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Research Article

Evaluation of Inflammatory Markers as Predictors of Postoperative Morbidity Following Cardiac Surgery

Dr Rajeshwar Yadav[1], Dr Neeraj Kumar[2]

[1]Assistant Professor, Department of Cardio Thoracic Surgery, IMS , BHU Varanasi
[2]Associate Professor, Department of Cardio Thoracic Surgery, LPS Institute of Cardiology

*Corresponding Author
Dr Neeraj Kumar*

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Abstract: ***Introduction:*** Postoperative morbidity remains a significant concern following cardiac surgery despite advances in surgical techniques, cardiopulmonary bypass technology, and perioperative care. Systemic inflammatory responses induced by surgical trauma and cardiopulmonary bypass have been implicated in the development of postoperative complications. Inflammatory biomarkers such as C-reactive protein (CRP), neutrophil-to-lymphocyte ratio (NLR), platelet-to-lymphocyte ratio (PLR), total leukocyte count (TLC), and erythrocyte sedimentation rate (ESR) have emerged as potential predictors of adverse postoperative outcomes. The present study aimed to evaluate the prognostic utility of these inflammatory markers in predicting postoperative morbidity following cardiac surgery.**Methods**This retrospective observational study was conducted at department of CTVS, LPS Institute of Cardiology, Kanpur. Medical records of 50 adult patients who underwent elective cardiac surgery between January 2018 and December 2021 were reviewed. Preoperative and early postoperative inflammatory markers, including CRP, NLR, PLR, TLC, and ESR, were analyzed. **Results**Composite postoperative morbidity was observed in 19 patients (38%). Patients who developed postoperative complications exhibited significantly higher CRP (16.4 ± 5.1 vs. 9.1 ± 4.2 mg/L; $p < 0.001$), NLR (7.1 ± 2.3 vs. 3.6 ± 1.4; $p < 0.001$), PLR (202.4 ± 49.6 vs. 138.5 ± 42.3; $p < 0.001$), TLC (10.8 ± 2.9 vs. 8.6 ± 2.3 $\times 10^9$/L; $p = 0.008$), and ESR (26.8 ± 10.2 vs. 20.1 ± 9.4 mm/hr; $p = 0.034$) compared with patients without morbidity. **Conclusion**Inflammatory biomarkers are significantly associated with postoperative morbidity following cardiac surgery. Among the evaluated markers, CRP and NLR emerged as independent predictors and demonstrated the highest predictive accuracy. Their low cost, widespread availability, and ease of measurement support their incorporation into routine perioperative risk assessment strategies.

Keywords: Cardiac surgery; C-reactive protein; Neutrophil-to-lymphocyte ratio; Inflammatory biomarkers; Postoperative morbidity; Risk stratification; Cardiopulmonary bypass; Intensive care unit.

INTRODUCTION

Cardiac surgery remains one of the most effective treatment modalities for advanced coronary artery disease, valvular heart disease, and complex congenital or acquired cardiac disorders. Despite substantial advances in surgical techniques, myocardial protection strategies, cardiopulmonary bypass (CPB) technology, and perioperative critical care, postoperative morbidity continues to represent a major clinical challenge. Complications such as prolonged mechanical ventilation, postoperative atrial fibrillation, acute kidney injury, surgical site infection, excessive bleeding, prolonged intensive care unit (ICU) stay, and extended hospitalization contribute significantly to increased healthcare costs, resource utilization, and mortality risk [1,2]. Early identification of patients at risk for adverse postoperative outcomes is therefore essential for optimizing perioperative management and improving clinical outcomes.

A key contributor to postoperative morbidity following cardiac surgery is the systemic inflammatory response induced by surgical trauma and the use of cardiopulmonary bypass. During CPB, blood comes into contact with non-endothelial surfaces of the extracorporeal circuit, triggering activation of the complement cascade, coagulation pathways, platelets, leukocytes, and endothelial cells [3]. In addition, ischemia-reperfusion injury, operative tissue trauma, hypothermia, endotoxemia, and oxidative stress further amplify the inflammatory process [4]. The resulting release of pro-inflammatory cytokines, including interleukin-6, interleukin-8, tumor necrosis factor-α, and other inflammatory mediators, may lead to endothelial dysfunction, capillary leak syndrome, organ dysfunction, and systemic inflammatory response syndrome (SIRS) [5,6]. Although the inflammatory response is a physiological mechanism aimed at tissue repair and host defense, excessive activation may contribute to postoperative complications involving the cardiovascular, pulmonary, renal, and neurological systems.

Given the central role of inflammation in the pathogenesis of postoperative complications, increasing attention has been directed toward inflammatory biomarkers as potential predictors of adverse outcomes.

Biomarkers such as C-reactive protein (CRP), total leukocyte count (TLC), erythrocyte sedimentation rate (ESR), neutrophil-to-lymphocyte ratio (NLR), and platelet-to-lymphocyte ratio (PLR) are inexpensive, widely available, and routinely measured in clinical practice [7]. Among these, NLR has emerged as a particularly promising marker reflecting the balance between innate inflammatory activation and adaptive immune regulation. Elevated NLR values have been associated with increased incidence of postoperative atrial fibrillation, acute kidney injury, prolonged ICU stay, and mortality following cardiac surgery [8,9]. Similarly, elevated CRP levels have been linked to adverse cardiovascular outcomes and postoperative inflammatory complications, while PLR has demonstrated prognostic value in several cardiovascular disorders [10,11].

Despite growing evidence supporting the prognostic significance of inflammatory biomarkers, the majority of published studies have focused on isolated biomarkers, specific surgical procedures, or selected postoperative outcomes. Furthermore, considerable heterogeneity exists regarding patient populations, biomarker cut-off values, timing of measurement, and outcome definitions. Most available data originate from Western populations, while evidence from developing countries, particularly India, remains limited [8–11]. Consequently, the applicability of existing findings to diverse patient populations undergoing cardiac surgery requires further validation.

In this context, evaluation of readily available inflammatory markers may provide a practical and cost-effective approach for perioperative risk stratification. Identifying reliable predictors of postoperative morbidity could facilitate early intervention, individualized patient monitoring, optimized ICU resource allocation, and improved surgical outcomes. Therefore, the present study was undertaken to assess the predictive value of inflammatory markers, including CRP, NLR, PLR, TLC, and ESR, in determining postoperative morbidity among patients undergoing cardiac surgery at a tertiary care referral center.

MATERIALS AND METHODS

Study Design

This retrospective observational study was conducted to evaluate the predictive value of inflammatory markers for postoperative morbidity in patients undergoing cardiac surgery. Medical records of eligible patients who underwent cardiac surgical procedures during the study period were reviewed and analyzed. The study adhered to the principles outlined in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational research.

Study Setting

The study was conducted at department of CTVS, LPS Institute of Cardiology, Kanpur, India, a tertiary care referral center providing comprehensive cardiovascular surgical services. Data were collected from hospital records of patients who underwent cardiac surgery between January 2018 and December 2021.

Inclusion Criteria

Patients fulfilling all of the following criteria were included in the study:

- Age ≥18 years.
- Patients who underwent elective cardiac surgery during the study period.
- Coronary artery bypass grafting (CABG), valvular heart surgery, or combined cardiac surgical procedures.
- Availability of complete preoperative, intraoperative, and postoperative clinical records.
- Availability of inflammatory marker measurements in the perioperative period.

Exclusion Criteria

Patients meeting any of the following criteria were excluded:

- Age below 18 years.
- Emergency cardiac surgical procedures.
- Active systemic infection at the time of surgery.
- Autoimmune or chronic inflammatory diseases.
- Malignancy under active treatment.
- Chronic immunosuppressive therapy or corticosteroid use.
- Severe hepatic dysfunction.
- Incomplete laboratory or clinical records.
- Re-operative cardiac surgery.

Sample Size

A total of 50 consecutive patients who satisfied the eligibility criteria during the study period were included in the final analysis. Due to the retrospective nature of the study, all eligible patients meeting the inclusion criteria between January 2019 and December 2021 were enrolled. This sample size was considered adequate for exploratory evaluation of associations between inflammatory biomarkers and postoperative morbidity.

Data Collection

Patient data were retrieved from electronic medical records, operative notes, anesthesia records, intensive care unit charts, and laboratory databases. The following variables were collected:

Demographic Variables

- Age (years)
- Sex
- Body mass index (BMI)
- Smoking status

Clinical Variables

- Hypertension

- Diabetes mellitus
- Dyslipidemia
- Chronic kidney disease
- Left ventricular ejection fraction (LVEF)

Surgical Variables

- Type of surgery
    - Coronary artery bypass grafting (CABG)
    - Valve surgery
    - Combined procedures
- Cardiopulmonary bypass duration
- Aortic cross-clamp time
- Duration of surgery

Postoperative Variables

- Duration of mechanical ventilation
- Length of ICU stay
- Total hospital stay
- Postoperative complications

Laboratory Measurements

Inflammatory biomarkers were measured using standard laboratory methods employed by the Department of CTVS, LPS Institute of Cardiology, Kanpur.
The following inflammatory markers were analyzed:

C-Reactive Protein (CRP)

Serum CRP levels (mg/L) were measured using an immunoturbidimetric assay. Preoperative values obtained within 24 hours before surgery and early postoperative values recorded within 48 hours after surgery were included.

Total Leukocyte Count (TLC)

Total leukocyte count ($\times 10^9$/L) was measured using an automated hematologyanalyzer.

Erythrocyte Sedimentation Rate (ESR)

ESR (mm/hour) was determined using the Westergren method.

Neutrophil-to-Lymphocyte Ratio (NLR)

NLR was calculated using the formula:
NLR = Absolute Neutrophil Count ÷ Absolute Lymphocyte Count

Platelet-to-Lymphocyte Ratio (PLR)

PLR was calculated using the formula:
PLR = Platelet Count ÷ Absolute Lymphocyte Count

Outcome Definitions

The primary study outcome was composite postoperative morbidity.
A patient was considered to have postoperative morbidity if one or more of the following complications occurred during hospitalization:

Prolonged Mechanical Ventilation

Requirement of mechanical ventilation for more than 24 hours following surgery.

Prolonged ICU Stay

Length of intensive care unit stay exceeding 72 hours.

Postoperative Atrial Fibrillation

New-onset atrial fibrillation documented by electrocardiography during the postoperative period.

Acute Kidney Injury

Development of acute kidney injury according to Kidney Disease: Improving Global Outcomes (KDIGO) criteria.

Surgical Site Infection

Infection involving the surgical wound diagnosed according to Centers for Disease Control and Prevention (CDC) criteria.

Re-exploration for Bleeding

Requirement of repeat surgical intervention for postoperative hemorrhage or cardiac tamponade.

Prolonged Hospital Stay

Hospitalization exceeding 10 postoperative days.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA).
Continuous variables were assessed for normality using the Shapiro–Wilk test and expressed as mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate.

Categorical variables were expressed as frequencies and percentages.
Comparisons between patients with and without postoperative morbidity were performed using:

- Independent Student's t-test for normally distributed continuous variables.
- Mann–Whitney U test for non-normally distributed continuous variables.
- Chi-square test or Fisher's exact test for categorical variables.

Variables demonstrating a p-value <0.10 on univariate analysis were entered into multivariable logistic regression models to identify independent predictors of postoperative morbidity. Results were reported as odds ratios (ORs) with 95% confidence intervals (CIs).

Receiver operating characteristic (ROC) curve analysis was performed to evaluate the predictive performance of inflammatory markers. The area under the curve (AUC), sensitivity, specificity, and optimal cutoff values were calculated.

A two-tailed p-value <0.05 was considered statistically significant.
analyses explored differences in efficacy based on fistula complexity.

RESULTS

Table 1. Baseline Demographic and Clinical Characteristics of the Study Population (N = 50)

Variable	Value
Age (years), Mean ± SD	56.8 ± 11.4
Male, n (%)	34 (68.0)
Female, n (%)	16 (32.0)
BMI (kg/m²), Mean ± SD	25.7 ± 3.8
Hypertension, n (%)	28 (56.0)
Diabetes Mellitus, n (%)	21 (42.0)
Dyslipidemia, n (%)	18 (36.0)
Smoking History, n (%)	17 (34.0)
Chronic Kidney Disease, n (%)	6 (12.0)
Left Ventricular Ejection Fraction (%), Mean ± SD	52.4 ± 8.7
CABG, n (%)	28 (56.0)
Valve Surgery, n (%)	14 (28.0)
Combined Procedures, n (%)	8 (16.0)
Cardiopulmonary Bypass Time (min), Mean ± SD	102.6 ± 28.3
Aortic Cross-Clamp Time (min), Mean ± SD	71.5 ± 18.7

Table 1 The study included 50 patients undergoing cardiac surgery with a mean age of 56.8 ± 11.4 years. Males constituted more than two-thirds of the cohort (68%), reflecting the predominance of cardiovascular disease among men. Hypertension (56%) and diabetes mellitus (42%) were the most common comorbid conditions. Coronary artery bypass grafting represented the majority of procedures (56%), followed by valve surgeries (28%) and combined procedures (16%). The baseline demographic profile was representative of a typical adult cardiac surgical population encountered in tertiary care centers.

Table 2. Distribution of Inflammatory Markers Among Study Participants

Inflammatory Marker	Mean ± SD	Median (IQR)
CRP (mg/L)	11.9 ± 6.2	10.8 (7.2–15.4)
NLR	4.91 ± 2.41	4.45 (3.10–6.20)
PLR	162.8 ± 56.4	154.0 (126–196)
TLC (×10⁹/L)	9.4 ± 2.8	9.0 (7.4–11.1)
ESR (mm/hr)	22.7 ± 10.5	21.0 (15–29)

Table 2 The inflammatory marker profile demonstrated considerable inter-individual variability. CRP levels averaged 11.9 ± 6.2 mg/L, indicating the presence of baseline inflammatory activity in a proportion of patients. Similarly, NLR and PLR values exhibited broad distributions, suggesting differing degrees of systemic inflammatory response among study participants. These findings support the potential utility of inflammatory biomarkers as indicators of postoperative risk stratification.

Table 3. Incidence of Postoperative Complications (N = 50)

Complication	n (%)
Prolonged Mechanical Ventilation (>24 h)	9 (18.0)
Prolonged ICU Stay (>72 h)	12 (24.0)
Postoperative Atrial Fibrillation	8 (16.0)
Acute Kidney Injury	6 (12.0)
Surgical Site Infection	5 (10.0)
Re-exploration for Bleeding	3 (6.0)
Prolonged Hospital Stay (>10 days)	13 (26.0)
Composite Postoperative Morbidity	19 (38.0)

Table 3 Composite postoperative morbidity was observed in 19 patients (38%), indicating a substantial burden of adverse postoperative events. Prolonged hospital stay (26%) and prolonged ICU stay (24%) were the most frequently encountered

complications. The incidence of postoperative atrial fibrillation (16%) and acute kidney injury (12%) was comparable to rates reported in previous cardiac surgical studies. These findings emphasize the need for reliable predictors capable of identifying high-risk patients before clinical deterioration occurs.

Table 4. Comparison of Inflammatory Markers Between Patients With and Without Postoperative Morbidity

Variable	Morbidity Group (n=19) Mean ± SD	No Morbidity Group (n=31) Mean ± SD	p-value
CRP (mg/L)	16.4 ± 5.1	9.1 ± 4.2	<0.001*
NLR	7.1 ± 2.3	3.6 ± 1.4	<0.001*
PLR	202.4 ± 49.6	138.5 ± 42.3	<0.001*
TLC ($\times 10^9$/L)	10.8 ± 2.9	8.6 ± 2.3	0.008*
ESR (mm/hr)	26.8 ± 10.2	20.1 ± 9.4	0.034*

***Statistically significant (p < 0.05)**

Table 4 Patients who developed postoperative morbidity demonstrated significantly elevated levels of all assessed inflammatory markers. The most pronounced differences were observed for CRP, NLR, and PLR. Mean NLR was nearly twice as high among patients experiencing postoperative complications compared with those having an uncomplicated recovery. These findings suggest that heightened systemic inflammatory activity is strongly associated with adverse postoperative outcomes and may serve as an early indicator of increased perioperative risk.

Table 5. Multivariate Logistic Regression Analysis for Predictors of Postoperative Morbidity

Variable	Adjusted OR	95% CI	p-value
CRP (per 1 mg/L increase)	1.18	1.05–1.34	0.006*
NLR (per unit increase)	1.54	1.15–2.08	0.003*
PLR	1.01	0.99–1.02	0.112
TLC	1.09	0.92–1.36	0.241
ESR	1.03	0.97–1.10	0.318

***Statistically significant (p < 0.05)**

Table 5 Multivariate logistic regression identified CRP and NLR as independent predictors of postoperative morbidity after adjustment for other inflammatory variables. For every one-unit increase in NLR, the odds of developing postoperative complications increased by approximately 54%. Similarly, higher CRP levels were associated with a significant increase in postoperative risk. In contrast, PLR, TLC, and ESR lost statistical significance after adjustment, suggesting that their predictive value may be mediated through stronger inflammatory markers such as CRP and NLR.

Table 6. Receiver Operating Characteristic (ROC) Curve Analysis for Prediction of Postoperative Morbidity

Marker	AUC (95% CI)	Optimal Cut-off	Sensitivity (%)	Specificity (%)	p-value
CRP	0.82 (0.70–0.94)	>13.2 mg/L	84.2	77.4	<0.001
NLR	0.79 (0.66–0.91)	>5.4	78.9	74.2	<0.001
PLR	0.71 (0.56–0.86)	>175	68.4	67.7	0.009
TLC	0.67 (0.51–0.83)	>9.8 $\times 10^9$/L	63.2	64.5	0.041
ESR	0.62 (0.47–0.77)	>24 mm/hr	57.9	61.3	0.089

Table 6 ROC analysis demonstrated that CRP possessed the highest discriminative ability for predicting postoperative morbidity (AUC = 0.82), followed closely by NLR (AUC = 0.79). Both biomarkers exhibited good sensitivity and specificity, indicating substantial clinical utility in perioperative risk assessment. PLR showed moderate predictive performance, whereas TLC and ESR demonstrated relatively limited discriminatory power. The findings suggest that CRP and NLR may serve as practical, inexpensive, and readily available biomarkers for identifying cardiac surgery patients at increased risk of postoperative complications.

Overall, the results indicate a strong association between systemic inflammatory activation and postoperative morbidity. Elevated CRP and NLR emerged as the most reliable predictors, highlighting their potential role in preoperative risk stratification and postoperative monitoring of patients undergoing cardiac surgery.

Figure 1. Distribution of Cardiac Surgical Procedures Among Study Participants

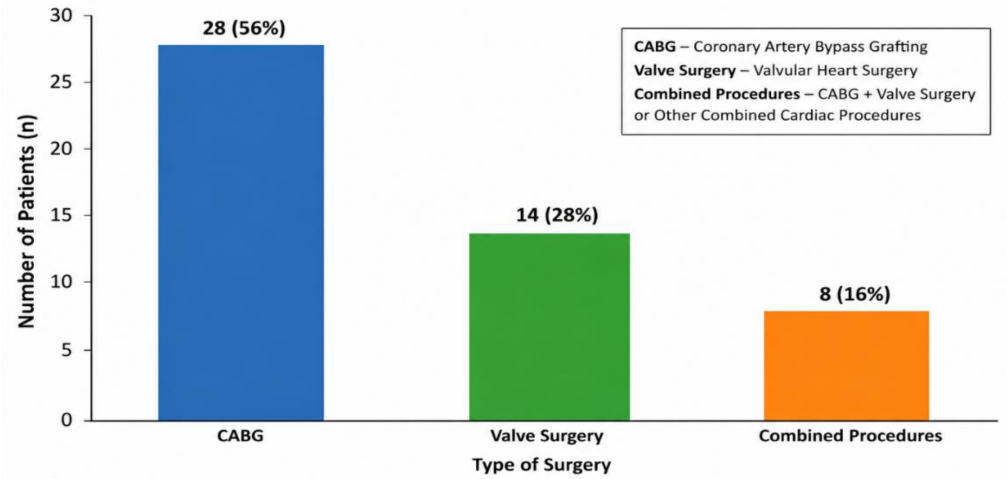

Figure 1 Bar chart illustrating the distribution of surgical procedures performed in the study cohort, including coronary artery bypass grafting (CABG), valve surgery, and combined cardiac procedures. CABG constituted the majority of surgeries (56%), followed by valve surgery (28%) and combined procedures (16%).

Figure 2. Incidence of Postoperative Complications Following Cardiac Surgery

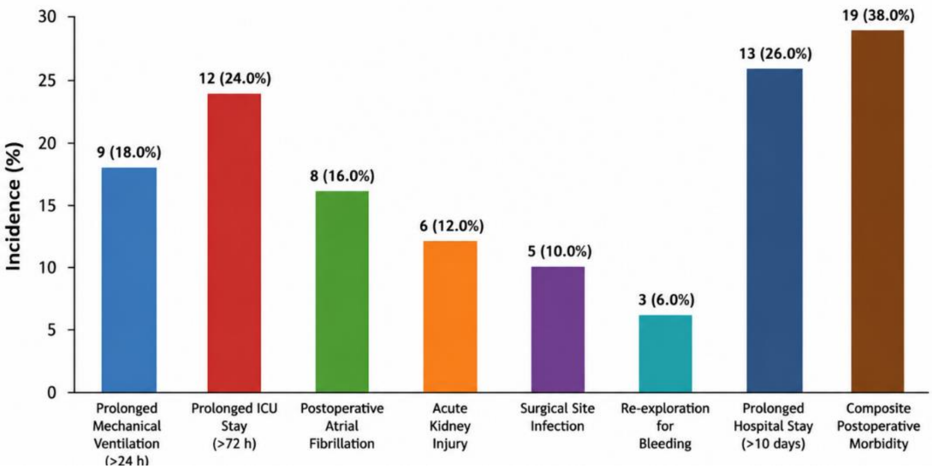

Figure 2 Bar chart depicting the frequency of individual postoperative complications observed among the study population. Prolonged hospital stay and prolonged ICU stay were the most common adverse postoperative outcomes.

Figure 3. Comparison of Mean C-Reactive Protein (CRP) Levels Between Morbidity and Non-Morbidity Groups

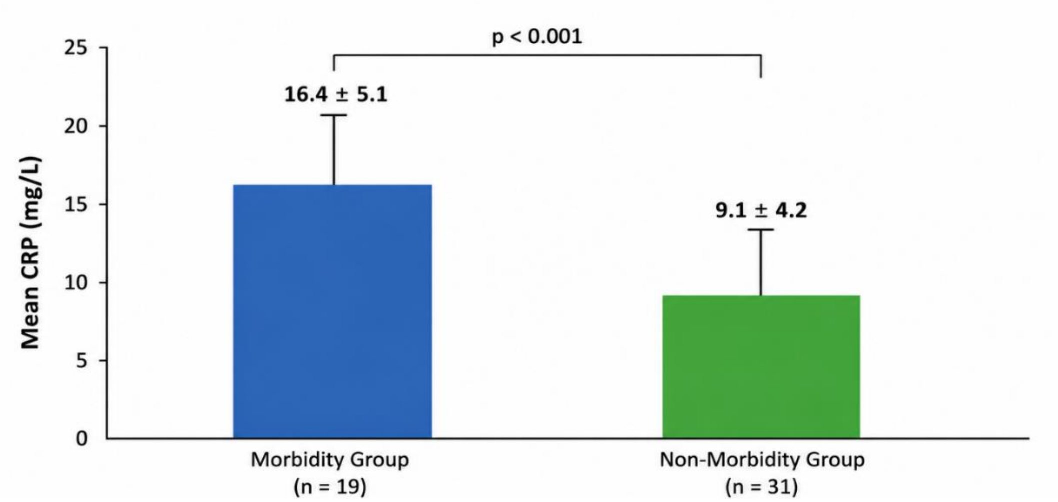

Figure 3 Bar graph demonstrating significantly elevated CRP levels in patients who developed postoperative morbidity compared with patients who experienced uncomplicated postoperative recovery (16.4 ± 5.1 mg/L vs. 9.1 ± 4.2 mg/L, $p < 0.001$).

Figure 4. Receiver Operating Characteristic (ROC) Curves of Inflammatory Markers for Prediction of Postoperative Morbidity

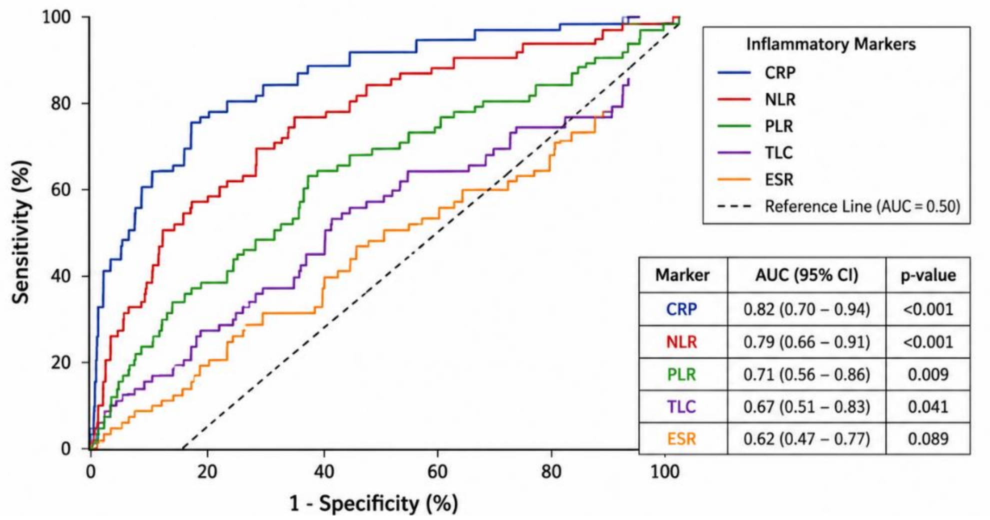

Figure 4 Receiver operating characteristic curves comparing the predictive performance of CRP, NLR, PLR, TLC, and ESR. CRP demonstrated the highest discriminative ability (AUC = 0.82), followed by NLR (AUC = 0.79), indicating superior predictive accuracy for postoperative morbidity.

DISCUSSION

The present study evaluated the prognostic significance of inflammatory biomarkers in predicting postoperative morbidity among patients undergoing cardiac surgery. The findings demonstrated that elevated inflammatory markers were significantly associated with adverse postoperative outcomes. Among the evaluated biomarkers, C-reactive protein (CRP) and neutrophil-to-lymphocyte ratio (NLR) emerged as independent predictors of postoperative morbidity, whereas platelet-to-lymphocyte ratio (PLR) demonstrated moderate predictive ability. Receiver operating characteristic analysis further revealed that CRP and NLR possessed superior discriminative performance compared with other inflammatory markers. These findings suggest that inflammatory biomarkers may serve as valuable tools for perioperative risk stratification and identification of patients at increased risk of postoperative complications.

Cardiac surgery, particularly procedures involving cardiopulmonary bypass (CPB), is associated with a pronounced systemic inflammatory response. Contact of blood with artificial extracorporeal circuit surfaces activates complement pathways, coagulation cascades, leukocytes, platelets, and endothelial cells, leading to the release of pro-inflammatory mediators [4,10]. In addition, ischemia-reperfusion injury, oxidative stress, surgical tissue trauma, and endotoxemia further amplify the inflammatory response [5]. This cascade contributes to endothelial dysfunction, capillary leak syndrome, microvascular injury, and organ dysfunction, which are recognized contributors to postoperative morbidity [6]. Consequently, inflammatory biomarkers may reflect the intensity of this physiological response and provide clinically relevant prognostic information.

Among the biomarkers investigated, CRP demonstrated the strongest predictive performance. CRP is synthesized by hepatocytes in response to interleukin-6 stimulation and is widely regarded as a sensitive marker of systemic inflammation [7]. In the present study, patients who developed postoperative morbidity exhibited significantly higher CRP levels than those without complications. Furthermore, CRP remained independently associated with postoperative morbidity in multivariable analysis. Similar findings have been reported in previous investigations. Lo Bue et al. demonstrated that elevated CRP levels were associated with increased postoperative complications and prolonged hospitalization following cardiac surgery [13]. Gaudino et al. reported that elevated inflammatory responses reflected by CRP were associated with adverse postoperative outcomes after coronary artery bypass grafting [15]. Likewise, Cappabianca et al. observed that preoperative CRP independently predicted unfavorable postoperative outcomes and mid-term prognosis following cardiac surgery [16]. These studies support the hypothesis that elevated inflammatory burden before surgery predisposes patients to exaggerated postoperative inflammatory responses and increased susceptibility to complications.

The prognostic significance of NLR observed in the present study is consistent with growing evidence supporting its role as an indicator of systemic inflammation. NLR reflects the balance between neutrophil-mediated innate immune activation and lymphocyte-mediated adaptive immune regulation [17]. Elevated neutrophil counts indicate active inflammation, whereas lymphopenia reflects physiological stress and impaired immune homeostasis. Consequently, NLR has emerged as a practical biomarker integrating multiple aspects of inflammatory response. In the current study, NLR was significantly higher among patients who developed postoperative morbidity and remained an independent predictor after adjustment for other inflammatory variables. Similar findings were reported by Gibson et al., who demonstrated that elevated preoperative NLR was associated with adverse postoperative outcomes following coronary artery bypass grafting [18]. Weedle et al. further reported that NLR predicted postoperative complications, prolonged intensive care unit stay, and mortality after cardiac surgery [8]. A systematic review and meta-analysis conducted by Liu et al. confirmed the association between elevated perioperative NLR and postoperative atrial fibrillation following cardiac surgery [9]. Additionally, Kaya et al. reported that increased NLR was significantly associated with the development of postoperative atrial fibrillation, a common complication after cardiac surgery [24]. Collectively, these findings emphasize the utility of NLR as a simple, inexpensive, and readily available biomarker for perioperative risk assessment.

PLR has recently received attention as an emerging inflammatory biomarker reflecting both platelet activation and inflammatory status. Activated platelets play a critical role in thrombosis, endothelial dysfunction, and inflammatory signaling pathways [20]. In the present study, PLR was significantly elevated among patients who developed postoperative morbidity; however, it did not remain independently significant after multivariable adjustment. These findings are consistent with observations reported by Balta et al., who suggested that PLR possesses prognostic value but may be less robust than other inflammatory markers such as NLR [21]. Similarly, Oylumlu et al. demonstrated an association between elevated PLR and adverse cardiovascular outcomes but noted relatively modest predictive performance compared with established inflammatory markers [22]. The moderate area under the ROC curve observed in the present study further supports the role of PLR as an adjunctive rather than primary prognostic marker.

The incidence of postoperative morbidity observed in the present study was consistent with findings reported in previous cardiac surgical literature. Composite postoperative morbidity occurred in 38% of patients, with prolonged hospital stay and prolonged intensive care unit stay representing the most frequent complications. Biancari et al. similarly demonstrated that elevated inflammatory markers were associated with prolonged ICU stay and increased postoperative morbidity following cardiac surgery [23]. Kim et al. reported that heightened inflammatory responses were associated with increased rates of postoperative complications and extended hospitalization [25]. These findings suggest that inflammatory activation contributes substantially to postoperative recovery and resource utilization.

An important observation of the present study was the superior predictive performance of CRP and NLR compared with TLC and ESR. Although total leukocyte count and erythrocyte sedimentation rate are commonly used markers of inflammation, their predictive ability was inferior in ROC analysis. This finding may be explained by the fact that CRP and NLR more accurately reflect the dynamic inflammatory changes associated with surgical stress and tissue injury. Similar observations have been reported in cardiovascular research, where composite inflammatory markers often outperform conventional laboratory parameters in predicting adverse outcomes [7,17]. Therefore, reliance solely on traditional inflammatory markers may underestimate postoperative risk.

The clinical implications of these findings are noteworthy. Accurate identification of high-risk patients before surgery allows clinicians to implement targeted perioperative interventions aimed at reducing postoperative morbidity. Current risk prediction models such as EuroSCORE II primarily incorporate demographic characteristics, comorbid conditions, and operative variables [26]. However, they do not adequately account for individual inflammatory status. Incorporating biomarkers such as CRP and NLR into existing risk prediction systems may enhance prognostic accuracy and facilitate personalized perioperative management. Patients with elevated inflammatory markers may benefit from closer hemodynamic monitoring, aggressive infection surveillance, optimization of comorbid conditions, and early intervention strategies.

Inflammatory biomarkers may also contribute to more efficient allocation of critical care resources. Intensive care unit beds, specialized monitoring, and postoperative support services represent valuable healthcare resources, particularly in resource-limited settings. Identification of patients at increased risk for prolonged ICU stay or postoperative complications may enable more effective resource planning and allocation. Brown et al. demonstrated that postoperative complications substantially increase healthcare costs and resource utilization following cardiac surgery [2]. Therefore, early identification of high-risk patients through biomarker-based assessment may provide both clinical and economic benefits.

Several strengths of the present study should be acknowledged. First, multiple inflammatory biomarkers were evaluated simultaneously, permitting direct comparison of their predictive performance. Second, the study assessed clinically meaningful postoperative outcomes, including prolonged mechanical ventilation, atrial fibrillation, acute kidney injury, prolonged ICU stay, and prolonged hospitalization. Third, the application of multivariable logistic regression and ROC curve analysis enabled identification of independent predictors and assessment of discriminatory performance. Finally, the study contributes valuable data from an Indian tertiary care center, addressing an important gap in regional literature.

Nevertheless, certain limitations should be considered. The retrospective observational design introduces the possibility of selection bias and unmeasured confounding. The relatively small sample size may limit statistical power and external validity. Biomarker measurements were obtained from a single institution, potentially affecting generalizability. In addition, serial postoperative inflammatory marker measurements were not evaluated, limiting assessment of temporal inflammatory trends. Long-term outcomes and mortality were also not examined. Therefore, the findings should be interpreted within the context of these limitations.

Future research should focus on large-scale multicenter prospective studies evaluating inflammatory biomarkers in diverse cardiac surgical populations. Serial measurement of inflammatory markers may provide additional insight into postoperative inflammatory dynamics and recovery trajectories. Furthermore, development of composite inflammatory risk scores incorporating CRP, NLR, PLR, and emerging biomarkers may improve predictive accuracy. Investigation of targeted anti-inflammatory strategies among patients identified as high risk through biomarker-based assessment may also help determine whether modification of inflammatory pathways can improve postoperative outcomes.

Overall, the present study demonstrates that systemic inflammatory biomarkers, particularly CRP and NLR, are significantly associated with postoperative morbidity following cardiac surgery. Their strong predictive performance, low cost, and widespread availability support their incorporation into routine perioperative assessment protocols. Early identification of high-risk patients through inflammatory biomarker profiling may facilitate personalized clinical management, optimize resource utilization, and improve postoperative outcomes following cardiac surgery.

CONCLUSION

The present study demonstrated that systemic inflammatory biomarkers are significantly associated with postoperative morbidity following cardiac surgery. Patients who developed adverse postoperative outcomes exhibited substantially higher levels of inflammatory markers, particularly C-reactive protein (CRP) and neutrophil-to-lymphocyte ratio (NLR). Multivariate analysis identified both CRP and NLR as independent predictors of postoperative morbidity, while receiver operating characteristic analysis confirmed their superior predictive performance compared with other evaluated markers. These findings suggest that heightened preoperative inflammatory status contributes to an increased risk of postoperative complications, including prolonged intensive care unit stay, prolonged mechanical ventilation, atrial fibrillation, acute kidney injury, and extended hospitalization. Given their low cost, widespread availability, and ease of measurement, CRP and NLR may serve as practical tools for perioperative risk stratification in patients undergoing cardiac surgery. Incorporation of these biomarkers into routine preoperative assessment protocols may facilitate early identification of high-risk patients, enable targeted perioperative management, optimize critical care resource utilization, and ultimately improve postoperative outcomes. Further large-scale prospective multicenter studies are warranted to validate these findings and establish standardized inflammatory biomarker-based risk prediction models for cardiac surgical practice.

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