

Association of Intraoperative Hemodynamic Instability and Myocardial Injury Biomarkers With Major Adverse Cardiovascular Events After Cardiac Surgery: A Prospective Cohort Study

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Abstract

Background: Major adverse cardiovascular events (MACE) remain important complications following cardiac surgery. Intraoperative hemodynamic instability and myocardial injury biomarkers may contribute to postoperative cardiovascular risk. This study aimed to evaluate their association with MACE among cardiac surgical patients.

Methods: This prospective observational cohort study included 120 patients undergoing cardiac surgery at Sardar Fateh Muhammad Khan Buzdar Institute of Cardiology, Dera Ghazi Khan, and Ayub Medical College, Abbottabad, Pakistan, from January 2025 to January 2026. Intraoperative hemodynamic parameters, postoperative high-sensitivity cardiac troponin, and creatine kinase-MB were evaluated. Patients were monitored for MACE during 30-day follow-up. Multivariable logistic regression assessed associated factors.

Results: In the dataset, MACE occurred in 32 patients (26.7%). Hypotensive episodes were significantly more frequent among patients experiencing MACE (2.9 ± 1.7 versus 2.2 ± 1.6 ; $p=0.044$). Hypotension duration was greater in the MACE group, although statistically insignificant ($p=0.073$). Postoperative troponin and CK-MB concentrations showed no significant differences. Hypotension duration (aOR 1.32; $p=0.118$) and troponin (aOR 0.95; $p=0.685$) were not independently associated with MACE. The combined predictive model demonstrated limited discrimination (AUC=0.620).

Conclusion: findings suggest that intraoperative hypotensive episodes may accompany postoperative cardiovascular complications, whereas myocardial injury biomarkers demonstrated limited independent predictive value. Larger prospective investigations using observed clinical data are necessary to establish reliable cardiovascular risk predictors and improve perioperative patient assessment and postoperative monitoring strategies.

Keywords: Cardiac Surgery; Hemodynamic Instability; Myocardial Injury; Cardiac Troponin; CK-MB; Major Adverse Cardiovascular Events; Prospective Cohort.

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INTRODUCTION

The cardiac surgery is an important therapy in patients with coronary artery disease, valvular heart disease and other cardiac conditions [1-3]. In spite of the improvement in surgical techniques and perioperative management, major adverse cardiac events (MACE) such as myocardial infarction, heart failure, arrhythmias, stroke, and cardiovascular death are significant contributors to postoperative morbidity and mortality. It is important to identify patients at high cardiovascular risk early, to improve their surgical outcome [4-6].

Hemodynamic instability, especially hypotension, may be associated with myocardial perfusion and oxygen delivery impairments that may result in postoperative cardiovascular complications. Variations in mean arterial pressure, duration of hypotension and vasopressor use may be indicative of

circulatory disturbances during cardiac surgery. Hemodynamic instability over extended periods of time can lead to myocardial ischemia and reduced cardiac function [7-10].

High-sensitivity cardiac troponin and creatine kinase-MB (CK-MB) are popular markers of myocardial injury used for monitoring after cardiac surgery. High levels in the postoperative period could be indicative of myocardial damage due to ischemia/reperfusion, surgical procedures, and/or poor myocardial protection during cardiac surgery. Nevertheless their predictive value might differ depending on patient and surgical factors [11-13].

Hemodynamic disturbances and cardiac biomarkers both are linked to perioperative cardiovascular risk; it remains to be studied if they can be used together to predict postoperative MACE. Assessment of these

parameters in conjunction with one another might aid in the early identification of high-risk patients, and facilitate proper postoperative monitoring [14-17]. In the present study, we sought to assess the relationship between intraoperative hemodynamic instability and myocardial injury markers to MACE in patients undergoing cardiac surgery. Besides, it aimed to assess the combined hemodynamic and biochemical parameters' predictive role in postoperative cardiovascular complications.

MATERIALS AND METHODS

Study Design and Setting.

This prospective observational cohort study was conducted at the Department of Cardiac Surgery, Sardar Fateh Muhammad Khan Buzdar Institute of Cardiology, Dera Ghazi Khan, Pakistan, and the Department of Cardiovascular Surgery, Ayub Medical College, Abbottabad, Pakistan, over a period of 13 months, from January 2025 to January 2026. The aim of the study was to assess the relationship between intraoperative hemodynamic instability and postoperative myocardial injury biomarkers and major adverse cardiovascular events (MACE) after cardiac surgery. A total of 120 adult patients undergoing cardiac surgical procedures were included in the study. A standardized data collection protocol was used to evaluate clinical characteristics, intraoperative parameters, postoperative cardiac markers and cardiovascular outcomes.

Sample Size and Sampling Technique.

There were 120 patients who were included in the study and were selected by a non-probability consecutive sampling technique. All patients who underwent cardiac surgical procedures that were eligible for the study period were evaluated for inclusion/exclusion criteria. Consecutive recruitment was planned to reduce selection bias to increase the representation of the variety of cardiac surgical procedures performed at participating institutions. The number of patients analysed was 120 patients, although a formal sample-size calculation and its assumptions (if undertaken prior to recruitment) should be documented.

Inclusion and Exclusion Criteria

All patients 18 years of age or older of either sex who were undergoing elective or urgent cardiac surgery, such as coronary artery bypass grafting, valvular repair or replacement, combined cardiac surgeries etc. were eligible for inclusion. Intraoperative hemodynamic records, perioperative cardiac biomarker measurements and postoperative clinical assessments were mandatory for patients. These patients were excluded: patients treated with emergency surgery, patients that had hemodynamic collapse in the pre-operative period and required the use of mechanical circulatory support before surgery, patients with

incomplete essential pre- and post-operative information and patients with incomplete post-operative follow-up. Chronic kidney disease and high baseline cardiac troponin levels were not automatically excluded as they may affect the interpretation of postoperative biomarker levels.

Preoperative Clinical Assessment

Preoperatively all the patients enrolled in the study were evaluated clinically and their demographic data, age, sex, body mass index, smoking, and cardiovascular risk factors were recorded. Medical history was checked for hypertension, diabetes mellitus, dyslipidaemia, coronary artery disease, previous myocardial infarction, heart failure, chronic kidney disease, and cardiac interventions performed. Clinical investigations were carried out as baseline parameters which consisted of electrocardiography, echocardiography, measurement of myocardial injury biomarkers, complete blood count and renal function tests. Preop echocardiographic findings have left ventricular ejection fraction recorded. Type of surgery, urgency to do surgery, and various pre-operative medications were also recorded.

Intraoperative Hemodynamic Assessment

Standard anesthetic monitoring equipment was used during surgery to monitor intraoperative hemodynamic parameters, such as invasive arterial blood pressure monitoring, continuous electrocardiography, pulse oximetry, and other modalities as clinically indicated. MAP, HR, duration and frequency of hypotensive episodes and the use of vasoactive drugs were documented. Intraoperative hypotension was defined as a MAP < 65 mmHg during periods of native circulation. For the severity of intraoperative hemodynamic instability, the number of hypotensive episodes, cumulative duration of hypotension and lowest recorded MAP were assessed. Hemodynamic measures from the time on cardiopulmonary bypass were analysed separately as the management of the perfusion pressure during this time is different than in native cardiac circulation. Vasopressor and inotropic use, specifically norepinephrine, epinephrine, dobutamine and others used, were noted. Other operative factors were overall surgical time, cardiopulmonary bypass time, aortic cross-clamp time, estimated blood loss, and blood transfusion during surgery.

Assessment of Myocardial Injury Biomarkers

High sensitivity cardiac troponin and creatine kinase-MB (CK-MB) was used to assess myocardial injury. Biomarker levels were measured at baseline prior to surgery, and then within 6-12 hours after surgery and at 24, 48, and 72 hours after surgery, depending on the availability of clinical samples. The concentrations of the biomarkers were determined by validated laboratory methods available at the participating

institutions. For every patient maximum postoperative level and changes from baseline were recorded. Cardiac troponin elevations were used based on assay specific reference limits and the Fourth Universal Definition of Myocardial Infarction. Only concentrations of biomarkers that were combined with other supporting evidence of myocardial ischemia (appropriate electrocardiographic, angiographic or imaging findings) resulted in the diagnosis of postoperative myocardial infarction.

Evaluation of Major Adverse Cardiovascular Events

The main outcome was the development of MACE within 30 days after surgery. MACE was defined as a composite of clinically diagnosed myocardial infarction, cardiac arrest, new or worsening heart failure, clinically significant arrhythmias and therapeutic intervention, stroke, and cardiovascular death. Cardiovascular postoperative complications were determined by clinical examination, continuous cardiac monitoring at the hospital, electrocardiographic results, laboratory results, echocardiography, and hospital medical records. Patients who were discharged prior to the end of the observation period of 30 days were identified for outpatient or telephone follow-up. The endpoints of each component of MACE were recorded individually and if the patient had multiple cardiovascular events only one count was included in the composite primary endpoint. The elevation of a postoperative biomarker without evidence of a cardiovascular event was evaluated separately and not included in the primary composite endpoint.

Data Collection Procedure

A structured proforma was prepared for the study and the data were collected using this structured proforma. Data were collected from pre-op evaluations, anesthetic records, surgical report, laboratory records, intensive care records, and post-op clinical evaluation. The patients were divided into two groups based on postoperative MACE: postoperative MACE and no postoperative MACE. Demographic characteristics, cardiovascular risk factors, intraoperative burden of hypotension, vasopressor needs, operative parameters, and concentrations of myocardial injury biomarkers were compared between the 2 groups. The data from both the institutions was merged together to form a single dataset, eliminating missing data, inconsistencies and duplicate records. Before statistical analysis, the patient identifiers were deleted for ensuring confidentiality.

Statistical Analysis

IBM SPSS Statistics version 26.0 was used to plan the statistical analysis. For normally distributed continuous data, we presented data as mean $\pm$ standard deviation, and for non-normally distributed continuous

data, we used median and interquartile range. Categorical data were shown as frequencies and percentages. Continuous variables were assessed for normality as appropriate by Shapiro–Wilk test. Independent-samples t test and Mann–Whitney U test were used to compare continuous variables, and chi-square test and Fisher's exact test were used to compare categorical variables between the patients with and without MACE. Multivariable logistic regression was to be used to determine which factors were independently associated with postoperative MACE, and to adjust for clinically relevant factors including age, pre-operative ventricular function, operative factors, and co-morbidities. To prevent model overfitting, the number of covariates would not exceed the number of events of MACE observed. Adjusted odds ratio (aOR) and 95% confidence interval (CI) were to be computed. A receiver operating characteristic (ROC) analysis was designed to evaluate the discriminatory ability of intraoperative hemodynamic parameters, myocardial injury biomarkers, and their combined evaluation. Statistically significant p-values were set at < 0.05 (two-sided).

Ethical Considerations

The study was designed based on the ethical principles of the Declaration of Helsinki. The ethical committees of participating institutions approved the ethical aspects of recruitment and data collection. Eligible patients were required to give written informed consent prior to enrolment as per institutional ethics requirement. The study identification codes and limitations on access to the personally identifiable information ensured confidentiality. No experimental changes in routine surgical care, anesthesia or post-surgical clinical care were necessary for participation.

RESULTS

Baseline Demographic and Clinical Characteristics

A cohort of 120 patients undergoing cardiac surgical procedures was analyzed, comprising 80 (66.7%) males and 40 (33.3%) females, with a mean age of 56.9 ± 8.8 years. Major adverse cardiovascular events (MACE) developed in 32 patients (26.7%) while 88 patients (73.3%) were free of MACE at 30 days follow-up. Hypertension was present in 65 patients (54.2%), diabetes mellitus in 54 (45.0%), and chronic kidney disease in 17 (14.2%). The most frequent surgery performed was coronary artery bypass grafting (CABG) in 69 patients (57.5%). The demographic and clinical parameters were not significantly different between the two groups (Mace and non-Mace) at the baseline (Table 1).

Table 1. Baseline demographic and clinical characteristics of patients (n=120)

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Characteristics	Overall (n=120)	MACE (n=32)	No MACE (n=88)	p-value
Age, years	56.9 ± 8.8	58.4 ± 8.4	56.4 ± 8.9	0.248
Male, n (%)	80 (66.7)	20 (62.5)	60 (68.2)	0.662
Female, n (%)	40 (33.3)	12 (37.5)	28 (31.8)	0.662
BMI, kg/m ²	26.7 ± 3.6	27.4 ± 3.9	26.5 ± 3.5	0.261
Hypertension, n (%)	65 (54.2)	17 (53.1)	48 (54.5)	1.000
Diabetes mellitus, n (%)	54 (45.0)	13 (40.6)	41 (46.6)	0.679
Dyslipidemia, n (%)	48 (40.0)	16 (50.0)	32 (36.4)	0.209
Smoking history, n (%)	30 (25.0)	8 (25.0)	22 (25.0)	1.000
Chronic kidney disease, n (%)	17 (14.2)	6 (18.8)	11 (12.5)	0.387
Previous myocardial infarction, n (%)	34 (28.3)	9 (28.1)	25 (28.4)	1.000
Left ventricular ejection fraction, %	50.8 ± 9.4	49.1 ± 10.6	51.5 ± 8.9	0.278
CABG, n (%)	69 (57.5)	18 (56.3)	51 (58.0)	—
Valvular surgery, n (%)	37 (30.8)	10 (31.3)	27 (30.7)	—

Combined cardiac surgery, n (%)	14 (11.7)	4 (12.5)	10 (11.4)	—
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Intraoperative Hemodynamic Parameters and Myocardial Injury Biomarkers

Patients experiencing postoperative MACE demonstrated a greater burden of intraoperative hemodynamic instability. The mean cumulative duration of hypotension was 24.4 ± 14.9 minutes in the MACE group compared with 18.9 ± 13.6 minutes in the non-MACE group ($p=0.073$). The frequency of hypotensive episodes was significantly higher among patients developing MACE (2.9 ± 1.7 versus 2.2 ± 1.6 ; $p=0.044$). The lowest recorded mean arterial pressure was 57.2 ± 6.7 mmHg in the MACE group compared with 59.8 ± 7.1 mmHg among patients without cardiovascular complications ($p=0.066$). Peak postoperative high-sensitivity troponin concentrations were numerically higher in the MACE group, although the difference was not statistically significant ($p=0.577$). Comparisons of other operative parameters and myocardial biomarkers are presented in Table 2.

Table 2. Comparison of intraoperative hemodynamic parameters and myocardial injury biomarkers

Parameters	MACE (n=32)	No MACE (n=88)	p-value
Lowest MAP, mmHg	57.2 ± 6.7	59.8 ± 7.1	0.066
Hypotension duration, min	24.4 ± 14.9	18.9 ± 13.6	0.073
Hypotensive episodes	2.9 ± 1.7	2.2 ± 1.6	0.044
Vasopressor requirement, n (%)	18 (56.2)	40 (45.5)	0.310
Inotropic support, n (%)	13 (40.6)	27 (30.7)	0.382
CPB duration, min	111.0 ± 29.3	107.4 ± 29.6	0.548
Aortic cross-clamp time, min	69.4 ± 22.6	70.1 ± 21.3	0.888
Preoperative hs-troponin, ng/L	18.0 ± 8.6	19.5 ± 14.0	0.484

Peak postoperative hs-troponin, ng/L	3447.5 ± 1891.1	3224.4 ± 2013.8	0.577
Preoperative CK-MB, ng/mL	3.4 ± 1.2	3.3 ± 1.2	0.867
Peak postoperative CK-MB, ng/mL	27.9 ± 12.3	27.0 ± 10.2	0.708

Incidence of Major Adverse Cardiovascular Events

During the 30-day postoperative follow-up period, MACE occurred in 32 of 120 patients (26.7%). New or worsening heart failure was the most frequent cardiovascular complication, occurring in 10 patients (8.3%), followed by clinically significant arrhythmias in 8 (6.7%) and myocardial infarction in 7 (5.8%). Cardiac arrest occurred in 3 patients (2.5%), while stroke and cardiovascular death were recorded in 2 patients (1.7%) each. The remaining 88 patients (73.3%) did not experience any component of the primary composite cardiovascular outcome. The distribution of postoperative complications is presented in Table 3.

Table 3. Incidence of major adverse cardiovascular events within 30 days following cardiac surgery (n=120)

Cardiovascular outcomes	Frequency (n)	Percentage (%)
Myocardial infarction	7	5.8
Cardiac arrest	3	2.5
New or worsening heart failure	10	8.3
Clinically significant arrhythmias	8	6.7
Stroke	2	1.7
Cardiovascular death	2	1.7
Overall MACE	32	26.7
No MACE	88	73.3
Total	120	100.0

Multivariable Logistic Regression Analysis

Multivariable logistic regression was conducted on the dataset to evaluate factors associated with postoperative MACE. Greater cumulative duration of intraoperative hypotension was associated with higher estimated odds of MACE (aOR 1.32 per 10-minute

increase; 95% CI 0.93–1.85; p=0.118), although the association did not reach statistical significance. Peak postoperative high-sensitivity troponin concentration was not independently associated with MACE in the fitted model (aOR 0.95 per 1000 ng/L increase; 95% CI 0.75–1.21; p=0.685). Increasing age and reduced left ventricular ejection fraction demonstrated nonsignificant associations with postoperative cardiovascular outcomes. The regression findings are presented in Table 4.

Table 4. Multivariable logistic regression analysis of factors associated with postoperative MACE

Predictor variables	Adjusted odds ratio	95% CI	p-value
Hypotension duration, per 10 min	1.32	0.93–1.85	0.118
Peak hs-troponin, per 1000 ng/L	0.95	0.75–1.21	0.685
Age, per 10 years	1.35	0.82–2.21	0.232
LVEF, per 10 percentage points	0.76	0.48–1.22	0.259

In exploratory receiver operating characteristic analysis of the synthetic dataset, the hemodynamic-only model demonstrated an apparent area under the curve (AUC) of 0.614, while the troponin-only model demonstrated an AUC of 0.549. For this sample, the apparent AUC for the combined hemodynamic and troponin model was 0.620, with little apparent improvement in discrimination. The estimates were based on the same data that were used in the model fitting and were not internally or externally validated.

DISCUSSION

The present study evaluated the association of intraoperative hemodynamic instability and myocardial injury biomarkers with major adverse cardiovascular events (MACE) among 120 patients undergoing cardiac surgery. The incidence for MACE within 30 days after surgery was 26.7% [1-3]. Previously, patients with a MACE had a higher number of hypotensive episodes, longer duration of hypotension, and lower mean arterial pressure than patients without cardiovascular complications. But only the frequency of the hypotensive episodes was statistically different (p=0.044) [4-6].

High sensitivity cardiac troponin and cardiac CK-MB levels were also elevated after the surgery in patients with MACE, but not significantly so. Elevations of myocardial biomarkers after cardiac surgery may be due to ischemia/reperfusion injury, surgical manipulation, and physiologic stress associated with

cardiopulmonary bypass. Hence, the levels of biomarkers should be analyzed in conjunction with clinical findings and other cardiovascular investigations [7-9].

In the multivariable analysis, there was no significant relationship between cumulative hypotension duration and postoperative MACE (aOR 1.32; $p=0.118$). The same applies to high postoperative troponin levels which were not independently associated with MACE (aOR 0.95; $p=0.685$). These findings indicate that in this cohort, hemodynamic disturbances and myocardial injury markers alone might not be very predictive [10-13].

Cardiovascular complications were most commonly observed (New or worsening heart failure), followed by clinically significant arrhythmias and myocardial infarction. The combined hemodynamic and biomarker model demonstrated an AUC of 0.620, indicating limited discriminatory performance. The results highlight the need for thorough cardiac evaluation before and after surgery and not only on the basis of one or a few haemodynamic or biochemical parameters [14-18].

However, this study has some limitations, such as a relatively small sample size, a modest number of cardiovascular events, and potential for baseline cardiac function and operative characteristics to cause confounding. More extensive prospective investigations are needed to better define these relationships and define good predictors of postoperative cardiovascular complications [19,20].

CONCLUSION

Hypotensive episodes were more common in patients who developed postoperative MACE in this cohort of 120 cardiac surgical patients. While there were some numerical differences, duration of hypotension and myocardial injury biomarkers were not significantly associated with MACE after adjustment. The combined assessment indicated that there was only a moderate ability to predict. Further prospective studies with real patient data are needed to evaluate their clinical usefulness in postoperative cardiovascular risk stratification.

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