Predictive Value of C-reactive Protein/Albumin Ratio and Neutrophil/Lymphocyte Ratio in Elderly Patients With Acute Kidney Injury Following On-pump Coronary Artery Bypass Graft

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Zhanlei Wang[1], Jidan Fan[1], Guoliang Yuan[2], Wei Li[2], Xuyang Pan[2]

[1]Heart and Vascular Center, Taizhou People's Hospital, 225300 Taizhou, Jiangsu, China
[2]Department of Cardiovascular Medicine, Shuyang Hospital of Traditional Chinese Medicine, 223600 Shuyang, Jiangsu, China

AIM: This study intended to investigate the predictive value of C-reactive protein (CRP)/albumin ratio (CAR) and neutrophil/lymphocyte ratio (NLR) in elderly patients with acute kidney injury (AKI) following on-pump coronary artery bypass graft (CABG).
METHODS: The clinical information of elderly patients undergoing on-pump CABG admitted to Taizhou People's Hospital was collected for retrospective analysis (n = 150). The patients were divided into two groups based on their postoperative AKI status: injury group (n = 58, with AKI) and non-injury group (n = 92, without AKI). All patients with postoperative AKI were further divided into three groups based on AKI stage: stage 1 group (n = 40), stage 2 group (n = 12), and stage 3 group (n = 6). The CAR and NLR were calculated. Multivariate logistic regression analysis was utilized to explore the risk factors for AKI after on-pump CABG in elderly patients. Receiver operating characteristic (ROC) curve analysis was conducted to predict their diagnostic utility in AKI.
RESULTS: Compared with the non-injury group, the injury group exhibited reduced lymphocyte count ($p < 0.001$) and higher European System for Cardiac Operative Risk Evaluation II (EuroSCORE II) score, cardiopulmonary bypass (CPB) time, NLR, CRP, and CAR (p = 0.006, 0.002, <0.001, <0.001, and <0.001, respectively). Multivariate logistic regression analysis showed that CPB time (p = 0.005, odds ratio [OR] = 1.034, 95% confidence interval [CI] = 1.010–1.058), NLR (p = 0.003, OR = 1.476, 95% CI = 1.139–1.911), and CAR ($p < 0.001$, OR = 4.460, 95% CI = 2.237–8.890) were the independent influencing factors of AKI in elderly patients after on-pump CABG. The area under the curve (AUC) of CPB time, NLR, CAR, and the combination of NLR and CAR were 0.650, 0.787, 0.790, and 0.838, respectively. DeLong test demonstrated that the combined model incorporating NLR and CAR had significantly greater predictive performance than models using CAR alone (p = 0.011), NLR alone (p = 0.008), and CPB time alone (p = 0.001). Compared to stages 1 and 2, stage 3 patients had significantly higher EuroSCORE II scores ($p < 0.05$). CRP and CAR levels and age of patients were significantly higher in stage 3 than in stage 1 ($p < 0.05$), but the difference was not statistically significant compared to stage 2.
CONCLUSIONS: NLR, CAR, and CPB time are identified as independent predictors of AKI in elderly patients undergoing on-pump CABG. The combined use of NLR and CAR demonstrates superior predictive performance for postoperative AKI compared with either indicator alone.

Keywords: acute kidney injury; coronary artery bypass graft; cardiopulmonary bypass; elderly patients; predictive biomarkers

Introduction

Coronary artery disease (CAD) is a common cardiovascular disease with a high incidence rate, posing a substantial public health burden worldwide [1]. Coronary artery bypass graft (CABG) is a surgical approach predominantly applied in clinical practice to relieve symptoms and improve prognosis in CAD patients [2,3]. However, CABG is associated with an increased risk of postoperative complications, with acute kidney injury (AKI) being one of the notable complications following CABG. Based on data from different study cohorts, the incidence rate of AKI after CABG was about 10–20% in CAD patients [4,5]. The pathological basis for the risk of postoperative AKI is complex, involving both physiological factors of the patients and surgical factors. For instance, both age and cardiopulmonary bypass (CPB) have been identified as risk factors for AKI post-CABG [6,7], as elderly patients may experience diminished renal function and CPB induces inflammation, blood flow fluctuations, and renal hypoperfusion. These pathophysiological alterations significantly increase the incidence rate of AKI after on-pump CABG in elderly patients, and affect their prognosis [8]. Therefore, exploring new indicators for early identification of AKI to improve prognosis is of great clinical significance for elderly patients undergoing on-pump CABG.

The predictive value of various biomarkers for AKI after CABG, such as arterial lactate [9], C-reactive protein (CRP) [10], and renal biomarkers [11], has been explored in several studies. These indicators are readily influenced by factors such as diet, infections, and stress, and reflect

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Correspondence to: Xuyang Pan, Department of Cardiovascular Medicine, Shuyang Hospital of Traditional Chinese Medicine, 223600 Shuyang, JiangSu, China (e-mail: panxuyangpanxy@163.com).
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only a single pathophysiological dimension. Furthermore, the universal adoption of certain indicators is hindered due to cost. C-reactive protein/albumin ratio (CAR) and neutrophil/lymphocyte ratio (NLR) are novel inflammatory markers that comprehensively reflect patients' inflammation and nutritional status. CAR could be used to predict AKI in cases with moderate to severe chronic kidney disease [12]. However, few studies explored the predictive value of CAR in postoperative AKI following on-pump CABG. NLR has been identified as a marker of AKI progression in critically ill patients [13]. It has also been reported that NLR combined with blood creatinine had better predictive performance for AKI after on-pump CABG [14]. However, the predictive utility of NLR for AKI after on-pump CABG in high-risk, elderly patients remains to be explored.

According to a growing body of evidence, the diagnostic and prognostic value of inflammatory markers is superior when they are used in combination rather than in isolation. For instance, the combination of CAR and CRP/lymphocyte ratio demonstrates better predictive value for periprosthetic joint infection compared to single indicator [15]. CAR–NLR combination could be useful in predicting prognosis of patients with gastric cancer [16]. However, the prognostic value of CAR and NLR in elderly patients with AKI after on-pump CABG remains unclear. Thus, this study was designed to explore the predictive value of CAR and NLR in elderly patients with AKI following on-pump CABG, providing a reference for informing the development of diagnostic and preventive strategies for AKI that arises after CABG.

Methods

Study Participants

This study was a retrospective analysis. A total of 150 patients with CAD were enrolled in Taizhou People's Hospital from January 2021 to January 2025. The inclusion criteria are as follows: (1) patients diagnosed by cardiac ultrasound and coronary angiography who underwent on-pump CABG, which was performed by the same surgical team; (2) patients aged ≥70 years; and (3) patients with complete clinical data. Patients who meet any of the following criteria were excluded: (1) pre-existing renal dysfunction, including long-term dialysis, chronic kidney disease, uremia, or kidney transplantation; (2) concomitant vascular and valvular surgery during CABG; (3) preoperative infection or a history of AKI within the past 3 months; (4) previous history of cardiac surgery; and (5) death within 48 hours after surgery.

Postoperative AKI was defined as an increase in serum creatinine (Scr) of at least 50% from baseline within 7 days, or an elevation of Scr exceeding 26.5 μmol/L within 48 h after surgery [17]. The baseline Scr was detected within 24 hours before surgery. Since hypovolemia and diuretics use could confound urine output measurements, urine output was not included in the diagnostic criteria for AKI in this study. All patients were classified into two groups according to their postoperative AKI status: injury group (n = 58, with AKI) and non-injury group (n = 92, without AKI). Furthermore, AKI was further staged based on the following criteria: (1) stage 1: an increase in Scr to 1.5–1.9 times the baseline value, or an absolute increase of ≥26.5 μmol/L; (2) stage 2: an increase in Scr to 2.0–2.9 times baseline; (3) stage 3: an increase in Scr to ≥3.0 times baseline, or an absolute increase ≥353.6 μmol/L [17]. Accordingly, the AKI patients were divided into three group: stage 1 group (n = 40), stage 2 group (n = 12), and stage 3 group (n = 6). This study has been approved by the Ethics Committee of Taizhou People's Hospital (approval number: LSKY 2025-156-01). All procedures were conducted in compliance with the Declaration of Helsinki. The need for a signed informed consent was waived by the Ethics Committee of Taizhou People's Hospital, because all patients had signed a general informed consent form upon admission, authorizing the use of the collected data for research on the condition of anonymity.

Collection of Clinical Information

The clinical information was obtained from medical records, including age, gender, body mass index (BMI), European System for Cardiac Operative Risk Evaluation II (EuroSCORE II), diabetes, hypertension, hyperlipidemia, previous diseases, smoking history, extent of CAD, left ventricular ejection fraction (LVEF), CPB time, cross-clamp time, operative time, red blood cell transfusion, perfusion flow, and laboratory data. Laboratory indicators were measured within 24 hours before surgery, including Scr, uric acid, white blood cell (WBC) count, neutrophil count, lymphocyte count, hemoglobin, albumin, and CRP. EuroSCORE II is a predictive model for mortality risk after cardiac surgeries in adults [18]. A high EuroSCORE II score indicates elevated mortality risk. A score <3 indicated low predicted mortality risk; a score of 3–5 indicated intermediate predicted mortality risk; and a score >5 indicated high predicted mortality risk.

Determination of CAR and NLR

Fasting venous blood was collected from patients within 24 hours before surgery. Next, blood cell analyzer was used to detect neutrophils and lymphocytes. CRP was analyzed using commercial kits (20232401032, Donglin Biotechnology, Guangzhou, China). Albumin was measured using an automatic biochemical analyzer (Hitachi 7080, Hitachi, Tokyo, Japan). The CAR and NLR were calculated using the available laboratory data. CAR was computed by determining the ratio of CRP level (mg/L) to albumin level (g/dL), whereas NLR was calculated by determining the ratio of neutrophil count (10^9/L) to lymphocyte count (10^9/L).

Statistical Analysis

SPSS software (version 27.0, IBM Corp., Armonk, NY, USA) was utilized for data analysis. Normality of continuous data was assessed using the Shapiro–Wilk test. Normally distributed data are expressed as mean ± standard deviation (SD). Independent *t*-test (for two groups) and analysis of variance (for multiple groups, with Tukey's post hoc test) were used to compare differences in these data. Non-normally distributed data are presented as median and quartiles, and Mann–Whitney *U* test (for two groups) and Kruskal–Wallis test (for multiple groups) were employed for comparative analysis. Expressed as count and percentage, categorical data were compared using chi-square test or Fisher's exact test. Logistic regression analysis was utilized to explore the risk factors for AKI in elderly patients after undergoing on-pump CABG. Factors demonstrating significant differences in univariate analysis were incorporated into multivariate analysis. Prior to the multivariate analysis, the multicollinearity of all variables was examined. CRP and CAR showed evidence of multicollinearity, as indicated by a variance inflation factor (VIF) greater than 5; and CAR inherently included CRP. Therefore, CRP was excluded from the multivariate analysis. Moreover, to ensure the independence of the tested variables, lymphocyte count was excluded from the multivariate logistic regression analysis, as the NLR inherently incorporates lymphocyte count. Receiver operating characteristic (ROC) curve analysis was conducted to evaluate the diagnostic performance for AKI. The predictive probability of the combined NLR and CAR was estimated using a logistic regression model and then applied to construct ROC curves. The area under the curve (AUC) of the combined indicator was compared with that of each single indicator using the DeLong test. A $p < 0.05$ was regarded as statistically significant.

Results

Comparison of General Information

There were no significant differences between the injury and non-injury groups in age, sex, BMI, diabetes, hypertension, hyperlipidemia, previous stroke and myocardial infarction, smoking history, extent of CAD, LVEF, cross-clamp time, red blood cell transfusion, perfusion flow, operative time and baseline Scr and uric acid ($p > 0.05$). The EuroSCORE II score and CPB time were higher in the injury group than in the non-injury group ($p = 0.006$, 0.002) (Table 1).

Comparison of Laboratory Indicators

Compared with the non-injury group, the injury group exhibited lower lymphocyte count ($p < 0.001$) and higher NLR, CRP and CAR ($p < 0.001$). There were no significant differences between the two groups in WBC count, neutrophil count, hemoglobin, and albumin ($p > 0.05$) (Table 2).

Logistic Regression Analyses

Univariate analysis showed that EuroSCORE II score ($p = 0.004$, odds ratio [OR] = 1.577, 95% confidence interval [CI] = 1.156–2.152), CPB time ($p = 0.001$, OR = 1.031, 95% CI = 1.012–1.050), lymphocyte count ($p < 0.001$, OR = 0.207, 95% CI = 0.109–0.393), NLR ($p < 0.001$, OR = 1.593, 95% CI = 1.285–1.974), CRP ($p < 0.001$, OR = 1.503, 95% CI = 1.289–1.752), and CAR ($p < 0.001$, OR = 5.742, 95% CI = 3.053–10.801) were significantly associated with AKI after on-pump CABG.

Factors with statistical significance ($p < 0.05$) in the univariate analysis were incorporated into the multivariate analysis. Lymphocyte count and CRP were excluded from the multivariate analysis to avoid multicollinearity and ensure the independence of variables. The results of multivariate analysis showed that CPB time ($p = 0.005$, OR = 1.034, 95% CI = 1.010–1.058), NLR ($p = 0.003$, OR = 1.476, 95% CI = 1.139–1.911), and CAR ($p < 0.001$, OR = 4.460, 95% CI = 2.237–8.890) were the independent predictors of AKI in elderly patients after undergoing on-pump CABG (Table 3).

ROC Curve Analysis

The AUC of CPB time, NLR, CAR, and the combination of NLR and CAR were 0.650, 0.787, 0.790, and 0.838, respectively (Table 4, Fig. 1). The DeLong test demonstrated that NLR combined with CAR had significantly higher predictive efficacy compared with CAR alone (Z = 2.549, $p = 0.011$), NLR alone (Z = 2.647, $p = 0.008$), and CPB time alone (Z = 3.204, $p = 0.001$) (Table 4).

Comparison of Clinical Information Among AKI Stage–Stratified Groups

Significant differences in age, EuroSCORE II score, CRP, and CAR ($p = 0.047$, 0.005, 0.022, and 0.010) were noted among AKI stage–stratified groups. Compared with stages 1 and 2, the EuroSCORE II scores of patients in stage 3 were significantly higher. The CRP and CAR levels and age of patients in stage 3 were higher than those in stages 1 and 2, but there was no statistically significant difference compared with stage 2 (Table 5).

Discussion

CABG is the primary surgical approach for treating CAD, particularly in patients with multivessel disease and left main artery lesions, offering benefits such as amelioration of clinical symptoms, improved myocardial perfusion, and prolonged survival [19]. AKI is a common complication after CABG surgery and an independent risk factor for mortality [20]. AKI heightens the risks of hospitalization and long-term mortality in patients undergoing CABG [20,21]. Several investigations reported that advanced age and CPB are risk factors of AKI after CABG [6,22]. In this research, we found that CPB time, NLR, and CAR were the independent influencing factors of AKI in elderly patients after

Table 1. Comparison of general information between the injury and non-injury groups.

General information	Non-injury group (n = 92)	Injury group (n = 58)	$t/Z/\chi^2$	p
Sex, *n* (%)			0.001	0.975
Male	51 (55.43%)	32 (55.17%)		
Female	41 (44.57%)	26 (44.83%)		
Age (years)	75 (73, 79)	76 (73, 80)	1.233	0.218
BMI (kg/m^2)	24.45 ± 2.79	25.24 ± 2.75	1.698	0.092
Diabetes, *n* (%)			0.328	0.567
Yes	36 (39.13%)	20 (34.48%)		
No	56 (60.87%)	38 (65.52%)		
Hypertension, *n* (%)			2.951	0.086
Yes	56 (60.87%)	27 (46.55%)		
No	36 (39.13%)	31 (53.45%)		
Hyperlipidemia, *n* (%)			0.551	0.458
Yes	34 (36.96%)	18 (31.03%)		
No	58 (63.04%)	40 (68.97%)		
Previous stroke, *n* (%)			0.054	0.816
Yes	4 (4.35%)	3 (5.17%)		
No	88 (95.65%)	55 (94.83%)		
Previous myocardial infarction, *n* (%)			0.092	0.762
Yes	11 (11.96%)	6 (10.34%)		
No	81 (88.04%)	52 (89.66%)		
Smoking history, *n* (%)			1.078	0.299
Yes	26 (28.26%)	12 (20.69%)		
No	66 (71.74%)	46 (79.31%)		
Extent of CAD, *n* (%)			0.344	0.842
1 vessel	5 (5.43%)	3 (5.17%)		
2 vessels	17 (18.48%)	13 (22.41%)		
3 vessels	70 (76.09%)	42 (72.41%)		
LVEF, *n* (%)			0.065	0.968
>50%	70 (76.09%)	45 (77.59%)		
30%–50%	20 (21.74%)	12 (20.69%)		
<30%	2 (2.17%)	1 (1.72%)		
EuroSCORE II score	3.0 (2.3, 3.8)	3.5 (2.8, 4.5)	2.735	0.006
CPB time (min)	96 (84, 111)	105 (94, 121)	3.096	0.002
Cross-clamp time (min)	57 (45, 74)	66 (51, 76)	1.417	0.157
Red blood cell transfusion (units)	2 (1, 2)	2 (1, 2)	0.506	0.613
Perfusion flow (L/min/m^2)	2.5 (2.3, 2.6)	2.4 (2.3, 2.5)	1.118	0.263
Operative time (h)	4.77 ± 0.75	4.92 ± 0.76	1.187	0.237
Baseline Scr (μmol/L)	88.40 (79.56, 112.71)	79.56 (68.5, 106.08)	1.927	0.054
Baseline uric acid (μmol/L)	345.14 ± 88.25	363.80 ± 82.32	1.294	0.198

Abbreviations: BMI, body mass index; CAD, coronary artery disease; CPB, cardiopulmonary bypass; EuroSCORE II, European System for Cardiac Operative Risk Evaluation II; LVEF, left ventricular ejection fraction; Scr, serum creatinine.

undergoing on-pump CABG. Our study also revealed that NLR combined with CAR had a better predictive performance in estimating postoperative AKI compared to NLR, CAR, and CPB time. To our knowledge, this study was the first to explore the predictive value of NLR and CAR for AKI in elderly patients after undergoing on-pump CABG. Findings of this study underscore the potential of NLR and CAR as indicators for the early identification of AKI after on-pump CABG, facilitating timely interventions in clinical settings.

Among the 150 elderly patients undergoing CABG enrolled for this study, 38.7% of them (58/150) suffered from AKI, and according to the AKI stage stratification, slightly more than two-thirds of the AKI patients were in stage 1 (69%), followed by stage 2 (21%) and stage 3 (10%). The incidence rate of AKI in this study was higher than that reported in another study (26%) [23]. This high AKI incidence rate observed in our study may be attributable to aging (≥70 years old) and CPB. Another retrospective study that also investigated AKI following CABG in elderly patients re-

Table 2. Comparison of laboratory indicators between the injury and non-injury groups.

Index	Non-injury group (n = 92)	Injury group (n = 58)	t/Z	p
WBC count (10^9/L)	8.47 ± 1.89	9.01 ± 2.33	1.555	0.122
Neutrophil count (10^9/L)	5.67 ± 1.30	6.02 ± 1.40	1.559	0.121
Lymphocyte count (10^9/L)	1.97 ± 0.59	1.39 ± 0.63	5.711	<0.001
NLR	2.91 (2.23, 3.58)	4.69 (3.29, 6.52)	5.914	<0.001
Hemoglobin (g/L)	122.37 ± 13.23	120.40 ± 12.88	0.897	0.371
Albumin (g/dL)	3.90 ± 0.32	3.81 ± 0.26	1.799	0.074
CRP (mg/L)	6.03 ± 2.04	9.24 ± 3.64	6.917	<0.001
CAR	1.55 ± 0.51	2.43 ± 0.94	7.421	<0.001

Abbreviations: CRP, C-reactive protein; CAR, C-reactive protein/albumin ratio; NLR, neutrophil/lymphocyte ratio; WBC, white blood cell.

Table 3. Logistic regression analyses of risk factors for AKI in elderly patients after on-pump CABG.

Index	Univariate analysis					Multivariate analysis				
	β	SE	Wald	OR (95% CI)	p	β	SE	Wald	OR (95% CI)	p
Sex (male)	−0.011	0.337	0.001	0.989 (0.511–1.916)	0.975					
Age	0.040	0.033	1.491	1.040 (0.976–1.109)	0.222					
BMI	0.103	0.061	2.828	1.109 (0.983–1.250)	0.093					
Diabetes	−0.200	0.349	0.328	0.567 (0.413–1.623)	0.819					
Hypertension	−0.580	0.339	2.927	0.560 (0.288–1.088)	0.087					
Hyperlipidemia	−0.264	0.357	0.550	0.768 (0.382–1.544)	0.458					
Previous stroke	0.182	0.783	0.054	1.200 (0.259–5.566)	0.816					
Previous myocardial infarction	−0.163	0.538	0.092	0.850 (0.296–2.438)	0.762					
Smoking history	−0.412	0.398	1.071	0.662 (0.303–1.446)	0.301					
Extent of CAD										
1 vessel				1.000 (Reference)	/					
2 vessels	0.243	0.818	0.088	1.275 (0.256–6.333)	0.767					
3 vessels	0.000	0.756	0.000	1.000 (0.227–4.400)	>0.999					
LVEF										
<30%				1.000 (Reference)	/					
30%–50%	0.182	1.278	0.020	1.200 (0.098–14.690)	0.887					
>50%	0.251	1.240	0.041	1.286 (0.113–14.597)	0.839					
EuroSCORE II score	0.456	0.159	8.269	1.577 (1.156–2.152)	0.004	0.388	0.205	3.573	1.474 (0.986–2.205)	0.059
CPB time	0.030	0.009	10.507	1.031 (1.012–1.050)	0.001	0.033	0.012	7.882	1.034 (1.010–1.058)	0.005
Cross-clamp time	0.016	0.009	3.032	1.016 (0.998–1.034)	0.082					
Red blood cell transfusion	0.126	0.194	0.420	1.134 (0.775–1.659)	0.517					
Perfusion flow	−1.146	1.030	1.238	0.318 (0.042–2.392)	0.266					
Operative time	0.281	0.224	1.574	1.324 (0.854–2.054)	0.210					
Baseline Scr	−0.012	0.007	3.460	0.988 (0.975–1.001)	0.063					
Baseline uric acid	0.003	0.002	1.660	1.003 (0.999–1.006)	0.198					
WBC count	0.127	0.082	2.382	1.135 (0.966–1.333)	0.123					
Neutrophil count	0.197	0.128	2.399	1.218 (0.949–1.564)	0.121					
Lymphocyte count	−1.576	0.327	23.208	0.207 (0.109–0.393)	<0.001					
NLR	0.465	0.109	18.073	1.593 (1.285–1.974)	<0.001	0.389	0.132	8.701	1.476 (1.139–1.911)	0.003
Hemoglobin	−0.012	0.013	0.809	0.988 (0.964–1.014)	0.368					
Albumin	–1.043	0.581	3.220	0.352 (0.113–1.101)	0.073					
CRP	0.407	0.078	27.022	1.503 (1.289–1.752)	<0.001					
CAR	1.748	0.322	29.401	5.742 (3.053–10.801)	<0.001	1.495	0.352	18.043	4.460 (2.237–8.890)	<0.001

Abbreviations: AKI, acute kidney injury; CABG, coronary artery bypass graft; OR, odds ratio.

ported an AKI incidence rate measuring 40.3%, which is much higher than our results, with patients in Acute Kidney Injury Network (AKIN) stage 1 accounting for most of the AKI cases (71.8%) [8]. Taken together, these results indicated a high risk of postoperative AKI in elderly patients undergoing CABG, emphasizing the importance of early prediction and intervention.

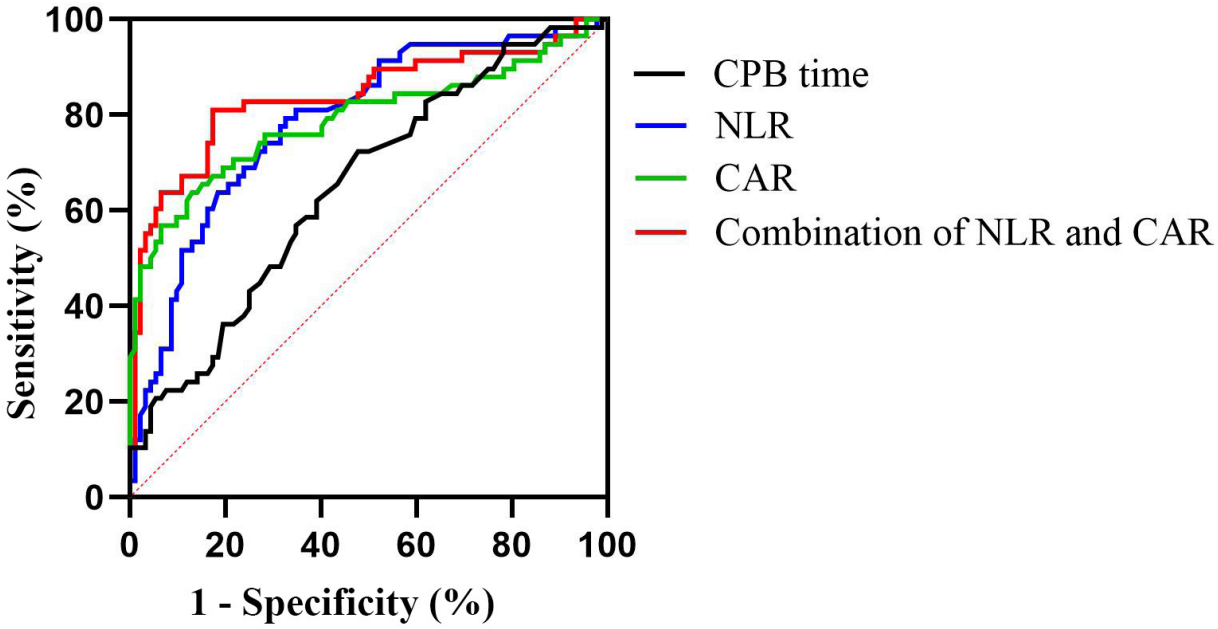

Fig. 1. ROC curves of selected indicators for predicting AKI in elderly patients after undergoing on-pump CABG. Abbreviations: AKI, acute kidney injury; CABG, coronary artery bypass graft; CAR, C-reactive protein/albumin ratio; CPB, cardiopulmonary bypass; NLR, neutrophil/lymphocyte ratio; ROC, receiver operating characteristic.

Table 4. ROC curve analysis of selected indicators for AKI in elderly patients after undergoing on-pump CABG.

Index	AUC	*p*	95% CI	Sensitivity	Specificity	Cut-off value	Compared with combination of NLR and CAR (DeLong test)	
							Z	*p*
CPB time	0.650	0.002	0.561–0.739	0.726	0.522	96.500	3.204	0.001
NLR	0.787	<0.001	0.712–0.862	0.793	0.674	3.155	2.647	0.008
CAR	0.790	<0.001	0.707–0.872	0.638	0.870	2.135	2.549	0.011
Combination of NLR and CAR	0.838	<0.001	0.764–0.911	0.810	0.826	/	/	/

Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.

As a biomarker of infections and inflammation, increased CRP levels are associated with elevated inflammation, which contributes to the apoptosis and oxidative stress of renal tubular epithelial cells [24,25]. High CRP levels may also influence the contraction of vascular endothelial cells and the renal perfusion [24]. Serum albumin is mainly synthesized and secreted by the liver, reflecting the nutritional status of the body. In addition to malnutrition and inflammation that play an inhibitory role in the synthesis of albumin [26], declining renal function—a condition common in patients with chronic kidney disease—is associated with low serum albumin level [27]. CAR is a comprehensive indicator reflecting both inflammation and nutritional status. This study observed higher CRP and CAR values in AKI patients compared to non-AKI patients, but no significant between-group difference was detected in serum albumin. Additionally, our analyses determined that CAR is a risk factor of postoperative AKI. Further analysis showed that patients with stage 3 AKI exhibited higher CRP and CAR values than those in stages 1 and 2, but the difference was not statistically significant when compared with stage 2. Complementing our findings, a recent study has shown that CAR demonstrates strong predictive performance for acute renal failure following CABG [28].

NLR is a comprehensive inflammatory indicator, where elevated values reflect increased neutrophils and/or decreased lymphocytes. It has been reported that patients with high preoperative NLR are at increased risk of AKI after on-pump CABG [14]. A study by Ishikawa *et al.* [29] identified NLR and serum albumin as potential predictors of AKI following CABG. In the present study, patients with postoperative AKI have a lower lymphocyte count and a higher NLR value. NLR was a risk factor for AKI in elderly patients after undergoing on-pump CABG. We also found that NLR and CAR have greater predictive value for postoperative AKI in elderly patients, consistent with previous studies. An excessive neutrophil-driven inflammatory response, together with lymphocyte-mediated immune dysfunction, disrupts immune homeostasis in the kidneys, leading to apoptosis and oxidative stress in renal tubular ep-

Table 5. Comparison of clinical information among the AKI stage–stratified groups.

Index	Stage 1 group (n = 40)	Stage 2 group (n = 12)	Stage 3 group (n = 6)	p
Sex, n (%)				0.663
Male	21 (52.50%)	8 (66.67%)	3 (50.00%)	
Female	19 (47.50%)	4 (33.33%)	3 (50.00%)	
Age (years)	75 (73, 78)	76 (74, 82)	83 (79, 90)*	0.047
BMI (kg/m^2)	25.33 ± 2.98	24.50 ± 2.34	26.11 ± 1.66	0.478
Diabetes, n (%)				0.725
Yes	15 (37.50%)	3 (25.00%)	2 (33.33%)	
No	25 (62.50%)	9 (75.00%)	4 (66.67%)	
Hypertension, n (%)				0.618
Yes	17 (42.50%)	7 (58.33%)	3 (50.00%)	
No	23 (57.50%)	5 (41.67%)	3 (50.00%)	
Hyperlipidemia, n (%)				0.258
Yes	10 (25.00%)	6 (50.00%)	2 (33.33%)	
No	30 (75.00%)	6 (50.00%)	4 (66.67%)	
Previous stroke, n (%)				0.750
Yes	2 (5.00%)	1 (8.33%)	0 (0.00%)	
No	38 (95.00%)	11 (91.67%)	6 (100.00%)	
Previous myocardial infarction, n (%)				0.090
Yes	4 (10.00%)	0 (0.00%)	2 (33.33%)	
No	36 (90.00%)	12 (100.00%)	4 (66.67%)	
Smoking history, n (%)				0.879
Yes	9 (22.50%)	2 (16.67%)	1 (16.67%)	
No	31 (77.50%)	10 (83.33%)	5 (83.33%)	
Extent of CAD, n (%)				0.385
1 vessel	2 (5.00%)	0 (0.00%)	1 (16.67%)	
2 vessels	7 (17.50%)	4 (33.33%)	2 (33.33%)	
3 vessels	31 (77.50%)	8 (66.67%)	3 (50.00%)	
LVEF group, n (%)				0.885
<30%	31 (77.50%)	10 (83.33%)	4 (66.67%)	
30%–50%	8 (20.00%)	2 (16.67%)	2 (33.33%)	
>50%	1 (2.50%)	0 (0.00%)	0 (0.00%)	
EuroSCORE II score	3.4 (2.7, 4.1)	3.4 (2.8, 4.4)	5.4 (4.4, 6.5)*#	0.005
CPB time (min)	105.93 ± 20.15	110.25 ± 20.53	121.33 ± 25.07	0.232
Cross-clamp time (min)	64.93 ± 20.04	63.92 ± 18.45	79.83 ± 25.11	0.229
Red blood cell transfusion (units)	2 (1, 2)	2 (1, 2)	1 (1, 2)	0.393
Perfusion flow (L/min/m^2)	2.4 (2.3, 2.5)	2.4 (2.4, 2.6)	2.4 (2.3, 2.6)	0.897
Operative time (h)	4.97 ± 0.79	4.70 ± 0.74	5.08 ± 0.61	0.711
Baseline Scr (μmol/L)	87.96 ± 29.76	83.98 ± 29.56	78.08 ± 23.33	0.339
Baseline uric acid (μmol/L)	360.95 ± 83.47	367.04 ± 89.41	376.33 ± 70.93	0.905
WBC count (10^9/L)	9.27 ± 2.45	8.58 ± 2.11	8.17 ± 1.79	0.436
Neutrophil count (10^9/L)	6.00 ± 1.48	6.08 ± 1.30	6.05 ± 1.20	0.984
Lymphocyte count (10^9/L)	1.41 ± 0.66	1.39 ± 0.65	1.23 ± 0.43	0.814
NLR	4.73 (3.12, 6.24)	4.50 (3.59, 6.19)	5.38 (3.70, 7.25)	0.856
Hemoglobin (g/L)	120.00 ± 12.22	122.00 ± 11.86	119.83 ± 20.25	0.892
Albumin (g/dL)	3.84 ± 0.26	3.76 ± 0.24	3.73 ± 0.31	0.471
CRP (mg/L)	8.54 ± 3.59	9.79 ± 2.69	12.77 ± 3.89*	0.022
CAR	2.23 ± 0.92	2.60 ± 0.64	3.41 ± 0.97*	0.010

Note: *$p < 0.05$ compared with stage 1, #$p < 0.05$ compared with stage 2.

ithelial cells, thereby contributing to the development and progression of AKI [30,31].

Our study also identified CPB time as an independent risk factor of AKI in elderly patients after undergoing on-pump CABG. The mechanisms underlying CPB-induced postoperative AKI are complex. Possible explanations include: (1) renal hypoperfusion during CPB; (2) activation of the complement system by the CPB system, triggering inflam-

matory responses and the release of inflammatory mediators; (3) microemboli generated during CPB obstructing renal microarteries and capillaries; (4) hemolysis and release of free hemoglobin causing renal tubular damage; and (5) reperfusion-induced oxidative stress and inflammatory response [32,33]. CPB time has also been identified as a risk factor of postoperative AKI in a previous study [22].

EuroSCORE II is widely used to evaluate perioperative mortality in cardiac surgery. It quantifies the surgical risk of patients through standardized calculations based on multiple indicators, such as age, sex, renal function, cardiac function, lung disease, and surgical type [34]. In this study, we found that AKI patients had higher EuroSCORE II scores than non-AKI patients. The difference in the EuroSCORE II score may be attributed to the presence of pulmonary disease. Pulmonary disease is directly related to the EuroSCORE II score and may contribute to AKI through mechanisms such as hypoxemia, renal hypoperfusion, and inflammatory pathways [35]. Moreover, univariate analysis indicated that EuroSCORE II was significantly associated with AKI in elderly patients after undergoing on-pump CABG; however, this association was not observed in multivariate analysis. This may be because EuroSCORE II is a composite scoring system encompassing multiple domains, and its effect on the postoperative AKI could be confounded by other variables in the multivariate model.

Furthermore, this study found that patients with stage 3 AKI were older and had higher EuroSCORE II score, CRP and CAR levels, compared with those in stage 1. The increases in CRP and CAR indicated the intensified inflammatory response in stage 3 patients. Proactive anti-inflammatory and infection control during the perioperative period may contribute to preventing severe AKI postoperatively. We also found that patients in stage 3 exhibited higher EuroSCORE II scores, which may serve as an indicator for predicting the occurrence of severe AKI. The lack of significant difference in NLR among the three AKI stage groups is probably attributed to the complex interplay between multiple factors influencing postoperative AKI, such as intraoperative procedures and postoperative management. However, preoperative NLR was weakly correlated with these factors. In this study, the small sample size may represent a potential reason for the undetectable difference in NLR. Notably, there were only six patients in stage 3, which could reduce the statistical power and stability of the results. The correlation between these indicators and AKI stages needs to be validated in larger clinical cohorts in future studies.

Several shortcomings of this research should be acknowledged. Firstly, the retrospective nature of this study, along with the small sample size, may lead to biased conclusions. To address these limitations, it is necessary to entail a larger cohort for prospective exploration. Additionally, the small sample size limited the development of robust clinical prediction models. Future studies could utilize large-scale clinical cohorts for constructing clinical prediction models. Secondly, long-term survival of AKI patients was not investigated in this study. Hence, long-term follow-up should be conducted to explore the impact of these indicators on the long-term survival of patients. Moreover, the single-center design adopted in this study is a critical limitation. With such a limited study design, we were unable to capture the variations in temperature regulation and perfusion flow rates, which could vary with the different CPB management modes utilized across various institutions. Additionally, in this single-center study, there is a risk of patient selection bias, which may limit the generalizability of the findings. External validation across multiple centers is warranted in future studies. Furthermore, elderly patients with renal dysfunction were excluded from this study to reduce confounding from baseline differences in renal function, which may hinder the universal applicability of the results. Future research can include elderly patients with mild to moderate renal impairment and further explore the predictive efficacy of NLR and CAR in this high-risk population. Moreover, certain variables, such as pulmonary disease and intraoperative hypotension, were not included in this study. Their absence may lead to insufficient control of confounding factors and biased conclusions. Future research should aim to collect comprehensive perioperative data and control for potential confounding factors through model adjustment or stratified analysis. Additionally, NLR and CAR were assessed within 24 h preoperatively in this study. These indicators may increase intraoperatively due to surgical trauma and CPB and then gradually decrease after surgery due to the implementation of anti-inflammatory measures and self-regulation. These dynamic changes may also be associated with the development of postoperative AKI. Future studies should investigate the impact of dynamic changes in NLR and CAR on postoperative AKI through continuous monitoring during the perioperative period.

Conclusions

In summary, our study demonstrated that NLR, CAR, and CPB time are the independent predictors of AKI in elderly patients after undergoing on-pump CABG. The combination of NLR and CAR has superior predictive value for postoperative AKI compared with individual indicators. Preoperative evaluation of these markers may facilitate early identification of high-risk elderly patients and guide the implementation of targeted preventive interventions.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

ZW and XP designed the research study. JF collected and organized the data. GY and WL analyzed the data. ZW wrote the first draft. All authors have been involved in revising the manuscript critically for important intellectual

content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Taizhou People's Hospital (approval number: LSKY 2025-156-01). All procedures were conducted in compliance with the Declaration of Helsinki. The need for a signed informed consent was waived by the Ethics Committee of Taizhou People's Hospital, because all patients had signed a general informed consent form upon admission, authorizing the use of the collected data for research on the condition of anonymity.

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Conflict of Interest

The authors declare no conflict of interest.

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