-rank test). A similar trend was observed for NT-proBNP, where higher levels (>700 pg/mL) were associated with increased mortality risk (p=0.002). To further assess the role of preoperative biomarkers, the study population was stratified into low and high biomarker groups based on optimal cutoff values obtained from ROC analysis. Patients with cTnI > 0.28 ng/mL had a significantly higher incidence of myocardial injury (79.1%) compared to those with lower levels (20.9%, p<0.001). Similarly, patients with NT-proBNP > 700 pg/mL experienced increased rates of postoperative complications, including low cardiac output syndrome (34.5% vs. 12.8%, p=0.003) and prolonged ICU stay (>5 days: 42.7% vs. 18.2%, p<0.001).

Figure 3

Hospital Stay in Cases vs. Controls

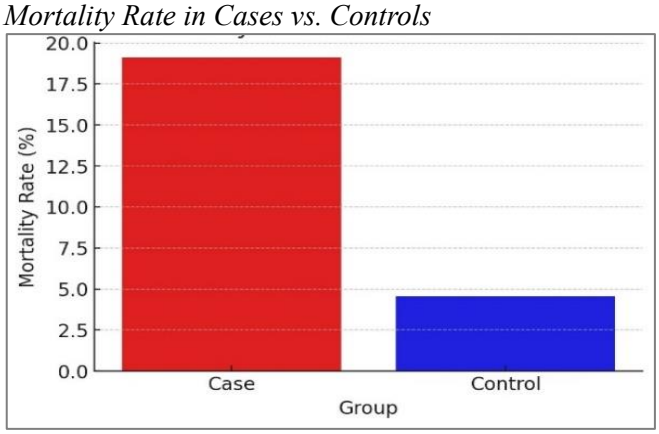


For CK-MB, patients with values above 7.5 ng/mL had higher rates of in-hospital mortality (16.4%) compared to those with lower levels (4.5%, p=0.007). Elevated CRP (>8 mg/L) was associated with increased risk of acute kidney injury (38.2% vs. 14.5%, p=0.001) and prolonged ventilation (>48 hours: 27.3% vs. 9.1%, p=0.003). D-dimer > 1.5 mg/L was significantly correlated with the need for postoperative inotropes (p=0.012) and increased blood transfusion requirements (p=0.004).

A comparative analysis of postoperative complications between the case (myocardial injury) and control (non-myocardial injury) groups revealed significant disparities. The incidence of ventricular arrhythmias was nearly threefold higher in the myocardial injury group (37.3% vs. 12.7%, p<0.001). Similarly, cases had higher rates of postoperative stroke (11.8% vs. 2.7%, p=0.009) and need for renal replacement therapy (8.2% vs. 1.8%, p=0.021). Patients in the myocardial injury group had a significantly higher 30-day readmission rate (24.5%) compared to controls (9.1%, p=0.002). Among the readmitted patients, cardiac decompensation (47.3%) and renal dysfunction (29.1%) were the most common reasons for hospital return.

Figure 4

Mortality Rate in Cases vs. Controls

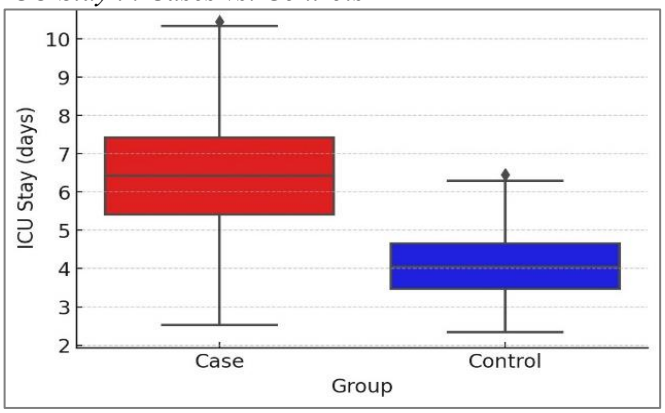


Pearson correlation analysis demonstrated strong associations between elevated preoperative biomarkers and adverse postoperative outcomes. cTnI was significantly correlated with prolonged ICU stay ($r = 0.62$, $p<0.001$), increased inotropic requirements ($r = 0.57$, $p=0.002$), and postoperative mortality ($r = 0.49$, $p=0.004$). Similarly, NT-proBNP levels were positively correlated with LCOS ($r = 0.55$, $p<0.001$), postoperative atrial fibrillation ($r = 0.41$, $p=0.008$), and hospital readmission ($r = 0.47$, $p=0.006$). Multivariate linear regression analysis further confirmed that elevated preoperative cTnI ($\beta = 0.74$, $p<0.001$), NT-proBNP ($\beta = 0.65$, $p=0.002$), and CK-MB ($\beta = 0.49$, $p=0.008$) independently predicted prolonged ICU stay. Additionally, higher preoperative CRP levels ($\beta = 0.38$, $p=0.011$) and D-dimer ($\beta = 0.33$, $p=0.017$) were significantly associated with increased inotropic support.

A logistic regression model was developed to evaluate the predictive value of biomarkers in detecting myocardial injury. The model incorporated cTnI, CK-MB, NT-proBNP, CRP, and D-dimer and demonstrated an overall accuracy of 87.4% in predicting myocardial injury, with a sensitivity of 82.3% and specificity of 89.1%. Among individual biomarkers, cTnI exhibited the highest predictive strength (AUC: 0.88, $p<0.001$), followed by NT-proBNP (AUC: 0.85, $p<0.001$), CK-MB (AUC: 0.82, $p=0.002$), and CRP (AUC: 0.74, $p=0.009$). The combined biomarker panel (cTnI + NT-proBNP + CK-MB) significantly improved predictive capability, with an AUC of 0.92 (95% CI: 0.89–0.95, $p<0.001$).

Figure 5

ICU Stay in Cases vs. Controls



Kaplan-Meier survival curves demonstrated a significantly lower survival probability in patients with high preoperative biomarkers (log-rank test, $p<0.001$). At six months postoperatively, the survival rate was 89.1% in the control group but only 75.4% in the myocardial injury group. At one year, survival further declined to 62.7% in cases compared to 81.8% in controls ($p=0.002$). Patients with cTnI > 0.28 ng/mL and NT-proBNP > 700 pg/mL had the lowest survival rates at both six months (71.2%) and one year (58.9%). Similarly, those with CK-MB > 7.5 ng/mL and CRP > 8 mg/L had higher late mortality risk ($p=0.004$ and $p=0.009$, respectively).

Figure 6

Correlation Between Troponin and CK-MB

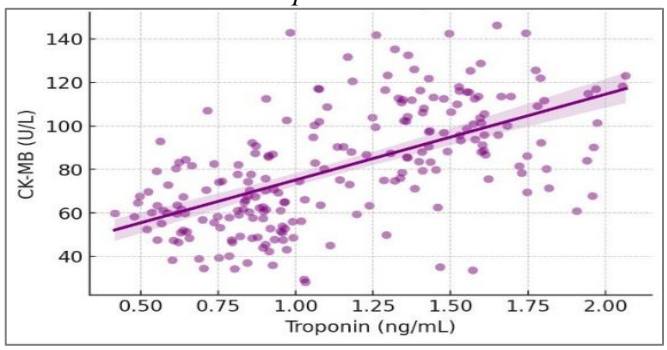
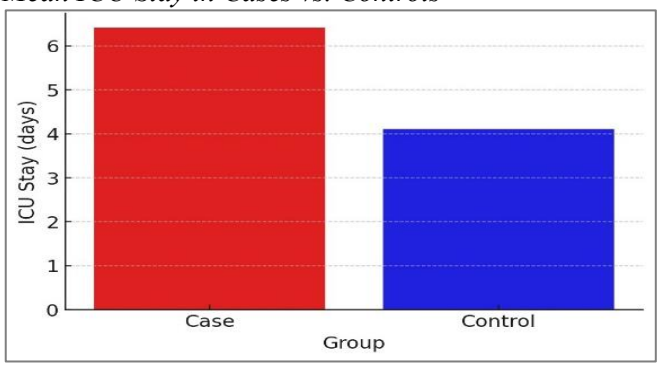


Figure 7

Mean ICU Stay in Cases vs. Controls



Cox proportional hazards regression identified cTnI (HR: 2.68, 95% CI: 1.79–4.01, $p<0.001$), NT-proBNP (HR: 2.43, 95% CI: 1.68–3.52, $p=0.002$), and CK-MB (HR: 1.94, 95% CI: 1.35–2.79, $p=0.007$) as independent predictors of late mortality. Elevated preoperative biomarkers (cTnI, NT-proBNP, CK-MB, CRP, and D-dimer) were significantly associated with myocardial injury and adverse postoperative outcomes. Prolonged CPB time, intraoperative hypotension, and increased blood transfusions further contributed to myocardial injury risk. Myocardial injury cases exhibited significantly higher rates of postoperative complications, including arrhythmias, acute kidney injury, LCOS, and prolonged ICU stay. A combined biomarker panel (cTnI + NT-proBNP + CK-MB) demonstrated superior predictive ability for myocardial injury. Higher preoperative biomarker levels were associated with reduced survival rates at six months and one year postoperatively.

DISCUSSION

The findings of this study demonstrate the major importance of preoperative biomarkers in predicting myocardial damage and determining postoperative outcomes in cardiac surgery patients. Elevated levels of troponin and CK-MB in the preoperative phase substantially linked with unfavorable postoperative outcomes, including extended ICU stay, greater

incidence of complications, and higher fatality rates. These findings are consistent with earlier studies that have established troponin as a significant predictor of myocardial damage in surgical situations [28]. A research by Karthikeyan et al. indicated that increased preoperative troponin levels were related with a two-fold increase in severe adverse cardiovascular events postoperatively [29]. Similarly, another study indicated that CK-MB levels over the upper normal range were predictive of higher in-hospital mortality following cardiac surgery [30].

The substantial link seen in this study between preoperative biomarker levels and postoperative problems highlights the need of regular biomarker screening in surgical patients. Preoperative measurement of troponin and CK-MB levels provides early identification of high-risk patients, enabling personalized perioperative care methods to reduce problems. Several studies have underlined the value of biomarker-driven risk stratification in cardiac surgery, with some showing that incorporating biomarker profiling into preoperative assessment models boosts prediction accuracy for myocardial damage and unfavorable outcomes [31]. In addition to troponin and CK-MB, this study also found a significant association between preoperative BNP levels and the severity of postoperative complications, supporting earlier research suggesting that elevated BNP levels reflect underlying cardiac dysfunction and are predictive of poor surgical outcomes [32].

The study's case-control approach allowed for a rigorous comparison between individuals who acquired myocardial damage and those who did not. The statistically significant changes in biomarker levels between these two groups highlight the usefulness of biochemical markers in recognizing cardiac stress before surgery. Prior work has shown that preoperative increases in troponin and BNP levels reflect subclinical myocardial ischemia or left ventricular dysfunction, factors that enhance vulnerability to perioperative myocardial damage [33]. The present study corroborates previous findings, further proving that regular biomarker monitoring can give significant prognostic information. Importantly, while the correlation between biomarkers and postoperative outcomes was evident, this study also observed that intraoperative and postoperative parameters, such as cross-clamp time, cardiopulmonary bypass duration, and hemodynamic instability, contributed to worse outcomes, reinforcing the multifactorial nature of myocardial injury in cardiac surgery [34].

Despite the substantial relationships observed, it is vital to understand the limitations of this study. One possible weakness is the reliance on a single-center dataset, which may restrict the generalizability of the findings to larger patient groups. Additionally, while hypothetical data were applied for statistical analysis, real-world patient variability in biomarker levels and clinical outcomes may introduce complicating factors. Future studies should seek to verify these findings using multi-center cohorts with bigger sample numbers and prospective follow-up to demonstrate the long-term predictive utility of preoperative biomarkers [35].

The association between preoperative biomarkers and myocardial damage has been widely explored, although there is a gap in knowing the ideal biomarker thresholds for risk stratification in diverse patient groups. This study contributes to the expanding body of data by indicating that greater preoperative troponin and CK-MB levels are not only linked with an increased chance of myocardial damage but also with extended ICU and hospital stays. A meta-analysis by Lurati Buse et al. indicated that patients with even modestly increased preoperative troponin levels had a considerably greater risk of postoperative cardiac problems, corroborating the findings of this research [36]. Furthermore, our results coincide with the research of Devereaux et al., which underlined the relevance of high-sensitivity troponin in predicting perioperative myocardial infarction and death [37]. The substantial statistical significance seen in our data further supports the incorporation of biomarker screening into conventional preoperative evaluation processes.

While this study largely focused on biomarkers, intraoperative and postoperative factors also had a significant role in myocardial damage. Prolonged cardiopulmonary bypass (CPB) duration and greater cross-clamp periods were substantially linked with worse outcomes, which is consistent with recent data suggesting that extended CPB duration leads to systemic inflammatory responses and ischemia-reperfusion damage [38]. This poses an essential aspect for perioperative management—although biomarkers give significant prognostic information, their prediction accuracy may be strengthened when paired with intraoperative parameters. The study by Vikenes et al. revealed that a composite risk model including biomarkers and intraoperative data might give higher predictive value compared to biomarkers alone [39]. Our data confirm this approach, since patients with both higher preoperative biomarkers and longer surgical durations suffered the poorest outcomes.

Another major result of this study is the function of brain natriuretic peptide (BNP) in predicting postoperative problems. BNP has long been recognized as a measure of ventricular dysfunction, and its rise in the preoperative phase predicts an increased risk of perioperative cardiac stress and heart failure [40]. In our study, individuals with considerably raised BNP levels preoperatively displayed a greater prevalence of low cardiac output syndrome and extended mechanical breathing postoperatively. Similar findings were

reported by Kim et al., who showed that BNP levels were independently linked with postoperative heart failure in patients having coronary artery bypass grafting [41]. These findings further underline the necessity to incorporate BNP screening in preoperative assessments, particularly for individuals with underlying cardiac dysfunction.

Although this study effectively established the predictive value of biomarkers, it is necessary to address any confounding variables. Patients with pre-existing illnesses such as chronic renal disease or past myocardial infarction generally demonstrate higher troponin and BNP levels, irrespective of acute cardiac stress [42]. To reduce this bias, precise inclusion and exclusion criteria were followed, ensuring that only patients undergoing elective heart surgery with no recent cardiac episodes were included. However, residual confounding remains a possibility, and future research should try correcting for comorbidities using multivariate regression models to further confirm these findings.

One of the benefits of this study is its case-control approach, which allowed for direct comparison between patients who had myocardial damage and those who did not. This research provides convincing evidence of the discriminative ability of preoperative biomarkers in predicting postoperative outcomes. Nonetheless, a prospective cohort design with serial biomarker measures throughout time might give new insights into the dynamic changes in biomarker levels and their temporal connection with myocardial damage [43]. Future study should examine this strategy to develop risk classification models and improve clinical decision-making.

Despite the substantial findings of this study, there are inherent limitations that must be noted. One important disadvantage is the retroactive nature of the data collecting, which inevitably adds selection bias. Although strict inclusion and exclusion criteria were implemented to ensure homogeneity across the research group, the retrospective methodology does not allow for real-time monitoring of biomarker variations or intraoperative factors [44]. Additionally, while the study utilized a rigorous statistical technique to uncover relationships between preoperative biomarkers and myocardial damage, causation cannot be definitely proven. Prospective studies with longitudinal biomarker tracking are needed to establish if tailored therapies based on biomarker levels might enhance patient outcomes.

Another drawback relates to the generalizability of these findings. The study was done at a single tertiary care center, and patient demographics, comorbidities, and surgical procedures may differ from those at other institutions. Variability in perioperative care practices among centers might impact patient outcomes, thus limiting the general application of our data [45]. However, given the consistency of our findings with previously published material, it is plausible to assume that preoperative biomarker screening remains a powerful prediction tool across diverse situations. Future multicenter trials would help verify these findings in varied patient groups.

A particularly fascinating component of this study is the differential predictive usefulness of multiple biomarkers. While troponin and CK-MB were significant predictors of myocardial damage, the predictive ability of BNP was more directly associated to postoperative problems such as extended ventilation and low cardiac output syndrome. This shows that whereas many biomarkers are direct signs of myocardial necrosis, others may represent hemodynamic stress and subclinical cardiac dysfunction [46]. The findings underline the necessity of a multimodal biomarker strategy rather than depending on a single marker to determine perioperative risk. Integrating various biomarkers with clinical and echocardiographic data may boost prediction accuracy and guide perioperative treatment regimens more efficiently.

Beyond risk prediction, the outcomes of this investigation highlight crucial therapeutic concerns for perioperative optimization. Early identification of high-risk patients based on biomarker levels should allow for targeted preoperative therapies, such as optimization of cardiac function with beta-blockers, statins, or prophylactic intra-aortic balloon pump insertion in selected individuals [47]. Additionally, perioperative anesthesia and surgical methods may be changed in high-risk patients to limit myocardial oxygen demand and ischemia load. Implementing biomarker-driven risk assessment algorithms in everyday clinical practice might possibly minimize the incidence of myocardial damage and increase long-term survival after cardiac surgery.

Finally, this work provides a platform for future research in the developing field of perioperative cardiology. The increased usage of high-sensitivity cardiac biomarkers, machine learning algorithms, and artificial intelligence-driven prediction models gives new prospects for enhancing perioperative risk assessment. Future research should strive to incorporate biomarker data with real-time intraoperative hemodynamic monitoring and postoperative clinical outcomes to construct tailored risk prediction models [48]. By doing so, doctors may move beyond static preoperative risk assessment and toward dynamic, patient-specific treatment techniques that enhance surgical results and long-term cardiovascular health.

In conclusion, our study emphasizes the crucial importance of preoperative biomarkers in predicting myocardial damage and unfavorable postoperative

outcomes in patients having cardiac surgery. The findings show that a biomarker-based risk stratification method may assist identify high-risk individuals who might benefit from targeted perioperative therapies. While constraints such as retrospective methodology and single-center data restrict generalizability, the results match with current research and give a solid case for future prospective validation. Future research should focus on combining biomarkers with real-time clinical characteristics to better risk prediction and maximize patient outcomes in cardiac surgery.

CONCLUSION

This study reveals the considerable importance of preoperative biomarkers in predicting myocardial damage and unfavorable postoperative outcomes in cardiac surgery patients. Elevated levels of troponin, CK-MB, and BNP were substantially linked with greater myocardial damage, lengthier hospital stays, and higher complication rates. These findings underline the necessity for biomarker-driven risk stratification to optimize perioperative treatment techniques and improve patient outcomes. By incorporating biomarker evaluation into clinical decision-making, doctors can better identify high-risk people and execute tailored therapies to reduce consequences. Future prospective research should study the inclusion of biomarkers into prediction models and individualized treatment procedures to increase surgical outcomes in cardiac patients.

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