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Article

The Role of CRP/Albumin Ratio in Predicting the Risk of Postoperative Acute Renal Failure in Patients Undergoing Coronary Bypass Surgery

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Abstract

Background: The evolution of acute kidney injury (AKI) following coronary artery bypass grafting (CABG) operations may have several immediate effects on the health of the patients. Whether the preoperative C-reactive protein (CRP)/albumin ratio is a biomarker that can be used to predict the development of AKI after CABG is still under investigation. This study examined the ability of the CRP/albumin ratio to predict the risk of postoperative AKI. **Methods**: This study was a retrospective analysis of 186 patients who underwent CABG surgery at the Eskisehir City Hospital. Patients were categorized into low and high-risk groups based on preoperative CRP/albumin ratios. The diagnosis of AKI was based on an increase in serum creatinine level or oliguria according to the Kidney Disease Improving Global Outcomes (KDIGO) criteria. Preoperative CRP and albumin values, demographic characteristics, postoperative creatinine, estimated glomerular filtration rate (eGFR) and length of hospitalization were evaluated. **Results**: In patients who developed AKI, their CRP/albumin ratio was 2.48 (1.24–4.48), vs non-AKI patients; 1.21 (0.53–2.34); $p < 0.001$. The CRP/albumin area under the Receiver Operating Characteristic (ROC) curve (AUC) ratio in ciR was 0.782 with an AUC of 74.2% sensitivity and 71.8% specificity at a threshold value of 1.85. Patients who developed AKI also had a mean Intensive Care Unit (ICU) stay of 5 (3–8) days and a mean length of stay of 12 (9–18) days, which was longer than the control group, regardless of the cause of the hospitalization; ($p < 0.001$). **Conclusion**: High CRP/albumin ratio is an important risk marker for the development of AKI after CABG. Assessing the preoperative CRP/albumin ratio could be beneficial in predicting the risk of AKI and in devising appropriate postoperative management protocols for these patients.

Keywords

coronary artery bypass; C-reactive protein; serum albumin; acute kidney injury; inflammation mediators; biomarkers

Introduction

Coronary artery bypass grafting (CABG) is a widely used treatment in patients with cardiovascular disease; however, acute kidney injury (AKI) that may develop following this procedure results in major complications [1]. In patients with increased inflammatory responses during surgery, the risk of postoperative AKI increases, significantly increasing mortality [2]. C-reactive protein (CRP) and albumin, key biomarkers of inflammation, are associated with the development of postoperative AKI, and elevated CRP and reduced albumin levels have been identified as independent risk factors for AKI [3,4]. The development of postoperative acute kidney injury is a complication that can significantly worsen surgical outcomes [5].

A high CRP/albumin ratio is considered a significant indicator for predicting renal dysfunction, especially in patients with the potential for an increased inflammatory response [6]. Since this ratio directly reflects inflammatory processes, it may have more predictive value than other biomarkers for complications due to AKI [7]. Low preoperative albumin levels have been shown to increase the risk of AKI and are associated with prolonged hospital stays [8]. A high CRP/albumin ratio not only increases the risk of AKI but also contributes to other postoperative complications following CABG, potentially serving as a predictive marker for AKI [9]. Although multiple studies have examined inflammatory markers in cardiac surgery patients, there remains a significant knowledge gap regarding the specific predictive value of the CRP/albumin ratio for post-CABG AKI, therefore, this study sought to investigate its role in predicting postoperative AKI.

With the increased aging of the population, the proportion of elderly patients undergoing CABG is increasing, and these patients are particularly vulnerable to postoperative renal impairment. CABG is currently recognized as the optimal treatment for patients with triple-vessel coronary disease. AKI remains a common and serious complication post-CABG. Studies indicate that 17% to 41% of CABG patients experience AKI [10], and even minor postoperative increases in serum creatinine levels—below the threshold for AKI diagnosis—can lead to a poor prognosis [1]. In elderly patients, off-pump CABG does not significantly reduce the incidence or severity of postoperative AKI [11]. Preoperative evaluation, early diagnosis, and timely intervention are essential to prevent deterioration of renal function and improve outcomes. There is now evidence that combined inflammatory and nutritional indices, such as the HALP score (haemoglobin, albumin, lymphocyte, and platelet), may also predict adverse outcomes in cardiovascular patients. A recent study demonstrated that a lower HALP score was independently associated with increased in-hospital mortality in ST-elevation myocardial infarction patients undergoing a primary percutaneous coronary intervention [12], highlighting the importance of inflammation and the nutritional status in cardiovascular disease, which aligns with the focus of our study on the CRP/albumin ratio.

This study focused on assessing the utility of CRP/albumin ratio for predicting the risk of AKI after CABG, the association of renal function and inflammation as noted by this marker postoperatively, and evaluating whether this ratio could enhance the assessment of risk in patients undergoing cardiac surgery.

Methods

Study Objects, Materials and Participants

We assessed the effectiveness of the preoperative CRP/albumin ratio in predicting postoperative AKI among patients undergoing CABG at the Eskişehir City Hospital. In this retrospective study, 186 patients who underwent elective CABG surgery at the Cardiovascular Surgery Clinic of the Eskisehir City Hospital between October 2018 and January 2024 were analyzed. The aim of the study was to evaluate the potential role of CRP/albumin ratio in the prediction of postoperative AKI. Inclusion criteria included having a CABG under elective conditions, while the exclusion criteria included cases of emergency surgery, a left ventricular ejection fraction less than 40%, chronic renal failure or dialysis requirement, and early postoperative mortality.

Preparation and Selection of Participants

In a total of 342 patients scanned from the patient database of Eskişehir City Hospital, 156 patients were excluded from the study due to the exclusion criteria (emergency surgery n = 64, preoperative chronic kidney disease (CKD) n = 28, previous cardiac surgery n = 22, missing data n = 42). Age, gender, body mass index (BMI) and comorbid diseases such as hypertension, chronic obstructive pulmonary disease (COPD) and diabetes were evaluated in 186 patients included in the study (Fig. 1).

Study Design

This study was a retrospective cohort; no randomization or blinding was performed. All patient data were retrieved from the electronic database and analyzed. AKI was diagnosed by a 50% increase in serum creatinine level within 7 days or $\geq$0.3 mg/dL increase within 2 days or oliguria for $\geq$6 hours according to the KDIGO criteria [13].

Interventions and Treatment Methods

During CABG, intraoperative cardiopulmonary bypass time, aortic cross-clamping time, and postoperative inotropic support requirements were recorded. Perioperative management focused on avoiding the cardiorenal syndrome, which can develop when cardiac dysfunction leads to kidney injury. Standard perioperative care protocols included maintaining hemodynamic stability, ensuring adequate renal perfusion with mean arterial pressure >65 mmHg, avoiding nephrotoxic drugs, maintaining sufficient urine output (>0.5 mL/kg/h), and careful fluid management. For high-risk patients, renal consultation was obtained preoperatively. During the postoperative period, patients were followed with daily routine blood tests; both preoperative CRP/albumin ratios and postoperative biochemical parameters were analyzed.

Measurement Methods and Calculations

All laboratory measurements were performed in the central laboratory of the hospital with devices accredited following ISO 15189 standards. The Immunoturbidimetric method (Roche Diagnostics, normal range: 0–5 mg/L) was used for CRP measurements and the bromcresol green method (Roche Diagnostics, normal range: 3.5–5.2 g/dL) was used for albumin measurements. Laboratory quality controls were performed and documented regularly on a daily, weekly and monthly basis. Biochemical tests such as hemogram, urea, creatinine, spartate aminotransferase (AST), Alanine transaminase (ALT), Lactate dehydrogenase (LDH), calcium and potassium were performed on preoperative and postoperative days 1, 3 and 5. Preoperative blood samples were collected within 24 hours before the op-

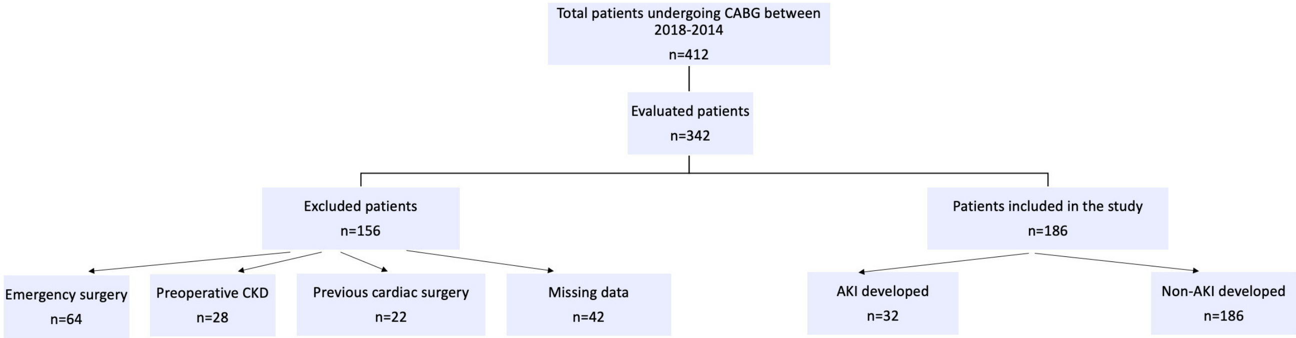

Fig. 1. Flowchart of CABG patients (2018–2024). CABG, coronary artery bypass grafting; AKI, acute kidney injury.

eration and all samples were analyzed within 2 hours. All test results were obtained through the hospital's laboratory information system.

Statistical Analysis and Model Construction

Statistical analyses were performed with SPSS software (Version: 18.0; IBM, NY, USA). Normality testing was conducted using Kolmogorov-Smirnov (KS) and Shapiro-Wilk (SW) tests. Normally distributed continuous variables were expressed as mean $\pm$ standard deviation (SD) and analyzed using Student's *t*-test with corrected variance. Non-normally distributed data were expressed as median (25th percentile, 75th percentile) and analyzed using Mann-Whitney U test (which is equivalent to the Wilcoxon rank sum test). Categorical variables were analyzed using Chi-square test. A two-sided p value of less than 0.05 was considered statistically significant. For the multivariate logistic regression analysis, variables with $p < 0.1$ in univariate analyses were included in the initial model. The backward elimination method was used for model construction, with a removal criterion of $p > 0.05$. The Hosmer-Lemeshow test was performed to assess model fit, and variance inflation factors were calculated to check for multicollinearity. The final model retained only independent predictors, with odds ratios (OR) and 95% confidence intervals (CI) calculated for each variable. We specifically examined the CRP/albumin ratio as our primary predictor variable of interest, adjusting for established risk factors for AKI including age, diabetes, baseline renal function, cardiopulmonary bypass time, and intraoperative parameters. Kaplan-Meier survival analysis was performed to compare patients with CRP/albumin ratio above and below 1.85. Differences between groups were evaluated using the log-rank test. Patients were followed at standardized time points (days 0, 5, 10, 15, 20, and 30), and death, cardiac events, or rehospitalization were considered as endpoints in the survival analysis. For the survival curves, the number of patients at risk was documented at each time point to ensure appropriate interpretation of the data throughout the follow-up period.

Results

Baseline Characteristics and Demographic Data

The mean age of the patients who developed AKI was 69.2 $\pm$ 8.4 years and 63.5 $\pm$ 7.6 years in those who did not develop AKI (p = 0.001). The mean body mass index (BMI) was 28.8 $\pm$ 4.2 kg/m^2 in the group with AKI and 27.1 $\pm$ 3.8 kg/m^2 in the group without AKI (p = 0.028). Among the categorical variables, the rate of diabetes was 50.0% (n = 16) in those who developed AKI and 33.8% (n = 52) in the non-AKI group. A significant difference was not found (χ^2 = 3.010, p = 0.083). Since CRP levels among continuous variables did not show normal distribution, non-parametric testing was used, and a significant difference was found as 8.2 (4.1–14.8) mg/L in patients with AKI and 4.6 (2.0–8.9) mg/L in patients without AKI ($p < 0.001$). Normal albumin levels were 3.3 $\pm$ 0.4 g/dL in patients with AKI and 3.8 $\pm$ 0.3 g/dL in patients without AKI ($p < 0.001$). Similarly, creatinine values which did not show normal distribution were evaluated by non-parametric testing; 1.3 (0.9–1.7) mg/dL in patients with AKI and 0.9 (0.7–1.2) mg/dL in patients without AKI ($p < 0.001$), while eGFR values showing normal distribution were 67.8 $\pm$ 19.2 mL/min/1.73 m^2 and 83.4 $\pm$ 15.2 mL/min/1.73 m^2, respectively ($p < 0.001$). Hemoglobin levels were also lower in those who developed AKI; 11.6 $\pm$ 1.7 g/dL and 12.8 $\pm$ 1.3 g/dL in the non-AKI group (p = 0.001). A significant difference was also found in terms of cardiopulmonary bypass time; it was 98 (78–125) min in those who developed AKI and 84 (65–102) min in those who did not develop AKI (p = 0.032) (Table 1).

CRP/Albumin Ratio and Clinical Outcomes

The CRP/albumin ratio was significantly greater among patients with AKI as compared to patients who did not have AKI. The medians were also clearly different - patients with AKI had a ratio of 2.48 (1.24–4.48) while those without AKI had a ratio of 1.21 (0.53–2.34) ($p < 0.001$). Creatinine levels on the first day after surgery for the AKI patients was higher than normal levels at 1.8 (1.4–

Table 1. Demographic and clinical characteristics of patients (n = 186).

Variable	AKI (n = 32)	No AKI (n = 154)	*p*-value
Demographic Characteristics			
Age (years)*	69.2 ± 8.4	63.5 ± 7.6	0.001
Gender (Male)†	22 (68.8)	106 (68.8)	0.994
BMI (kg/m^2)*	28.8 ± 4.2	27.1 ± 3.8	0.028
Comorbid Conditions			
Diabetes mellitus†	16 (50.0)	52 (33.8)	0.083
Hypertension†	23 (71.9)	95 (61.7)	0.284
COPD†	7 (21.9)	22 (14.3)	0.284
Peripheral artery disease†	9 (28.1)	26 (16.9)	0.146
Preoperative Laboratory			
CRP (mg/L)‡	8.2 (4.1–14.8)	4.6 (2.0–8.9)	<0.001
Albumin (g/dL)*	3.3 ± 0.4	3.8 ± 0.3	<0.001
Creatinine (mg/dL)‡	1.3 (0.9–1.7)	0.9 (0.7–1.2)	<0.001
eGFR (mL/min/1.73 m^2)*	67.8 ± 19.2	83.4 ± 15.2	<0.001
Hemoglobin (g/dL)*	11.6 ± 1.7	12.8 ± 1.3	0.001
Operative Data			
CPB duration (min)‡	98 (78–125)	84 (65–102)	0.032
Cross-clamp duration (min)‡	68 (52–88)	56 (44–72)	0.024
Number of grafts‡	3 (2–4)	3 (2–4)	0.682
EuroSCORE II‡	3.9 (2.5–6.4)	2.5 (1.7–4.0)	<0.001

Notes: Data presented as Mean ± Standard Deviation (*), Number (percentage) (†), or Median (Interquartile Range) (‡). Statistical analysis used: Student's *t*-test for normally distributed continuous variables (*), Mann-Whitney U test for non-normally distributed continuous variables (‡), and Chi-square test for categorical variables (†). Statistical significance set at $p < 0.05$.

Abbreviations: BMI, Body Mass Index; COPD, Chronic Obstructive Pulmonary Disease; CRP, C-Reactive Protein; eGFR, Estimated Glomerular Filtration Rate; CPB, Cardiopulmonary Bypass; AKI, Acute Kidney Injury.

2.3) mg/dL, on day 3 it was 2.2 (1.6–2.8) mg/dL and on day 5 AKI patients had a creatinine level of 1.9 (1.5–2.6) mg/dL. Similarly, for non-AKI patients, day 1 creatinine levels were 1.1 (0.8–1.4), day 3 levels were 1.0 (0.8–1.3) and day 5 was 0.9 (0.7–1.2) mg/dL on average ($p < 0.001$). There was also a difference in the length of stay in the ICU 5 (3–8) days with patients that had some degree of AKI and 2 (1–3) days for those without AKI. For the length of hospitalization, patients with AKI stayed for an average of 12 (9–18) days, while those without AKI stayed for an average of 7 (6–9) days ($p < 0.001$). The 30-day mortality was 9.4% with the AKI patients and 1.3% for those without AKI ($p = 0.008$). When patients were stratified based on the CRP/albumin ratio with a cutoff value of 1.85, we observed that patients with a CRP/albumin ratio >1.85 had significantly higher rates of AKI (18.0% vs 16.7%, $p = 0.008$), elevated postoperative creatinine levels ($p < 0.001$), longer ICU stays (4 [2–7] vs 2 [1–4] days, $p < 0.001$), extended hospitalization (11 [8–16] vs 8 [6–10] days, $p < 0.001$), and increased 30-day mortality (5.1% vs 0.9%, $p = 0.014$). Additionally, patients with an elevated CRP/albumin ratio demonstrated a higher incidence of major adverse cardiac events (MACE) (11.5% vs 7.4%, $p = 0.042$) and rehospitalization rates (9.0% vs 5.6%, $p = 0.036$), though the difference in repeat revascularization requirements did not reach statistical significance (5.1% vs 1.9%, $p = 0.086$) (Tables 2,3).

ROC Analysis and Cutoff Value Determination

The analysis of the receiver operating characteristic (ROC) curves demonstrated adequate discriminatory ability of the CRP/albumin ratio for prediction of AKI in the postoperative phase. The area under the ROC curve (AUC) was 0.782, which is equivalent to 78.2%. CI = 0.684–0.880 (at 95%). The best cut-off value of this ratio was derived to be 1.85, with asensitivity of 74.2% and a specificity of 71.8%. This optimal cut-off value may differ from other studies due to variations in laboratory measurement methods and population characteristics, yet it provides strong discriminatory power for identifying patients at risk for post-CABG AKI in our cohort (Fig. 2).

Table 2. Comparison of patients with and without AKI (n = 186).

Variable	AKI Developed (n = 32)	AKI Not Developed (n = 154)	*p*-value
Preoperative Values			
CRP/Albumin ratio‡	2.48 (1.24–4.48)	1.21 (0.53–2.34)	<0.001
Postoperative Creatinine			
Day 1 (mg/dL)‡	1.8 (1.4–2.3)	1.1 (0.8–1.4)	<0.001
Day 3 (mg/dL)‡	2.2 (1.6–2.8)	1.0 (0.8–1.3)	<0.001
Day 5 (mg/dL)‡	1.9 (1.5–2.6)	0.9 (0.7–1.2)	<0.001
Clinical Outcomes			
ICU length of stay (days)‡	5 (3–8)	2 (1–3)	<0.001
Hospital length of stay (days)‡	12 (9–18)	7 (6–9)	<0.001
30-day mortality†	3 (9.4)	2 (1.3)	0.008

Notes: Data presented as Median (Interquartile Range) (‡) or Number (percentage) (†). Statistical significance set at $p < 0.05$.

Abbreviations: ICU, Intensive Care Unit.

Table 3. Comparison of clinical outcomes based on CRP/albumin ratio.

Variable	CRP/Albumin >1.85	CRP/Albumin ≤1.85	*p*-value
AKI rate (%)	18.0	16.7	0.008
Postoperative Creatinine			
Day 1 (mg/dL)‡	1.4 (1.1–1.8)	1.0 (0.8–1.3)	<0.001
Day 3 (mg/dL)‡	1.5 (1.1–2.0)	1.0 (0.8–1.3)	<0.001
Day 5 (mg/dL)‡	1.3 (0.9–1.8)	0.9 (0.7–1.2)	<0.001
Clinical Outcomes			
ICU length of stay (days)‡	4 (2–7)	2 (1–4)	<0.001
Hospital length of stay (days)‡	11 (8–16)	8 (6–10)	<0.001
30-day mortality (%)	5.1	0.9	0.014
Major adverse cardiac events (%)	11.5	7.4	0.042
Re-hospitalization rates (%)	9.0	5.6	0.036
Repeat revascularization (%)	5.1	1.9	0.086

Notes: Data presented as Median (Interquartile Range) (‡) or percentages. Statistical significance set at $p < 0.05$.

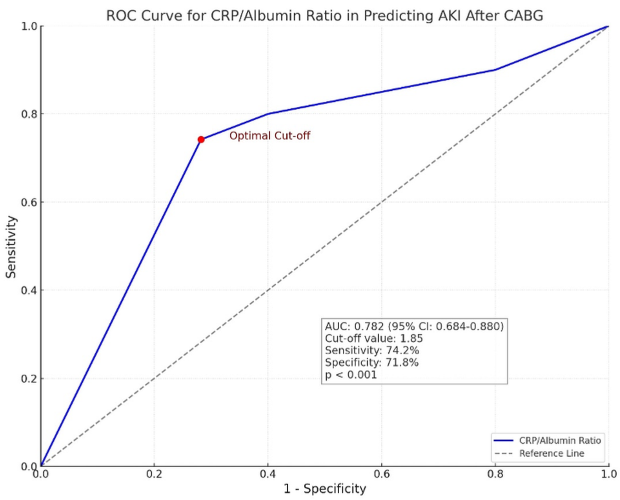

Fig. 2. ROC curve for CRP/albumin ratio in predicting post-CABG AKI. ROC, receiver operating characteristic; CRP, C-reactive protein.

Perioperative Hematologic and Biochemical Parameters

Significant differences in perioperative hematologic and biochemical parameters between patients with and without AKI were observed. The mean preoperative hematocrit level was 35.2 ± 4.8% in patients who developed AKI, whereas it was 38.4 ± 4.2% and significantly higher in those who did not develop AKI (p = 0.002). The minimum hematocrit level during CPB was 22.4 ± 3.2% in patients with AKI and 25.8 ± 3.6% in those without AKI; this difference was statistically significant ($p < 0.001$). In terms of the volume of erythrocyte suspension (ES) transfusion, it was observed to be 3 (2–4) units in patients with AKI and 1 (0–2) unit in patients without AKI ($p < 0.001$). In addition, 81.3% of patients who developed AKI received an ES transfusion, while this rate was 53.2% in patients who did not develop AKI (p = 0.004). Fresh frozen plasma (FFP) transfusion volume was also significantly higher with an average of 2 (1–4) units given to the group with AKI and 1 (0–2) unit in those without AKI (p = 0.002). Regarding biomarkers, preoperative lactate levels were 1.8 (1.2–2.6) mmol/L

Table 4. Perioperative hematological and biochemical parameters of patients (n = 186).

Variable	AKI (n = 32)	No AKI (n = 154)	*p*-value
Hematocrit and Blood Transfusion			
Preoperative Hct (%)*	35.2 ± 4.8	38.4 ± 4.2	0.002
CPB minimum Hct (%)*	22.4 ± 3.2	25.8 ± 3.6	<0.001
PRBC transfusion (Units)‡	3 (2–4)	1 (0–2)	<0.001
PRBC transfusion rate†	26 (81.3)	82 (53.2)	0.004
FFP transfusion (Units)‡	2 (1–4)	1 (0–2)	0.002
Perioperative Biomarkers			
Preop lactate (mmol/L)‡	1.8 (1.2–2.6)	1.2 (0.8–1.6)	0.003
CPB peak lactate (mmol/L)‡	4.2 (3.1–5.8)	2.8 (2.1–3.6)	<0.001
Preop magnesium (mg/dL)*	1.82 ± 0.24	2.04 ± 0.28	0.012
Postop magnesium (mg/dL)*	1.68 ± 0.22	1.92 ± 0.26	0.008
Nutrition and Inflammation			
PNI score*	42.6 ± 5.8	48.4 ± 6.2	<0.001
Preop NLR‡	3.8 (2.6–5.4)	2.4 (1.8–3.2)	<0.001
Postop Day 1 NLR‡	8.6 (6.4–12.2)	5.2 (3.8–7.4)	<0.001

Notes: Data presented as Mean ± Standard Deviation (*), Number (percentage) (†), or Median (Interquartile Range) (‡). Statistical significance set at $p < 0.05$.
Abbreviations: Hct, Hematocrit; PRBC, Packed Red Blood Cells; FFP, Fresh Frozen Plasma; PNI, Prognostic Nutritional Index; NLR, Neutrophil-to-Lymphocyte Ratio.

in patients with AKI and 1.2 (0.8–1.6) mmol/L in patients without AKI (p = 0.003). Peak lactate levels during cardiopulmonary bypass (CPB) were also significantly higher in those who developed AKI (4.2 (3.1–5.8) mmol/L) and 2.8 (2.1–3.6) mmol/L in those who did not ($p < 0.001$). Magnesium levels were 1.82 ± 0.24 mg/dL in those with AKI and 2.04 ± 0.28 mg/dL in those without AKI, (p = 0.012); postoperative levels were similarly lower in those with AKI (p = 0.008). The prognostic nutritional index (PNI) was 42.6 ± 5.8 in patients with AKI and 48.4 ± 6.2 in those without AKI ($p < 0.001$). The neutrophil/lymphocyte ratio (NLR) was 3.8 (2.6–5.4) preoperatively in patients with AKI and 2.4 (1.8–3.2) in patients without AKI. Postoperative day 1 NLR values were also significantly higher in the group with AKI (8.6 (6.4–12.2) vs. 5.2 (3.8–7.4), $p < 0.001$) (Table 4).

Correlation Between CRP/Albumin Ratio and Renal Function

In this study, a significant positive correlation was found between the preoperative CRP/albumin ratio and the highest postoperative creatinine level. Patients with a higher preoperative CRP/albumin ratio were more likely to have higher postoperative creatinine levels. The preoperative CRP/albumin ratios of patients who developed AKI were significantly higher than those who did not develop AKI. The Spearman correlation coefficient was ρ = 0.624, and this relationship was highly significant ($p <$ 0.001). Fig. 3 illustrates this relationship through scatter and box plots, clearly demonstrating the distribution of CRP/albumin ratios in patients who did and didn't develop AKI, as well as the positive correlation between higher CRP/albumin ratio and increased postoperative creatinine levels.

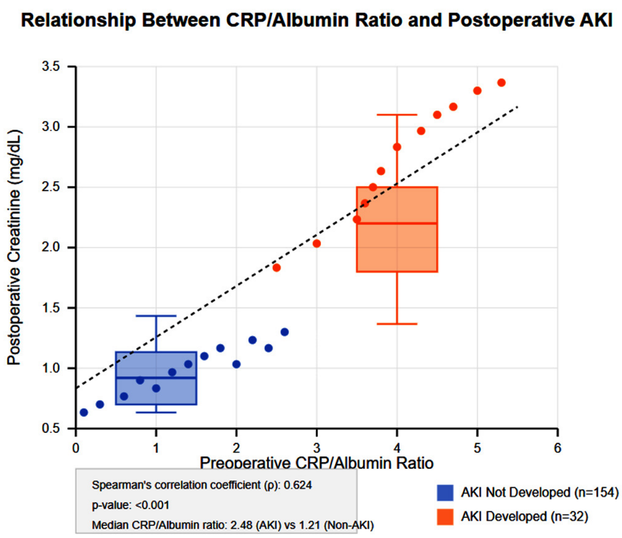

Fig. 3. Relationship between CRP/albumin ratio and postoperative AKI.

Multivariate Analysis of Risk Factors for AKI

The multivariate logistic regression model showed good calibration (Hosmer-Lemeshow goodness-of-fit test: χ^2 = 7.82, p = 0.45), and no significant multicollinearity was detected among predictor variables (all variance inflation factors <2.5). The results of multivariate logistic regression analysis demonstrated several independent factors that increase the risk of developing AKI, including a CRP/albumin ratio above 1.85, being older than 65 years, and the presence of diabetes mellitus (DM). In addition, a CPB duration exceeding 90 minutes, an eGFR below 60 mL/min/1.73 m^2, a minimum hematocrit level of less than

Table 5. Multivariate logistic regression analysis.

Risk factor	OR (95% CI)	p-value
CRP/Albumin >1.85	3.42 (2.18–5.36)	<0.001
Age >65 years	2.86 (1.74–4.68)	0.002
Presence of DM	1.94 (1.22–3.08)	0.015
CPB duration >90 min	1.78 (1.14–2.76)	0.024
eGFR <60 mL/min/1.73 m^2	2.24 (1.46–3.44)	0.008
CPB minimum Hct <24%	2.86 (1.82–4.48)	<0.001
PRBC transfusion >2 Units	2.44 (1.56–3.82)	0.002
Peak lactate >4 mmol/L	2.68 (1.74–4.12)	<0.001
PNI <45	2.12 (1.38–3.26)	0.004
Postop NLR >7	2.34 (1.52–3.60)	0.001

Notes: OR, Odds Ratio; CI, Confidence Interval; DM, Diabetes Mellitus; eGFR, Estimated Glomerular Filtration Rate; Hct, Hematocrit; PRBC, Packed Red Blood Cells.

24% during CPB, an erythrocyte suspension (ES) transfusion exceeding 2 units, a peak lactate value exceeding 4 mmol/L, a PNI score below 45, and a postoperative day 1 NLR value exceeding 7 are also among the risk factors. A CRP/albumin ratio higher than 1.85 increases the risk of AKI by approximately 3.42 times. Other factors, such as a minimum hematocrit (Hct) <24% during CPB and age >65 years, also significantly increase the risk of AKI. While our study identified multiple risk factors for AKI, we specifically focused on the CRP/albumin ratio because it represents a novel, easily obtainable biomarker that combines both inflammatory and nutritional status in a single parameter. Additionally, among all identified risk factors, the CRP/albumin ratio showed one of the strongest associations with AKI development (OR = 3.42), suggesting its particular importance in perioperative risk assessment. Furthermore, unlike many other identified risk factors that are either non-modifiable (such as age) or only become apparent during surgery (such as CPB time), the CRP/albumin ratio can be evaluated preoperatively, potentially allowing for early intervention strategies in high-risk patients (Table 5).

Long-term Outcomes and Survival Analysis

The long-term follow-up of patients revealed significant differences in both 6-month and 12-month outcomes between the groups. Patients who developed AKI postoperatively showed persistently higher creatinine levels and lower eGFR values at both follow-up periods compared to those without AKI. The progression to chronic kidney disease was significantly more frequent in the AKI group, with 28.1% showing progression at 12 months versus only 4.5% in the non-AKI group ($p < 0.001$). Similarly, patients with an elevated preoperative CRP/albumin ratio (>1.85) demonstrated worse renal outcomes, including higher rates of progression to end-stage renal disease requiring dialysis (3.8% vs 0.9%, $p = 0.046$). Regarding cardiac events, both the AKI group and the high CRP/albumin ratio group experienced significantly more MACE, more frequent hospitalizations, and worse functional capacity as measured by NYHA classification during the follow-up period. Mortality rates continued to diverge at both 6 and 12 months, with the AKI group showing a 21.9% mortality rate at 12 months compared to 7.8% in the non-AKI group ($p = 0.015$). Quality of life assessments at 12 months further confirmed these trends, with significantly lower scores in both the AKI group and high CRP/albumin ratio group (Table 6).

Patients with a CRP/albumin ratio >1.85 have a significantly lower survival rate in the first 30 days compared to those with a CRP/albumin ratio ≤1.85. The log-rank test confirms this difference ($p = 0.008$). The survival rate of patients with a high CRP/albumin ratio decreased faster each day. Those with lower ratios were stable and had a higher survival rate. This suggests that a high level of inflammation (CRP/albumin ratio) may have a negative impact on postoperative short-term survival (Fig. 4) (Table 7).

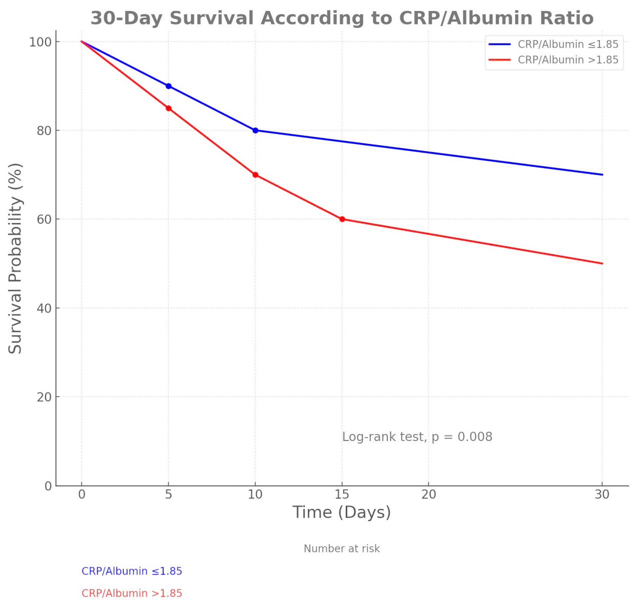

Fig. 4. Relationship between CRP/albumin ratio and postoperative AKI.

Discussion

We evaluated the power of the preoperative CRP/albumin ratio to predict the development of postoperative AKI in patients undergoing coronary bypass surgery. The risk of AKI was significantly increased in patients with a high CRP/albumin ratio. In particular, the risk of AKI was approximately 3.4 times higher in patients with a CRP/albumin ratio above 1.85. The findings of this study demonstrate the detrimental effects of inflammation on renal function. The CRP/albumin ratio is an accurate marker for predicting the occurrence of postoperative

Table 6. Long-term outcomes at 6 and 12 months follow-up.

Outcome	AKI Group (n = 32)	Non-AKI Group (n = 154)	p-value	CRP/Albumin >1.85	CRP/Albumin ≤1.85	p-value
Renal Outcomes						
Mean Creatinine at 6 months (mg/dL)‡	1.7 (1.2–2.3)	0.9 (0.7–1.1)	<0.001	1.3 (0.9–1.8)	0.8 (0.7–1.1)	<0.001
Mean Creatinine at 12 months (mg/dL)‡	1.8 (1.3–2.5)	0.9 (0.7–1.2)	<0.001	1.4 (1.0–2.0)	0.9 (0.7–1.1)	<0.001
Mean eGFR at 6 months (mL/min/1.73 m^2)*	58.6 ± 18.4	82.1 ± 14.8	<0.001	65.2 ± 19.6	80.8 ± 15.2	<0.001
Mean eGFR at 12 months (mL/min/1.73 m^2)*	54.8 ± 20.2	81.5 ± 15.3	<0.001	63.5 ± 20.8	79.4 ± 16.1	<0.001
Progression to CKD at 12 months (%)†	28.1	4.5	<0.001	18.6	6.2	0.004
Progression to ESRD requiring dialysis (%)†	6.3	0.6	0.017	3.8	0.9	0.046
Cardiac Outcomes						
Major adverse cardiac events at 6 months (%)†	18.8	6.5	0.024	14.1	7.2	0.038
Major adverse cardiac events at 12 months (%)†	25.0	10.4	0.022	17.9	10.8	0.047
Re-hospitalization at 12 months (%)†	31.3	12.3	0.006	24.4	13.6	0.029
NYHA Class III–IV at 12 months (%)†	15.6	5.2	0.035	12.8	5.5	0.042
Overall Outcomes						
Mortality at 6 months (%)†	15.6	5.2	0.034	10.3	5.4	0.048
Mortality at 12 months (%)†	21.9	7.8	0.015	15.4	8.1	0.040
Quality of life score at 12 months*	62.4 ± 15.8	78.6 ± 12.3	<0.001	68.5 ± 14.6	77.3 ± 13.2	<0.001

Notes: Data presented as Mean ± Standard Deviation (*), Number (percentage) (†), or Median (Interquartile Range) (‡). Statistical significance set at $p < 0.05$.

Abbreviations: CKD, Chronic Kidney Disease; ESRD, End-Stage Renal Disease; NYHA, New York Heart Association functional classification.

Table 7. 30-Days Survival According to CRP/Albumin Ratio.

Time (Days)	0	5	10	15	20	30
CRP/Albumin ≤1.85	112	108	102	100	98	95
CRP/Albumin >1.85	74	68	60	55	53	50

AKI. The identification of the CRP/albumin ratio as an independent prognostic factor for AKI after CABG adds further evidence to the existing literature on this subject and demonstrates its potential clinical value during preoperative risk evaluation and surgical planning. These results substantiate the routine use of the CRP/albumin ratio in perioperative assessment protocols. In patients identified with preoperative high CRP/albumin ratios, we suggest a modified treatment approach including renal consultation, more stringent hemodynamic monitoring, optimization of intravascular volume, avoidance of nephrotoxic agents, and early intervention at the first signs of renal dysfunction. Patients with a high CRP/albumin ratio should be monitored more closely.

The role of the CRP/albumin ratio in predicting AKI has been reported in the literature. Studies have shown that a lower eGFR and albuminuria are independently associated with increased risks of AKI, regardless of diabetes and hypertension status [14]. Research on cardiac surgery patients demonstrates that decreased serum albumin and increased high urinary albumin/creatinine ratio (UACR) after surgery correlate with a lower eGFR, indicating renal injury. Hypoalbuminemia and elevated UACR within 24 hours post-surgery serve as significant AKI predictors [15]. Additionally, research on CRP/albumin ratio in acute pancreatitis has shown that CRP/albumin ratio on days 2 and 3 is associated with severe outcomes, including organ failure [16]. This ratio combines markers of inflammation (CRP) and nutritional status (albumin), potentially offering better predictive performance for identifying high-risk patients.

Similar trends have been observed with other inflammatory biomarkers, such as the HALP score (combining hemoglobin, albumin, lymphocytes, and platelets), which has been shown to predict in-hospital mortality in patients with ST-elevation myocardial infarction [12]. In this study, we found that low albumin and high CRP levels play a critical role in the development of AKI and that the CRP/albumin ratio reflects the increased inflammation burden and increases the risk of AKI. All these findings support the association of the CRP/albumin ratio with the risk for AKI.

In addition to the increasing effect of the CRP/albumin ratio on AKI risk, when the interaction of CRP/albumin ratio with other risk factors is considered, age, presence of DM, duration of CPB, eGFR level and low hematocrit levels are among the prominent risk factors. Our study shows that the CRP/albumin ratio is an independent predictor for the development of AKI and significantly increases the risk of AKI, especially when combined with other risk factors such as age >65 years and DM. These findings are in line with studies by James and colleagues who found that the risk of AKI increased with a lower eGFR and albuminuria levels in the presence of DM and hypertension [14]. Similarly, Senghor *et al*. [15] reported that low serum albumin levels and UACR can predict AKI risk in patients undergoing cardiac surgery. In addition, the findings of Yu *et al*. [10] showing an increased risk of AKI in patients with a high CRP/albumin ratio support the results of our study. Accordingly, the predictive power of the CRP/albumin ratio on the development of AKI increases this risk even more when combined with other risk factors such as low hematocrit and low eGFR.

Our findings suggest that the CRP/albumin ratio has an important predictive value in the development of postoperative AKI after CABG. The AUC value of 0.782 obtained in our ROC analysis demonstrated that this ratio has an effective discriminatory power in the clinical setting. These results are in line with the findings of Zhao *et al*. [16] who observed the predictive utility of this ratio in assessing severity and prognosis, particularly in inflammatory conditions such as acute pancreatitis, where higher CRP/albumin ratios are associated with more adverse outcomes. Similarly, Park *et al*. [17] found that the CRP/albumin ratio was associated with a high 28-day mortality rate in critically ill patients, which also supports our findings. In addition, Li *et al*. [18] demonstrated that inflammation and nutritional markers such as the albumin-fibrinogen ratio provide robust indicators for predicting 28-day mortality in sepsis patients and that ratios such as CRP/albumin may be effective in predicting outcomes in cases of intense inflammation. These studies are consistent with our ROC findings and suggest that the CRP/albumin ratio may be a valuable and practical tool for risk stratification in patients undergoing CABG, especially in the early identification of patients with increased inflammation and AKI risk.

The CRP/albumin ratio, as an independent risk factor indicating high inflammation and malnutrition, has a significant impact on 30-day mortality and survival. Studies after intensive care and oncologic surgery found that a high CRP/albumin ratio is associated with short survival times [19–23]. Several studies have shown that an increase in the CRP/albumin ratio increases the risk of early mortality and is associated with shorter survival time after surgery. Tak Kyu Oh and colleagues [21] found that the CRP/albumin ratio was a strong predictor of 30-day and 1-year mortality. Similarly, in patients undergoing hepatocellular carcinoma surgmery, those with a higher CRP/albumin ratio had a shorter tumor-free survival time [24]. Our extended follow-up data at 6 and 12 months further reinforce these findings, demonstrating that the prognostic value of CRP/albumin ratio extends well beyond the immediate postoperative period. The higher rates of CKD progression, MACE, rehospitalization, and mortality in patients with elevated CRP/albumin ratios highlight the long-term clinical implications of this biomarker. The CRP/albumin ratio shows a strong association with short survival time, reflecting high levels of inflammation, and can be used as an important indicator to predict the risk of mortality and aid in clinical decision-making.

Biomarkers such as CRP/albumin ratio, hematocrit, NLR, lactate and PNI are among the important indicators that signal the development of AKI. In this study, an independent association between CRP/albumin ratio and the risk of AKI was found; high inflammation and low nutritional indicators were found to trigger the development of AKI. Wang *et al*. [23] reported that in critically ill patients, mortality increased when the CRP/albumin ratio was high, and that this ratio played a decisive role in the development of AKI. Similarly, Xie *et al*. [24] reported that inflammation and malnutrition negatively affect the prognosis of patients with AKI, and a high CRP/albumin ratio increases mortality. Karabağ *et al*. [6] determined that a high CRP/albumin ratio significantly increased the risk of AKI in patients with myocardial infarction and emphasized the effect of inflammation on AKI. Abu Alfeilat and colleagues [25] demonstrated that a high NLR may be an important biomarker in predicting the development of AKI and emphasized the value of early monitoring of the inflammatory response.

Our study differs from previous studies in that we now report the evaluation of the CRP/albumin ratio in the CABG population, its correlation with short- and long-term outcomes, and its overall implications. A specific cutoff of 1.85 was established that has a practical value for clinicians regarding risk stratification since it possesses good sensitivity and specificity. Using this value, we can more accurately predict those patients who are more likely to suffer from AKI and institute preventive treatment strategies. Our findings also reinforce the use of inflammation markers in the context of perioperative risk evaluation. We strongly recommend their inclusion into existing AKI prediction models following cardiac surgery.

There are some limitations of this study. First, the retrospective design makes it difficult to establish a causal relationship due to the retrospective examination of the data. In addition, the fact that CRP and albumin levels can be affected by various diseases and individual factors makes it difficult to measure them under the same conditions in every patient, which may limit the generalizability of the results. The use of the small sample size in this study means additional studies involving a larger population of patients are necessary to validate our results.

In future research, it would be useful to have a prospective design and to observe the changes in the CRP/albumin ratio over time so that the evaluation of its role in the course of AKI would be more definitive. Since our study is retrospective and from a single-center, prospective multi-center trials are needed to validate our results. We recommend monitoring changes in the CRP/albumin ratio pre- and postoperatively, evaluating the outcomes of targeted treatments based on these biomarkers, and devising more sophisticated models of risk prediction that include other inflammatory factors beyond the standard laboratory markers currently used in practice. Understanding the mechanisms of inflammation in relation to AKI within the CABG population could provide new opportunities for prevention strategies. Evaluation of various inflammatory and nutritional markers together with the CRP/albumin ratio will need to be conducted in different centers to aid in the development of a more comprehensive risk model for predicting the risk of AKI, and identify preventive strategies to reduce the risk of AKI after surgery.

Conclusion

Our research found thatin individuals who undergo artery bypass graft surgery, having a high ratio of protein-to-albumin level, could potentially serve as an accurate indicator for developing AKI followingsurgery. Patients with a high CRP/albumin ratio are approximately 3.4 times more at risk of developing AKI. In addition, these patients had significantly longer ICU and hospital stays. Preoperative assessment of the CRP/albumin ratio provides a clinically valuable indicator for early detection and close follow-up of patients at high risk for AKI. This simple but effective biomarker may have an important role in risk stratification and developing postoperative care protocols for patients undergoing CABG.

Availability of Data and Materials

All data points generated or analyzed during this study are included in this published article.

Author Contributions

HG: Substantial contributions to the design of the work; and the acquisition, analysis, and interpretation of data for the work; drafting the work. ICK: Substantial contributions to the design of the work; and the acquisition, analysis, and interpretation of data for the work. ASK: Substantial contributions to the design of the work; and the acquisition, analysis, and interpretation of data for the work. RDA: Analysis, and interpretation of data for the work. MO: Substantial contributions to the design of the work, drafting the work. AD: Analysis, and interpretation of data for the work. YG: Substantial contributions to the design of the work; and the acquisition, analysis, and interpretation of data for the work. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Eskisehir City Hospital in accordance with the 1964 Declaration of Helsinki. Informed consent was obtained from all patients, and the study was conducted with the approval of the ethics committee dated and numbered ESH/GOEK 2024/78.

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Conflict of Interest

The authors declare no conflict of interest.

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