

Predictive Value of Perioperative Lactate Clearance Rate for 30-Day Composite Adverse Outcomes after Off-Pump Coronary Artery Bypass Grafting

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Abstract: The objective of this study was to investigate the predictive value of perioperative lactate clearance rate (LCR) for 30-day composite adverse outcomes in patients undergoing off-pump coronary artery bypass grafting (OPCAB). A total of 480 patients who underwent elective OPCAB between June 2024 and June 2026 were included, of whom 80 had composite adverse outcomes and 400 had favorable outcomes. Perioperative clinical baseline data, blood lactate levels, and laboratory parameters were collected. Factors influencing 30-day composite adverse outcomes after OPCAB were analyzed, and receiver operating characteristic (ROC) analysis was performed to evaluate the predictive performance of lactate clearance rate for short-term postoperative adverse outcomes. Univariate analysis showed that age, history of preoperative hypertension, history of diabetes mellitus, proportion of patients with preoperative NYHA class III-IV, operative duration, intraoperative blood loss, perioperative blood glucose, cTnI, NT-proBNP, CRP, and D-dimer levels were higher in the adverse outcome group than in the favorable outcome group, whereas oxygenation index, eGFR, PLT, and ALB levels and lactate clearance rates at postoperative T6, T12, and T24 were lower than those in the favorable outcome group ($P<0.05$). Multivariate Logistic regression analysis showed that preoperative NYHA class III-IV, high perioperative NT-proBNP, low ALB, decreased lactate clearance rates at postoperative T6, T12, and T24, and increased EuroSCORE II score were independent risk factors for 30-day composite adverse outcomes after OPCAB ($P<0.05$). ROC curve analysis showed that postoperative T12 lactate clearance rate had the best predictive value, with an area under the curve (AUC) of 0.887. After correction by 1,000-bootstrap internal validation, the AUC was 0.861, with no significant attenuation in predictive performance. The AUC of T12 lactate clearance rate was higher than that of the EuroSCORE II score (AUC=0.742, $P<0.001$). DCA results showed that within the risk threshold range of 0.05-0.85, the clinical net benefit of the T12 lactate clearance rate model was superior to that of the EuroSCORE II score alone. Lactate clearance rates at postoperative T6, T12, and T24 were independent factors influencing short-term postoperative adverse outcomes. Postoperative 12-h lactate clearance rate retained excellent predictive performance after internal validation and demonstrated incremental predictive value compared with the traditional EuroSCORE II score, and it can be used as a predictive indicator for the early clinical identification of high-risk patients after OPCAB.

Keywords: lactate clearance rate; off-pump coronary artery bypass grafting; predictive value; adverse outcomes

1. Introduction

Off-pump coronary artery bypass grafting (OPCAB) is a major surgical procedure for the treatment of severe coronary heart disease, with advantages including less surgical stress, faster postoperative recovery, and shorter hospital stays [1]. However, procedures such as cardiac displacement, temporary coronary artery occlusion, and hemodynamic fluctuations during surgery may also lead to impaired myocardial and systemic tissue perfusion, resulting in postoperative risks such as low cardiac output, infection, and renal dysfunction, and severe cases may result in death [2]. Therefore, it is particularly important to identify stable, accurate, and dynamically monitorable perioperative prognostic indicators. Clinical assessment of postoperative OPCAB risk mainly relies on static preoperative indicators such as cardiac function, biochemical parameters, and EuroSCORE II, which cannot reflect the real-time postoperative microcirculatory perfusion status. Intraoperative cardiac displacement and coronary artery occlusion can easily induce tissue hypoxia and increase the risk of multiple organ complications, creating an urgent need for dynamically monitored biomarkers. Lactate clearance rate can quantify the degree of microcirculatory recovery and has been used for prognostic assessment in sepsis and heart failure [3-4]. However, existing OPCAB-related studies have relatively small sample sizes, lack Bootstrap internal validation, have not compared with EuroSCORE II, and lack clinical benefit analysis by DCA, indicating methodological limitations. This study improved multiple statistical validation methods and analyzed the predictive value of lactate clearance rate at multiple time points, aiming to address the limitations of existing studies. Based on this, the clinical data of 480 patients who underwent OPCAB at our hospital between June 2024 and June 2026 were collected to investigate the predictive value of perioperative lactate

clearance rate for short-term adverse outcomes after OPCAB. The results are reported as follows.

2. Materials and Methods

2.1 General Information

Based on relevant literature on OPCAB prognosis, the estimated incidence of 30-day composite adverse events after surgery was set at 17%, with an expected AUC of 0.85 for the target indicator, T12 lactate clearance rate, $\alpha=0.05$, and a test power of $1-\beta=0.80$. According to the ROC sample size calculation formula, the minimum required baseline sample size was 426 cases, and 480 patients were included in this study, meeting the sample size requirements. The cases were enrolled between June 2024 and June 2026, and all 480 patients underwent elective OPCAB. Inclusion criteria: ① meeting the indications for OPCAB; ② age 40-75 years; ③ complete clinical medical records; ④ complete follow-up information. Exclusion criteria: ① presence of important organ damage; ② preoperative hyperlactatemia or metabolic acidosis; ③ conversion to coronary artery bypass grafting under cardiopulmonary bypass during surgery; ④ undergoing another cardiac-related surgery during the perioperative period. This study was approved by the Ethics Committee, approval number 20210928.

2.2 Criteria for Determining Postoperative Adverse Outcomes

The criteria for determining 30-day composite adverse outcomes after surgery were established with reference to relevant criteria used in domestic cardiac surgery prognostic studies. Composite adverse outcomes included any of the following: ① all-cause death within 30 days after surgery; ② newly developed acute heart failure or malignant arrhythmia after surgery; ③ acute kidney injury; ④ severe pulmonary infection or respiratory failure requiring mechanical ventilation support for >48 h; ⑤ newly developed myocardial infarction or cerebral infarction during the perioperative period.

2.3 Methods

2.3.1 Baseline Data Collection

The basic clinical baseline information of all enrolled patients was collected. The specific statistical indicators included age, sex, BMI, history of smoking, history of long-term alcohol consumption, and history of chronic underlying diseases; preoperative cardiac function classification was recorded, and LVEF was measured. Surgery-related data included operative duration, number of bypass grafts, intraoperative blood loss, intraoperative fluid infusion volume, postoperative ICU stay, and length of hospital stay. Criteria for EuroSCORE II scoring: according to the European System for Cardiac Operative Risk Evaluation II, corresponding scores were assigned to each variable according to its grade, and all scores were converted into the predicted mortality risk percentage, with a theoretical score range of 0.5%-78.9%; clinical risk stratification was as follows: low risk, 0-2.99%; moderate risk, 3-5.99%; high risk, $\geq 6.0\%$. A higher score indicated a higher risk of death within 30 days after surgery.

2.3.2 Perioperative Laboratory Parameter Testing

All procedures for blood sample collection, submission, and testing followed the standardized operating procedures of the laboratory department of our hospital. Venous blood samples were uniformly collected into procoagulant tubes and centrifuged at 3,000 r/min for 10 min to separate serum; arterial blood gas samples were protected from air exposure after collection and analyzed within 30 min. All testing instruments were regularly calibrated, and internal quality control was maintained within acceptable limits. Abnormal indicators were rechecked and confirmed before being entered into the database. The following indicators were measured: fasting blood glucose, serum albumin (ALB), and estimated glomerular filtration rate (eGFR) were measured using the Mindray BS-1100M automatic biochemical analyzer; cardiac troponin I (cTnI), N-terminal pro-B-type natriuretic peptide (NT-proBNP), and D-dimer were measured using the Getein Biotech GETein-1200 fluorescence immunoassay analyzer; platelet count and C-reactive protein (CRP) were measured using the Mindray BS-7500 hematology analyzer; the oxygenation index was measured using the Siemens-RP500 automatic blood gas analyzer.

2.3.3 Lactate Measurement and LCR Calculation

For all patients, 2 mL of radial arterial blood was collected at 1 day before surgery (T0), 6 h after surgery (T6), 12 h after surgery (T12), and 24 h after surgery (T24), and arterial blood lactate (Lac) levels were measured using the Siemens-RP500 automatic blood gas analyzer. The formula for calculating lactate clearance rate was as follows: lactate clearance rate = (preoperative lactate value at T0 – lactate value at the corresponding postoperative time point) / preoperative lactate value at T0 $\times 100\%$. Lactate clearance rates at postoperative T6, T12, and T24 were calculated separately. A negative clearance rate indicated that postoperative lactate was higher than preoperative lactate, suggesting impaired lactate clearance and poor

tissue perfusion recovery.

2.4 Statistical Methods

All data in this study were analyzed using SPSS 21.0 statistical software. The t-test was used for continuous data, the x² test was used for categorical data, and the rank-sum test was used for ordinal categorical data. The significance level was set at $\alpha=0.05$. Logistic regression analysis was performed to analyze the factors influencing 30-day composite adverse outcomes after OPCAB. ROC curve analysis was used to evaluate predictive performance. A $P<0.05$ was considered statistically significant.

3. Results

3.1 Comparison of Baseline Data Between the Two Groups

A total of 480 patients undergoing OPCAB were included in this study, of whom 80 developed composite adverse outcomes within 30 days after surgery, with a total incidence rate of 16.67%. The adverse outcome group had higher age, history of hypertension, history of diabetes mellitus, proportion of patients with preoperative NYHA class III-IV, operative duration, intraoperative blood loss, postoperative ICU stay, and length of hospital stay than the favorable outcome group ($P<0.05$). See Table 1.

Table 1. Comparison of Baseline Data Between the Two Groups

Baseline data	Adverse outcome group (n=80)	Favorable outcome group (n=400)	t/χ^2 value	P value
Age (years, $\bar{x}\pm s$)	67.82 $\pm$ 7.35	60.35 $\pm$ 7.96	7.757	<0.001
Sex (male/female, n)	51/29	293/107	2.963	0.085
BMI (kg/m ² , $\bar{x}\pm s$)	24.69 $\pm$ 2.31	24.55 $\pm$ 2.22	0.511	0.609
History of smoking [n (%)]	42(52.50)	198(49.50)	0.240	0.624
History of alcohol consumption[n(%)]	33(41.25)	162(40.50)	0.016	0.901
History of hypertension[n(%)]	65(81.25)	241(60.25)	12.722	<0.001
History of diabetes mellitus[n(%)]	39(48.75)	118(29.50)	11.224	0.001
History of hyperlipidemia[n(%)]	44(55.00)	213(53.25)	0.082	0.775
NYHA class III-IV[n(%)]	54(67.50)	143(35.75)	27.773	<0.001
LVEF (% , $\bar{x}\pm s$)	52.63 $\pm$ 6.81	54.41 $\pm$ 7.05	1.926	0.055
Operative duration (min, $\bar{x}\pm s$)	223.75 $\pm$ 31.24	182.93 $\pm$ 28.16	11.616	<0.001
Intraoperative blood loss (ml, $\bar{x}\pm s$)	416.92 $\pm$ 84.13	307.65 $\pm$ 71.34	12.121	<0.001
ICU stay (d, $\bar{x}\pm s$)	4.68 $\pm$ 1.21	2.25 $\pm$ 0.79	22.715	<0.001
Length of hospital stay (d, $\bar{x}\pm s$)	18.19 $\pm$ 4.22	12.15 $\pm$ 3.11	14.858	<0.001

3.2 Comparison of Laboratory Parameters Between the Two Groups

The levels of blood glucose, cTnI, NT-proBNP, CRP, and D-dimer were higher in the adverse outcome group than in the favorable outcome group, while the levels of oxygenation index, eGFR, PLT, and ALB were lower than those in the favorable outcome group, with statistically significant differences ($P<0.05$). See Table 2.

Table 2. Comparison of Laboratory Parameters Between the Two Groups ($\bar{x}\pm s$)

Laboratory Parameters	Adverse outcome group (n=80)	Favorable outcome group (n=400)	T-value	P-value
Blood glucose (mmol/L)	9.79 $\pm$ 2.18	7.23 $\pm$ 1.61	12.172	<0.001
cTnI (ng/mL)	3.09 $\pm$ 0.88	1.65 $\pm$ 0.64	17.152	<0.001
NT-proBNP (pg/mL)	1849.76 $\pm$ 431.28	924.63 $\pm$ 316.72	22.326	<0.001
Oxygenation index	228.16 $\pm$ 36.15	319.27 $\pm$ 41.85	18.161	<0.001
eGFR (mL/min/1.73m ²)	72.51 $\pm$ 8.67	86.74 $\pm$ 7.42	15.206	<0.001
CRP (mg/L)	28.47 $\pm$ 7.46	12.29 $\pm$ 5.33	23.028	<0.001
D-Dimer (mg/L)	2.82 $\pm$ 0.95	1.40 $\pm$ 0.67	16.019	<0.001
PLT ($\times 10^9$ /L)	158.22 $\pm$ 43.15	219.36 $\pm$ 37.92	12.855	<0.001
ALB (g/L)	32.24 $\pm$ 4.31	39.75 $\pm$ 3.79	15.801	<0.001
EuroSCORE II score (%)	6.85 $\pm$ 1.72	3.26 $\pm$ 1.15	23.225	<0.001

3.3 Comparison of Perioperative Lactate Parameters Between the Two Groups

There was no significant difference in baseline lactate levels at preoperative T0 between the two groups ($P>0.05$). Lactate levels in both groups at T6, T12, and T24 after OPCAB were higher than those at preoperative T0, and the lactate levels at each time point were higher in the adverse outcome group than in the favorable outcome group ($P<0.001$). The lactate clearance rates at postoperative T6, T12, and T24 were lower in the adverse outcome group than in the favorable outcome group ($P<0.05$). See Table 3.

Table 3. Comparison of Perioperative Lactate Parameters Between the Two Groups

Lactate Parameters	Adverse outcome group (n=80)	Favorable outcome group (n=400)	T-value	P-value
Preoperative T0 lactate (mmol/L)	1.24±0.33	1.21±0.31	0.782	0.435
Postoperative T6 lactate (mmol/L)	3.82±0.89	2.13±0.62	20.529	<0.001
Postoperative T12 lactate (mmol/L)	3.18±0.82	1.65±0.50	22.090	<0.001
Postoperative T24 lactate (mmol/L)	2.75±0.76	1.42±0.48	20.243	<0.001
Postoperative T6 lactate clearance rate (%)	8.52±5.16	26.72±8.05	19.430	<0.001
Postoperative T12 lactate clearance rate (%)	16.15±6.72	42.52±9.16	24.457	<0.001
Postoperative T24 lactate clearance rate (%)	22.36±7.25	48.65±8.32	26.329	<0.001

3.4 Multivariate Logistic Regression Analysis of 30-Day Composite Adverse Outcomes After OPCAB

Preoperative NYHA class III-IV, high perioperative NT-proBNP, low ALB, decreased lactate clearance rates at postoperative T6, T12, and T24, and increased EuroSCORE II score were independent risk factors for 30-day composite adverse outcomes after OPCAB ($P<0.05$). See Table 4.

Table 4. Multivariate Logistic Regression Analysis of 30-Day Composite Adverse Outcomes After OPCAB

Independent Variable	B-Value	SE-Value	Wald χ^2 Value	OR-Value	95%CI	P-Value
Preoperative NYHA Class III-IV	0.925	0.342	7.326	2.522	1.281 ~ 4.965	0.007
High NT-proBNP	1.026	0.365	7.925	2.789	1.362 ~ 5.712	0.005
Low ALB	0.885	0.336	6.952	2.423	1.254 ~ 4.682	0.008
Increased EuroSCORE II Score	0.763	0.304	6.297	2.145	1.182 ~ 3.894	0.012
Decreased T6 Lactate Clearance Rate	1.102	0.372	8.765	3.009	1.453 ~ 6.228	0.003
Decreased T12 Lactate Clearance Rate	1.325	0.405	10.725	3.762	1.708 ~ 8.285	0.001
Decreased T24 Lactate Clearance Rate	1.216	0.386	9.926	3.374	1.587 ~ 7.162	0.002

3.5 Predictive Performance of Lactate Clearance Rate for Adverse Outcomes After OPCAB

ROC curve analysis showed that T6, T12, and T24 lactate clearance rates and EuroSCORE II could all predict 30-day composite adverse outcomes after OPCAB ($P<0.001$); the original AUC of T12 lactate clearance rate was the highest (0.887), superior to those of T24 and T6 lactate clearance rates and the EuroSCORE II score. Internal validation with 1,000 bootstrap resamples was performed separately for T6, T12, and T24 lactate clearance rates without splitting the dataset into training and validation sets; the adjusted AUC of T12 lactate clearance rate was 0.861, with only a slight decrease, indicating no obvious overfitting and good predictive stability of the model. The adjusted AUC of T12 lactate clearance rate was higher than that of EuroSCORE II (AUC=0.742, $P<0.001$). Furthermore, the calibration curve and decision curve analysis (DCA) of the T12 lactate clearance rate model were plotted for supplementary validation. The calibration curve showed that the model-predicted risk curve closely fitted the ideal reference curve without obvious deviation, indicating good consistency between the predicted probability and the actual incidence of adverse events and reliable model calibration. DCA results showed that within the clinical risk threshold range of 0.05-0.85, the clinical net benefit of the T12 lactate clearance rate model was consistently superior to that of the EuroSCORE II score alone, demonstrating incremental clinical decision-making value. Table 5 presents the predictive performance parameters of each indicator, Figure 1 shows the ROC curves, Figure 2 shows the calibration curve of the T12 lactate clearance rate prediction model, and Figure 3 shows the decision curve of T12 lactate clearance rate.

Table 5. Predictive Performance of Lactate Clearance Rate for Adverse Outcomes After OPCAB

Indicator	Original AUC	Bootstrap-Corrected AUC	Sensitivity (%)	Specificity (%)	Accuracy (%)	95%CI
T6 Lactate Clearance Rate	0.819	0.795	77.50	76.75	76.88	0.762 ~ 0.876
T12 Lactate Clearance Rate	0.887	0.861	83.75	84.75	84.58	0.835 ~ 0.939
T24 Lactate Clearance Rate	0.862	0.838	81.25	81.50	81.46	0.808 ~ 0.916
EuroSCORE II	0.742	-	68.75	67.00	67.29	0.681 ~ 0.803

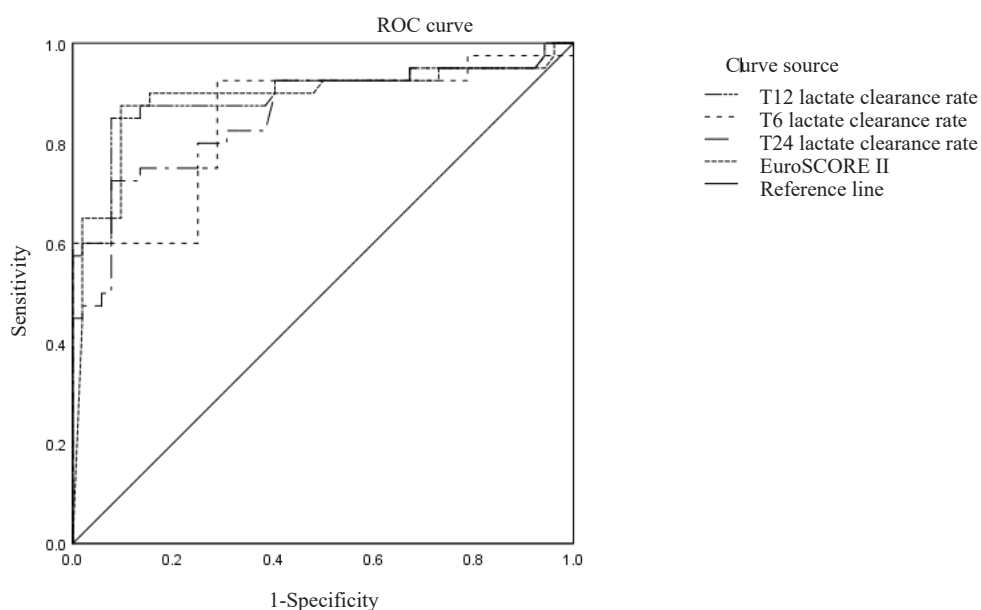


Figure 1. ROC Curves of Various Indicators for Predicting Adverse Outcomes After OPCAB

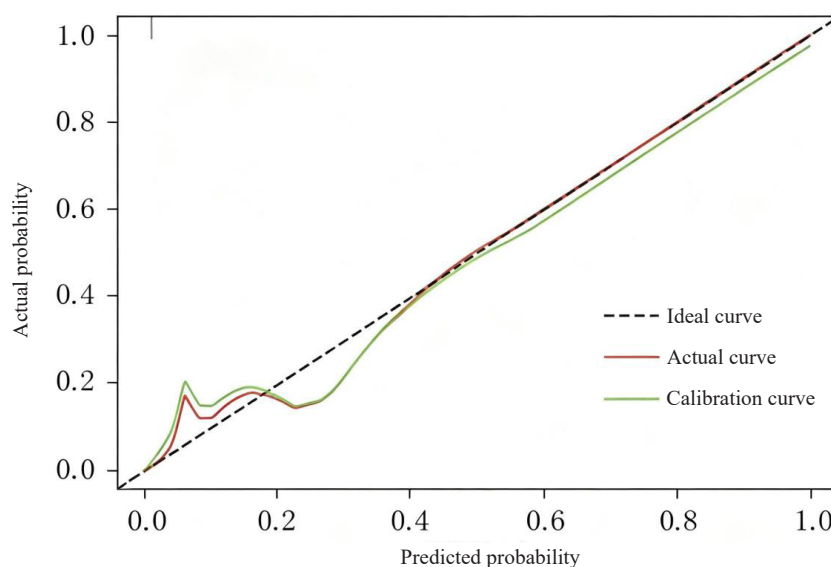


Figure 2. Calibration Curve of the T12 Lactate Clearance Rate Prediction Model

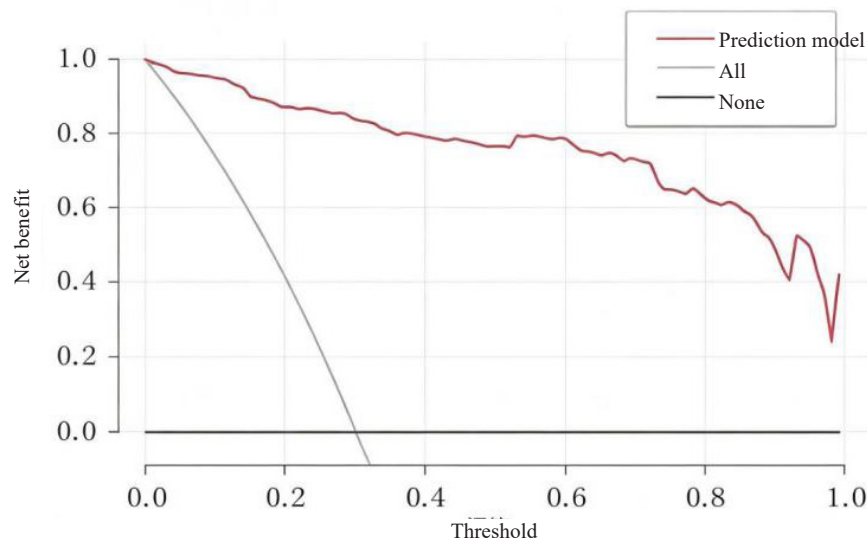


Figure 3. Decision Curve of T12 Lactate Clearance Rate

4. Discussion

Postoperative microcirculatory dysfunction in cardiac surgery is an important mechanism underlying multiple organ complications. Although OPCAB avoids severe organ injury caused by cardiopulmonary bypass, surgical trauma, transient myocardial ischemia-reperfusion, and perioperative hemodynamic fluctuations may still induce systemic microcirculatory dysfunction and imbalance between tissue oxygen supply and demand, resulting in postoperative multisystem complications. At present, clinical risk assessment after OPCAB mainly relies on cardiac function and biochemical parameters, with limited assessment efficacy. Lactate clearance rate is calculated based on the differences in arterial lactate levels at different time points and can quantify the body's ability to eliminate anaerobic metabolic products and reflect the degree of improvement in microcirculatory perfusion, demonstrating unique advantages in postoperative risk stratification after major cardiac surgery [5].

The results of this study showed that the incidence of 30-day composite adverse outcomes after surgery among 480 patients undergoing OPCAB was 16.67%. Univariate analysis showed that the adverse outcome group had high-risk characteristics including advanced age, poor baseline cardiac function, concomitant diabetes mellitus and hypertension, greater surgical trauma, elevated inflammatory and myocardial injury markers, and decreased albumin, renal function, and oxygenation levels, suggesting that insufficient baseline organ reserve, intraoperative stress injury, and systemic inflammatory activation jointly increased the risk of postoperative adverse events. Multivariate Logistic regression analysis showed that preoperative NYHA class III-IV, high NT-proBNP, low serum albumin, and decreased lactate clearance rates at postoperative T6, T12, and T24 were independent risk factors for short-term composite adverse outcomes. NYHA classification and NT-proBNP reflect preoperative myocardial contractile reserve and volume load. Patients with impaired cardiac function have limited circulatory compensatory capacity, and even minor fluctuations in perfusion during surgery may induce tissue hypoxia. Low albumin indicates poor preoperative nutritional status and increased vascular permeability, which may aggravate postoperative interstitial edema and microcirculatory stasis and inhibit lactate metabolism and clearance. Lactate clearance rates at all three time points were included in the regression model, indicating that impaired lactate clearance was not a transient phenomenon, and persistent lactate accumulation in the early postoperative period was an independent adverse risk signal distinct from traditional cardiac function and biochemical parameters. The lower the lactate clearance rate in the early postoperative period, the more persistent the hypoxic state of the myocardium and peripheral tissues, making it difficult to reverse anaerobic metabolism and consequently triggering composite endpoint events such as myocardial injury, acute kidney injury, and severe pulmonary infection [6-7]. ROC curve analysis showed that the AUC of T12 lactate clearance rate for predicting adverse outcomes reached 0.887, with an adjusted AUC of 0.861, indicating higher clinical discrimination performance. At 6 h after surgery, the body is at the peak of acute intraoperative stress, with massive catecholamine release and tissue hypoxia not yet initially compensated, resulting in substantial interference of systemic stress with lactate clearance. At 24 h after surgery, circulation tends to stabilize and organ perfusion is gradually restored, making differences in lactate

clearance more likely to be diluted by other confounding factors. In contrast, 12 h after surgery is an important time point for stress resolution and microcirculatory perfusion reconstruction and is more suitable as a monitoring time point for postoperative risk stratification, providing a basis for the early clinical identification of high-risk patients and adjustment of treatment strategies [8].

However, this study was a single-center retrospective study and only Bootstrap internal validation was performed, without multicenter external cohort validation, resulting in potential selection bias. Only short-term outcomes within 30 days after surgery were followed, precluding assessment of long-term prognosis, and a combined predictive model incorporating lactate clearance rate and EuroSCORE II was not constructed. Future studies should conduct multicenter prospective research, incorporate long-term cardiovascular event endpoints, construct a combined predictive model and perform external validation, and further optimize postoperative risk stratification strategies.

In conclusion, early postoperative lactate clearance rate after OPCAB, particularly the 12-h postoperative lactate clearance rate, is an important indicator for assessing short-term adverse outcomes and can provide evidence-based support for clinical patient stratification and individualized intervention.

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